AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Food production and nutrition — AH10-0000-0000

B. SECONDARY: Pests of plants

2. TITLE AND SUBTITLE

Proceedings of the Second International Working Conference on Stored-Product Entomology, Ibadan, Nigeria, 1978

3. AUTHOR(S)

(101) Permanent Committee on Int. Working Conferences on Stored Product Entomology, Inc.
Int. Working Conf. on Stored-Product Entomology, 2nd, Ibadan, Nigeria, 1978

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1979	455p.	ARC 631.56.I61

7. REFERENCE ORGANIZATION NAME AND ADDRESS

PCSPE

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(Sponsored by the National Science and Technology Development Agency of Nigeria)

9. ABSTRACT

10. CONTROL NUMBER

PN-AAG-694

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Storage
Insect control
Insecticides
Post harvest
Pest control
Grain loss
Ecology
Tropics
Meetings

13. PROJECT NUMBER

931115511

14. CONTRACT NUMBER

AID/ta-G-1485

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

PROCEEDINGS OF THE SECOND INTERNATIONAL WORKING CONFERENCE ON STORED-PRODUCT ENTOMOLOGY

SEPTEMBER 10-16, 1978
IBADAN, NIGERIA

AID/ta-G-1485

Grant No.: 931-1155.11
TAB/PPU/EUI
Technical Assistance Bureau
Agency for International Development
Washington, D.C. 20523

Savannah, Georgia, U.S.A.
1979

FOREWARD

Following upon the successful First International Working Conference on Stored-Product Entomology in Savannah, Georgia, U.S.A. in 1974, a Second International Working Conference was held in Ibadan, Nigeria, from 10-16 September, 1978. The Second Conference which was sponsored by the National Science and Technology Development Agency of Nigeria (NSTDA) was hosted by the University of Ibadan, Ibadan, Nigeria. The meetings were held at the Conference Centre of the University of Ibadan.

The Conference aimed at furthering the primary objective of providing a continuing forum for the dissemination and discussion of current research and development needs and priorities in the field of stored-products protection. It also reviewed progress made in respect of the urgent need for action on the provision and preservation of food supplies for mankind called for in its October 11, 1974, statement on "Preservation of Staple Food Stock following Production." These objectives were admirably achieved largely by the efforts of the Symposium and Panel Organisers: Prof. G. H. Caswell, Dr. S. C. Saxena, Dr. Jan H. Boczek, Dr. B. R. Champ, Dr. R. Davis, Dr. M. Calderon, Dr. J. O. Oyeniran, to whom we express our deep appreciation.

We also wish to express our profound appreciation to the personnel of our institutions and agencies, the Institute of Agricultural Research & Training (IAFT), University of Ife, the Nigerian Stored Products Research Institute (NSPRI), the International Institute of Tropical Agriculture (IITA), and the Department of Agricultural Biology, University of Ibadan, who assisted in the planning and execution of the Conference activities. Our gratitude goes to the commercial and publishing houses and the chemical and other agro-allied industries which provided financial, technical, and moral support to participants and partial funding for the Conference; a list of names and addresses of our benefactors is given on the inside of the front cover of this Proceedings.

A total of 69 scientists, technologists, administrators, and agricultural marketing specialists, from over 20 nations, participated in the symposia, panel presentations, and discussions. More than 36 symposium and panel presentations and 20 submitted papers provided for excellent scientific interaction in stored-product entomology and technology. Special addresses were delivered by the Acting Vice-Chancellor, University of Ibadan, the Federal Director of Agriculture - on behalf of the Honourable Federal Commissioner for Agriculture and Rural Development -, and the representative of the Executive Secretary of the National Science and Technology Development Agency.

A second formal meeting of the Permanent Committee of International Working Conferences on Stored Product Entomology was held at the Institute of Agricultural Research & Training, Moor

Plantation, on Thursday, 14 September, 1978, with the following in attendance:

Jan H. Boczek (Poland)
Moshe Calderon (Israel)
Dana P. Childs (U.S.A.) - Secretary
Robert Davis (U.S.A.) - Chairman
S. C. Saxena (India)
T. Ajibola Taylor (Nigeria)
P. F. Prevett (United Kingdom)
F. L. Watters (Canada)
H. J. Banks (Australia)

The meeting received reports on the first meeting and on the organisation of the Second Conference. A draft constitution for the Permanent Committee was adopted and Drs. R. Davis and Dana P. Childs were returned as the Committee's Chairman and Secretary, respectively.

The Permanent Committee accepted the confirmed invitation from Dr. Jan H. Boczek (Poland) to hold the Third Working Conference on Stored Product Entomology in Poland in 1982. This acceptance was later ratified at an informal meeting of the participants on Friday, 15 September, 1978, and we all look forward to the Third Conference in Poland in 1982.

Finally, we would like to state that it was a distinct pleasure and privilege to host the Second Conference. We believe that the Conference has provided a valuable forum for leading world authorities to meet and exchange scientific and technological information on a subject of great significance to the world food problem; it has also provided a unique opportunity for exposure to and discussion of tropical and developing country storage problems, current research, and future needs.

In the preparation of these Conference Proceedings, we have adopted the uniform format and approach of the First Proceedings. We hope that this publication, as an extension of the Conference, will enhance the flow of information and technology necessary for greater impact of stored-product entomology on world food economy.

The Organizers

G. H. Caswell, Ahmadu Bello Univ., Zaria
W. H. Boshoff, IITA, Ibadan
A. M. Daramola, University of Llorin (Sec.)
S. O. Dina, NCRI, Ibadan
S. A. Adesuyi, NSPRI, Ibadan
S. R. Singh, IITA, Ibadan
M. F. Ivbijaro, Univ. of Ibadan
S. A. O. Adeyemi, CRIN, Ibadan
T. Ajibola Taylor, IAR&T, Ibadan (Chairman)

OPENING CEREMONIES

PROFESSOR T. A. TAYLOR: The representative of the Honourable Commissioner for Agriculture and Rural Development, the acting Vice-Chancellor, distinguished participants, ladies and gentlemen, it is my pleasure and privilege to introduce our guests for the formal opening of the Second International Working Conference on Stored-Product Entomology. On behalf of the Organisers, I wish to welcome our colleagues in Stored-Product Entomology from different parts of the world. Of course, I will not take over the role of the Vice-Chancellor, because both the acting Vice-Chancellor of Ibadan University and the Honourable Commissioner, who is represent here by the Federal Director of Agriculture, will be welcoming you formally to the campus of the University of Ibadan and to Nigeria.

Our main guest for this morning is the representative of the Honourable Commissioner of Agriculture and Rural Development of the Federal Republic of Nigeria. He will convey the apologies of the Honourable Commissioner, who owing to pressing State duties, is unable to come in person to open the Second International Working Conference on Stored-Product Entomology. Alhaji Liman, who is sitting on my immediate right and who is the Federal Director of Agriculture has had a long and abiding interest in storage Technology and I think it is very appropriate that he should represent the Honourable Commissioner at this opening. Our next guest and host, and he wears two caps, is the acting Vice-Chancellor of the University of Ibadan, whose Institution is providing the essential facilities for this Conference, is Professor T. O. Adedipe, the Dean of Agriculture; he is on my immediate left. Thirdly, and unfortunately, the Executive Secretary, N. S. T. D. A. is unavoidably absent. I am told he has just arrived from a trip abroad yesterday and much as he would have wished to be here in person, he is unable to attend the formal opening. However, we have Mr. J. C. Obi, who is sitting next to Mr. Alhaji Liman, as representing the N. S. T. D. A. as one of the major sponsors of this Conference. Next to Mr. Obi is Dr. S. A. Adesuyi, acting Director of the Nigerian Stored-Products Research Institute.

On my extreme left is Dr. Robert Davis, who was Chairman of the First International Working Conference on Stored-Product Entomology and is Chairman of the Permanent Committee of International Working Conferences on Stored-Product Entomology. He is handing over the baton to me for this Conference in Nigeria, but he can be rightly referred to as the father of the International Working Conferences on Stored-Product Entomology because it was as a result of his initiative, his imagination and drive that the first International Working Conference was held in Savannah, Georgia, in 1974. On that occasion, the Stored-Product Insects Research and Development Laboratory, USDA, was host and organised the first Working Conference. Therefore, it is a great pleasure

to see him continuing not only as the Chairman of the Permanent Committee of the International Working Conferences on Stored-Product Entomology, but to be present on this occasion when Nigeria is playing host to the Second International Working Conference on Stored-Product Entomology. I now have the pleasure to call on the acting Vice-Chancekkor of the University of Ibadan to deliver his welcome address.

PROFESSOR N. O. ADEDIPE (acting Vice-Chancellor): Thank you very much Mr. Chairman. I am standing in for the Vice-Chancellor, who is unavoidably absent due to previous commitments since he is now outside Ibadan. May I therefore on his behalf welcome you all to this International Conference. The Honourable Commissioner for Agriculture and Rural Development, the Honourable Commissioner for Agriculture Oyo State, the Executive Secretary N. S. T. D. A., eminent entomologists and scientists, ladies and gentlemen, I have the pleasure to welcome you all on behalf of the University community to Nigeria and particularly to the University of Ibadan campus. I learnt that the first Conference of your organisation took place in Savannah, Georgia, U.S.A., four years ago, and that the University of Ibadan is happy to host the Second International Working Conference on Stored-Product Entomology. The very important role of entomologists as biologists who concentrate most of their efforts on the boundless limits of the insect world in the production of food and supply to mankind cannot be overempasised.

Insects as the most biologically successful animals in terms of their large numbers, ability to survive and to reproduce under varying environmental conditions, and also to occupy almost every ecological niche, constitute one of the major constraints to agricultural production throughout the world. Insect pests are the greatest competitors of men for food and their devastating effects both in the field and in the storage are well pronounced in the tropical and subtropical regions where the physical factors of the environment favour their development and activities almost all the year. Food and food products, especially grains, legumes, dried fish and other animal and forest products are stored for a number of reasons as you all well know. These include the seasonality of cropsand the fluctuation of market prices, but most of the present farmers in the third world store part of their harvest primarily for consumption during the period of scarcity. I am informed that about 40-60% losses have been recorded in many parts of this country for such crops as maize, guinea corn and cowpea within six months of storage. These grains and legumes constitute the major source of carbohydrates and protein to the teeming population of this country.

Many of our cash crops like cocoa, groundnuts and kolanuts on which this country depended for a long time for economic development and take-off also suffer heavy losses from insect pests. Our experiences in the last couple of years from instability and uncertainties surrounding all revenues have shown that agricultural

products are the most reliable sources of foreign exchange earnings. However, one notes with pleasure and with a feeling of hope that your Conference is holding at this point in time when the various governments of the developing countries are making frantic efforts to increase food production. The N. A. F. P. P. and the O. F. N. are some of the efforts of the Federal Military Government of Nigeria at the national level to encourage increased food production.

The problem of storage therefore requires serious attention by stored-product entomologist, microbiologists and engineers in order to minimise the losses in storage. It is my belief tht you would use your knowledge and wealth of experience to formulate effective and efficient controls against the storage pests under the tropical and subtropical conditions, bearing in mind especially the limitations of most of our present day farmers which include illiteracy, poverty and total lack of modern technology. I like to say at this juncture that this University is very proud of the activity of its Faculty of Agriculture and Forestry with reference to its contribution to the development of Agriculture in this country and particularly the Department of Agriculture Biology in which Ertomology is one major component.

Notice to Participants

This Proceedings contains the papers presented at the Conference and provided to the Permanent Committee for publication. Every effort has been made to reproduce these papers as they were received. Unfortunately many papers submitted were carbon copies or photo copies of the originals and errors may have inadvertently been made. Also, many of the tables, figures, and half-tones were not of the desired quality for camera-ready printing. The editor will provide an errata sheet for mailing to all recipients of the Proceedings if the authors corrections are received within a reasonable period of time following the distribution of the Proceedings. Because of the Permanent Committee's financial position it will not be possible to include tables, figures, and half-tones in the errata page. Separates of the Proceedings will not be available but authors desiring separates may produce them locally at their own expense.

Robert Davis

TABLE OF CONTENTS

FOREWARD iii

OPENING CEREMONIES v

NOTICE TO PARTICIPANTS viii

TABLE OF CONTENTS xi

SYMPOSIUM ON TROPICAL STORED-PRODUCT ENTOMOLOGY

The Identification of Season and Place of Maximum Grain Loss - G. H. Caswell 14.

Traditional Practices as a Basis for the Improvement of On-farm Stored Product Preservation in Tropical Africa - W. H. Boshoff 17.

Insect Problems in Storage and Control Techniques Under Indian Conditions - G. K. Girish 22.

The Role of the Nigerian Stored Products Research Institute in Storage and Protection of Tropical Products - S. A. Adesuyi 23.

Loss Assessment Methodology - The Current Situation - R. A. Boxall, P. S. Tyler, and P. F. Prevett 29.

Tropical Storage Entomology by the End of the Twentieth Century - T. Ajibola Taylor 37.

Ecology and the Integrated Control Approach Under Tropical Conditions - C. P. F. De Lima 44.

Losses Caused to Stored Products by Insect Pests in Pakistan and Measures for their Control - Hafiz Abdul Qayyum 49.

SYMPOSIUM ON BIOLOGY, ECOLOGY AND INTEGRATED CONTROL

Application of Pheromones and Behavior-Modifying Techniques in Detection and Control of Stored Product Insects - Wendell E. Burkholder 56.

Integrated Manipulation of Storage Insects by Pheromones and Food Attractants - H. Z. Levinson and A. R. Levinson 66.

Ecological Aspects of Control of a Stored Product Insect by Ozonation - Howard E. Erdman 75.

The Biology and Impact of the Predatory Bug *Xylocoris flavipes* (Reuter) - Richard T. Arbogast 91.

A Controlling Effect of a Juvenile Hormone Analogue on *Ephestia cautella* (Wlk.) by Non-direct Application - M. Gonen and A. Schwartz 106.

PANEL SESSION ON BIOLOGY, ECOLOGY AND INTEGRATED CONTROL

SYMPOSIUM AND PANEL ON PESTICIDES, OTHER CHEMICAL, TOXICITY AND INSECT RESISTANCE

Attitudes and Prospects for Use of Chemicals in Protecting World Food Supplies - J. T. Snelson 116.

The Residual Behavior of Chemicals on Stored Grain - J. M. Desmarchelier and M. Bengston 138.
A Review of U.S. Research on In-transit Shipboard Fumigation of Grain - Robert Davis and H. B. Gillenwater 152.
Pesticide Resistance and Its Current Significance in Control of Pests of Stored Products - B. R. Champ 159.
Limiting Considerations for Fumigation Efficiency in the Control of Insect Pests - C. H. Bell 182.
Analysis of Formulations and Residues - Some Current Considerations - J. M. Desmarchelier 193.

SYMPOSIUM ON RADIATION AND OTHER NON-CHEMICAL MEANS OF INSECT CONTROL
Recent Advances in the Use of Modified Atmospheres for Stored Product Pest Control - H. J. Banks 198.
Current Status of Irradiation for Use in Insect Control - E. W. Tilton 218.
The Potential of Fluidized-bed Techniques in Insect Control - D. E. Evans and T. Dermott 222.
The Use of Electromagnetic Energy to Detect Hidden Insect Infestation - W. A. Bruce and M. W. Street 230.
A Review of the Use of Physical Storage Procedures in East Africa: Aspects for Improvement and Extension - C. P. F. De Lima 237.

PANEL SESSION ON RADIATION AND OTHER NON-CHEMICAL MEANS OF INSECT CONTROL
Potential and Limitations of the Use of Low Temperatures to Prevent Insect Damage in Stored Grain - Robert B. Mills 244.
Large-Scale Trials on the Use of Controlled Atmospheres for the Control of Stored Grain Insects - S. Navarro, M. Gonen, and A. Schwartz 260.
The Effects of UV Radiation on Stored-Product Insects - W. A. Bruce and P. T. M. Lum 271.
Potential of Accelerated Electrons for Insect Control in Stored Grain - F. L. Watters 278.

PANEL ON MICRO-ORGANISMS AND RODENTS IN STORAGE
The Role of Fungi in the Deterioration of Tropical Stored Products - J. O. Oyeniran 288.
The Deterioration of Commercial Maize (*Zea mays*) by Insects and Fungi - Matt. F. Ivbijaro 309.

FIRST SESSION OF SUBMITTED PAPERS
The Problems of Insect Infestation of Stored Dried Yam Chips in Nigeria - S. A. Adesuyi 314.
Effect of Tricalcium Phosphate on *Tyrophagus putrescentiae* (Schr.) (Acari: Acaridae) - Jan Boczek and Stanislaw Ignatowicz 320.

An Unusual Mortality of *Sitophilus zeamais* Mots. Caused by *Sitotroga cerealella* (Oliv.) in Mixed Laboratory Cultures - J. N. Ayertey 328.
The Development of Two Kola Weevils, *Sophrorhinus gbanjaensis* D & T and *Balanogastris kolae* (Desbr.) on Wild Kola, *Cola gigantea* Chev. - Ajibola M. Daramola 338.
Non-uniform Application of Grain Protectants in Commercial Storages - T. G. Amos, P. Williams, and W. Minett 344.
The Ovipositional Response of the Cigarette Beetle to Temperature and to Selected Odors - L. W. Fletcher, L. C. Garrett, and C. P. Childs 350.

SECOND SESSION OF SUBMITTED PAPERS

Regulation of the Bean Weevil Reproduction (*Acanthoscelides obectus* Coleoptera Bruchidae) and Research on Techniques of Protection of Stored Beans - Jacques Huignard 360.
Selection of Suitable Food to be Used as Bait for Rodent Control in Jamaica - D. S. Jayasingh and K. R. Walker 372.
The Importance of Phycitines on Imports to Britain in Relation to Their Biology - P. D. Cox 380.
The Prevention of Insect Infestation in Stored Dates - T. J. McCallum-Deighton and Ala-Ud-Din Daoud Ali 396.
Microencapsulated Pesticides - A Novel Control Release System for Insect Control - Joseph Simkin 404.

THIRD SESSION OF SUBMITTED PAPERS

Selection of New Insecticides for Use in Maize Storage at the Farmer's Level in Nigeria - S. A. Adesuyi 406.
Solar/Wind Energy to Cool Tobacco Storages for Insect Control - D. P. Childs, L. W. Fletcher, F. A. Iachetta, J. T. Beard, and R. D. Flack 412.
Methacrifos - A New Insecticide for Grain Protection - A. Renfer, R. Wyniger, F. Knüsel, and W. Gfeller 419.
Controlling Insect Pests of Stored Tobacco by Reducing Their Reproductive Potential - W. Arthur Manzelli 432.
Sex Ratio Agent in *Cadra cautella* (Walker) -- Its Expression by Temperature, Genetics, and Mass Production of the Virgin Female Moths for Sex Pheromone Study - Fumiki Takahashi 437.

SYMPOSIUM ON TROPICAL STORED-PRODUCT ENTOMOLOGY

Convener - PROFESSOR G. H. CASWELL
Institute of Agricultural Research
Ahmadu Bello University
Zaria, NIGERIA

THE IDENTIFICATION OF SEASON AND PLACE OF MAXIMUM GRAIN LOSS

G. H. CASWELL
Institute for Agricultural Research
Ahmadu Bello University
Zaria, NIGERIA

INTRODUCTION: It is very easy to devote time and effort to the most spectacular source of grain loss or to a period or place which is particularly interesting. But this may not be where most loss occurs or where time and effort can most profitably be spent.

I shall look very briefly at a hypothetical situation which could exist in the tropics and see if it is possible to identify when and where control measures could be applied most effectively.

CONSIDERING THE SEASON: Let us assume that there is a grain crop of two million tonnes harvested in October and all consumed by the end of the following September. It is also assumed that consumption is uniform throughout the year and that loss through insect damage continues at a steady rate of 5% per month. As a rough approximation it is also assumed that when 5% of the grains have been damaged 0.5% of the produce will have been lost. The results of these assumptions is given in the table below.

It will be seen that half the total loss has already taken place by January, showing very clearly the importance of early application of control measures. It will also be seen that the total loss is 64,000 tonnes which is a little over 3% of the total production. This is a good deal less than might have been expected.

CONSIDERING THE LOCATION OF THE GRAIN: Initially grain is stored by the farmer. He has several thousand years of experience, trial and error to support the methods he uses. It is unlikely that those of us who are unfamiliar with his way of life and the resources at his disposal will be able to improve on what the best farmers do. We can best serve the farming community by learning from the best of them and encouraging the others to improve. Here and there innovation arising out of modern knowledge may occasionally be introduced. For the most part it will cost too much and the necessary material will not be readily available.

A hundred years ago our hypothetical state had two million people living in it and all but a few chiefs grew their own food. There would have been some exchanage of produce between one area and another but no large scale marketing organisation. Now our state has five million people and only three million are farming, the rest live in towns and cities and have to be fed. This is a profitable occupation for many people. Grain is bought from the farmers and passed through the hands of four or five traders until

TABLE I. Hypothetical seasonal loss of grain when production is two million tonnes.

Month	Stock (,000 tones)	Damage %	Loss per month (,000 tonnes)	Cumulative loss (,000 tones)
Oct.	2,000	5	10.0	10.0
Nov.	1,833	10	9.1	19.1
Dec.	1,667	15	8.3	27.4
Jan.	1,500	20	7.5	34.9
Feb.	1,333	25	6.6	41.5
Mar.	1,167	30	5.8	47.3
Apr.	1,000	35	5.0	52.3
May	833	40	4.2	56.5
Jun.	667	45	3.3	59.8
Jul.	500	50	2.5	62.3
Aug.	333	55	1.7	64.0
Sep.	167	60	0.8	64.8

it reaches an urban centre where it remains until bought by the consumer. Each trader will keep it for as short a time as possible because he needs to make a profit and recover his investment to use again. He will try to anticipate the demands of the urban centres and not buy more than can be sold but inevitably grain will accumulate and new grain coming in will be better than that which has been there for some weeks and is likely to be sold first or at a higher price. So grain stocks will build up in these centres and there will be large pest populations. Traders and storekeepers hope to sell their stock for a good price tomorrow and so will be reluctant to spend money on control today. Here is a new situation in which there is no tradition and little experience. The successful traders are likely to leave the business for more reliable sources of income as soon as they have accumulated enough capital and their places will be taken by newcomers with no experience. This is an area where great losses can occur and where investigation may not be welcome.

The next stage is the consumer who sees good quality produce at the beginning of the season at a price which is bound to go up later. There is a great temptation to buy a stock of grain while it is cheap and keep it at home for later use. Rodents, insects and water will certainly cause much damage and after six months in a room in a compound the grain could be much worse than that being offered in the local market and the saving could be completely lost. This is another area where there is little or no experience and where substantial losses occur. Fortunately these people welcome advice and can be reached through the media, however they are mostly the "middle class" and higher priority may be given to helping those who are destitute or near it.

Finally the state will intervene and set up stores of grain to act as a buffer for price control, as a famine reserve and to hold stocks for export. This is an area where modern techniques can be used. Suitable methods and structures are well known and training is available for staff to operate the stores. It is a question of selecting the methods most suited to the situation and then ensuring efficient operation.

TO SUMMARISE: At the farmers' level there is a need to study what he does and extend the best techniques to others. The urban stores and markets are likely to be the most profitable areas for reducing grain loss but also the most difficult to deal with. Advice can be given to the consumer and will be welcomed by him. The most suitable methods need to be chosen for state stores and training provided for the personnel to run them.

TRADITIONAL PRACTICES AS A BASIS FOR THE IMPROVEMENT OF ON-FARM STORED PRODUCT PRESERVATION IN TROPICAL AFRICA

W. H. BOSHOFF
FAO/Danida African Rural Storage Centre
International Institute of Tropical Agriculture
Ibadan, NIGERIA

INTRODUCTION: Many examples exist of novel storage methods and structures that have been advocated for on-farm grain storage. The basic aim in most cases appears to have been to introduce dramatic improvements over the traditional systems, relying on the use of such inputs as metal drums and silos, concrete silos, plastic bags, insecticides, and the use of mechanical driers.

There are virtually no examples where such novel introductions have succeeded in being universally accepted by the majority of growers. In fact, adoption usually comes to an abrupt stop the moment the extension efforts of the initiators are removed.

Almost invariably, failures can be traced to ignoring the fact that traditional practices are based on many years of experience by farmers. The techniques adopted thus fully take into consideration such factors as the effect of climate, availability of bought inputs, limitations in technical and managerial skills, and a host of socio-economic constraints which are not immediately evident to the newcomer on the scene.

In other instances, proposed improvements have contained distinct technical and practical weaknesses, which, through inadeqate prior evaluation, had not been revealed before encouraging farmers to adopt it.

An appreciation of the need for studying traditional practices and for the development of improvements based on them and with actual farmer participation is becoming increasingly recognized (1, 2).

The current paper underlines this need by relating some experiences associated with, respectively, humid and dry zones, and suggesting possible future approaches to the problem.

DRYING OF GRAIN CROPS IN HUMID ZONES: In humid zones in West Africa there is a bimodal rainfall pattern. In these areas when a major crop is a grain, such as maize, it ripens largely during periods of intensely humid conditions. To the casual observer, the drying of the crop under these conditions would seem possible only through the use of some form of artificial means. As a result, many attempts have been made to provide mechanical drying and related bulk silo storage facilities at strategic centres, where small producers can have their maize dried, shelled,

and stored. These have not succeeded, largely as unavoidable delays between harvesting of the crop and ultimate drying regularly results in heavy losses and deterioration of the crops, notably through fungal attack. This system is of course feasible on large scale farms, where the harvest rate and drying capacity can be matched, but is impossible to achieve when the supply of material is provided intermittently by numerous small producers.

A study of traditional practices for maize in the humid tropics will reveal a significant appreciation by farmers that in spite of intense relative humidity conditions, the crop will nevertheless lose moisture under natural conditions after ripening at 35% moisture content. This is borne out in Figure 1, where it will be noticed that the equilibrium moisture content of the crop is in the order of 16% even if the daily mean relative humidity reaches 85%, which is the level attained in highly humid conditions.

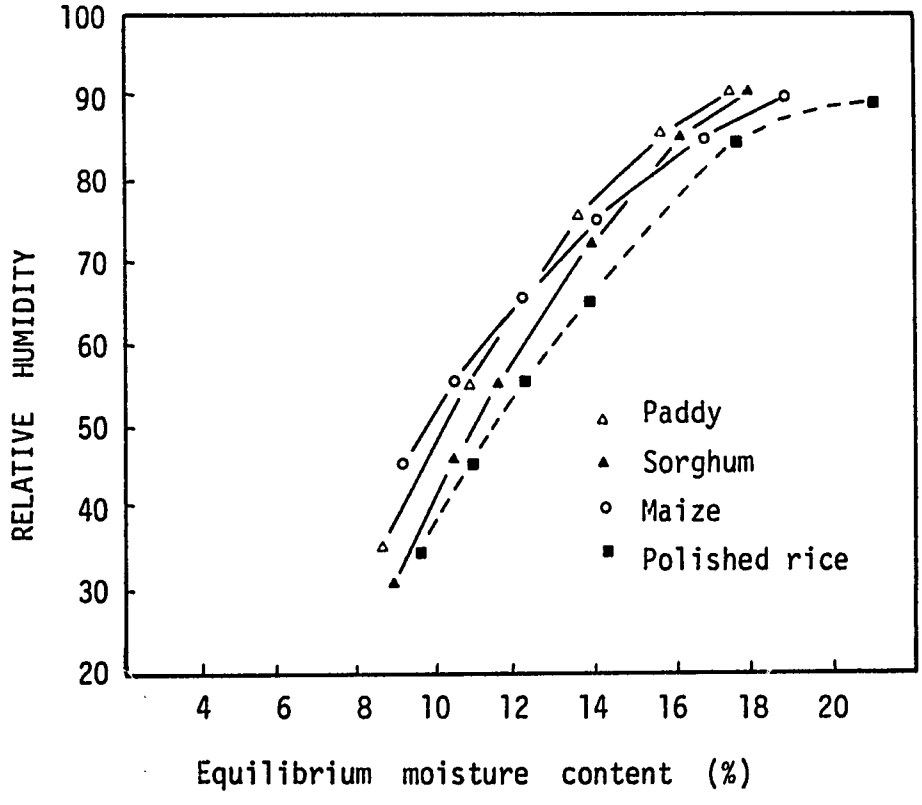


FIGURE 1. Equilibrium moisture content of common grain crops in relation to atmospheric mean daily relative humidity

Farmers also appreciate that the loss of moisture will be slow, but the crop would be quite safe from fungal attack, providing it is kept in an environment allowing the free circulation of air around it.

This is reflected in the traditional practices, where maize cobs undehusked, and thus partially protected from insects, are suspended in trees, on poles and in roofs of domestic houses. In slightly more advanced cases, maize cobs are heaped on platforms under which periodic fires are lit to somewhat speed up the drying and to repel insects.

As the scale of production increases, especially when commercial levels of production are aimed at, these techniques become rather limiting and the tendency is to leave the crop unharvested in the field until it reaches a moisture content of around 18-20% and to then place it in simple round structures having slatted walls or similar means to allow for the free passage of air through the undehusked cobs.

The period of field drying exposes the crop to many hazards, and field losses are inevitable. The opportunities for using the land for a second crop in the same year are also reduced and often nullified.

In examining the scope for natural drying under highly humid conditions (3), it has been established that dehusked maize cobs, harvested at over 35% moisture content (soon after ripening) will dry equally well without the danger of fungal infection provided it is placed in very ventilated conditions. Such conditions can be achieved in cribs with an appropriate width, ranging from 60 cm in extremely humid conditions, to 150 cm under more moderate conditions.

Attempts to introduce the crib concept to farmers has been only moderately successful, largely as the structures initially recommended were based on construction materials that were costly and seldom readily available. An evaluation of these cribs with farmer participation would have revealed this shortcoming much earlier.

In more recent times, cribs based on the use of exactly the same home-grown materials that are traditionally available have been developed and are being evaluated on farms. Some resistance to the concept of a rectangular structure, rather than the traditional round structure, is being encountered. Although much more material is required to build a number of small diameter round structures to hold the same volume of cobs as would a rectangular one, the innovators may have to succumb to popular opinion and give equal stress to round and rectangular structures initially.

The control of insects in cribs, although somewhat reduced by really early harvesting of crops grown for commercial purposes, remains an important problem. Effective and easily

applied insecticides are being produced for application to dehusked cobs, but their general use thus far is restricted primarily by a lack of efficient supply lines to farmers. For the time being farmers who have no access to such inputs have little alternative choice but to accept losses in weight in the order of 5% to 8% over a 3-month drying period for untreated dehusked cobs in cribs and to shell and dispose of the crop at this stage to agencies in the marketing chain, which have access to and are better able to carry out insect control measures.

It is significant to note that the storage of shelled grain in solid walled structures in very humid conditions is not traditionally practiced. It implies that farmers are aware and unable to cope with the many pitfalls that this technique holds, in humid zones. These are primarily problems relating to getting the grain dry enough for bulk storage, the shading of the structure to avoid undue temperature fluctuations and hence condensation, and of course the control of insects.

STORAGE IN DRY ZONES: In zones where a distinct dry season follows the ripening of the crops, usually associated with mono-modal rainfall patterns, the drying of the crop is seldom a problem.

The dominant grain crops in these areas are sorghum and millet, which are traditionally stored on the farm in the unthreshed form, in solid walled traditional mud structures (4).

On the whole, damage and losses by insects are insignificant for the first part of the storage period, due to favourably dry conditions. As the new rainy season commences, some 5 to 6 months after the harvest, damage due to moths becomes noticeable.

Storage of the crops in the threshed form can reduce the extent of moth damage, but many of the mud walled traditional structures are not sufficiently strong to withstand the extra stresses imposed by the higher density material.

A more substantially walled structure would seem to be an improvement worth considering, more especially if it could be damp proof, air tight, and rat proof.

Many excellent examples of novel developments of such improved silos are available. They depend almost exclusviely on the use of one or more bought input, such as cement, wire netting, and galvanized iron sheeting. Few have generally been adopted, suggesting that a modification, much closer in material specification and cost, to the traditional may yet have to be developed.

In fact, many existing traditional structures already come close to the ideal specifications and a valuable starting point for improvement is obviously to encourage the less enlightened farmers to adopt the techniques of the better informed in the region.

CONCLUSIONS: A superficial look at traditional practices for the preservation of stored products will reveal many obvious weak elements in the system which could potentially be eliminated by alternative practices.

However, when attempting to persuade farmers to adopt alternative practices and techniques, the reaction is seldom positive. A closer examination of the reasons behind this reveals many constraints which the innovators do fully take into account. Among the more obvious are factors such as the cost of the improvements and more especially the availability of bought inputs. The more subtle sociological and managerial factors are even less readily identifiable.

As a starting point for improvement, a thorough knowledge of traditional practices and reasons for them are essential. The encouragement of the less enlightened farmers to adopt the techniques of the better informed within a society can often result in notable improvements in the short run.

More elaborate modifications, including novel introductions should evolve, rather than be imposed, on farmers, and this can only be achieved by developing such innovations with actual farmer participation.

REFERENCES:

(1) Nyanteng, V. K. The storage of foodstuffs in Ghana. Technical Publication series No. 18, Inst. of Stat., Soc., and Econ. Research, Legon, Ghana (1972).

(2) Anon. Appropriate Technology for Grain Storage - Report of a Pilot Project. Community Development Trust Fund of Tanzania in Collaboration with the Institute of Adult Education, Dar es Salaam, Tanzania (1977).

(3) FAO. Interim Report of the African Rural Storage Centre, IITA, Ibadan (1977).

(4) Giles, P. H. The storage of Cereals by Farmers in Northern Nigeria. Samaru Research Bulletin No. 42, Institute for Agricultural Research, Ahmadu Bello University, Zaria (1965).

INSECT PROBLEMS IN STORAGE AND CONTROL TECHNIQUES UNDER INDIAN CONDITIONS

G. K. GIRISH
Deputy Commissioner (Storage and Research)
Government of India, Department of Food
Krishi Bhavan, New Delhi-110 001
INDIA

(This paper has been published elsewhere and is presented as an abstract for informational purposes. Those interested should contact the author for additional information.)

ABSTRACT: Nearly one thousand species of insects have been found associated with stored products in various parts of the world. The majority of the insect pests belong to the order Coleoptera and Lepidoptera, which accounts for about 60% and 8-9% respectively of the total number of species of stored product insect pests.

Under Indian conditions the most important insect pests of stored grain are *Sitophilus oryzae* Linn. (rice weevil), *Rhizopertha dominica* Fab. (borer beetle), *Trogoderma granarium* Everts (khapra beetle), *Sitotroga cerealella* Olivier (grain moth), *Corcyra cephalonica* Staint. (rice moth), *Ephestia (Cadra) cautella* Water. (fig or almond moth), *Callosobruchus maculatus* Linn. (pulse beetle), *Tribolium castaneum* Herbst (rust red flour beetle), *Oryzaephilus surinamensis* Linn. (sawtoothed grain beetle), *Latheticus oryzae* Water. (longheaded) flour beetle), and *Plodia interpunctella* Hübner (meal worm moth).

Out of the various stored product insects, eleven species of insect are mainly responsible for damaging stored food grains/ milled product/pulses, etc. under Indian conditions.

The role of various environmental factors, viz. temperature, relative humidity of the environment, moisture content of the grain, food, etc. which affect the rate of metabolism, growth, development, reproduction, general behaviour, and distribution of the stored product insects have been described in the paper.

Various technologies of insect control, viz. (1) Hygiene Technology, (2) Hermetic Technology, (3) Mechanical Technology, (4) Physical Technology (a) Drying of Grain (b) Heat Treatment (c) Cold Treatment (d) Use of Radiant Energy (e) Use of Ultraviolet Light and X-rays (f) Use of Aeration (g) Atomic Energy (h) Mixing of Inert Dusts (i) Use of Centrifugal Force (5) Chemical Technology (i) Surface Treatment (ii) Dusts (iii) Fumigation, (6) Biological Technology, which have been employed for minimizing insect activities have been described.

Forty-three references have been cited in the paper which illustrate the work of the author on insect problems in storage and control techniques under Indian conditions.

THE ROLE OF THE NIGERIAN STORED PRODUCTS RESEARCH INSTITUTE IN STORAGE AND PROTECTION OF TROPICAL PRODUCTS

S.A. ADESUYI
Nigerian Stored Products Research Institute
P.M.B. 12543, Lagos, NIGERIA

INTRODUCTION: Research into storage of agricultural products in Nigeria started in 1948 when a survey team was sent to Nigeria financed from Colonial Development and Welfare funds. The terms of reference were: (a) To survey stored food produce in the West African Colonies. (b) Losses and deterioration due to insects and other causes were to be studied and recommendations made for reducing them. (c) The bionomics of the main infesting pests were to be worked out. The West African Pest Infestation Survey Team (W.A.P.I.S.) Reported in 1950 and recommended a continuation and extension of research into the conservation of food supplies and methods of quality improvement. This was arranged and the name of the organisation was slightly changed to West African Pest Infestation Research Unit (W.A.P.I.R.U.). In 1954, the Unit was made permanent and funded entirely from Nigeria. The name was modified to West African Stored Products Research Unit (W.A.S.P.R.U.) thereby widening the scope of research to stored products general rather than infestation only.

For a long time, the work was oriented towards export crops with little work on locally used foods. The name Nigerian Stored Products Research Institute was adopted in 1963.

The Institute's work is expected to cover the whole of Nigeria. In doing this the Institute established branches in the main climatic zones of Nigeria which cover the very humid tropical areas of Southern Nigeria to the dry Northern Sahelian Zones. Purpose designed laboratories in Ibadan and Kano were occupied in 1957 while the Port Harcourt laboratory was opened in 1958. The Headquarters is at Lagos and a relatively new branch is located at Sapele.

Lagos, Port Harcourt and Sapele cater for the Port storage and very high humid zones of the country, Ibadan for the high humid zones and Kano for the low humid areas.

TERMS OF REFERENCE: The Decree establishing the Institute stipulates that it shall carry out Research into bulk storage problems of export commodities and local food crops, and in particular it shall conduct research into: (a) improvement and maintenance of the quality of bulk of export commodity crops including cocoa, groundnuts, palm produce i.e. (kernel and oil). (b) Improvement and maintenance of the quality of local food crops including

cereals, pulses, tubers and any other local commodity under bulk storage. (c) Special studies such as stored product pests, pesticide formulations and residues, and mycotoxin surveys. (d) provision of advice and training of extension workers in problems associated with stored products and materials used in storage and pest control including storage structure, new insecticides, new items of equipment and new techniques; and (e) any other related matters as may be determined from time to time by the National Science and Technology Development Agency.

MODUS OPERANDI OF THE INSTITUTE: As stated earlier, the Institute has branches covering all the climatic zones in Nigeria because storage problems are more related to climatic zones than any other parameter.

Investigations are carried out on all the crops enumerated above to find the causes of deterioration during harvesting, handling and storage with a view to evolving economically sound methods for reducing or eliminating the substantial losses to which harvested crops are prone under tropical conditions. The different disciplines involved are entomology, microbiology, and chemistry, zoology (rodents mainly), storage physiology and storage engineering. An interdisciplinary approach is employed in investigating the storage problems. Also, priority is given to most pressing or urgent problems.

From the beginning of the work on stored products, much emphasis was laid on practical demonstration. From 1956, an Annual Report was issued giving brief accounts of the research work and other activities of the Institute but in 1960 the Annual Report was expanded to include more detailed reports of research. This system continued with reprints of technical reports being made available for distribution. In all 265 technical reports have been printed together with 46 in other Journals.

Research into Stored Product Entomology has followed the following procedure over the years: (a) Work starts with the survey of insect pests of the commodities. They are identified and classified into order of importance in relation to such commodities.

(b) The biology and ecology of the important pests on each commodity are studied. This gives an idea of when they can be present and at what time to apply control or preventive measures in storage.

(c) Studies are carried out on insecticides that can be used to control the insect infestation. This starts with laboratory trials and if found promising, followed by large scale trials in the field or stores or in silos.

(d) When the facilities are available or in liaison with other research organisations insecticide residues from the large scale trials are analysed. This is to follow the rate of breakdown to permissible residue levels.

(e) The effect of the insecticides or conditions of storage on the food constituents, and other parameters such as viability and organoleptic acceptance etc. is studied.

(f) After all these studies have been satisfactorily carried out, recommendations on insect pest control measures are made.

The highlights of our research results can be found in our Annual reports referred to earlier.

TRANSFER OF INSTITUTE TECHNOLOGY TO USERS: The past and present systems in use on storage and pest control on groundnuts and cocoa are based on N.S.P.R.I.'s advice exclusively, supported by ongoing training of Produce Inspection and Pest Control personnel given by N.S.P.R.I. at the request of state Authorities concerned. The training includes practical demonstrations and courses in storage technology primarily for workers involved in pest control in both private and public sectors. No treatment is allowed other than those recommended by N.S.P.R.I. All the the Federal and state pest control teams were set up by N.S.P.R.I. Grain Storage at state level is carried out in warehouses and the Produce Inspection Divisions are charged with the quality control responsibilities. All storage and pest control recommendations are made by the Institute. Assistance with storage problems is also given to the National Grain Production Company. Farmers and Village Communities in the five South-Western States are storing maize, using a method recommended by N.S.P.R.I.

SPECIFIC RESEARCH RESULTS THAT HAVE BEEN APPLIED ARRANGED ACCORDING TO COMMODITY AND IN CHRONOLOGICAL ORDER:

1. Groundnuts:

Year	Production
1956	The use of Sizalkraft paper for dunnage to replace husks was extended and it was shown that its universal use on the plinth of groundnut pyramids saved 50,000 per annum in the form of improved quality compared with use of husks.
1957	Malathion was introduced as spray for groundnut pyramids and proved more effective than Lindane.
1961	Malathion was dropped for use on groundnut pyramids because of resistance by *Tribolium castaneum*, the major pest.
1963	The shape of groundnut pyramid was changed to facilitate fumigation with Methyl Bromide. Better distribution of gas was found and the new shape became standard.
1964	The use of standard fumigation covers to fit the standard pyramids adopted was introduced after being found satisfactory.

1964	Polythene sheets were successfully used as dunnage for groundnut pyramids and put into practice with effect from 1964/65 season.
1966	The use of warfarin rodenticides at the groundnut pyramid sites was recommended after investigation.
1968	Phosphine was introduced for fumigation of groundnuts at Port after research investigation.
1968	Expertise gathered by work on Aflatoxin contamination of groundnuts started to be put to use in support of international negotiation.
1970	Iodofenphos was tested and found suitable for use on warehouse walls to control *Trogoderma granarium* on groundnut cake at port. Recommendations are adopted up to the present.

2. Cocoa:

Year	Production
1957	Termination of misting of cocoa warehouses with pyrethrins caused by no useful effect being discovered.
1957	D.D.T. was adopted for spraying walls of cocoa stores during moratorium period between seasons.
1958	Use of methyl bromide as a standard procedure was adopted after studies and advice.
1963	Revised standard system for fumigation of large stacks of cocoa was adopted after testing by N.S.P.R.I.
1967	Standard fumigation technique for use of methyl bromide at new cocoa warehouse at Ikeja worked out by N.S.P.R.I. and was adopted by the State Produce Inspection Division.
1970	Recommendation for use of DDT on walls of cocoa warehouses in the moratorium period was abandoned and tetrachlorvinphos substituted after tests by N.S.P.R.I.

3. Grain Storage:

Year	Production
1969	Investigations on use of plastic envelopes to enable fumigation of grain stored in warehouses and the embedding of the sheet in insecticide dust were successful, and began to be put into practice. Fumigation is with Phosphine or Methyl Bromide.
1969	Work on crib storage of maize and pest control resumed and used in supporting extension work in local villages. This has been going on with more and more villages using correct techniques for applying Lindane to cribs for protection against insect pests

and correct crib design to prevent rodent attack and aid drying. Safer and more effective organophosphorus insecticides are now being introduced. The work has spread to five states already. Demonstration cribs are now being constructed in various parts of the Federation and the Institute's involvement in extension work is to be expanded.

Better storage of grains and pulses in Nigeria is coming about as a result of publications based on research results disseminated by Annual Reports, brochures, radio, television broadcasts in both English and Vernacular, visits to storage sites and practical demonstrations to farmers and extension workers of State Ministries of Agriculture, traders and industrialists. It is now possible to store grains and pulses for longer than a year. Many food packaging industries have been established with the help of N.S.P.R.I.

However, a number of research results have not led to practical recommendations but have provided background information in which to gain wider experience so that N.S.P.R.I. experts can discuss cocoa storage, groundnut storage, village-level grain storage, pest control, yam storage etc. at conferences and meetings in Nigeria and overseas.

This expertise so improved leads to more meaningful practical recommendations when the need arises.

FEEDBACK: The institute has several sources of feedback to evaluate its recommendations and formulate new programmes of work. Some of the sources are as follows: (a) Overseas complaints on export crops to Federal Ministry of Trade are referred to the Institute for investigation. Similar complaints have been investigated for the Ministry of Health. (b) Problems of international trade are referred to the Institute through our representation on Scientific and Technical Committees of the African Groundnut Council and the Cocoa Producers Alliance. (c) Problems are brought to our attention by the United Kingdom Produce Inspection Service and the Tropical Products Institute in London. (d) We are approached directly by State Produce Inspection Services, Ministries of Agriculture, the Ministry of Trade, the National Grain Production Company and the Commodity Boards when storage problems arise. (e) Organisations involved in storage and pest control work and interested University departments and Institutes are invited to our work programme review committee meetings when new problems can be discussed. (f) Surveys of existing storage sites, facilities and techniques and visits to farmers are made from time to time by N.S.P.R.I. officers when problems are discussed and

and advice given or new research proposals suggested. (g) N.S.P.R.I. participated in the preparation of the F.A.O. Action prgoramme for reducing post-harvest food losses, so as to implement the resolution of the seventh special session of the United Nations General Assembly of September 1975 which set a target of a 50% reduction of these losses by 1985. (h) We are approached by various companies or their prospective customers to test their products.

Despite several limitations of N.S.P.R.I. I have tried in this paper to give in broad outline the role N.S.P.R.I. has been playing for the past thirty years to improve the storage and protection of tropical crops. We have always realized that storage is a key factor in agricultural production and processing. An effective storage technique has helped in stimulating voluntary increase in agricultural production because the farmer is sure that his surplus crop will not go to waste. So also, effective storage has stimulated establishment of viable agricultural processing industries because the investor has seen that he can have steady supply of high quality raw materials throughout the year thereby keeping his labour force and machinery busy throughout. The consumer is happy too with the good quality food he buys throughout the seasons, and with the reduction in fluctuation of prices. With all these desirable effects of good storage techniques, N.S.P.R.I. is aware of the arduous task before it and if supplied with all the necessary resources we would continue to fight the pests that are attacking our stored products. Thank you.

LOSS ASSESSMENT METHODOLOGY - THE CURRENT SITUATION

R. A. BOXALL, P. S. TYLER, AND P. F. PREVETT
Tropical Products Institute
Tropical Stored Products Centre
London Road
Slough, Berks, ENGLAND

INTRODUCTION: The Seventh Session of the United Nations General Assembly, meeting in 1975, delcared the intention to strive for 50% reduction of post-harvest losses by 1985. However, the Assembly omitted to define what losses it required to be reduced by half. It is hardly surprising that the meeting could not give guidance since it is unlikely that it was in possession of reliable estimates of losses on which to base its intention.

We consider that it is timely therefore to devote attention to the subject of post-harvest losses in this conference. As stored product entomologists we cannot fail to recognize the potential and actual damage that major beetle and moth pests cause to cereal and pulse grains. It is a far more difficult task to interpret this damage in realistic terms of loss. We see the purpose of this session as having the following objectives:

Firstly to consider the available data on post-harvest losses and its relevance.

Secondly to consider some of the problems involved in the estimation of losses (such as having agreed definitions of loss and an agreed methodology),

Finally we think that we should consider how we can and should use loss assessment as the means for obtaining realistic evaluation of loss reduction programmes.

For example, whilst numerous references to examples of losses can be quoted, very few have been obtained as a result of comprehensive surveys. As a consequence their validity and relevance is questionable. Frequently the figures quoted are either an upper extreme or an unqualified average. In neither instance do they take into account the representativeness of the data obtained or its reproducibility. The justification for the use of remedial measures such as pest control to reduce losses must therefore be in doubt.

OBJECTIVENESS IN LOSS ASSESSMENT: A recent bibliography on post-harvest losses in cereals and pulses with particular reference to tropical and sub-tropical countries (1), considered that of 126 field estimates of loss only 11 were complete estimates, that is providing the reader with sufficient information on the methods employed to enable a decision to be made about the reliability of the estimate. Most of these were also limited to a study of one aspect of the post-harvest system and data on which to base loss reduction inputs was frequently lacking.

Indeed, a major criticism that can be made of many surveys is that objectivity was lacking. For example, on-farm losses recorded at one period during the storage season will not give an indication of overall losses throughout the year. If the objective is to know what losses farmers are suffering then a study over the whole storage season is vital. Also, such a survey must be seen from the viewpoint of the person suffering from the loss. It will be found that a relatively large loss in times of plenty may be quite acceptable to the farmer whereas he would regard even a small loss in times of shortage as serious.

Isolated measurements of loss, for example the much quoted global figure of 10% for post-harvest losses of cereal grains to insects after harvest, may serve as a preliminary indicator to draw the attention of administrators and others responsible for post-harvest matters to the fact that some loss is occurring - and the need for more detailed study. Single observations, especially where insect damage is involved, do not enable the losses to be put into any form of perspective and using such figures it is quite impossible to decide the nature and scale of priorities for a programme to reduce the losses. Only once the whole post-harvest system (from threshing through storage and to processing) has been fully understood can accurately determined estimates of losses of grain be realistically related to the system. The figure obtained (whether for high or low losses) can then be used in the determination of priorities for loss reduction work in a positive way.

Moreover, when remedial measures have been introduced subsequent measurements of loss made using the same technique will enable the effectiveness of the remedial measures to be determined. Repeated measurements can be used to provide permanent monitoring of a potential loss situation and can be used as an indication of the efficiency of the system or process. The loss measurements must be undertaken with a positive aim in view - that of loss reduction. Too often this has not been done.

DEFINITIONS OF LOSS: The methodology to measure post-harvest losses is of necessity complex because consideration has to be given to the assessment of the various causes of loss at all stages throughout the post-harvest system. Storage is but one part of this system in which losses are finite and, unlike growing crop losses, cannot be made up by further plant growth.

There have been many attempts to define the term "loss" and much confusion has arisen since "loss" has frequently been used synonymously with "damage". Loss is a measureable decrease of the foodstuff which may be quantitative or qualitative. It is difficult to categorize loss. However the following categories are listed for convenience and should not be regarded as exclusive. In any assessment of losses, it will be necessary for the investigator to draw up his own definition of loss relevant to his specific situation.

TYPES OF LOSS: 1. Weight loss - Reduction in weight is obvious but it does not necessarily indicate loss - it may be due to reduced moisture content and this is often recognized in commerce by a shrinkage factor. Weight loss may result from the feeding of insects, rodents and birds or from spillage. The latter may be due to handling or the activities of pests.

Moisture changes may lead to an increase in weight and in some cases production of water by an insect infestation may partly offset the weight loss.

Let us consider an example: if we compare the weight of a sack of produce before storage with its weight after storage, any reduction in weight may be described as the apparent loss. However during this period of storage the moisture content of the commodity may have changed and insects may have consumed some of it, producing non-edible dust, frass, etc. Since additional moisture and the non-edible results of insect attack do not constitute food they form part of the true loss. So, the true loss = apparent loss + change in moisture content + non-edible material.

2. Loss in quality - Quality of produce is assessed in different ways according to the circumstances considered important by the local population and traders concerned. Generally quality is assessed and products graded on the basis of appearance, shape, size, etc., but smell and flavour are sometimes included. Foreign matter content and contaminants are factors in loss of quality. Foreign matter may be in the form of insect fragments, frass, rodent hairs and excreta; weed seeds, part of plants, earth, stones, glass, etc. Contaminants cannot be readily removed; they include soluble excretions of pests, oils, pesticides, pathogenic organisms spread by rodents or insects and toxins arising from fungal infections. In particular instances chemical changes may be important, e.g. in oilseeds. Infestation in groundnuts may cause an increase in the free fatty acid level leading to rancidity in the oil; similarly in maize meal.

3. Nutritional loss - This, in a sense, is the product of the quantative and qualitative losses; but more specifically, it is the loss in terms of nutritional value to the human population concerned which, in turn, will depend on the nutritional status of that population.

Weight loss during storage (not due to a loss of moisture) is a measure of food loss but the latter may be proportionately larger owing to selective feeding by the pests. Rodents and moth larvae may preferentially attack the germ of the grain thus removing a large percentage of the protein and vitamin content, whereas weevils feeding mainly on the endosperm will reduce the carbohydrate content. Many pests may eat the bran of cereals reducing vitamins such as thiamin. Other storage factors such as moisture and fungal infection also lead to changes in vitamin content. In beans in particular, loss of protein is very important where there is bruchid infestation, as up to 25% of the dry matter may be crude protein.

4. Loss of seed viability - This relates to loss in seed germination which is important for its effect on future food supplies. Seed grain is usually more carefully stored than food grain owing to its greater potential value. Loss may be caused by changes of light, temperature, moisture, excessive respiration, infestation and, in some cases, the methods used to control infestation. Insects that selectively attack the germ will cause a greater loss in germination than others.

5. Commercial losses - Commercial losses may be a consequence of any of the foregoing factors (1-4) or be the preventive or remedial actions required, as well as equipment costs. For example, any control measure that has to be employed to render or keep the commodity saleable can be counted as an economic loss and this is perhaps the most easily accountable loss. Also the indirect consequence of loss may be encountered where measures have to be taken to prevent loss of goodwill or to cover legal actions arising from the marketing of commercially unacceptable commodities.

THE MEASUREMENT OF LOSSES: Recent reviews by TPI (2) and FAO (3) to determine the extent of available information on post-harvest losses in cereals have demonstrated a lack of standardization in both the terminology and methodology applied to loss assessment. Secondly there was inadequate information relating to specific sectors within the post-harvest system, particularly in relation to certain geographic areas. There was clearly a need to develop a suitable methodology for those aspects on which information was both inadequate and lacking. What progress has been made?

A manual of methodology to be used for post-harvest grain loss assessment has been prepared by the American Association of Cereal Chemists and the League for International Food Education (AACC/LIFE) Project on Post-Harvest Grain Losses. A draft of the manual has already been widely distributed and was in fact presented to delegates from 31 developing countries attending the TPI Seminar on Post-Harvest Grain Losses held in London during March 1978. In its conclusions, the meeting recognized "the importance of loss assessment using a standardized methodology in the identification of areas for loss reduction activities and for monitoring the effectiveness and economic value of these activities".

Since that meeting the manual has been revised and this version will soon be available; although it is inevitably lacking in some aspects we feel that it provides an acceptable basis to guide those intending to conduct loss assessment field studies. By adopting this methodology the results obtained will be more reliable and comparable than has hitherto been possible.

ASSESSMENT OF STORAGE LOSSES CAUSED BY INSECTS: Let us now consider in more detail the standardized methodology for assessment of storage losses. The need for adoption of satisfactory survey and sampling methods is essential but this is outside the scope of this paper. We shall concentrate on the principal agent causing

loss in storage, namely insects. A methodology for determining loss by insects is particularly well developed. The methods recommended are of three basic types. The first and most accurate involves the determination of the weight of a measured volume of grain. The volume occupied by the same number of damaged or undamaged grains will be the same but the weight of the former will be less. The loss in weight in samples taken over a known period of time compared with a baseline sample taken at the beginning of the storage period is a reflection of losses caused by insects and, to a lesser extent, micro-organisms and other factors.

The method of obtaining the volume attempts to eliminate variations in packing, but with grain samples containing very high levels of damage, some of the grains may become crushed and lead to inaccuracies. Small grains may be sieved or winnowed out and lost from the sample.

The weight of the standard volume is also affected by variety and growing conditions. In addition, moisture content changes will affect the weight but this can be allowed for by measuring the moisture content and correcting to dry weight.

This is the ideal method but it is often necessary to make loss estimates in the middle of the storage period when no baseline has been previously determined. Under these circumstances the standard volume/weight method may be used but with an artificial baseline obtained by selecting undamaged samples from the grain present in the store at the time of the loss determination. The loss is then the difference in weight between the undamaged and damaged sample.

Unreliable results may be produced if, during the selection of undamaged grains from the stored grains there is internal infestation, preferential feeding and egg deposition by insects in grains of different sizes, or a difference in moisture contents. These errors can be reduced as much as possible by taking large random samples.

A simpler method using only hand counting and a balance has been described by French workers(4), whereby the grain sample is separated into damaged and undamaged portions according to the cause of the damage. Grains in each portion are counted and weighed, the resultant data being substituted into a formula to give percentage weight loss.

This method assumes that insects choose grains at random which may not be true. It also does not account for hidden infestation, because grains containing such an infestation are classed as un damaged. Both these factors cause misleading, even negative, results at very low levels of infestation. At very high levels of infestation misleading results occur because of multiple infestation in such large grains as maize, beans and some sorghums. However it is a useful quick field method if allowance is made for the problems occurring at the extremes.

Attempts have been made to overcome the problem of hidden infestation by dissection to establish the undamaged fraction, but

this is tedious and all calculations need to be done on dry weights as moisture contents change during the procedure. Other simple methods of determining hidden infestation also suffer from problems of grain destruction and moisture content changes.

A third and simple method of estimating weight loss which can be used in the absence of weighing facilities involves separating the sample into undamaged and damaged grains but only counting the grains in each portion. The percentage of damaged grains may be converted into an approximate percentage weight loss by multiplying by a predetermined factors, e.g. for sorghum damaged by a major grain boring insect multiply the percentage of damaged grains by $\frac{1}{4}$, for shelled maize by 1/8th. This loss determination is only applicable when the damage has been largely done by insects which leave a clear exit hole in the grain (*Sitophilus*, *Sitotroga* and *Bruchidae*).

Unfortunately the method is complicated in the larger grains by multiple infestation leading to several emergence holes per grain and variation in the weight loss per grain. This could be avoided by using number of emergence holes per 100 grains instead of percentage damaged grain.

ESTIMATION OF TOTAL LOSSES: Due to Insects - An important consideration in making loss estimations is to relate losses in a sample to the pattern of grain consumption. If a whole consignment of grain remains undisturbed throughout the storage period and at the time of removal the estimated loss is 10%, then this represents the total loss due to insects over the storage period. However in most cases, and particularly in farm stores, grain is removed at intervals during the storage period and each quantity removed will have suffered a different degree of loss since it will have been exposed to insect infestation for different lengths of time. Allowance has to be made for this factor when determining the total estimate of loss. A similar procedure is followed when assessments of loss by fungi and by rodents are carried out.

Losses caused by fungi - Although the above methods were formulated with insect damage in mind, they are equally applicable to fungal damage. A considerable proportion of the grain rejected by the farmer is often discarded because of mould and the presence of infected grain causes a drop in quality grading. Therefore the impact of fungal infection on loss can be estimated by including the separation of mould damage from other types of damage during the analysis.

Losses caused by vertebrate pests - Losses caused by vertebrates such as rodents and birds are difficult to assess directly since whole grains are frequently removed from store. Vertebrate pests are usually blamed for all losses that cannot be accounted for in any other way. Some attempts to estimate losses have been made using population censuses and feeding trials, but with limited accuracy in relation to the effort expended. Both pests utilize stored food as part of their diet only, so feeding trials may over-estimate the consumption of stored food.

LOSS ASSESSMENT AS PART OF LOSS REDUCTION: Loss assessment forms an important and necessary part of any loss reduction programme. It serves as a means of justifying and evaluating intervention methods to reduce loss and will enable cost/benefit ratios to be determined.

Improvements intended to reduce losses have often been introduced in ignorance of the nature, type and true cause of loss or of the acceptability of the new measure. Also they have been introduced either at the most prominent or the most readily accessible point in the system. This is often because of an outside pressure such as the availability of a particular input, of funds to provide the input, or because of the need to have a project completed within a limited time scale, or simple local politics. Sometimes only concurrent with or even after the introduction of the loss-reducing procedure there has been an evaluation of its effectiveness for reducing losses. Too many schemes based on these lines have subsequently been proved unacceptable or inappropriate having made little contribution to the reduction of loss in the short-term and none in the long-term.

With prior knowledge obtained from an assessment of losses in the whole post-harvest system, such disasters can be avoided. For example, with subsistence farmers having limited resources and ability, only extremely modest measures for reducing losses are appropriate. These might be: encouraging the wider use of simple modifications to traditional storage structures to incorporate design features already found to be satisfactory in some stores (in humid areas particularly to aid drying); encouraging the use of effective traditional pest control methods and improving store hygiene (thereby reducing risk of cross-infestation). Where such simple modifications and improvements can yield an adequate benefit (which satisfies the farmer) then they should always be tried first, even in areas where more complicated techniques and greater changes might be acceptable.

Where the traditional farming pattern has been disturbed and the farmer has demonstrated an ability to accept new concepts (particularly following the introduction of improved cultivation methods and new crop varieties), some adaptation of the storage procedures may be essential if losses are to be minimal. To the farmer who has adopted better cultural methods the wisdom of also improving storage may be readily appreciated. For example it may be considered desirable to improve the basic design of a store and to incorporate modern building materials or to introduce synthetic pesticides. In order to do this satisfactorily the shortcomings of the existing system in relation to how they result in loss must be determined and the appropriateness of candidate improvements obtained.

Alternatively the procedure for reducing loss can involve a drastic change away from the traditional home storage practice whereby grain is passed by the farmer into some form of centralized storage. At the primary marketing level (traders, cooperatives,

produce boards), a different set of criteria for assessing loss may apply. The produce clearly has an accountable cash value and the total weight of grain received is usually known. A sampling system should be applied and the criteria for acceptance of grain should be well defined. Store management will have responsibilities for ensuring that bookkeeping procedures are adhered to. By making use of these measurements a more precise assessment of loss can be made. Decisions as to the appropriate remedial measures and an evaluation of their effectiveness for reducing loss are more easily determined.

FUTURE WORK: Taking stock of the current situation regarding post-harvest losses, we suggest that the important aspects can be summarized as follows:

1. Hitherto most assessments of loss have been made in isolation and without cognizance of the true significance of the loss in relation to the post-harvest system affecting the grain. More attention needs to be paid to obtaining meaningful data and evaluating it realistically. The reliability of the results obtained needs to be openly discussed.
2. The methodology is often inadequately described. There is need to use agreed methodology wherever possible and to publish full descriptions of techniques used and assumptions made.
3. A major criticism of loss reduction programmes has been that they cannot be justified in economic terms. Loss assessment provides the means whereby losses may be determined both before and after remedial measures are introduced.

More use must be made of the methodology to enable us to more closely assess the value of our pest control programmes where they are aimed at loss reduction.

REFERENCES

(1) ADAMS, J.M. A bibliography on post-harvest losses in cereals and pulses with particular reference to tropical and sub-tropical countries. Rep. Trop. Prod. Inst. G.110 (1977).

(2) ADAMS, J.M. A review of the literature concerning losses in stored cereals and pulses published since 1964. Trop. Sci. 19 1 (1977).

(3) UN:FAO. Analysis of an FAO survey of post-harvest crop losses in developing countries. AGPP: MISC/27 (1977).

(4) ANON. Rapport d'activite de la commission d'evaluation des pertes dans les denrees stockees cree a l'issue du congres de Marseilles sur la protection des cultures tropicales. Agron. Trop. 24 9 (1969) 872.

TROPICAL STORAGE ENTOMOLOGY BY THE END OF THE TWENTIETH CENTURY

T. AJIBOLA TAYLOR
Institute of Agricultural Research and Training
University of Ife
Moor Plantation
P.M.B. 5029
Ibadan, NIGERIA

INTRODUCTION: The twentieth century in the tropical regions of the world has largely been characterised principally by a rapid explosion in human population and a decline in the quantity and quality of food available for consumption. In the developing countries, in particular, there is now a widening gap between total calorie and protein requirements of human and animal populations and some scientists have even gone as far as predicting a catastrophic shortage in human food by the end of the century. Comparison of food consumption patterns of developed and underdeveloped countries show great disparities not only in per capita calories consumption but also in the ratios of carbohydrates, fats and proteins and the sources and quality of proteins. These characteristics manifest themselves in terms of hunger, malnutrition and what Ruthenberg (1) refers to as 'harmonious undernourishment.' Poverty and malnutrition are therefore still largely characteristic of tropical countries where even the 0.2% excess rate of growth of food production over population increase recorded in the 60's have not been sustained in the 70's and the optimism of food production and the green revolution seem now to be even more elusive. A more complex picture evolves when we realise that in the period 1850 to 1950 the world population doubled and that the figure of about 3,500 million in 1970 indicates that it would take perhaps only 35 years for the next doubling to occur. But in fact the population doubling in the developing countries is likely to take about 24 years because of the rate of population growth of 2-3% in contrast to 0.5-1% in the developed and industrialized countries of the world. With about 7,000 more people every hour and over 160,000 everyday, in all probability there will be 6,000-7,000 million in the world by 2,000 A.D.

The state of food and nutrition in relation to this phenomenal and reasonably certain world increase in population is often considered in terms of increases in agricultural production to be achieved through the extension of cultivated areas, the improvement of genetic potential of crop plants for increased productivity, and increases in yields per unit area of cultivation (2). These three well-publicised cornerstones of the 'Green Revolution,' however, fail to take into cognizance the urgent and pressing need for the conservation and preservation of the harvested crop. It is obviously erroneous to assume that all the increase in food production would reach the consumer when we are fully aware that storage losses ranging from as little as 2-5% in

some developed countries to over 30% in many developing countries occur. It is therefore faulty strategy to attempt to increase yields by a factor of 5-10% through massive scientific and technological inputs in crop production only to lose 20% of the crop during handling and storage. Estimated annual world losses in maize, a major cereal staple in most countries of the tropical world, provide a good example of the extent of the severity of losses due to insects and other agents (Table I).

TABLE I. Estimated annual world losses in maize (millions of tons).*

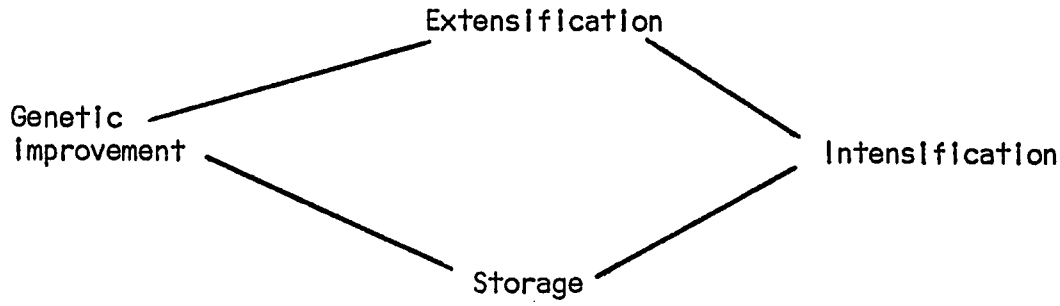
Region	Production		Losses		Total
	Actual	Potential	Insects	Diseases	
North and Central America	102.9	144.7	16.9	13.6	30.5
South America**	19.1	31.8	6.3	3.2	9.5
Europe	28.3	32.9	6.3	3.2	9.5
Africa**	14.9	47.5	9.5	6.5	16.0
Asia**	16.5	26.2	2.6	3.1	5.7
Oceania	0.2	0.2	0.01	0.01	0.02
USSR and China	36.5	56.1	7.0	5.2	12.2
World Totals	218.4	339.4	44.0	32.6	76.6

* Source: H. H. Cramer (1967): Defensa Vegetaly Cosecha Mundial Bayer. Pflanzenschutz Leverkusen p. 179.

** Developing countries.

Losses due to insects in monetary terms range from about 5% in Europe to about 20% in Africa and South America and although some of these losses are field losses a substantial part of these are storage losses which according to Wheatley (3) range from 3.6 per cent to 23 per cent and amount to about 2 M ton/year. Such losses or even more severe losses are recorded in the whole range of agricultural produce, including other cereals, yams, cassava, grain legumes, pulses and other major commodities produced in tropical countries. It is, therefore, clear that the solution to the food and nutrition problem of the developing countries lies

not in the triangle of 'Green Revolution' but in a diamond in which storage forms a fourth important and crucial cornerstone.



STORAGE PRACTICES AND THEIR EVOLUTION: Attempts to store and preserve agricultural produce are nearly as old as agriculture, although major strides were only made in the last few decades. It is now a far cry from the era when the infestation and consequent deterioration of agricultural produce was regarded as inevitable, and commodities were thought to 'generate life.' Storage entomology has not only shown that the most important agents of deterioration during storage are insects, mites, fungi, bacteria, rodents and other vertebrate pests but has emphasized that deterioration and losses may set in the produce which appear uninfested at harvest but often have undetectable pre-harvest infestation which serve as the nucleus of post-harvest and storage losses. The conditions of the produce at harvest and the environmental conditions of post-harvest handling and storage have also been shown to have a major impact on losses due to microorganisms and vertebrate pests. Storage practices have therefore evolved to create conditions for the disinfestation of produce, the prevention of deterioration and reinfestation and the preservation of the quality of produce during periods of storage which may vary from a few months to a number of years depending on the purpose of storage and the nature of the commodity.

Storage under tropical conditions is hazardous because of the climatic conditions, the physical characteristics of commodities and facilities available for adequate disinfestation and preservation. The high ambient temperatures (25°-35°C) and humidity (70% or more) accelerate the growth and multiplication of the various agents of deterioration and often contribute to the inefficiency of traditional methods of storage that have been evolved. The physical characteristics of the commodities often make them susceptible to biodeterioration by a range of organisms; for example, high moisture content (20-30%) which is often encountered in tropical maize after harvest leads to deterioration by fungi and attack by *Sitophilus* and other insects. Adequate drying therefore has to form an integral part of post-harvest handling and storage in all storage practices in the tropics. Facilities available for adequate disinfestation and preservation often depend on the value of the crop, the accessibility of the

farmer to the necessary capital for improved structures and other inputs and the availability of such imputs. All these are in contrast to conditions in some temperate and semitemperate countries where as indicated by Watters (4) few grain storage problems are experienced because of the cold winters and well-developed bulk handling systems.

In the main, storage practices in the tropics have evolved through traditional methods which depend largely on physical factors such as natural drying, storage and preservation in simple structures with little or ineffective provision for the prevention of reinfestation and the preservation of quality, and little or no use of pesticides. Hence in many parts of the developing world, storage practices involve traditional structures such as simple wooden platforms, storage baskets, timber tripods, vertical or horizontal poles or racks, varieties of cribs made from wooden or grass materials, 'rhumbus,' pots or other earthen containers, gourds and other types of granaries. These structures and practices are largely ineffective in the prevention of deterioration of stored agricultural produce. Under such conditions, Taylor (5) indicated that losses due to insect infestation, biodeterioration by microorganisms and rodent damage are considerable. Until recently, very limited inputs of pesticides for safe disinfestation of produce were used but recent developments which combined improvements in the designs of cribs and storage bins with the wise use of pesticides such as lindane, malathion, pirimiphos-methyl and synthetic pyrethrins show great promise for the future. In particular, successes that have been achieved in incorporating these grain disinfestation and protection methods into traditional storage practices in Nigeria, Kenya, Zambia, India and many other countries in tropical Africa are now beginning to have major impact on the reduction of losses at the farm level and therefore on the economy and nutrition of the small farmer. Surveys in some developed countries, for example, in England and Scotland (6), in the last decade also showed increases in the use of malathion and fenitrothion for the protection of stored grain and old and new rodenticides for the control of harmful vertebrate pests; this trend is likely to continue and be strengthened in the rest of the century. These developments indicate that future strategies should focus attention on the application of storage and protection technologies at the farm level, since most of the losses occur at this level, at the level of the handling and distributing agents and, as medium and large scale production develop, at the major bulk storage centres where highly efficient and sophisticated systems of drying, disinfestation by fumigation, and storage can be employed. Such applications at these various levels of storage, handling and distribution are destined to make considerable impact on the quantity and quality of available food and other agricultural produce in the last two decades of this century.

AGRICULTURAL PRODUCTION AND MODERN STORAGE TECHNOLOGY IN THE NEXT TWO DECADES: The present trends in agricultural production patterns and systems and the displacement of populations from the rural to urban areas seem to indicate that in the remaining two decades of this century decreasing percentages of human populations are likely to be directly involved in farming, small farms are likely to give way to medium scale and large scale farms, and the storage of agricultural produce is likely to evolve along the lines of greater coordination and cooperation in the use of modern techniques of disinfestation and storage. Already in many developing countries, the percentages of agricultural workers are going down from 60-70% of the total working force to 40-50% and greater efforts are going into the organisation of coordinated and centralised storage systems which would receive surplus agricultural produce and utilize modern techniques of storage to ensure their preservation and release into the marketing channels as and when necessary. Although this trend is likely to continue and be strengthened in the immediate future, it must be realised that it would depend on a fundamental understanding of the role of the farmer, small or large scale, in the first stage handling and disinfestation necessary to ensure that produce delivered to medium and long-term storage depots do not constitute foci of infestation and deterioration of the bulk of stored items. In other words, clear guidelines which now form the basis of on-farm disinfestation and handling of agricultural produce should be retained and strengthened and the inputs necessary for their observance ensured at the farm level.

Considerable progress appears to have been made in the organisation of such network services, for example, in Kenya and Zambia, where maize represents a major staple in the diet of the people. The result is that when adequate precautions are taken in accordance with the established practices of farmer, depot and warehouse handling and disinfestation, the quality of the stored maize even after many months of storage remained high and losses are kept to the minimum. The success of the system can be seen to depend largely on the efficiency of the delivery systems of necessary inputs such as insecticides, jute bags, etc., effective communication and rapid delivery and handling and the use of modern techniques of drying, fumigation and bag treatment, and storage in well-designed warehouses and silos. In Kenya, these are guaranteed through a network of District and Central Depots with facilities for grading, drying, fumigation and storage in warehouses and bins. Even here, the farmer's role is considered crucial because of the need to halt pre-harvest infestation by treatment with malathion or lindane before delivery to the depots. Fumigation with methyl bromide or phosphine, or bag treatment with insecticides combined with store hygiene maintain the quality of the produce whilst in the district or central depots.

A modification of such a coordinated and centralised system is operated by the NAMBoard in Zambia. The focus of grain

collection in this case are the Rural Depots and the Rail Line Depots to which produce are delivered by farmers as soon as possible after harvest. The depots serve dual functions of receiving grain and supplying inputs for stimulating production, including fertilizers, pesticides, herbicides, jute bags, etc. Here also efficient transportation and communication is important to ensure early evacuation of produce to larger central depots where fumigation and storage take place in silos or on hardstandings under sheets. Provisions are made in all cases for fumigation or grain treatment at rural depots in order to avoid further deterioration in grain which on inspection show a potentially dangerous level of infestation. In Nigeria, where a programme for the handling and storage of 600,000 tons of grain as operational and reserve stocks is currently being implemented, a similar network is envisaged. The Agro-Service Centres which are being located within 20 km of individual farmers will serve as the depots not only for the supply of inputs, including pesticides, fertilizers, improved seed and technical advice, but also for the receipt and purchase of grains from small farmers. They will also serve to receive surplus grains from large-scale farms in the future. In this context and in other parts of the tropics, one of the major problems at such depots is likely to be the moisture content of grain at delivery, especially in the humid and sub-humid zones. It may, therefore, be necessary, as is the case in some parts of Kenya, to provide some rapid drying and handling facilities at some of the larger depots to ensure that the moisture content of the grain can be brought down to a safe 12% or less before storage in bags in warehouses or in silos. Details of some of these proposals for Nigeria and how they are expected to function in a changing agricultural economy are discussed by Taylor (7, 8). Such a network if efficiently operated in Nigeria is likely to improve the quality of agricultural produce and reduce storage losses to 5% or less. In addition, it will provide an avenue for the build up of reserve stocks that can be used during periods of drought, crop failure or other natural disasters and may even generate the beginnings of an external trade in grains and stored agricultural produce. These components in themselves have a major role to play in the world food problems of the rest of this century.

THE FUTURE: The last two decades of this century will be crucial in the efforts of man to expand and improve agricultural production and protection in order to feed itself at a level compatible with modern and acceptable concepts of social and economic welfare. The intensification of agricultural production must be matched with the pursuit and application of modern storage technologies if the gains to be realised by such intensification are to be maintained so that they could reach the consumer. Tropical storage entomology has many of the answers in terms of developed technology, organisation and relevant research. It is my view

that we may yet avert a possible food crisis before the end of this century and indeed close the food and nutrition gap and strengthen the economies of the developing countries of the tropical world.

REFERENCES:

(1) Ruthenberg, H., The world food problem. Appl. Sci. & Dev. 2 (1973) 7.

(2) Glaser, G., Food production and the 'Green Revolution' in developing countries. Appl. Sci. & Dev. 5 (1975) 124.

(3) Wheatley, P. E., Post-harvest deterioration - the maize storage problem in the less developed countries of Africa. Chem. & Industry Nov. 1973 (1973) 1049.

(4) Watters, F. L., Impact of research on grain storage practices in Canada. EPPO Bull. 4 (1974) 297.

(5) Taylor, T. Ajibola, Motivation and method in ensuring protection of tropical produce from grower to his market. Proc. 1st International Working Conf. Stored Prod. Ent., Savannah, Georgia (1974).

(6) Papworth, D. S. et al., Protection of stored grain and the control of harmful mammals on British farms. Inter. Pest Control Mar./Apr. (1975).

(7) Taylor, T. Ajibola, The ecology of large scale storage of grains in Nigeria. Proc. Ecol. Society Nigeria (in press) (1976).

(8) Taylor, T. Ajibola, Tropical storage entomology and the small farmer. Proc. XV. Inter. Cong. Ent., (1976) 673.

ECOLOGY AND THE INTEGRATED CONTROL APPROACH UNDER TROPICAL CONDITIONS

C. P. F. DE LIMA
National Agricultural Laboratories
Ministry of Agriculture
P.O. Box 14733, Nairobi, KENYA

INTRODUCTION: In most tropical countries more than four-fifths of the harvest is stored for subsistence in traditional granaries. The remaining 20 per cent is generally stored in large scale warehouses in urban areas and is handled by national grain agencies. The ecological conditions for pest development vary widely under these two contrasting conditions of storage and there are important differences between the pest fauna.

THE INTEGRATED CONTROL APPROACH: The study of the ecology of the pest complex in each situation is of special importance in the context of integrated control. Way (1) states that integrated control is "nowadays usually defined as involving the compatible use of a combination of appropriate methods of pest control." With growing crops in the field, integrated control in the above sense has found several applications and has resulted in less dependency on the use of chemical pesticides. In stored produce however, there are several difficulties to be overcome, the main one being that of the economic injury level. In affluent countries one insect in a packet of rice could be considered a pest at the economic injury level if the packet is rejected. In tropical countries especially in the rural areas there is a higher threshold of tolerance to insects in stored produce and to insect damaged grain. De Lima (2) estimated economic damage in subsistence storage by considering the cost of the insecticide treatment and the amount of grain that would be saved by its use.

CHEMICAL WITH PHYSICAL STORAGE METHODS: Physical barriers like the husk cover in maize, the pod cover in beans and the husk on paddy are often able to protect grain from damage by insects. It is necessary however that these physical barriers be intact but since only a fraction of the harvest normally has suitable physical protection, the rest of the harvest needs to be preserved by chemical or other means. A study of the pest population on maize with a poor husk, a good (intact) husk and without a husk showed (Fig. 1) that the intact husk was significantly able to protect the maize from pest damage. A comparison of chemical control to de-husked cobs (Table 1) showed that the intact husk with fumigation was as effective as fumigated de-husked cobs treated with a chemical dust in preventing damage to maize grain.

VALUE OF PARASITES IN STORAGE: In rural storage the possibility exists for the use of natural parasites for control of the pest

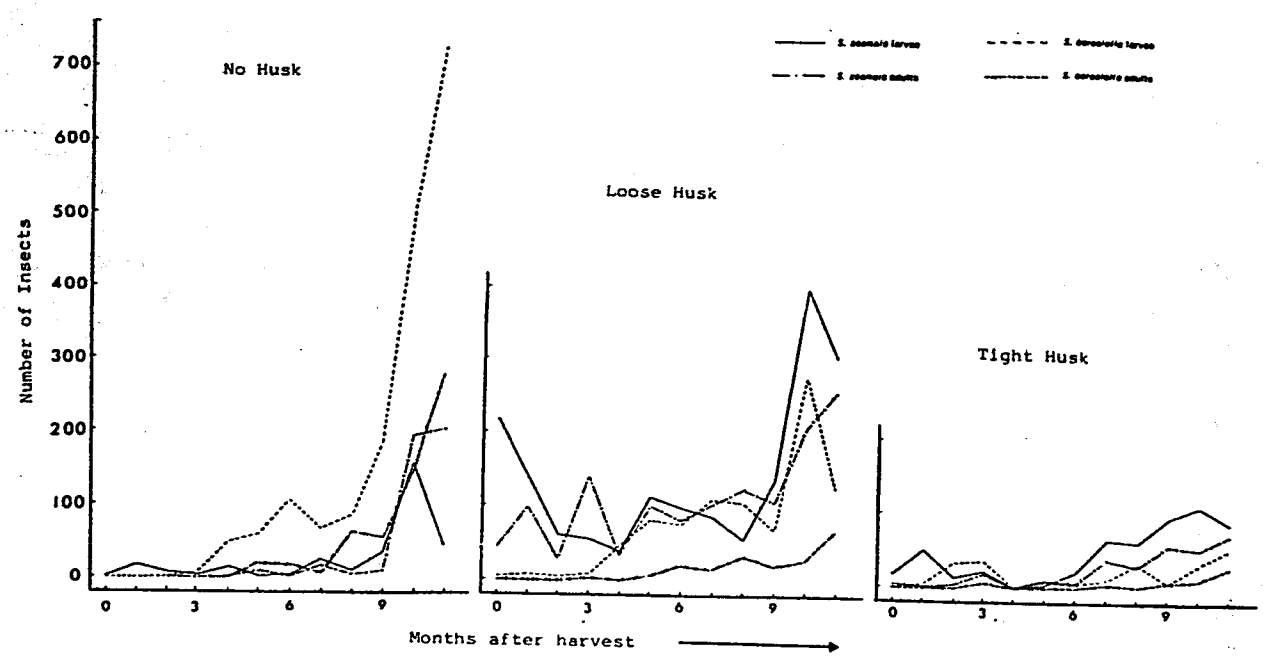


FIGURE 1. Control of damage to maize grain by use of the natural cover to physically exclude insect pests (1973-74 trial in Kitale).

TABLE I. Damage to maize in an insecticidal dust and fumigant trial in the 1976-77 storage season in Njoro (mean ± damaged ± standard error).

Time after treatment	Fumigation only	Fumigation + intact husk	Fumigation + malathion dust (10 ppm)	Untreated control (de-husked)
6 months	8.34± 1.04	1.83± 0.69	4.62± 1.30	37.60± 6.73
12 months	66.45± 3.46	18.37± 3.34	23.89±11.68	90.22± 2.10

population if these parasites are effective. This is because the subsistence farmer would tolerate some damaged grain as would occur due to dependence on biological control. Unfortunately insect parasites are generally ineffective and exert little control over the pest population. The percentage parasitism recorded in an ecological study on the pest fauna in traditional stores was extremely low and the parasites were not able to effectively control the host species. Figure 2, gives some

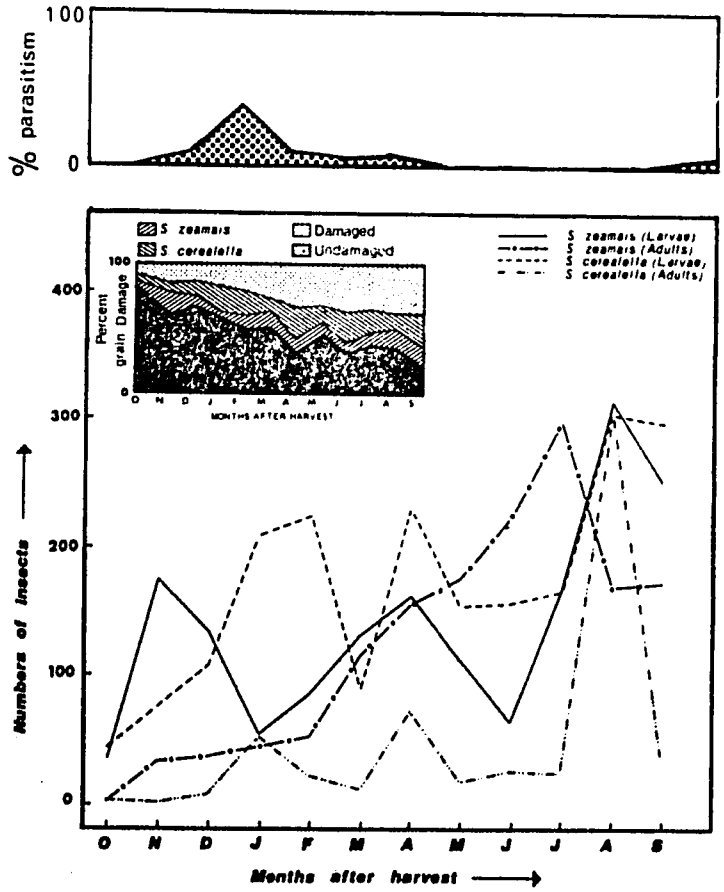


FIGURE 2. Effect of parasites on the development of a pest population in maize grain (1973-74 in Kisii).

information in one of the places, Kisii, where the highest levels of parasitism were recorded, and it was seen that even there the parasites were not able to reduce the pests and the proportion of the grain destroyed was extremely high. A search through the literature likewise fails to reveal any evidence of economic control from parasites in stored produce.

INTEGRATED CONTROL POSSIBILITIES IN LARGE SCALE STORAGE: As mentioned earlier, the possibilities for integrated control in large scale stores are difficult to achieve in the true sense of the definition of "integrated control." Thus, Way (1) indicates that pesticides should be introduced into the integrated control context only when necessary to avoid predictable economic damage and should be used to complement and supplement other methods when these cannot keep pest populations below economic injury levels.

In an urban situation where one bean weevil or one damaged bean constitutes economic injury, most store managers and grain boards will view with skepticism suggestions on integrated control especially if the definition involves cost of control versus (value of) loss in weight of produce due to pest damage.

So what is there to offer? I believe that in the scientific field (as opposed to the commerce of stored produce) we can look at the entire storage network in a country and consider the options. For example we can consider that one fraction which will be consumed fairly quickly, that is within 3-4 months after harvest, needs only to be fumigated while another fraction needs to be treated with an insecticide as well to suppress re-infestation because it will not be needed until the 5th month after harvest. For grain that will be stored for more than one year before being consumed we may consider the possibilities of storing under hermetic conditions.

In Kenya, hermetic storage in semi-underground "Cyprus" bins has proved to be an extremely effective way of preserving a "famine reserve" for 3 years or more with little dependence on the use of pesticides. The economics of handling grain in this way also make the storage of grain very worthwhile from the national point of view (3).

Other areas where possibilities exist for integrated control in large scale stores are to combine the release of synthetic pheremones from traps which also contain an insecticide to kill attracted adults (4). There are also advantages in introducing aeration to cool the produce and thus reduce the rate of pest development (5). This, however, may not be entirely economical (often because the grain is sold to the consumer at a controlled price) and so would have to be limited to very valuable commodities like coffee (6).

DISCUSSION: Good store hygiene is of vital importance under any circumstances and cannot be too strongly stressed under tropical conditions. Combining chemical control with the physical control

of natural barriers like the intact husk is important under substistence storage conditions as this may mean less expenditure on chemicals and also less insecticide in the farmers' diet. Plant breeders should take note of the benefits of an intact husk and pod and include such characteristics in the breeding programme.

More use may be made of synthetic pheremones, as these are developed, to serve as an early warning guide for store managers. In some situations possibilities exist for using micro-organisms to control stored-product pests but these are likely to be viewed with caution by the general public and applications may have to be limited to surface sprays and to the store fabric. There appears to be limited possibility for introduction of biological control by use of insect parasites and predators. Possibilities exist for the use of ionising and non-ionising radiations to control storage pests, especially in more valuable commodities. Within the next 15-20 years there is considerable scope in the tropics for improved control by combining chemical control with the development of physical barriers for the samll scale farmer and for rationalising chemical control with the use of controlled and inert atmospheres in large scale storage.

REFERENCES:

(1) Way, J. J., Integrated control - practical realities. Outl. Agric. 9, (1977) pp.127-135.

(2) De Lima, C. P. F., A technical report on twenty-two grain storage projects at the subsistence farmer level in Kenya - Unpublished report PROJ/RES/AG 21 Ministry of Agriculture, Kenya (1973).

(3) De Lima, C. P. F., A review of the use of physical storage procedures in East Africa: aspects for improvement and extension. Proc. of the 2nd Int. Wkg. Conf. Stored Prod. Ent. Ibadan, Nigeria, Sept 10-16 1978 (1978).

(4) Haines, C. P., The potential for use of synthetic sex pheremones for control of *Ephestia cautella* in tropical countries. Proc. XV Int. Congr. Ent., Washington, D.C., U.S.A. (1976) pp. 688-690.

(5) Navarro, S., Aeration of grain as non-chemical method for the control of insects in the grain bulk. Proc. of the 1st Int. Wkg. Confer. Stored Prod. Ent., Savannah, Ga., U.S.A. (1974) pp. 341-353.

(6) Stirling, H. G., Further experiments on the factors affecting quality loss in stored arabica coffee. Kenya Coffee, January, 1975 (1975).

LOSSES CAUSED TO STORED PRODUCTS BY INSECT PESTS IN PAKISTAN AND MEASURES FOR THEIR CONTROL

HAFIZ ABDUL QAYYUM
Professor of Entomology
University of Agriculture Faisalabad
PAKISTAN

INTRODUCTION: Pakistan is predominantly an agricultural country and before independence it was considered to be granary of India and used to meet most of the food requirements of the Indian population. After independence, the country continued to maintain its reputation in raising food grains for 4-5 years and met total domestic requirements. With the increase in population and also with the immigration of Muslim population from India to Pakistan, the problem of food became more and more important. Imports were made from foreign countries to meet the food requirements of the country. Every effort was made to increase the food production within the country so as to achieve self-sufficiency in food. Since it was the responsibility of the Government to meet the food requirements of urban and rural population, it was in the fitness of things to maintain huge reserves with a view to make a regular supply to the needy public all around the year. For this purpose the bulk of stored grain, particularly the wheat, imported form foreign countries under various programmes and that produced from within the country had to be stored in large godowns. The Government realized the importance of agriculture and provided every help in the form of inputs to bring an increase in the agricultural production in general and that of food grain in praticular. Thanks to the efforts of the tiller of the land and the wheat breeders who brought green revolution in the country the production of wheat increased to 8.5 million tons in 1977-78. The rice production in Pakistan was 2.58 million tons by 1977-78. All efforts made towards increasing food production in this country may not achieve the desirable results if proper facilities of storage are not made available to the public and private sectors. Absence of adequate farm and village level storage facilities is one of the main problems in the country which results in substantial losses in food grain. Due to the fear of susceptibility of food grain to heavy losses during storage period of insect pests and rodents as well as due to his weak holding power the producer is forced to sell his surplus stock just after harvest. Before proceeding further it is imperative to make a critical analysis of the situation of farming profession in Pakistan since the conditions have a great bearing on the post-harvest activities of the farmer. The total farm area of the country is about 48 million acres and it is divided into 4.8 million land holdings; of these 77% fall in the category of small holdings; i.e., less than 12.5 acres. The area of these holdings is about 34% of the cropped area. As such the marketable surplus on these farms is small.

About 15% of the holdings vary in between 12.5 acres and 25 acres whereas the rest 7-8% are above 25 acres.

It may be mentioned here that in case of wheat, 20 to 25% of the total production is procured by the Government; 5-7% by a small percentage of urban population to meet their domestic requirements and the rest is retained at the farm. About 90% of the marketable surplus is brought to the market just after the harvest and about 10% marketable surplus is retained by a very small percentage of the farming community for disposal at later dates. However, depending upon the farm size, a good quantity of food grain is retained at the farm by the owners or tenants cultivating the farm. There are different types of godowns at village or farm level which include mud, bins, kothies, and other such constructions. The purpose of holding such stocks at farm level is to meet the continuous demand for consumption of the rural population. Moreover, it is meant to meet emergency needs or to overcome shortages during exigencies. The storage period for food grains held for consumption at the village or farm level ranges from 6 to 12 months. With regard to storage for commercial purposes the major portion of the grain in handled by the Department of Food which makes large scale procurement just after the harvest. Storage is done either in bulk or in bags.

There are, however, three types of godowns owned by the Government. They are Lahore sheds, House type godowns and Bins. The storage capacity of Lahore sheds is 6% of the existing stores. Unfortunately, they are not suitable for fumigation and they are used under very extreme conditions for very short terms. The House type godowns constitute 67% of the Government owned storages and are commonly in use. They are fit for fumigation. Bins represent 27% of the Government owned stores and are undoubtedly most suitable from the view point of grain storage as the infestation in these types of godowns has been found to be the lowest.

LOSSES: The loss caused to stored grain by insect pests and rodents is of a high magnitude in Pakistan and does not need any emphasis. On the basis of research conducted in Pakistan, it has been found that the losses to stored grain from insect pests and rodents may vary from 2-60% (1).

The relative importance of various food crops and the loss caused due to various factors is given on the following page.

The incidence of insect attack was found to vary from locality to locality and from commodity to commodity depending upon the type of godowns, type of storage (bulk or bag), ecological conditions, storage period and upon the fumigation and chemical treatments of godowns.

In Pakistan, 23 insect species have been recorded damaging the stored grain. Out of these, 6 are important. They are khapra beetle (*Trogoderma granarium*); the lesser grain borer (*Rhizopertha dominica*); the rice weevil (*Sitophilus oryzae*), red flour beetle (*Tribolium castaneum*); paddy grain moth (*Sitotroga*

cerealella) and Dhora beetle (*Callosobruchus chinensis*). These insects are found in all parts of Pakistan and their biology and nature of damage has been studied in detail with the ultimate object of finding out some effective control measures (2, 3, 4, 5, 6 & 7.

Food commodity	National or regional importance as food	Annual production (tons)	% of total annual food production
a. Wheat (*Triticum vulgare*)	Staple food production	8.5 million	72.6
b. Rice (*Oryzae sativa*)	Second major food	2.5 million	21.3
c. Maize (*Zea mays*)	Used as food in the villages	.07 million	6.1

Major stages of postharvest processing and storage (drying, parboiling, storing etc.)	Estimated losses	Causes of loss
a. Wheat (Storing & Milling)	2-16% (average 5%)	Moisture
b. Rice (Drying, parboiling & storing)	2-10% (average 5%)	Heating Development of mold
c. Maize (Drying & storing)	2-8% (average 5%)	Damage from insects Rodents Handling & transportation

VARIETAL SUSCEPTIBILITY: Studies conducted on the varietal susceptibility of various wheat, gram and rice varieties to insect pests of stored grain revealed that the most susceptible variety with regard to percentage loss in weight and percentage of damaged grains was AU-44. Variety C-273 was comparatively the least susceptible. The loss was found to start within one month of the beginning of the experiment and was found to increase to higher and higher levels from April onward till it reached its maximum during July. No variety was found to be totally immune to the attack of insects.

The varietal susceptibility of 30 gram varieties to the attack of *C. maculatus* was studied taking into consideration the number of eggs laid on 20 grains of each variety; the number of grains infested out of the eggs laid on 20 grains and the loss in weight on percentage basis. The results revealed that out of all the varieties the least susceptible was 6508.

The results of experiments conducted on the susceptibility of seven rice varieties revealed that the highest loss in weight was in rice variety Basmati-198. Varieties Basmati-197 and IRR-6 did not show any significant difference from each other.

MEASURES TO CONTROL: The effect of Malathion and Nogos each used in 0.05% and 0.1% concentrations was studied on the larvae of *T. granarium* at 25°C, and 35°C in combination with 52% and 75% relative humidities (8). The mortality of the pests recorded at 75% relative humidity was higher than at 52% relative humidity for all the treatments. Maximum mortality of the pests was recorded 24 hours after the application of the insecticides. Malathion 0.1% on over all basis proved to be the most effective insecticide.

As a result of studies conducted on the grain protectants of insect pests of stored products the use of Malathion was found to be the best for protecting the grains from the ravages of insect pests of stored products (1, 9 & 10). A commonly recommended dosage is one part of premium grade Malathion 75% E.C. in 25 parts of water for treatment of empty godowns, heaps of grain, empty and filled bags and other articles and places of storage in and outside the human dwellings.

Studies conducted by Qayyum (10) on the use of fumigants revealed that Phostoxin and E.D.C.T. gave 100% mortality of the insect pests of stored grains. The use of these two fumigants is practised by the Government agencies in Pakistan. However their use is restricted in rural areas because of improper storage facilities.

REFERENCES:

(1) Qayyum, H. A., Research on stored grain pests in Pakistan. Third Ann. Res. Rep., P.L. 480 Proj., Dept. Ent., Univ. Agri. Fd. (1973).

(2) Qayyum, H. A., Ecological studies on the mortality of *Sitophilus oryzae* (L.). Pak. Jour. Sci. 16(3) (1964) 146-153.

(3) Qayyum, H. A., Ecological studies on the oviposition of *Sitophilus oryzae* (L.). Pak. Jour Agri. Sci. 11(2) (1965) 127-153.

(4) Qammar, Z., and H. A. Qayyum, Effect of different temperatures and relative humidities on the bionomics and mortality of *Tribolium castaneum* (Hbst.). Pak. Jour. Sci. Res. 19(1) (1967) 44-50.

(5) Qayyum, H. A., Ecological studies on egg hatching and on larval instars of *Rhizopertha dominica* (F.). Pak. Jour. Sci. Res. 20(3) (1968) 40-45.
(6) Akbar, S., and H. A. Qayyum, Effect of environmental heterogeneity on the development of *Trogoderma granarium* Everts. Pak. Jour. Sci. Res. 21(1) (1969) 10-18.
(7) Qayyum, H. A. and T. Muhammad, Biology of *Rhizopertha dominica* (F.) under different environmental conditions. Pak. Jour. Sci. Res. 24(3-4) (1972) 214-221.
(8) Hussain, S. I. and H. A. Qayyum, Effectiveness of some insecticides for the control of *Trogoderma granarium* Everts at different temperatures and relative humidities. Pak. Jour. Sci. Res. 24(3-4) (1972) 227-233.
(9) Qayyum, H. A., Research on stored grain pests in Pakistan, Fourth Ann. Res. Rep., P.L. 480 Proj., Dept. Ent., Univ. Agri. Fd. (1974).
(10) Qayyum, H. A., Research on stored grain pests in Pakistan, Fifth Ann. Res. Rep., P.L. 480 Proj. Dept. Ent. Univ. Agri. Fd. (1975).

SYMPOSIUM ON BIOLOGY, ECOLOGY AND INTEGRATED CONTROL

Convener - DR. S. C. SAXENA
Toxicology Laboratory
Department of Zoology
University of Rajasthan
Jaipur - 302004, INDIA

APPLICATION OF PHEROMONES AND BEHAVIOR-MODIFYING TECHNIQUES IN DETECTION AND CONTROL OF STORED PRODUCT INSECTS

WENDELL E. BURKHOLDER
Stored Product and Household Insects Laboratory
Agricultural Research, SEA, USDA
Department of Entomology
University of Wisconsin
Madison, Wisconsin, 53706
U. S. A.

For many years insects that infest stored products have been controlled primarily by chemical pesticides and fumigants. Nevertheless, at present, there is tremendous potential for pest management programs that integrate chemical pesticides, biological chemicals (i.e. pheromones, hormones), other biological control agents (i.e. parasitoids, predators, microbial pathogens), physical methods (including design of proper facilities), culture methods (including sanitation), and legislative controls. There is a need for demonstration projects that incorporate research and education in broad areas of both chemical and nonchemical methods of control. Such projects would coordinate the efforts of all sectors of agribusiness including farmers, shippers, warehousemen, processors, pest control and regulatory personnel, and the consumer. Although we have knowledge of some excellent non-pesticidal control measures, little effort has been made to integrate the most effective procedures in an effective pest management program. My intention here is to discuss ways in which pheromones can be utilized to manage storage insect pests.

The pheromones of a number of important storage pests are known (Table I). I have proposed several strategies for using pheromones to manipulate storage pests (1,2) (Table II). In the first approach, pheromones would be used in traps to monitor and detect the presence, population density, and location of pest species. Then if the level of infestation exceeded a predetermined value, the appropriate corrective measures, which might include a pesticide application, would be taken. This use of pheromones is therefore involved indirectly in the control of pests.

The results obtained during a study of seasonal patterns of emergence of *Attagenus* and *Trogoderma* in warehouses in Milwaukee, Wisconsin show how this strategy works (3). Corrugated paper traps treated with the appropriate pheromones and an insecticide were placed in the warehouses with control traps. Many more males of the target species were recovered from the pheromone traps than from the control traps. In fact, a previously unknown infestation of *Trogoderma variabile* was detected at one site. Pheromones then can be powerful and effective tools for detecting the presence of insect Other trapping studies with the *Trogoderma* pheromones have been made recently in the United States, Mexico, Germany and Australia. For example, trapping has

TABLE I. Major pheromone components of some stored-product insects.

Family-Species and Sex that Produces Pheromones	Chemical Description of Synthesized Pheromones	References
Anobiidae		
Stegobium paniceum (L.) ♀	2,3-dihydro-2,3,5-trimethyl-6-(1-methyl-2-oxobutyl)-4H-pyran-4-one	23,24
Bostrichidae		
Rhizopertha dominica (F.) ♂	1-methylbutyl (E)-2-methyl-2-pentenoate	7,8
	1-methylbutyl (E)-2,4-dimethyl-2-pentenoate	
Bruchidae		
Acanthoscelides obectus (Say) ♂	(E)-(-)-methyl 2,4,5-tetradecatrioneate	6
Dermestidae		
Attagenus megatoma (F.) ♀	(E,Z)-3,5-tetradecadienoic acid	13,25
Attagenus elongatulus (Casey) ♀	(Z,Z)-3,5-tetradecadienonic acid	26,27,28
Anthrenus flavipes LeConte ♀	(Z)-3-decenoic acid	29,30
Trogoderma inclusum LeConte	(Z)-14-methyl-8-hexadecen-1-ol	13,31,32
Trogoderma variabile Ballion ♀	(Z)-14-methyl-8-hexadencenal	
Trogoderma glabrum (Herbst) ♀	(E)-14-methyl-8-hexadecen-1-ol (E)-14-methyl-8-hexadecenal	13,33,32
Trogoderma granarium Everts ♀	92:8 (Z):(E)-14-methyl-8-hexadecenal	34,32

TABLE I. Continued.

Family-Species and Sex that Produces Pheromones	Chemical Description of Synthesized Pheromones	References
Gelechiidae		
Sitotroga cerealella (Olivier) ♀	(Z,E)-7,11-hexadecadien-1-ol acetate	35,36
Phycitidae		
Ephestia elutella (Hübner)	(Z,E)-9,12-tetradecadien-1-ol acetate	37,38,39,40 41,42,43,44
Plodia interpunctella (Hübner)		
Cadra cautella (Walker)		
Anagasta kuehniella (Zeller)		
Cadra figulilella (Gregson)		
♀		

TABLE II. Strategies for manipulation of stored product insects with sex pheromones or other attractants.

I. Surveillance and detection of infestation

II. Control of infestation

1. Communication disruption
2. Mass trapping
3. Lures for insecticide treatments
4. Pheromones as lures in pathogen-dissemination devices

been conducted in California and Idaho to determine the species of *Trogoderma* present in areas where leaf-cutter bees are reared for alfalfa pollination. Also the *Trogoderma* pheromones plus a larval food attractant and a pesticide are being evaluated by USDA-APHIS and the California Dept. of Food and Agriculture for a khapra beetle detection program.

The second basic strategy for using pheromones to manipulate stored product insects involves direct control 1) by disrupting the communication between sexes, 2) by mass trapping, or 3) by luring the insects to non-food materials treated with deleterious agents. As an example of the effectiveness of communication disruption, one application of high levels of pheromone in sealed 208-liter fiber drums was sufficient to significantly reduce mating activity of *Attagenus megatoma* for up to one year (4). Also, Sower et al. (5) reported that in enclosed environments, the mating frequency of the Indian meal moths, *Plodia interpunctella*, was reduced in the presence of the synthetic sex pheromone, (Z,E)-9,12-tetradecadien-1-ol acetate. In fact the effectiveness of any dose of pheromone was markedly increased as population densities were decreased from 10 to 0.2 pairs/m^2 of wall and ceiling surface.

Direct removal of insects from a population (mass trapping) would be an effective control measure if we could remove both sexes. A system of this type may be practical with the pheromone produced by the male bruchid, *Acanthoscelides obtectus* (6) or with the population aggregation pheromone produced by the male lesser grain borer, *Rhizopertha dominica* (7). For example, the lesser grain borer pheromone has been identified and synthesized (8), and recent field tests have demonstrated attractancy (9). The pheromone placed in suspended traps may be effective in attracting flying insects; for crawling insects, it may be effective in traps placed directly on the grain. With an effective pheromone or other attractant, it becomes possible to lure insects to insecticide-treated materials such as corrugated paper, paper chips, or other low-cost and easily disposable materials. The use of miniature traps made from such materials could be placed within the grain mass. By using attractants, less total insecticide would be needed because the insects would focus on the toxicant. The idea of miniature traps is patterned after a successful method of marking grain that was developed several years ago (10) to deter theft: paper chips with a code number corresponding to the owner were mixed with the grain and could be removed easily in the cleaning process before milling and processing. A modified version of the paper chips used in combination with other control agents was discussed by Burkholder (11).

Another means of direct control, as well as detection of infestation, is based on the fact that mechanical disturbance affects the behavior of the granary weevil: weevils appear on the surface of disturbed areas (12). Current studies in my laboratory (9) have demonstrated that other species of grain weevils have a

similar response as do *Oryzaephilus* spp. and *Tribolium* spp. I suggest that grain probes could be placed permanently or temporarily in the grain mass to serve either as static traps or, when mechanically vibrated, as active traps. The physical attractiveness of the devices would be enhanced with food attractants or sex or population-aggregation pheromones. Such probes, designed with perforations to allow entry by insects, could be also sampled rapidly for insects by a vacuum device if they were placed at intervals of several meters and sampled weekly or at other regular intervals to determine infestation levels.

An innovative strategy is the use of pheromones as lures for devices that contain entomopathogens. The habitats of storage insects provide ideal conditions for inducing disease epizootics, particularly those caused by desiccation-resistant spore-formers. Even when the habitat is small and the population is localized it can contain highly concentrated populations of insects that have excellent potential for epizootics. With an effective pheromone-baited device, it should be just as easy to expose the attracted insects to a pathogen as to an insecticide. Of course the pathogen would not produce immediate kill. Rather the infected, spore-ladened insect would return to its natural habitat and infect others of its kind. This would seem to be an especially promising method of controlling stored-product insect pests.

The possible use of pheromones with pathogens and other biotic agents for suppression of dermestids was first proposed by Burkholder and Dicke (13) and later elaborated by Burkholder and Boush (14). The concept was put to the experimental test in an effort to suppress populations of the dermestid beetle, *Trogoderma glabrum*. In this trial, the sex pheromone of the beetle (14-methyl-8-hexadecenal) was combined with a protozoan pathogen, *Mattesia trogodermae* (Neogregarinida: Ophryocystidae) (15). Then we evaluated the numerous variables in pathogen transmission under conditions that we felt were highly conducive to population suppression. Because failure at any point in the sequence to bring the insect into contact with the pathogen would doom the strategy, our conditions were optimized: adult males emerged synchronously and prior to females; adult male populations were situated downwind from pheromone-spore-transfer sites; adult males were redistributed after luring and contamination among emerging females with subsequent mating; and dead adults were available as food for next generation offspring.

In this model system, subsequent generations of *T. glabrum* were substantially suppressed by a single introduction of *M. trogodermae* spores into dense populations of adult males via pheromone-baited, spore-transfer sites: high density (32 F_0 adults/m^2) treated populations increased only 4-fold in the 1st posttreatment generation (vs. a 24-fold increase in controls) and fell below pretreatment levels by the 2nd generation (vs. a total 100-fold increase in controls); low density treated populations

and also the low density controls (2 F_0 adults/m^2), increased 12-fold during the 1st generation. With the dense population 48-hour exposure of pheromone-spore-transfer sites was sufficient to distribute effective spore doses within a radius of 1.25 m around sites, but spore transfer to the subsequent generations was mainly by larval ingestion of either dead, contaminated adults or larval food that adults had contaminated by contact. Attracted males also attempted copulation with the pheromone source, which increased spore transfer to males. Although the maximum distance the spores were transferred (1.25m) was limited by the size of our experimental arenas, we are confident that in a normal environment the pathogen would be dispersed as far as infected adults could disperse. Such a distance might be substantial since flight is possible by contaminated adults.

Burges and Hurst (16) noted that mortality of storage moths (e.g. *Plodia interpunctella*) in maize storage facilities in Kenya was often sudden and spectacular when the insects were exposed to *Bacillus thuringiensis* though mortality of similar moths exposed in the same way in laboratory jars was only progressive. They therefore suggested that larval cadavers, because they contain so many more *B. thuringiensis* spores than do moth bodies, frass, or eggs, are the most potent source of infective materials and with their attendant crystals, are capable of rapidly killing larvae that feed on them. When they compared the effect of *B. thuringiensis* spores spread on the surface of jars with that of spores applied to one point source on the surface, significantly fewer spores were required to start an epizootic. It is thus possible for initial infestation, and possibly subsequent infections, to begin in newly harvested and untreated grain because of the presence of infected adult moths. Epizootics may also arise because infected larvae have immigrated from adjacent stored grain or residues of food from local farms, transport vehicles, terminal stores or bags contaminated with frass and insect bodies. Moreover, the Burges and Hurst study shows that healthy larvae sometimes feed on larval cadavers even when food other than cadavers is present. Therefore most susceptible larvae could succumb first and provide inoculum to infect the more resistant larvae. Those workers nevertheless suggest that such naturally occurring infections of *B. thuringiensis* rarely curb moth damage to food and that the main effect is to limit moth reproduction in some food residues in stores and mills. Burges (17) believes that predictable control and adequate protection of food can only be obtained by admixing a lethal dose, e.g. 2×10^9 spores/200 g throughout the food to kill most first-instar larvae.

Again since the severe mortality of moth larvae caused by *B. thuringiensis* in Kenya was enhanced by the high concentrations of spores in the larval cadavers, it might be possible to mimic nature by providing a high concentration of spores in an attractive paper chip or other material that would serve as a

simulated larval cadaver (SLC). The use of pheromones or other attractants to lure or aggregate larvae or adult stored product insects to sites that contain high concentrations of pathogens would therefore appear to be a promising method of insect population suppression.

Current studies at my laboratory indicate that there are promising larval attractants for dermestid beetles (18). These compounds could be combined with the available adult insect pheromones in an insect suppression system. It should be possible to incorporate baits into small paper chips or other devices that could be used to good advantage in a variety of ways. In grain, for example, a substance containing an attractant, a bait or feeding stimulant, and a pathogen such as *B. thuringiensis* might be formulated to simulate a larval cadaver. A domino effect might follow the introduction of a few SLC's. The initial rapid kill of larvae that would result would produce real cadavers, and their presence would accelerate the suppression of the population even further. A similar procedure was developed for use against the boll weevil, *Anthonomus grandis*, by McLaughlin et al. (19) with the sporozoans *Glugea gasti* and *Mattesia grandis*. Also, Montoya et al. (20) used a feeding stimulant to increase the lethality of a nuclear polyhedrosis virus of *Heliothis* spp.

I suggest a procedure in which the attractant would be selected to attract the young feeding stages that are particularly susceptible to the pathogen. They would then die before inflicting extensive damage on the stored grain. Ideally the SLC would be attractive both physically and chemically, would contain a feeding stimulant to ensure ingestion, and would contain enough pathogen to produce prompt kill. The SLC could be made from any of a variety of materials, corrugated paper, paper straws, or a natural material such as wheat straw, and then coated with the pathogen and attractant. A laminated structure incorporating safe and biodegradable materials would seem to be ideal. Materials such as adjuvants or stickers currently being used in the pesticide industry may be useful in binding pathogen to attractant in the SLC. Distribution of the SLC's in the walls or cracks of empty bins, under conveyors, or in other areas where residual populations might exist may also enhance population suppression.

Another method of effectively distributing a pathogen to stored-product insects is to provide a pheromone- or light-baited device with an open reservoir containing a pathogen such as *Bacillus thuringiensis*. The insects are attracted by the pheromone or light, become dusted with the pathogen, and distribute it within the insect population and habitat. Gard (21) has successfully used light as an attractant to induce night flying insects to disseminate virus material in California cotton fields. The attracted insects were dispersed after they were dusted with virus by using a timer that turned the light on and off in 15-minute cycles.

A critical unknown at this time is whether pheromones and other bioagents can or will be commercially developed. Without industrial development sufficient materials will not be available at reasonable prices. The Stanford Research Institute, under contract from the EPA, has studied the commercial feasibility of innovative pest control agents such as pheromones (22). The potential for commercial development of pheromones for actual control of stored product pests, i.e. mass trapping or mating disruption, was rated as high. In the same study, the likelihood of pest suppression programs involving pheromones of stored product pests was also rated as high. Efficacy, product specificity, market size and incentives, production, storage and field life characteristics, and toxicity were all evaluated.

Investigation of procedures for modifying insect behavior must continue. We need information about detection and control efficacy for all species of the storage-insect-pest complex. Also management procedures should be adaptable to small farms in any part of the world so local materials such as maize cobs, reeds, straw, wood or paper chips would be treated and used in place of manufactured materials. Modern grain handling facilities could easily adapt equipment for removing insects with miniature traps or other treated materials. "Fluidized-bed" or other similar techniques may be an efficient method of removal of both the insect, and the treated materials.

In summary, pheromones can be powerful tools that enhance pest management programs by permitting the early detection and control of storage insects. At the least, such regular monitoring of the storage facility, grain or stored commodity will aid in finding infestations early before extensive damage occurs. However management procedures of the type described might be used to suppress the infestations or to supplement and follow-up on treatment with conventional pesticides. On the basis of preliminary experiments, the prospect for success appears excellent.

ACKNOWLEDGEMENT: Research was supported by the College of Agriculture and Life Sciences, University of Wisconsin, Madison, and by a cooperative agreement between the University of Wisconsin and Agricultural Research, Science and Education Administration, U.S. Department of Agriculture.

REFERENCES:

(1) Burkholder, W. E., Insect Pheromones and their Applications (Proc. and Forestry, Tokyo (1976) 111.
(2) Burkholder, W. E., "Manipulation of insect pests of stored products", Ch. 20, Chemical Control of Insect Behavior: Theory and Application (H.H. Shorey, J.J. McKelvey, Eds.), Wiley, New York (1977).

(3) Barak, A. V., and W. E. Burkholder, Environ. Entomol. 5 1 (1976) 111.
(4) Burkholder, W. E., J. Econ. Entomol. 66 6 (1973) 1327.
(5) Sower, L. L., W. K. Turner, and J. C. Fish, J. Chem. Ecol. 1 3 (1975) 335.
(6) Horler, D. F., J. Chem. Soc. C (1970) 859.
(7) Khorramshahi, A., and W. E. Burkholder, J. Chem. Ecol. (In press) 1979.
(8) Williams, H. J., R. M. Silverstein, W. E. Burkholder, and A. Khorramshahi, J. Chem. Ecol. (In press) 1979.
(9) Unpublished data, 1978.
(10) Personal communication, Grain Identification Co., Cooperstown, N.D. 1975.
(11) Burkholder, W. E., Prevention and Control of Insects in Stored-Food Products (Proc. Symp. Manhattan, Kansas, 1978) Kansas State Unvi., Manhattan, Kansas (1978).
(12) Browning, H. C., Proc. Zool. Soc. Lond. 116 (1947) 675.
(13) Burkholder, W. E., and R. J. Dicke, J. Econ. Entomol. 66 6 (1973) 1327.
(14) Burkholder, W. E., and G. M. Bousch, Bull. OEPP (Organ. Eur. Mediterr. Prot. Plant) 4 (1974) 455.
(15) Shapas, T.J., W. E. Burkholder, and G. M. Bousch, J. Econ. Entomol. 70 4 (1977) 469.
(16) Burges, H.E., and J. A. Hurst, J. Invertebr. Pathol. 30 (1977) 131.
(17) Burges, H. E., Entomophaga Mem. Hors. Ser., 2 (1964) 323.
(18) Nara, J. M., and W. E. Burkholder, Environ. Entomol. (In preparation) (1978).
(19) McLaughlin, R. E., T. C. Cleveland, F. J. Daum, and M. R. Bell, J. Invertebr. Pathol. 13 (1969) 429.
(20) Montoya, E. L., C. M. Ignoffo, and R. L. McGarr, J. Invertebr. Pathol 8 (1966) 320.
(21) Gard, I. E., Microbial Control of Insect Pests: Future Strategies in Pest Management Systems (Proc. Conf. Gainesville, Florida, 1978) University of Florida (1978).
(22) Ayers, J. H., New, Innovative Pesticides: an Evaluation of Incentives and Disincentives for Commercial Development by Industry (Report, Stanford Research Institute, 1977) Menlo Park, California (1977).
(23) Kuwahara, Y., H. Fukami, S. Ishii, F. Matsumura, and W. E. Burkholder, J. Chem. Ecol. 1 4 (1975) 413.
(24) Kuwahara, Y., H. Fukami, R. Howard, S. Ishii, F. Matsumura, and W. E. Burkholder, Tetrahedron 34 (1978) 1769.
(25) Silverstein, R.M., J. O. Rodin, W. E. Burkholder, and J. E. Gorman, Science 157 (1967) 85.
(26) Barak, A. V., and W. E. Burkholder, J. Stored Prod. Res. 13 (1977) 169.
(27) Barak, A. V., and W. E. Burkholder, J. Stored Prod. Res. 13 (1977) 177.

(28) Fukui, H., F. Matsumura, A. V. Barak, and W. E. Burkholder, J. Chem. Ecol. 3 5 (1977) 541.
(29) Burkholder, W. E., M. Ma, Y. Kuwahara, and F. Matsumura, Can. Entomol. 106 (1974) 835.
(30) Fukui, H., F. Matsumura, M. Ma, and W. E. Burkholder, Tetrahedron Lett. 40 (1974) 3563.
(31) Rodin, J. O., R. M. Silverstein, W. E. Burkholder, and J. E. Gorman, Science, 165 (1969) 904.
(32) Cross, J. H., R. C. Byler, R. F. Cassidy, R. M. Silverstein, R. E. Greenblatt, W. E. Burkholder, A. R. Levinson, and H. Z. Levinson, J. Chem. Ecol. 2 (1976) 457.
(33) Yarger, R. G., R. M. Silverstein, and W. E. Burkholder, J. Chem. Ecol. 1 (1975) 323.
(34) Levinson, H. Z., and A. R. Barilan, Riv. P. 28 (1967) 27.
(35) Keys, R. E., and R. B. Mills, J. Econ. Entomol. 61 (1968) 46.
(36) Vick, K. W., H. C. F. Su, L. L. Sower, P. G. Mahany, and P. C. Drummond, Experientia 30 (1974) 17.
(37) Brady, V. E., Life Sci. 13 (1973) 227.
(38) Brady, V. E., and D. A. Nordlund, 10 (1971) 787.
(39) Brady, V. E., and R. D. Daley, Ann. Entomol. Soc. Am. 65 (1972) 1356.
(40) Brady, V. E., J. H. Tumlinson, III, R. G. Brownlee, and R. M. Silverstein, Science 171 (1971) 802.
(41) Brady, V. E., D. A. Nordlund, and R. C. Daley, J. Ga. Entomol. Soc. 6 (1971) 215.
(42) Kuwahara, Y., and J. E. Casida, Agric. Biol. Chem. 37 (1973) 781.
(43) Kuwahara, Y., C. Kitamura, S. Takahashi, H. Hara, S. Ishii, and H. Fukami, Science 171 (1971) 801.
(44) Kuwahara, Y., H. Hara, S. Ishii, and H. Fukami, Agric. Biol. Chem. 35 (1971) 447.

INTEGRATED MANIPULATION OF STORAGE INSECTS BY PHEROMONES AND FOOD ATTRACTANTS

H. Z. LEVINSON and A. R. LEVINSON
Max-Planck-Insitut für Verhaltensphysiologie
8131 Seewiesen bei Starnberg
FEDERAL REPUBLIC OF GERMANY

The established and more recently devised methods (physical and chemical) for prevention and control of insect infestation in food stores have been critically reviewed by Howe (1). Cooling by air circulation is certainly a useful means of control. However, its considerable expense and risk of reintroducing moisture to the stored product limits the application of this technique (2). Airtight storage, another efficient control measure, depends on keeping the oxygen level of the atmosphere constantly below 3% and requires circulation of nitrogen or carbon dioxide through the storage bins (3). The availability of gasproof structures and fabrics, which are not cheap, is a prerequisite for this kind of control. The usefulness of inert dusts (e.g. chalk, kaolin, silica aerogels, tricalcium phosphate) as grain additives is restricted by possible adverse influence on human beings as well as by abrasive effects on machinery (4, 5). The rather effective technique of ionizing radiations from a gamma or accelerated electron beam source did not become customary in warehouses, probably due to its expensiveness.

The most common chemical methods for controlling stored product pests are either spraying of contact insecticides or fumigation by insecticidal gases. The pyrethrins, possibly synergized by piperonyl butoxide, as well as malathion (0,0-dimethyl S-1,2-di (ethoxycarbonyl) ethyl phosphorodithioate) are probably among the few contact insecticides which may be directly applied to stored food without subsequent risk to the consumer; however, the repellent action of the pyrethrins for various insect species warrants maximal covering of the grain surface to achieve complete protection (6). In spite of the high contact and vapour toxicity of DDVP (dimethyl dichlorovinylphosphate) for storage insects, the permanent use of this insecticide may be hazardous to human beings particularly due to accumulation of harmful concentrations in closed premises and extensive adsorption on stored grain (7).

Several insecticidal gases are rather effective storage fumigants, among which methyl bromide and phosphine are used widely. Desorption of the former from exposed products is relatively slow, while the latter is scarcely adsorbed at all. Hence, fumigation by phosphine does not result in adverse residual effects on seed germination and human health, and a single treatment is relatively inexpensive (approx. \$8.00 per m^2 of grain). However,

a serious drawback resulting from the frequent use of such toxicants is the selection of resistant mutants, eventually leading to the necessity of increasing the insecticidal doses beyond the acceptable levels (8).

A new biotechnical approach to pest control recently suggested by Levinson (9, 10) depends on using insectistatics, i.e. agents decimating insect populations to a level that does not cause economic damage (insectistasis). Since most of the insect pheromones and feeding attractants comprise a relatively high signalizing value at exceedingly low activity thresholds, they can be readily employed for adverse modification of the normal behaviour of destructive species resulting in insectistasis (11). The pheromone composition of several species (mainly Coleoptera, Lepidoptera, and Orthoptera) being notorious pests of stored products has been studied in detail (9, 11, 12). Some of the more important components identified are listed in Figure 1. They are fairly volatile lipids of rather diversified structure such as unsaturated fatty acids and esters, branched olefinic aldehydes, a trienoate with two cumulative double bonds as well as hydrocarbons. The major components of certain sex and aggregation pheromones being integrated into sticky (Figure 2) or contact (Figure 3) traps are currently employed for the surveillance and detection of phycitid moths and dermestid beetles in warehouses (11, 13). Chemical feeding attractants for storage insects comprise components eliciting aggregation as well as feeding; e.g. oleopalmitin is known to act as a feeding aggregant and maltose as a feeding stimulant for *Tribolium confusum* (14, 15). The attractants released by a blend of seeds and fruits (enclosed in wire gauze bags, Figure 4) are also used for monitoring the presence of stored product pests (16, 17, 18). In both types of baits the attractants have to be adequately dosed in order to ensure quantitative predominance over the amounts of phagostimulants and sex pheromones occurring in the surroundings. Since food stores represent a rather closed system with fairly constant conditions and moderate levels of temperature, humidity, light intensity as well as rather slow air movement (about 0.1-0.5 m/sec) for the insects found in this environment, they are particularly suitable for the use of pheromone and food attractant traps.

On the background of the experience in chemical and biotechnical control measures we propose an integrated manipulation of the insect species infesting stored products. Figure 5 presents an outline of a feed-back system wherein a pest population is under continual supervision and control by traps baited with pheromones and food attractants in combination with insecticide treatments timed in accordance. There are up to three successive treatments involved. The first one serves to detect an infestation and to estimate its magnitude. For this purpose are a few traps permanently confronted with the pest biotope. In the

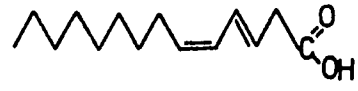
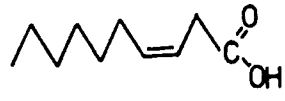
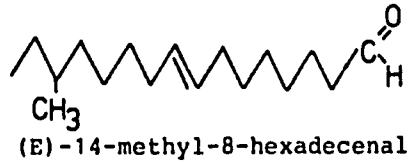
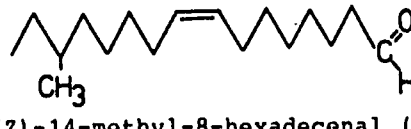
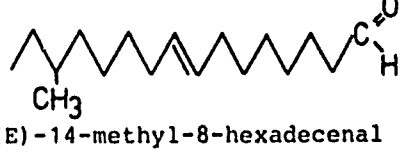
Family, Species and Sex	Formula	Reference
Dermestidae:		
Attagenus megatoma ♀	 (E,Z)-3,5-tetradecadienoic acid	(20)
Attagenus elongatulus ♀	(Z,Z)-3,5-tetradecadienoic acid	(21)
Anthrenus flavipes ♀	 (Z)-3-decenoic acid	(22)
Trogoderma inclusum ♀ Trogoderma variabile ♀	(Z)-14-methyl-8-hexadecenal	(23)
Trogoderma glabrum ♀	 (E)-14-methyl-8-hexadecenal	(23)
Trogoderma granarium ♀	 (Z)-14-methyl-8-hexadecenal (92%)  (E)-14-methyl-8-hexadecenal (8%)	(24)

FIGURE 1: Major pheromone components of some species of Coleoptera, Lepidoptera and Orthoptera infesting stored products.

Bruchidae:

Acanthoscelides obtectus

♂

methyl(-)-(E)-2,4,5-tetradecatrienoate (25)

Tenebrionidae:

1-pentadecene

Tribolium confusum

♂, ♀

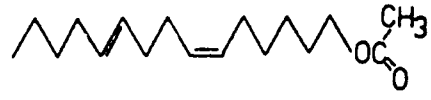
n-hexadecane (26)

1-heptadecene

Gelechiidae:

Sitotroga cerealella

♀



(Z,E)-7,11-hexadecadien-1-yl acetate (27)

Phycitidae:

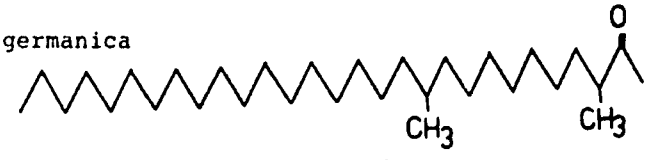
Ephestia elutella
Plodia interpunctella ♀
Cadra cautella
Anagasta kuehniella
Cadra figulilella

(Z,E)-9,12-tetradecadien-1-yl acetate (28)(29)

Blattidae:

Blattella germanica

♀



3,11-dimethyl-2-nonacosanone (30)

29-hydroxy-3,11-dimethyl-2-nonacosanone (31)

FIGURE 1: Continued.

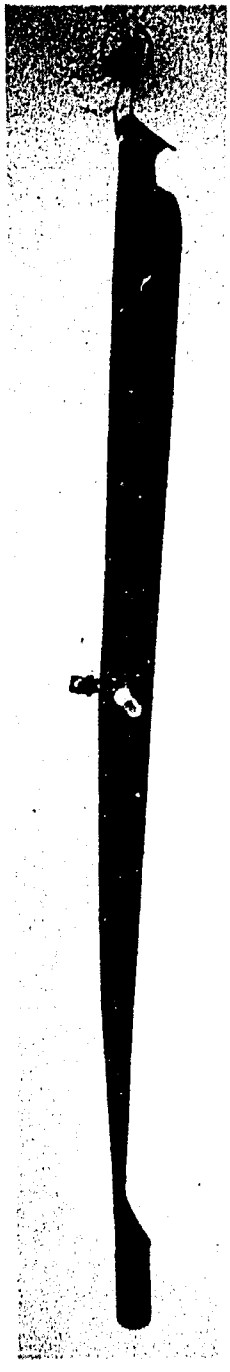


Fig. 2 (left). Trapping device for moths infesting stored products. It is a sticky paper strip (75x5 cm) provided with a polyethylene capsule (exchangeable) containing the mein pheromone component from the females of several phycitid species. An adequate amount of the attractive compound is adsorbed on the plastic capsule, which ensures slow vaporisation of the scent for several weeks.

Fig. 3 (below). Contact trap for dermestid beetles and larvae. It consists of four retangular sheets of gunny bag (11x9 cm) being stitched together on one side, and impregnated by the main pheromone component. The insects are first lured by the scent evaporating from the trap and then retained between its hairy sheets due to thigmotaxis.

Fig. 4. PICL-Food bait trap for various stored product beetles. An envelope [20x10 cm] of plastic or metal mesh [apertures 1.5 mm] is filled with crushed carobs, groundnuts, wheat, raisins and possibly other food stuffs, and closed. Attracted insects enter the trap through the perforations and remain on the food mixture (Pinninger 1975).

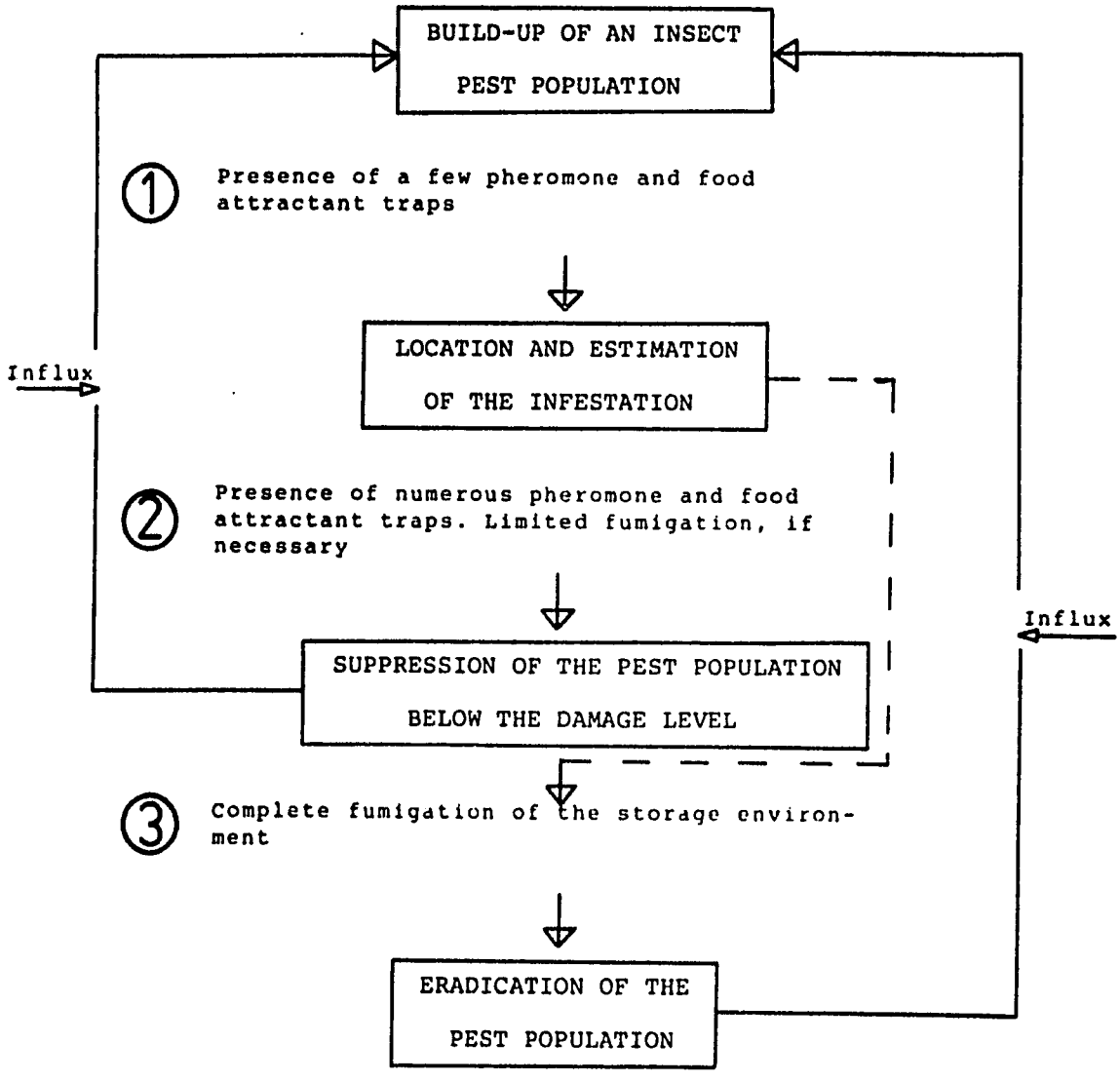


FIGURE 5. Flow sheet of insect manipulation in storage environment. The encircled numbers denote the successive measures to be undertaken under the conditions mentioned within the frames.

second one, suppression of the discovered population below the economic level is to be achieved. This step demands an adequate increase in the number of traps suspended so far. Control of regional infestations may also be supplemented by fumigation (e.g. with phosphine). The third treatment, complete fumigation of the storage environment, is carried out when a dense insect population has become evident. If rapid insect eradication in a commodity is necessary, one has to proceed directly from the detection of an infestation to complete fumigation. Integrated manipulation of storage insects by pheromones combined with insecticides is considerably cheaper than insecticidal control alone. It also meets the demand for methods of prevention rather than of control, as recently suggested by Burkholder (19).

Long term studies on the supervision and control of *Ephestia elutella* and *Plodia interpunctella* carried out in collaboration with Drs. R. Wohlgemuth and Ch. Reichmuth, Institut für Vorratsschutz, Berlin, support the possibility of introducing the above scheme to the practice of warehouse disinfestation.

REFERENCES:

(1) Howe, R. W. (1972) In: Kozlowski, T. T. (ed.), Seed Biology, 247-300, Academic Press, New York and London.
(2) Navarro, S, Donahaye, E., Calderon, M. (1969) J. Stored Prod. Res. 5, 73-81.
(3) Jay, E. G., Pearman, G. C. (1969) J. Ga. Entomol. Soc. 4, 181-191.
(4) Zacher, F. (1937) Verh. Deutsch. Zool. Ges. 264-271.
(5) Whitney, W. K. (1975) Proc. 1st Int. Working Conf. Stored Prod. Entomol., Savannah, 1974, 385-411.
(6) Braasch, H. (1969) Methodische Untersuchungen zum Nachweis von Attraktiv- und Repellenteffekten verschiedener Pflanzenschutzmittel auf Insekten, 1-145. Akademie-Verlag, Berlin.
(7) Green, A. A., et al. (1968) J. Stored Prod. Res. 4, 69-76.
(8) Dyte, C. E. (1974) EPPO Bull. 4, 275-289.
(9) Levinson, H. Z. (1975) Naturwissenschaften 62, 272-282.
(10) Levinson, H. Z. (1976) Z. ang. Ent. 81, 113-132.
(11) Levinson, H. Z. (1977) Z. ang. Ent. 84, 1-19.
(12) Burkholder, W. E. (1976) In: Kono, T., Ishii, S. (eds.), Insect Pheromones and Their Applications, Proc. Sympos., 111-122. Japan Plant Protection Association, Komagome, Toshima-ku, Tokyo.
(13) Reichmuth, Ch., et al. (1976) Z. ang. Ent. 82, 95-102.
(14) Loschiavo, S. R. (1965) Ann. Entomol. Soc. Amer. 58, 576-588.
(15) Starratt, A. N., Loschiavo, S. R. (1972) Can. Entomol. 104, 757-759.
(16) Pinninger, D. B. (1975) A Bait Trap Technique for Assessment of Stored Product Beetle Populations, PICL Maff, Slough (England), and Pest Infestation Control Laboratory Report 1971-73, 54-55, London: Her Majesty's Stationery Office.

(17) Dyte, C. E., Green, A. A., Pinninger, D. B. (1975) Proc. 1st Int. Working Conf. Stored Prod. Entomol., Savannah, 1974, 261-271.
(18) Bains, S. S., Battu, G. S., Atwal, A. S. (1976) Bull. Grain Technol. 14, 18-29.
(19) Burkholder, W. E. (1977) In: Shorey, H. H., McKelvey, J. J., Jr. (eds.) Chemical Control of Insect Behaviour, Theory and Application, Proc. Sympos. 345-351, Wiley and Sons, N.Y., London, Sydney, Toronto.
(20) Silverstein, R. M., et al. (1967) Science 157, 85-87.
(21) Fukui, H., et al. (1977) J. Chem. Ecol. 3, 539-548.
(22) Fukui, H., et al. (1974) Tetrahedron Letters 40, 3563-3566.
(23) Cross, J. H., et al. (1976) J. Chem. Ecol. 2, 457-468.
(24) Levinson, A. R., et al. (1977) J. Chem. Ecol., in press.
(25) Horler, D. F. (1970) J. Chem. Soc. (C) 859-862.
(26) Keville, R., Kannowski, P. B. (1975) J. Insect Physiol. 21, 81-84.
(27) Vick, K. W., et al. (1974) Experientia 30, 17-18.
(28) Brady, U. E., et al. (1971) Science 171, 802-803.
(29) Kuwahara, Y., Casida, J. E. (1973) Agr. Biol. Chem. 37,681-684.
(30) Nishida, R., et al. (1976) Agr. Biol. Chem. 40, 1407-1410.
(31) Nishida, R., et al. (1974) Experientia 30, 978-979.

ECOLOGICAL ASPECTS OF CONTROL OF A STORED PRODUCT INSECT BY OZONATION

HOWARD E. ERDMAN
Associate Professor of Biology
Biology Department
Texas Woman's University
Denton, Texas, U.S.A. 76204

INTRODUCTION: Microclimatic changes are effective in reducing insect populations; however, unexpected results such as increases of mite infestations, have occurred (1). Aeration to control insect infestation has met with limited success due to heavy infestation (2) and with almost complete success (3).

Ozone as a potential agent to control insect pests in stored products was chosen because of its oxidative ability to kill pathogenic bacteria (4, 5), viruses (6, 7, 8), fungi (9, 10). One mechanism of damage is associated with a membrane effect in bacteria (11), fungi (10), green plants (12), and mammalian cells (13, 14). Insect toxicity to ozone should prove interesting because of their tracheolar respiratory system rather than the complex alveolar system of humans.

Also, ozone is known for its radiomimetic effects: mutagenicity in bacteria (11); chromosome breakage in mice and chickens (15); chromatid breakage in human tissue culture cells (16); and mitotic inhibition in oysters (17). A documented compilation of comparable effects of ozone and ionizing radiation in living organisms includes these major areas: general, behavioral, congenital, physiological, chemoprotection, biochemical and genetic effects (18). Molecular events at the cellular level due to ozone, oxygen, and radiation were examined on the basis of interactions and the fate of free radicals in biological systems (19).

Ozone, like ionizing radiation, for control of insects might function as a killing agent and/or a sterilizing agent.

This report concerns the effects of ozone on specific life cycle stages and on population performance of two species of economically important insect pests of stored products, namely, wild type strains of the flour beetles, *Tribolium confusum* and *T. castaneum*.

MATERIALS AND METHODS: Wild type strains of the flour beetles, *Tribolium confusum* duVal and *T. castaneum* Herbst, were cultured on standard food at 30±2°C and 65-75 percent relative humidity.

An Orec Model 03Vi-0 ozonator (Ozone Research and Equipment Corporation, 3840 North 40th Avenue, Phoenix, Arizona 85019, U.S.A.) operated at 39 percent power setting, 46 volts, 0.50 amps with clean dry air flow at 0.33 liter per minute produced 450 ppm of ozone. A boric acid buffered potassium iodide absorbent and

UV photometry were used to determine the ozone concentration (20). All exposures were at room temperature in a vented hood.

Life cycle stages of both species as 15 and 20 day old larvae; 23 day old white unpigmented pupae; 28 day old pigmented pupae; and, stock adults were exposed to ozone for 1/4, 1/2, 3/4 hour and each hour and half-hour thereafter up to 7 hours. Five samples of 20 individuals per stage were observed for lethality and sterility one month after adult eclosion.

Single-species populations were begun with 50 stock adults and 3 g food. Monthly three replicates were given: no exposure-census-new food (control); air-census-new food; ozone-census-new food; or census-new food-ozone. Hereafter these groups will be referred to as: control, A-C-F, O-C-F, and C-F-O, respectively. Air or ozone was given for 5 hours. At each census numbers of living and dead larvae, pupae and adults were counted. Dead forms were discarded. Large larvae, pupae, and adults were restrained in a 0.0278 inch U.S. Standard Sieve. In the flour, larvae which were visible to the naked eye were counted and returned to the other live forms.

RESULTS AND DISCUSSION: Ozone effects on specific life cycle stages. A differential lethal response to ozone on a species basis for a given life cycle stage indicated that *T. castaneum* was consistently more ozone sensitive than *T. confusum* at the stages tested except as 15 day old larvae at which time the sensitivities were comparable (Figure 1). The 100 percent lethality induced by ozone for these species indicated that 20 day old larvae, white or unpigmented pupae, and adults of *T. castaneum* were more sensitive than those of *T. confusum* (Table 1). For both

Table I. Hours exposure to 450 ppm of ozone which induced 100 percent lethality at specific life cycle stages of wild-type strains of the flour beetles, *Tribolium confusum* and *T. castaneum*.

HOURS OF OZONE EXPOSURE FOR 100 PERCENT LETHALITY

LIFE CYCLE STAGE	T. CONFUSUM	T. CASTANEUM
15 DAY LARVAE	3 1/2	3 1/2
20 DAY LARVAE	6 1/2	5 1/2
WHITE PUPAE	5 1/2	3 1/2
PIGMENTED PUPAE	6	6
ADULTS	6 1/2	5

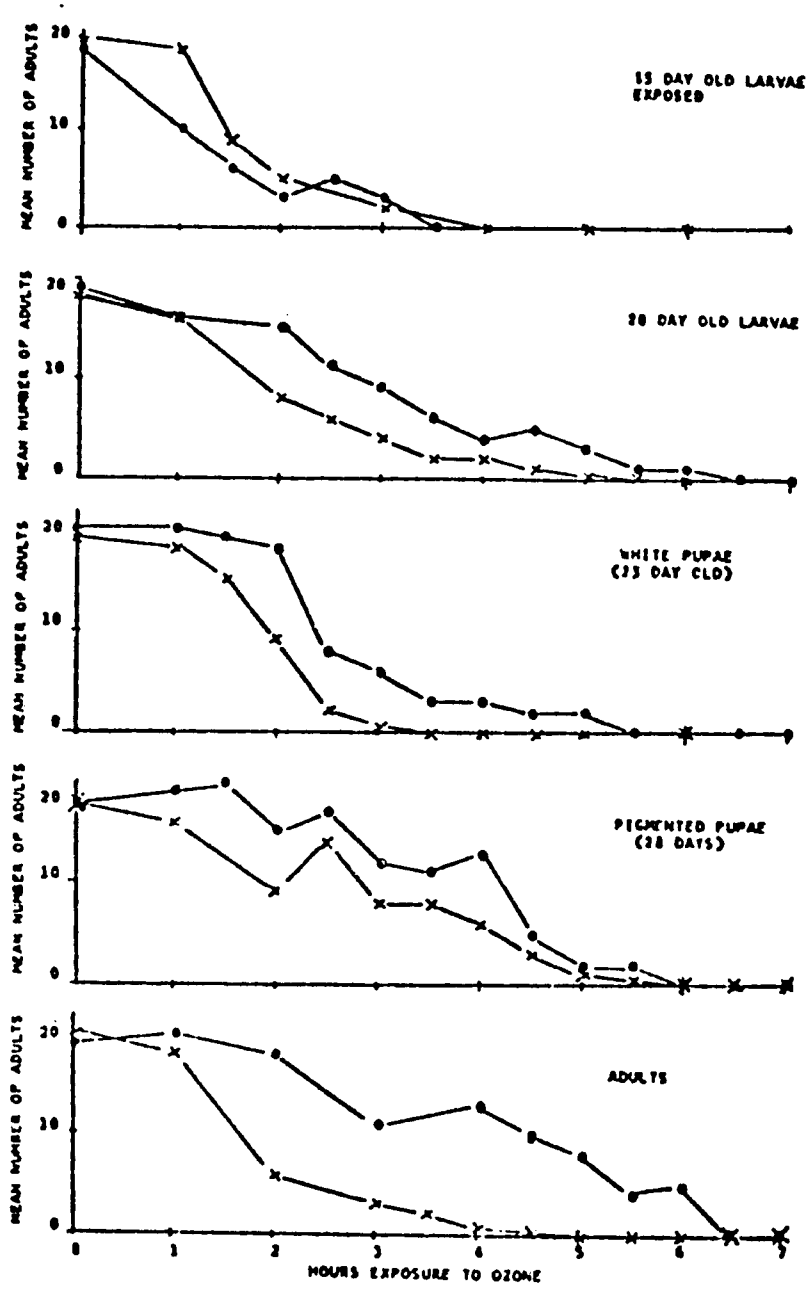


FIGURE 1. MEAN NUMBERS OF ADULTS OF THE FLOUR BEETLES, TRIBOLIUM CONFUSUM DU VAL (●) AND T. CASTANEUM HERBST (X) EXPOSED TO 450 ppm OZONE FOR VARIOUS TIME PERIODS AT SPECIFIC LIFE CYCLE STAGES.

species the youngest life cycle stage exposed (15 day old larvae) was most sensitive; the white pupal stage was the next most sensitive. These highly metabolically active stages in which immature tissues are changing into mature adult tissues reflect the greater sensitivity to ozone.

The percent mortality at the life cycle stages for specific durations of ozonation (Figure 2) showed that *T. confusum* could exploit an ozone-containing environment more successfully than *T. castaneum* could. All life cycle stages of *T. castaneum* exposed 2 hours or longer of ozone were comparatively sensitive.

The mean numbers of *T. confusum* adults obtained after ozonation of a life cycle stage (Table II) showed that sensitivity

Table II. Mean numbers of adults ± standard errors for *Tribolium confusum* duVal exposed to 450 ppm ozone for various periods of time at different life cycle stages

LIFE CYCLE STAGE IN DAYS

HRS OF O_3	LARVAE 15	LARVAE 20	PUPAE 23	PUPAE 28	STOCK ADULTS
0	18 ± 1	19 ± 1	20 ± .5	18 ± 1	19 ± 1
1	10 ± 3	16 ± 0	20 ± .5	19 ± 1	20 ± 1
2	3 ± 1	15 ± 1	18 ± .6	15 ± 2	18 ± 1
3	3 ± 0	9 ± 1	6 ± 2	12 ± 3	11 ± 1
3 1/2	0	6 ± 2	3 ± 1	11 ± 1	8 ± 2
4		4 ± 2	3 ± 1	13 ± 2	13 ± 1
4 1/2		5 ± 1	2 ± 1	5 ± 2	10 ± 1
5		3 ± 3	2 ± 1	2 ± 1	8 ± 2
5 1/2		1 ± .4	0	2 ± 1	4 ± .5
6		1 ± .4		0	5 ± 2
6 1/2		0			0

to ozone decreased with ontogeny from the larval through adult stages. The 20 day old larvae were unexplainably resistant to lethal effects from ozone. In general, this ozone response followed that of ionizing radiation induced lethality (21), namely, sensitivity decreased with increasing age.

Lethal effects of ozone on *T. castaneum* (Table III) occurred at 2 hours exposure and thereafter. The older larvae and pupae were more ozone resistant than the younger forms. Older larvae and pupae were more ozone tolerant than the adult stage. Pigmented pupae were the most resistant of all life cycle stages. The lethal trend for *T. castaneum* exposed to ozone did not follow that for ionizing radiation (21, 22).

One might postulate similar oxidative mechanisms for ozone and ionizing radiation induced lethalities for *T. confusum*. Radiomimetic effects of ozone were documented for Chinese hamster cells (23, 24), *E. coli* (11), *Vicia faba* root tip meristems (16)

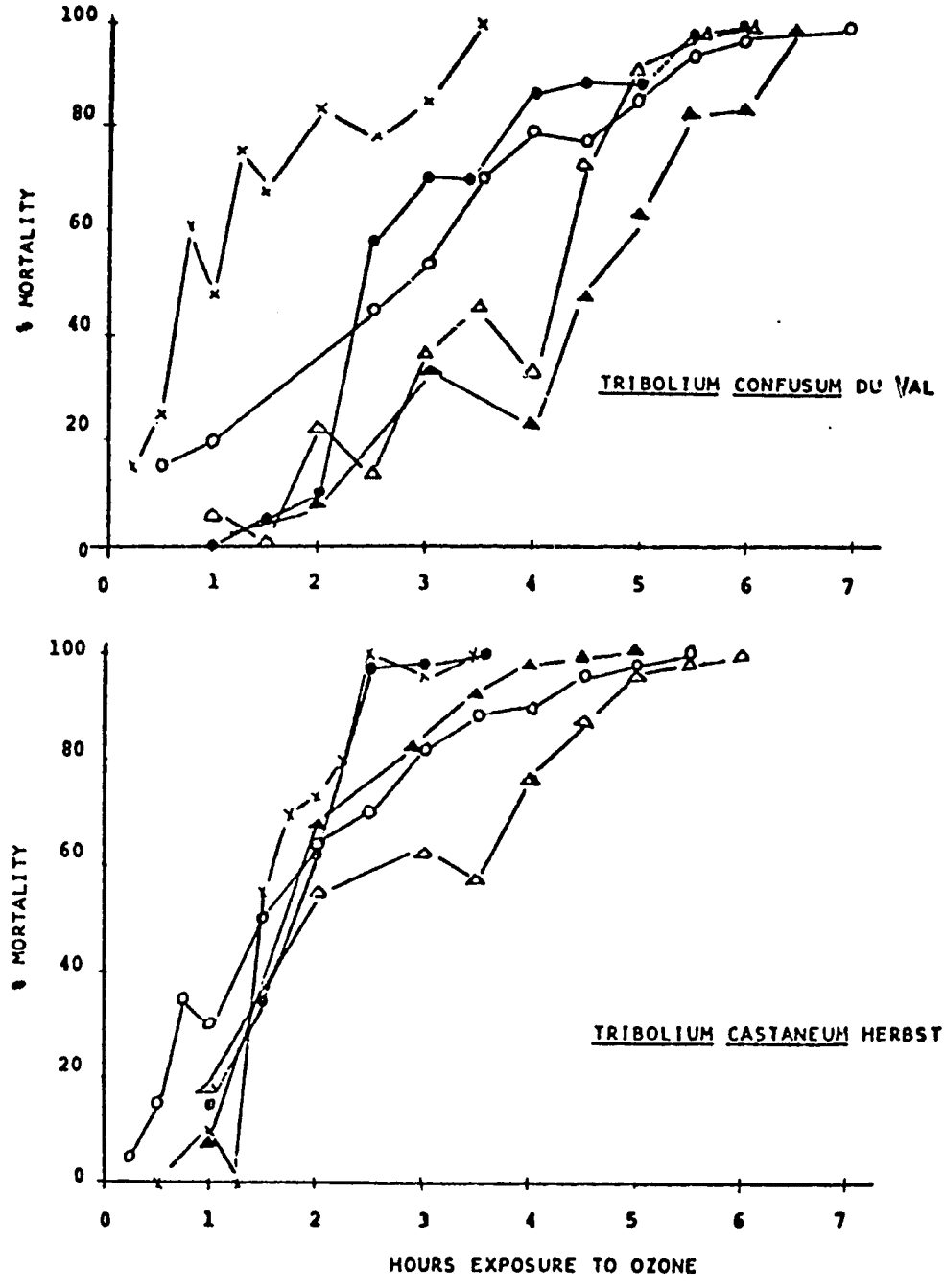


FIGURE 2. PERCENT MORTALITY OF FLOUR BEETLES EXPOSED TO 450 ppm OZONE FOR VARIOUS TIME PERIODS AT SPECIFIC LIFE CYCLE STAGES:

- X 15-DAY OLD LARVAE
- 0 20-DAY OLD LARVAE
- ▲ ADULTS
- ● 23-DAY OLD WHITE PUPAE
- △ 28-DAY OLD PIGMENTED PUPAE

rather than on older ones. This response is also a typical radiation response in studies featuring ontogeny (22).

Overall, ozone had a greater adverse effect on population performance of *T. castaneum* than that of *T. confusum* but significantly reduced population size for both species. The reproductive potential of *T. confusum* seemed more conservatively determined by the genotype thus maintaining a gene pool less easily changed by environmental conditions. Supportive evidence was found in these two examples: (1) When temperature (33) was an environmental factor *T. confusum* performed better in mixed-species culture than in single-species culture; (2) *T. confusum* also was more productive than *T. castaneum* at 32°C under chronic gamma radiation of 49 R/day and 170 R/day (34).

Unexpectedly, during the first 5-6 months more larvae were observed in the A-C-F and C-F-O populations of *T. confusum* than in the controls (Figure 4A) indicating a stimulation of

TABLE III. Mean number of adults ± standard errors for *Tribolium castaneum* Herbst. exposed to 450 ppm ozone for various periods of time at different life cycle stages

LIFE CYCLE STAGE IN DAYS

HRS OF O_3	LARVAE 15	LARVAE 20	PUPAE 23	PUPAE 28	ADULT
0	19 ± 1	18 ± 1	19 ± 1	18 ± 1	20 ± .4
1	18 ± 1	16 ± 1	18 ± 1	16 ± 2	18 ± 1
2	5 ± 1	8 ± 2	9 ± 2	9 ± 2	6 ± 2
3	2 ± 1	4 ± 1	1 ± .3	8 ± 2	3 ± .6
3 1/2	0	2 ± .5	0	8 ± 2	2 ± .8
4		2 ± 1		6 ± 2	1 ± 2
4 1/2		1 ± .7		3 ± .7	.2 ± .1
5		.4 ± 1		1 ± .7	0
5 1/2		0		.5 ± .5	
6				0	

and microsporocytes (25), chick fibroblasts (15) and nucleic acids (26, 27). Similar type chromosome aberrations were reported for barley (28) exposed to hydrogen peroxide 'precursors' which are active radicals (OH and HO_2) formed by high-energy radiations in water (29) or protoplasm and by the decomposition of ozone in solution (30).

The failure of *T. castaneum* to respond to ozone in a way similar to that of ionizing radiation like *T. confusum* did remains an enigma. One would expect that similarities of morphology and ecological requirements of these two species were endowed by similar metabolism and physiology which would respond to environmental stimuli in much the same way. Such was not the case at least for the postulated mechanism of reaction for ozone and ionizing radiations.

Observations indicated that any resulting adults were able to reproduce, but no quantitative data were recorded. Since surviving adults were fecund and fertile, a lack of gonad differential sensitivity during development to ozone is in opposition to the ionizing radiation response for these species (22). Ozone exposure for 8 hours (no concentration given) had slight effect on egg hatch and no effect on larvae or pupae of three dipteran species (31). In another series of experiment (32) the presumed ozone concentration reached 0.3 ppm or greater and after 22-26 days continuous exposure, no effects were noted for cockroaches, *Periplaneta americana (L.)*, *Nauphoeta cinerea* (Oliver) and the red fire ant, *Solenopsis invicta* Buren.

Insects are the most ozone tolerant organisms of which I know; nevertheless, their control by ozonation seems promising. They are also among the most radiation resistant multicellular organisms, insofar as induced sterility and/or lethality is concerned.

Ozone effects on single species populations. Counts of the mean numbers of larvae in all *T. castaneum* populations indicated that all treatments had an effect. These data presented as percent of control (Figure 3A) showed:(1) all treatments reduced the numbers of larvae; (2) A-C-F populations had the larval segment reduced to approximately 60 percent; however, an increase was noted after the 12th month; (3) the C-F-O populations persisted after month 4 with about 35 percent of control values; (4) the larval component of the O-C-F groups was severely reduced to less than 10 percent of the control. After 4 or 6 months, the larval populations reached the carrying capacity which remained relatively constant for the specific environment until the experiment was terminated except in the A-C-F populations in which an increase occurred.

The adult data presented as percent of control (Figure 3B) for *T. castaneum* reflected the performance of the larvae for a given set of experimental conditions. Apparently the adverse effects of air and/or ozone were on a younger life cycle stage

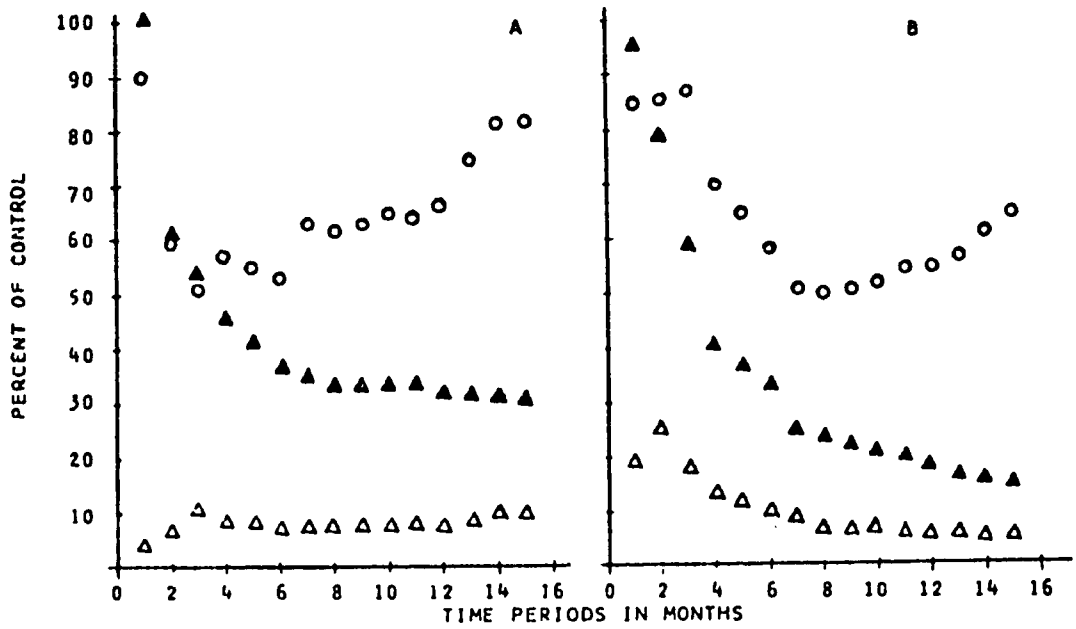


FIGURE 3. LARVAE (A) AND ADULTS (B) AS PER CENT OF CONTROL FOR THE FLOUR BEETLE, FOR TRIBOLIUM CASTANEUM, HERBST IN SINGLE-SPECIES POPULATIONS CENSUSED MONTHLY AND SUBJECTED TO THESE CONDITIONS:

- ○ AIR - CENSUS - NEW FOOD (A-C-F)
- △ OZONE - CENSUS - NEW FOOD (O-C-F)
- ▲ CENSUS - NEW FOOD - OZONE (C-F-O)

AIR OR 450 PPM OZONE WERE GIVEN FOR 5 HOURS EACH MONTH AT 0.3 ℓ/MIN.

oviposition. This response was also reported for house flies (31, 35). During this time if competition had been lessened by providing more food, perhaps more larvae would have developed into adults. Such a stimulated reproductive response would be economically attractive to insect culture facilities.

By month 9, C-F-O populations again showed an increase in numbers of larvae over control values. The larvae in the O-C-F populations were consistently approximately 35-40 percent of control values.

Numbers of *T. confusum* adults in A-C-F populations were comparable to those of controls (Figure 4B). Numbers of adults in

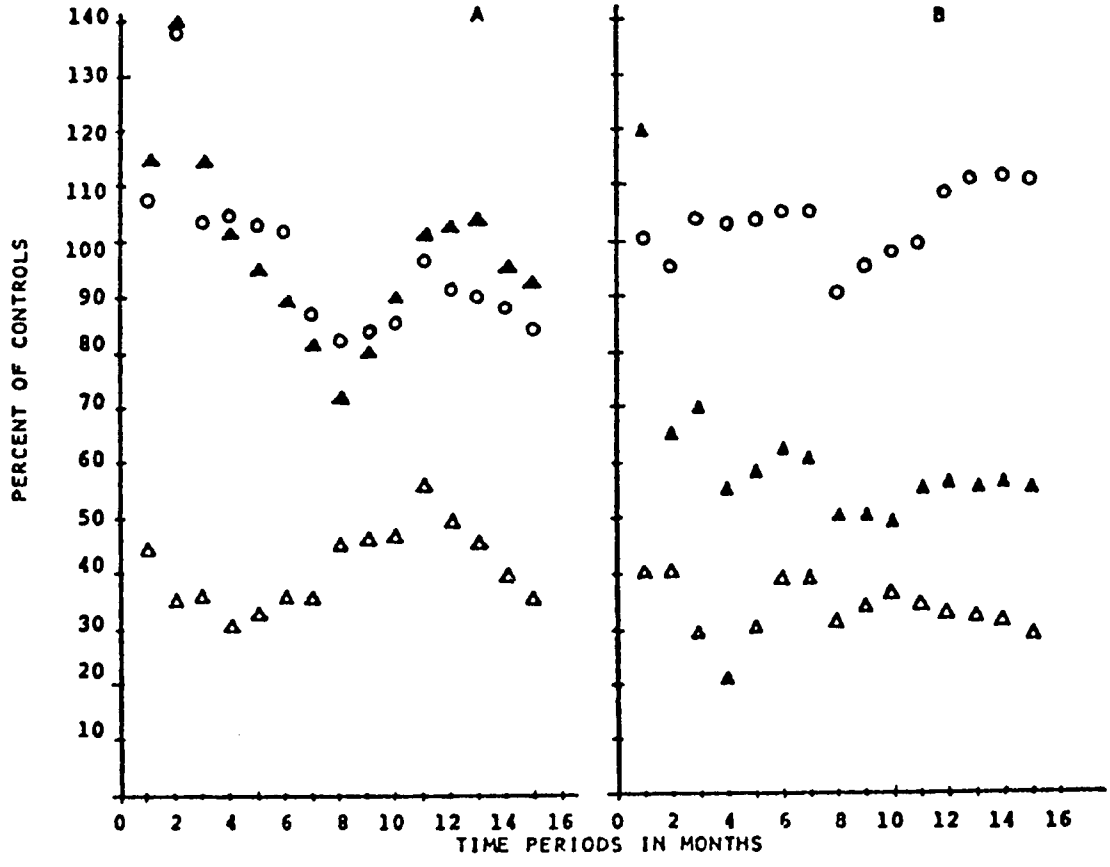


FIGURE 4. LARVAE (A) AND ADULTS (B) AS PER CENT OF CONTROL FOR THE FLOUR BEETLE, FOR TRIBOLIUM CONFUSUM DU VAL, IN SINGLE-SPECIES POPULATIONS CENSUSED MONTHLY AND SUBJECTED TO THESE CONDITIONS:

○ AIR - CENSUS - NEW FOOD (A-C-F)

△ OZONE - CENSUS - NEW FOOD (O-C-F)

▲ CENSUS - NEW FOOD - OZONE (C-F-O)

AIR OR 450 PPM OZONE WERE GIVEN FOR 5 HOURS EACH MONTH AT 0.3 ℓ/MIN.

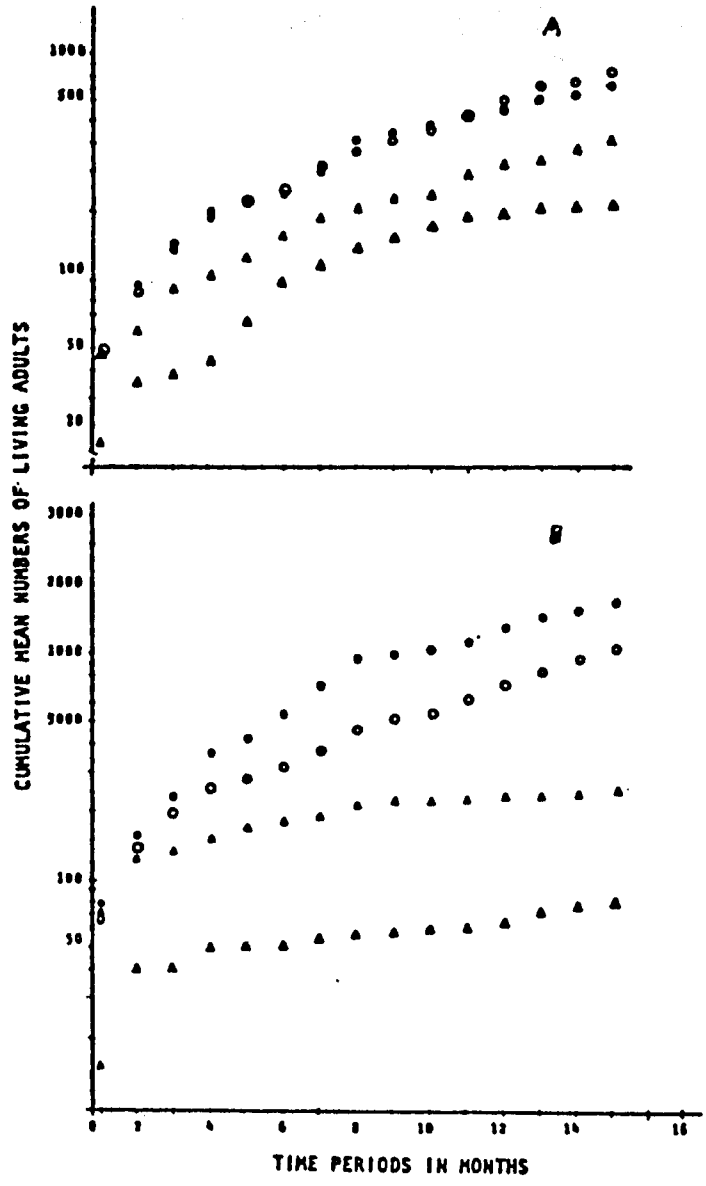


FIGURE 5. CUMULATIVE MEAN NUMBERS OF LIVING ADULTS IN SINGLE-SPECIES POPULATION OF FLOUR BEETLES, TRIBOLIUM CONFUSUM DU VAL (A) AND T. CASTANEUM HERBST (B). AIR OR 450 PPM OZONE WERE GIVEN FOR 5 HOURS MONTHLY AT WHICH TIME CENSUSES WERE TAKEN. EXPERIMENTAL CONDITIONS WERE:

- ● NO EXPOSURE - CENSUS - NEW FOOD (CONTROL)
- ○ AIR - CENSUS - NEW FOOD (A-C-F)
- △ OZONE - CENSUS - NEW FOOD (O-C-F)
- ▲ CENSUS - NEW FOOD - OZONE (C-F-O)

the O-C-F and C-F-O populations were significantly below control levels and maintained their numbers at 30 and 55 percent of controls, respectively, during the 15 months.

Based on progressively higher values for cumulative numbers of live adults within a species and between different environmental conditions, the populations could be ranked for *T. confusum* Figure 5A): O-C-F<C-F-O<A-C-F = control; for *T. castaneum* (Figure 5B) O-C-F<C-F-O<A-C-F<control. These data showed that 5 hours' exposure to 450 ppm O_3 reduced numbers of adult flour beetles in populations of either species; and, ozonated populations of *T. confusum* continued to increase in numbers of adults during the experimental 15 months; whereas, those of *T. castaneum* persisted at relative constant levels: 50 to 70 for O-C-F and 150 to 200 for C-F-O.

The total numbers of living forms for the populations of *T. confusum* (Figure 6A) and *T. castaneum* (Figure 6B) presented on a cumulative basis showed several trends which are important in an insect control technique program. Under these experimental conditions ozone is not effective as a control agent; although it reduced numbers in the population, it did not eliminate the populations or reduce their numbers to economically insignificant values. The ozone stimulation of productivity indicated by the *T. confusum* larvae (Figure 4A) was not reflected in the total numbers of living forms. Perhaps ozone had a residual toxic effect which occurred before the pupal stage.

Data for pupae were not given because in all groups the numbers of pupae ranged between 2 and 10. This was expected because the pupal stage is very brief compared to larval and adult stages.

One might anticipate that ozone would react with and cause the flour to have an adverse effect on those who ingested it; however, for both species the opposite response was observed (Figure 6), that is, C-F-O populations performed better than O-C-F populations. Perhaps the increased activity (metabolism) of census taking immediately after ozone exposure in the O-C-F populations accentuated the toxic effects of ozone.

Each ecological condition resulted in a different population maintenance pattern for the flour beetles (Figure 6). The separation of population census curves was more pronounced for *T. castaneum* (Figure 6B) than for *T. confusum* (Figure 6A). Control populations of *T. castaneum* contained more adults than those of *T. confusum* under these experimental conditions; however, ozone exposure more adversely affected populations of *T. castaneum* than those of *T. confusum*.

The population reduction by air exposure was unexpected. One might postulate a physical effect due to particles of flour and/or yeast interferring with beetle respiration because the air or ozone was given such that a constant flow at 0.3 liter per minute went through the flour containing the flour beetles. Such

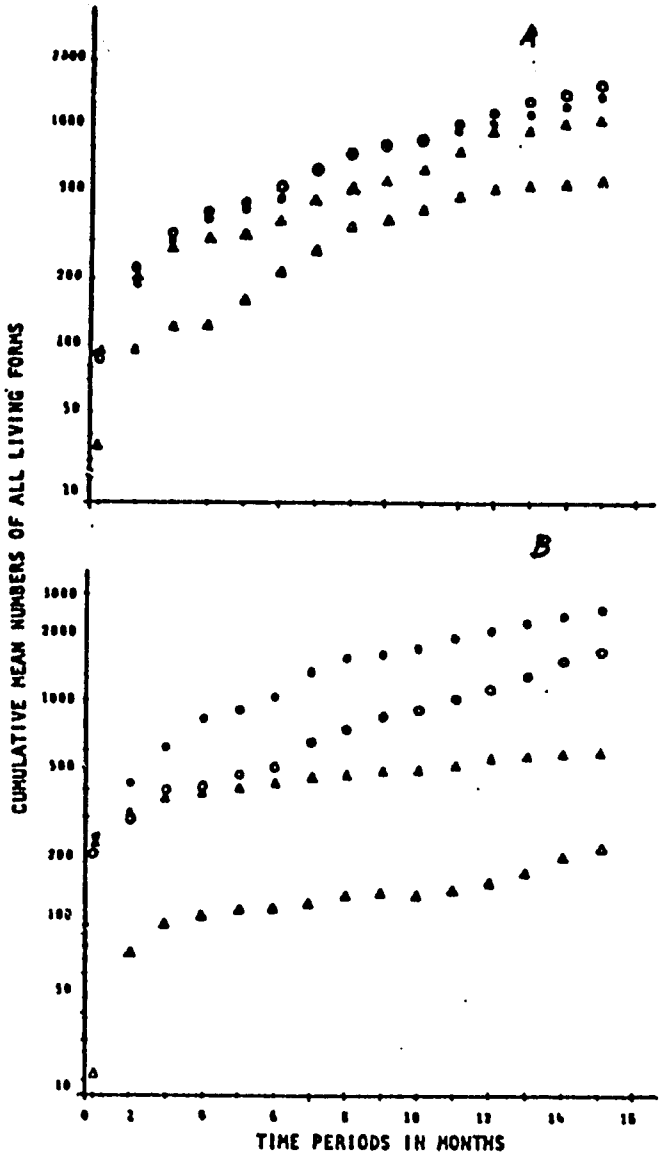


FIGURE 6. CUMULATIVE MEAN NUMBERS OF ALL LIVING FORMS (LARVAE, PUPAE, ADULTS) IN SINGLE-SPECIES POPULATION OF FLOUR BEETLES, TRIBOLIUM CONFUSUM DU VAL (A) AND T. CASTANEUM HERBST (B). AIR OR 450 PPM OZONE WERE GIVEN FROM 5 HOURS MONTHLY AT WHICH TIME CENSUSES WERE TAKEN. EXPERIMENTAL CONDITIONS WERE:

- ● NO EXPOSURE - CENSUS - NEW FOOD (CONTROL)
- ○ AIR - CENSUS - NEW FOOD (A-C-F)
- △ OZONE - CENSUS - NEW FOOD (O-C-F)
- ▲ CENSUS - NEW FOOD - OZONE (C-F-O)

a hypothesis was not supported by the number of dead individuals. The numbers of dead *Tribolium* seemed to cluster in two groups for *T. confusum* (Figure 7A), namely, the control and A-C-F populations

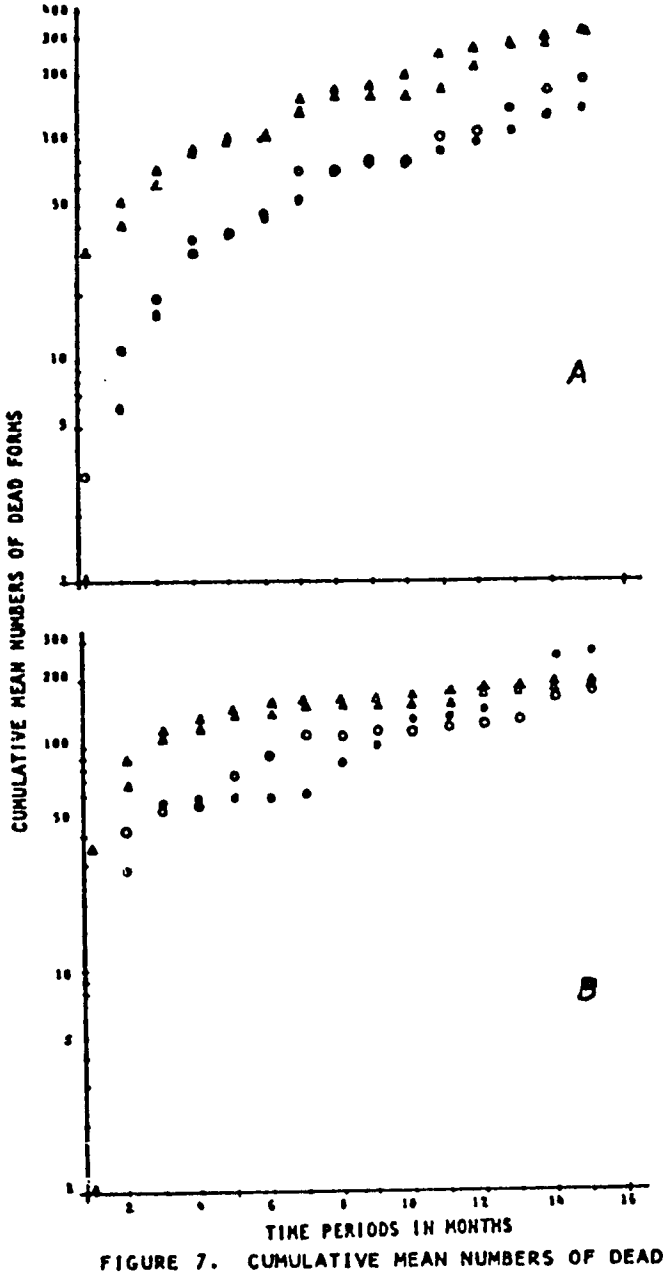


FIGURE 7. CUMULATIVE MEAN NUMBERS OF DEAD INDIVIDUALS IN SINGLE-SPECIES POPULATION OF FLOUR BEETLES, TRIBOLIUM CONFUSUM DU VAL (A) AND T. CASTANEUM HERBST (B). AIR OR 450 PPM OZONE WERE GIVEN FOR 5 HOURS MONTHLY AT WHICH TIME CENSUSES WERE TAKEN. EXPERIMENTAL CONDITIONS WERE:

- ● NO EXPOSURE - CENSUS - NEW FOOD (CONTROL)
- ○ AIR - CENSUS - NEW FOOD (A-C-F)
- △ OZONE - CENSUS - NEW FOOD (O-C-F)
- ▲ CENSUS - NEW FOOD- OZONE (C-F-O)

and the O-C-F and C-F-O populations with the latter group containing more dead individuals than the former. One would conclude that ozone was more toxic than air or no treatment. These two groups were not as clearcut for *T. castaneum* (Figure 7B) as they were for *T. confusum*.

These experiments showed that flour beetles, an economically important pest in stored food products, were resistant to high concentrations (450 ppm) of ozone given for long periods of time (5 hours). Perhaps ozone would predispose flour beetles to radiations for an effective control program; their action could be synergistic as reported in mouse studies concerned with C 3 H-tumors (36) and mortality (18) and in *E. coli* repair of DNA (11).

Another aspect of ozone in the control of harmful insect species in stored-products concerns the effects of ozone on the stored-product per se. Perpaps a highly oxidizing agent like ozone would change the stored-product making it objectionable to taste, in appearance and for marketability.

CONCLUSIONS: 1. Although 5 hour monthly exposures to 450 ppm O_3 at 0.3l/min. reduced the numbers of individuals in populations of *T. confusum* and *T. castaneum*, they did not result in elimination or a significant decrease in numbers which would be useful for a control program of these flour beetle species.

2. *T. castaneum* was more ozone sensitive than *T. confusum* at the life cycle stages investigated.

3. Induced lethality during ontogeny of *T. confusum* exposed to ozone followed that induced by ionizing radiations; consequently a similar oxidative effect mechanism is hypothesized. No comparable trends were noted for *T. castaneum*, except that the oldest life cycle stage (adult) was more ozone resistant than the youngest stage (15 day old larvae).

4. During the first five months of culture, ozone had a stimulating effect on productivity of *T. confusum;* a similar effect was not noted for *T. castaneum*.

5. One hour exposure to 450 ppm ozone at a flow rate of 0.3 l/min had no effect on either species as 15 day old larvae or older stages.

6. Within seven hours exposure to this ozone, lethality to all living forms including adults of both species was observed.

7. Control of flour beetles by ozone in stored products seems unlikely; however, ozone in an integrated control program might prove beneficial.

REFERENCES:

(1) Burrell, N. J., Grain cooling studies-II: Effect of aeration on infested grain bulks. J. Stored Prod. Res. 3 (1967) 145.

(2) Sutherland, J. W., Control of insects in a wheat store with an experimental aeration system. J. Agric. Eng. Res. 13(3) (1968) 210.

(3) Navarro, S., Aeration of grain as a non-chemical method for the control of insects in the grain bulk, Proc. First Internat. Work. Conf. on Stored-Product Entomol., Savannah, Georgia (1974) 341.

(4) Broadwater, W. T., et al., Sensitivity of three selected bacterial species to ozone. Appl. Microbiol. 26(3) (1973) 391.

(5) Burleson, G. R., et al., Inactivation of viruses and bacteria by ozone, with and without sonication, Appl. Microbiol. 29(3) (1975) 340.

(6) Berg, G., Removal of viruses from sewage, effluents and waters. Bull. Wld. Hlth. Org. 49 (1973) 451.

(7) Carazzone, M. M., Vanini, G. C., Richerche Sperimentali circa L'Azione dell'ozono sui virus, G. Batt. Virol. 62 (1969) 828.

(8) Majumdar, S. B., et al., Communication: Inactivation of polio virus in water by ozonation. J. Water Pollution Control Fed. 46 (8) (1974) 2048.

(9) Ewell, A. W., Ozone and its application in food preservation, Refrig. Eng. (1950).

(10) Hibben, C. R., Stotzky, G., Effects of ozone on the germination of fungus spores. Can. J. Microbiol. 15 (1969) 1187.

(11) Hamelin, C., Chung, Y. S., The effect of low concentrations of ozone on *Escherichia coli* chromosome, Mutat. Res. 28(1) (1975) 131.

(12) Duggar, B. M., et al., Physiological and biochemical effects of atmospheric oxidants on plants. J. Air Pollut. Cont. Assn. 16 (1966) 467.

(13) Brinkman, R., et al., Radiomimetic toxicity of ozonized air. Lancet 7325 (1964) 133.

(14) Dungworth, D. L., et al., Effect of ambient levels of ozone on monkeys, Federation Proceedings 34 (1975) 1670.

(15) Sachsenmaier, W., et al., Wirkung von Ozon auf Mauseascites-tumorzellen und auf Hühnerfibroblasten in der Gewebekultur, Zeitschrift für Krebsforschung 67 (1965) 113.

(16) Fetner, R. H., Ozone-induced chromosome breakage in human cell cultures, Nature 194 (1962) 793

(17) Maclean, S., et al., Effects of ozone-treated seawater on the spawned, fertilized, meiotic and cleaving eggs of the commercial American oyster, Mutation Res. 21 (1973) 283.

(18) Veninga, T. S., Toxicity of ozone in comparison with ionizing radiation, Strahlentherapie 134 (3) (1967) 469.

(19) Menzel, D., Toxicity of ozone, oxygen, and radiation, Ann. Rev. Pharmacol. 10 (1970) 379.

(20) Fiamm, P. L., Analysis of ozone at low concentrations with boric acid buffered KI, Environ. Sci. and Tech. 11 (10) (1977) 978.

(21) Erdman, H. E., Comparative x-ray sensitivity of *Tribolium confusum* and *Tribolium castaneum* (Coleoptera: Tenebrionidae) at different development stages during their life cycle, Nature 195 (1962) 1218.

(22) Erdman, H. E., Ontogeny and comparative radiation sensitivity in the confused flour beetle and strains of the red flour beetle, J. Econ. Entomol. 61 (1) (1968) 123.
(23) Zelac, R. E., et al., Inhaled ozone as a mutagen, I. Chromosome aberrations induced in Chinese hamster lymphocytes, Environ. Res. 4 (1971) 262.
(24) Zelac, R. E., et al., Inhaled ozone as a mutagen, II. Effect on the frequency of chromosome aberrations observed in irradiated Chinese hamsters, Environ. Res. 4 (1971) 325.
(25) Janakiraman, R., Harney, P. M., Effects of ozone on meiotic chromosomes of *Vicia faba*, Can. J. Genet. Cytol. 18 (1976) 727.
(26) Christensen, E., Giese, A. C., Changes in absorption spectra of nucleic acids and their derivatives following exposure to ozone and ultraviolet radiation, Arch. Biochem. Biophysica 51 (1954) 208.
(27) Prat, R., Effets de l'hypochlorite de sodium, de l'ozone et des radiations ionisantes sur les constituants pyrimidiques de *Escherichia coli*, Ann. Inst. Pasteur 114 (1968) 595.
(28) Phillips, L. L., Effects of free radicals on chromosomes of barley, Science 124 (1956) 889.
(29) Allen, A. O., The radiation Chemistry of Water and Aqueous Solutions, D. Van Nostrand Co., Inc., Princeton, N.J. (1961)
(30) Weiss, J., Investigations on the radical HO_2 in solution, Trans. Farad. Soc. 31 (1935) 668.
(31) Levy, R., et al., Effects of ozone on three species of Diptera, Environ. Entomol. 1 (5) (1972) 608.
(32) Levy, R., et al., Tolerance of three species of insects to prolonged exposures to ozone, Environ. Entomol. 3 (1) (1974) 184.
(33) Erdman, H. E., The influence of temperature on the performance of single and mixed species populations of flour beetles, Res. Pop. Ecol. 12 (1) (1970) 61.
(34) Erdman, H. E., Effects of chronic Co-60 (Gamma) radiation, dose rate, temperature and cohabitation on population performance of flour beetles, *Tribolium confusum* Duval and *T. castaneum* Herbst (Coleoptera: Tenebrionidae), Env. Entomol. 2 (1973) 41.
(35) Beard, R. L., Observation on house flies on high-ozone environments, Ann. Entomol. Soc. Am. 58 (1965) 404.
(36) Teske, H. J., et al., Tierexperimentelle Untersuchungen uber die Ozonewirkung auf Tumorwachstum und Bestrahlungseffekt, Strahlentherapie 145 (2) (1973) 155.

THE BIOLOGY AND IMPACT OF THE PREDATORY BUG *XYLOCORIS FLAVIPES* (REUTER)

RICHARD T. ARBOGAST
SEA, USDA
Savannah, Georgia, 31403
U. S. A.

INTRODUCTION: *Xylocoris flavipes* (Reuter) and several other anthocorid bugs of the subfamily Lyctocorinae frequently occur as predators in storage ecosystems. The cosmopolitan species *Lyctocoris campestris* (F.), for example, is found in granaries as well as in a wide variety of other habitats; and *Xylocoris galactinus* (Fieber), a species found chiefly in habitats where the temperature is high, has been recorded from heating grain in Scotland (1) and Canada (2). Also, the Australian species *Xylocoris queensladicus* Gross has been reported from stored peanuts in Queensland (3), and we have collected *Xylocoris sordidus* (Reuter) and *Dufourtellus ater* (Dufour) from stored peanuts in Georgia. (*Xylocoris sordidus* occurs in Central and South America as well as in the United States, and *D. ater* is indigenous to Europe, North Africa, and the Near East, where it is found beneath the bark of various trees, but it has been collected a number of times from stored products in North America.) *Nidicola marginata* Harris and Drake, a species limited in distribution to California, Arizona, and northern Sonora, Mexico, has been collected from guano in bat caves, bags of cottonseed meal, the nest of a wood rat, decaying dates, and a culture of *Sitotroga cerealella* (Olivier) (4).

The biology of these bugs and their role in regulating populations of storage pests have been largely neglected. It is important that this role be determined, first, because such information is essential to understanding how storage ecosystems function; and second, because it must be known before the potential of these predators as biocontrol agents can be evaluated.

The present paper describing our current knowledge of the biology and prey relationships of *X. flavipes* is a synthesis of previously published work and new information recently developed at the Savannah Laboratory. *Xylocoris flavipes* was selected for study at Savannah because it was readily available and because it is a widespread and relatively common species of storage ecosystems. It is found throughout the world in stored commodities and in cargos infested by the insects that serve as its prey, and although Carayon (5) mentioned that certain localities of capture, such as in the Canary Islands, suggest that it may sometimes occur outside the storage habitat, he stated that this was not certain. The cultures of *X. flavipes* maintained at Savannah were started with insects collected in rooms at the laboratory where large populations of stored-product insects were maintained to test insect-resistant packaging. Beyond this, the origin of the Savannah material is unknown.

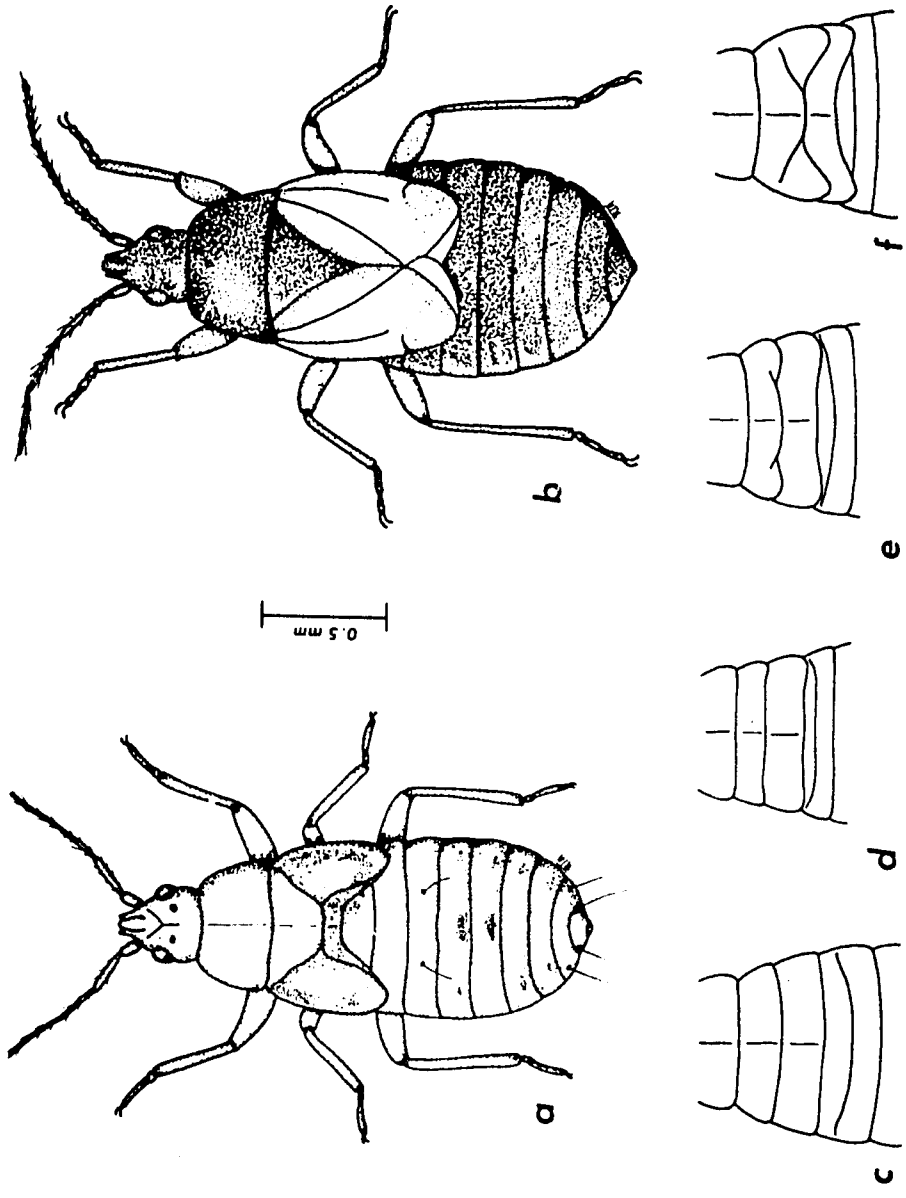


Fig. 1 *Xylocoris flavipes*. a, 5th instar nymph; b, brachypterous adult female; c-f, development of wing pads in instars 1-4 (not to scale).

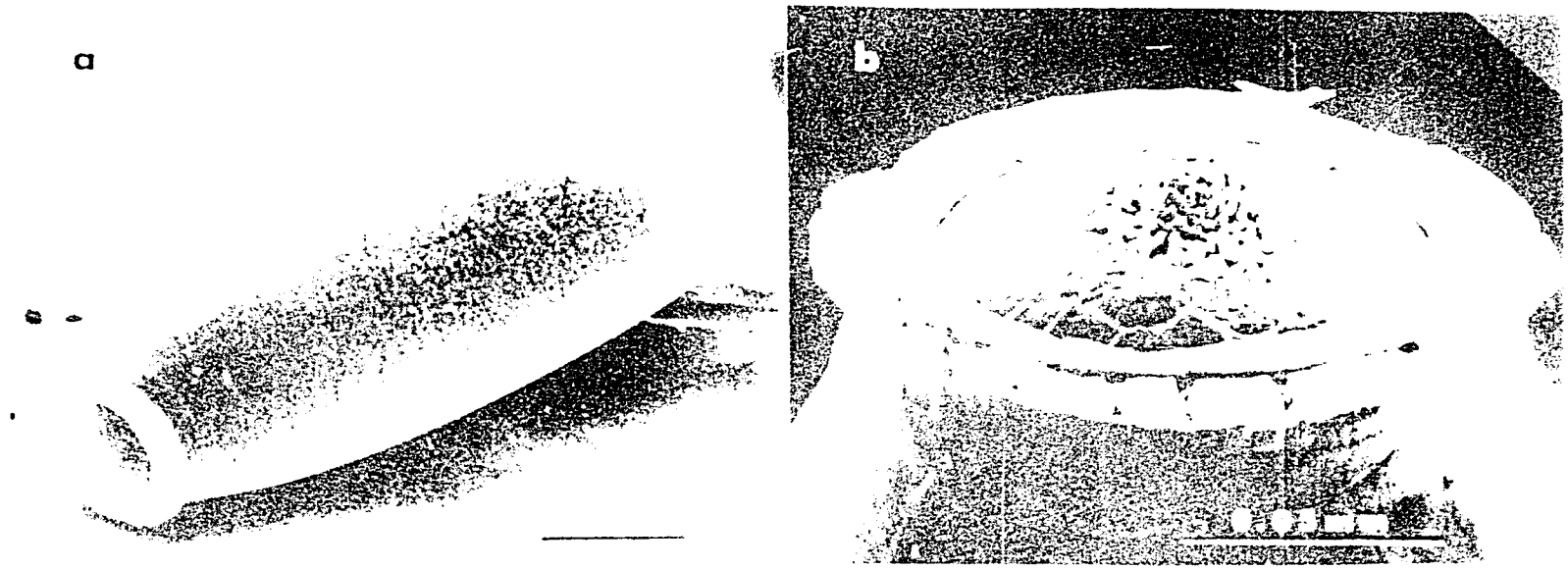


Fig. 2 *Xylocoris flavipes* egg. a, antero-lateral view; b, detail of operculum and expanded rim of chorion.

LIFE HISTORY AND DEMOGRAPHY: The developmental stages of *X. flavipes* were described by Arbogast et al. (6) and Awadallah and Tawfik (7). The adults (Fig. 1b) are shining brownish black with sparsely distributed pale setae. The rostrum, antennae, legs and hemelytra are brownish-yellow. The cuneus, the distal portion of the corium, and the inner margin of the clavus are tinged with black. The membrane is hyaline and without veins. The compound eyes are dark brown and the ocelli are red. The pronotum is somewhat convex with immarginate sides and very slightly rounded anterior angles. The scutellum is raised anteriorly. The antennae are 4-segmented with the 3rd and 4th segments much thinner than the other two and clothed with long erect setae. The rostrum and tarsi are 3-segmented.

The sexes can be distinguished by the shape of the abdomen, which is bilaterally symmetrical in females but in males is notched on the left side of segments 8 and 9. The aedeagus arises within the 9th segment and is directed to the left.

Brachypterous and macropterous forms occur in both sexes. The hemelytra of brachypterous adults do not reach the posterior margin of the 4th abdominal segment; those of the macropterous form always extend well beyond this segment and may reach the tip of the abdomen if the abdomen has not been distended by feeding. The brachypterous form is by far the more common of the two and in a sample of 105 adults 46% were brachypterous males, 42% brachypterous females, 3% macropterous males and 9% macropterous females.

As in most anthocorids, copulation in *X. flavipes* is extragenital traumatic (5), and seminal stimulus is necessary for normal egg development (8). The aedeagus of the male, which is sclerotized and sharply pointed, pierces the inter-segmental membrane between the 2nd and 3rd abdominal tergites of the female. Sperm are deposited directly into the haemocoel and migrate to the ovaries. The points of penetration are marked by plugs of tanned cuticle (copulation scars) that can be observed readily in specimens mounted and cleared in polyvinyl alcohol-lactic acid-phenol.

Awadallah and Tawfik (7) stated that mating usually occurs on the day of adult emergence. However, it appears from our observations that females are not sexually mature until 1 or 2 days later. When females were held for 1 or 2 weeks after the final molt and then paired with males, partially developed eggs could be observed in cleared specimens within 1 day, and oviposition began within 2; when they were paired as soon as they emerged, oviposition did not begin for 3 or 4 days.

The eggs (Fig. 2), which are scattered loosely throughout the habitat, are ellipsoidal, and the anterior end is capped by a nearly circular operculum surrounded by an expanded rim of the chorion. The chorion is marked by a faint reticulate pattern of polygons. The operculum bears a prominent tubercle at its center, which, in scanning electron micrographs (Fig. 2b), appears

to consist of a mass of nodules that have coalesced after deposition on the chorion. Newly deposited eggs are nearly colorless except for the rim of the chorion and the tubercle, which are white. As the eggs develop, they acquire a pale brownish yellow hue, and red eye spots appear about 2 days after oviposition (30°). Shortly before hatching, the eggs become deeply indented, and the red markings of the nymph are clearly visible.

At 30° C, the eggs hatch in 4 to 5 days. The nymph emerges by forcing open the operculum, which usually remains attached to the shell by the embryonic cuticle.

The nymphs (Fig. 1a) are shining and sparsely setose. The head is triangular, about as broad (across the eyes) as long. The thoracic nota are all transverse. The tarsi are 2-segmented with the 1st segment much shorter than the 2nd. The 3rd, 8th, and 9th abdominal terga each bear two long setae, one on either side. Those of the 3rd segment are located near the middle; the others are situated near the lateral margins. There are four pairs of dorsal abdominal scent gland openings as follows: a pair between segments 3 and 4, 4 and 5, and 5 and 6, with the openings of each pair joined by a groove, and a separated pair between segments 6 and 7 with the openings slightly mesad of the others.

Awadallah and Tawfik (7) reported that there are usually 5 nymphal instars, though the number ranges from 2 to 6. We have never observed any number other than 5. The instars differ mainly in size, development of the wing pads, and color; but color varies considerably within a given stage, particularly among 4th and 5th instars.

First-instar nymphs average 0.7 mm long. The body is pale brownish-yellow lightly suffused with orange-red, especially on the head and thorax. The head and thorax are tinged with black, and the 4th and 5th abdominal terga are each marked with a median orange-red spot. The eyes are deep brick red. The legs, antennae, and rostrum are nearly colorless except for a faint black tinge on the antennae. Wing pads are lacking, and there are two long setae on the 4th abdominal tergum, one near each lateral margin. These setae are lacking in later instars.

The orange-red suffusion usually becomes more extensive and intense after the 1st molt, and developing ocelli appear after the 2nd molt as small orange-red spots. Extensive black coloration first appears in the 4th instar but occurs more commonly and is usually heavier in the 5th.

Fifth-instar nymphs (Fig. 1a) are dark brownish-yellow to brown with pale brownish-yellow legs, antennae, and rostrum. The head and thorax, except for the scutellum, are tinged with black, especially on the wing pads. The abdomen may also be tinged with black and marked by a row of diffuse black spots on either side of the dorsum, but such black coloration is often faint or absent. In dark nymphs the median abdominal spots appear reddish-brown. In light nymphs they are orange-red as in earlier instars.

Development of the wing pads provides the most reliable method of separating instars 2-5. Wing pads first appear in the 2nd instar as barely perceptible protrusions on the latero-posterior margins of the meso- and metathoracic nota (Fig. 1d). Mesothoracic wing pads are well developed in the 3rd instar (Fig. 1e) but extend only slightly beyond the mid-posterior margin of the mesonotum. In the 4th instar, they extend well beyond this margin (Fig. 1f) and in the 5th instar they reach the tips of the metathoracic pads (Fig. 1a).

The mean duration of nymphal instars 1-4 is 2 days each at 30° C; the mean duration of instar 5 is 3 days. The lower developmental threshold apparently lies between 15 and 20° C. Eggs failed to hatch at 15° C, and when they were held at this temperature for 16 days or more, they failed to hatch even after they were transferred to temperature of 30° C (9). Also, exposure of eggs to 15° C for 6 days or more caused a sharp increase in subsequent mortality of 1st-instar nymphs. At 20° C development was protracted, and the duration of the developmental period was highly variable (10). As temperature was increased from 20 to 30° C, developmental time decreased and became less variable, but a temperature increase from 30 to 35° C produced little further change (Fig. 3a). Rate of development was not significantly influenced by humidity.

The effect of temperature and humidity on various other population parameters is illustrated in Fig. 3. These isopleths of the population parameters were constructed from previously reported data (10) by using a response surface technique that employed cubic equations in temperature and humidity. The lowest mortality among eggs and nymphs occurred between 20 and 30° C (Fig. 3b). Intermediate humidities favored survival above 25° C, but below this temperature higher humidities were more favorable. Adult lifespan and oviposition period (Fig. 3c, d) were longest at low temperatures and intermediate humidities. Both became progressively shorter as temperature increased, and the maxima shifted to progressively higher humidities. The maximum number of eggs was laid between 25 and 28° C (Fig. 3e). Humidity had little effect on oviposition below about 60% RH, but the number of eggs laid diminished with increasing humidity above this value. The rate of population growth was greatest within the zone bounded by 29 and 31° C and 60 and 70% RH (Fig. 3f). It declined rapidly with increasing temperature above 33° C, especially at low or high humidities, and also declined, but more gradually, with decreasing temperature.

PREY SELECTION: *Xylocoris flavipes* does not show a high degree of prey specificity. It is known to prey on at least 13 species of insects belonging to 3 orders (Table 1), and it will probably kill any prey that it can overpower. It does, however, seem to prefer certain species and stages over others, but these preferences probably reflect variable success in attacking prey that

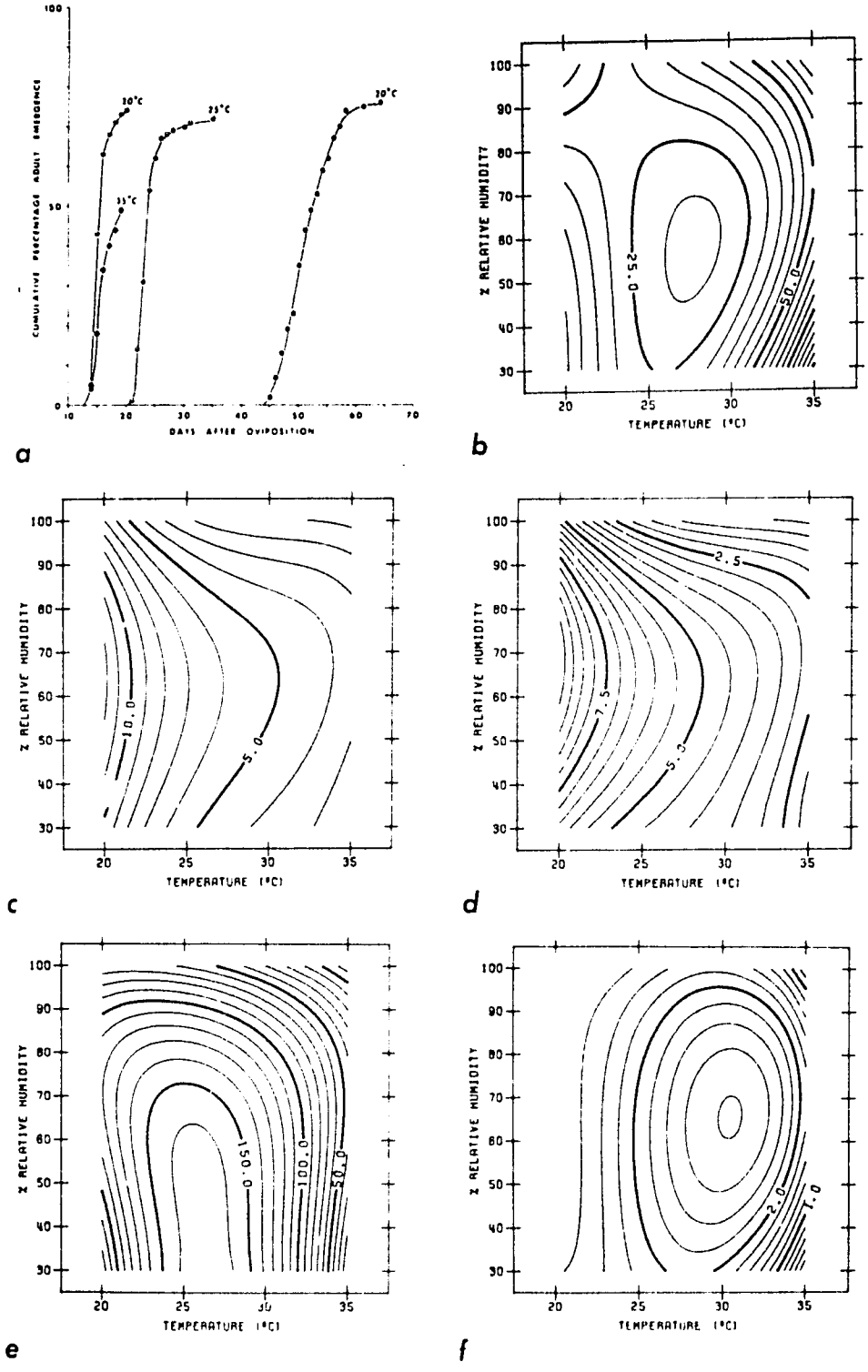


Fig. 3 Population parameters for *Xylocoris flavipes*. a, effect of temperature on rate of development; b, mortality of immature stages (%); c, mean adult lifespan (weeks); d, mean oviposition period (weeks); e, mean number of eggs laid in a lifetime; f, finite rate of increase (♂/♂/week).

Table I. Species of insects on which *X. flavipes* is known to prey.

Taxa	Selected references
Coleoptera	
Anobiidae	
Lasioderma serricorne (F.)	(11)
Bostrichidae	
Rhyzopertha dominica (F.)	(12)
Cucujidae	
Oryzaephilus surinamensis (L.)	(12), (13), (14)
Cathartus quadricollis (Guérin-Méneville)	J. W. Press (Personal communication)[1]
Dermestidae	
Attagenus megatoma (F.)	(15)
Trogoderma granarium Everts	J. L. Herring (Personal communication)[2]
Tenebrionidae	
Tribolium castaneum (Herbst)	(12), (14), (16)
Tribolium confusum Jacquelin duVal	(12), (17)

Table I. Continued.

Taxa	Selected references
Lepidoptera	
Pyralidae	
Galleria mellonella (L.)	H. M. Graham (Personal communication)[3]
Ephestia cautella (Walker)	(14), (18)
Plodia interpunctella (Hübner)	(6), (11), (12)
Gelechiidae	
Sitotroga cerealella (Olivier)	G. L. LeCato (Personal communication)[1]
Hymenoptera	
Braconidae	
Bracon hebetor Say	(19)

[1] Unpublished experimental data.

[2] Specimens in U.S. National Museum collected in Arizona in association with *T. granarium*.

[3] In cultures on honey combs at Tucson, Arizona.

differs in size, vestiture, degree of sclerotization, defensive behavior, or other factors.

Jay et al. (12) reported that *O. surinamensis* was the most vulnerable to *X. flavipes* of the species that they studied, followed in order, by *T. confusum*, *T. castaneum*, and *R. dominica*. LeCato and Davis (11) also found definite prey preferences when the larvae of various species were exposed to *X. flavipes*: *Oryzaephilus surinamensis* was again the most vulnerable followed, in order, by *T. castaneum*, *L. serricorne*, and *P. interpunctella*. Moreover, the predator killed more early stages of the larger species (*T. castaneum* and *P. interpunctella*) and more late stages of the smaller ones. The authors suggested that the size and thrashing movements of *T. castaneum* and *P. interpunctella* larvae when attacked may intimidate the predator and that the hirsute nature of *L. serricorne* larvae and the media clinging to their bodies may help discourage predation.

LeCato (15) subsequently demonstrated a clear preference of *X. flavipes* for *T. castaneum* larvae over those of *A. megatoma* and for certain stages of *T. castaneum* over others. He suggested that this preference could result from a number of factors including the larger size, heavier sclerotization, and heavier vestiture of *A. megatoma* or could perhaps reflect chemical differences. In these tests, the predator killed more *T. castaneum* than *A. megatoma*, regardless of whether the two species were exposed together or separately. However, it killed more *A. megatoma* when no *T. castaneum* were available than it did otherwise. This suggests that the persistence of attack increases with hunger and that it will kill prey when faced with starvation that it would otherwise reject. When all stages of *T. castaneum* were available *X. flavipes* concentrated on the immobile stages (eggs and pupae); they attacked fewer larvae and killed very few adults. Xylocoris nymphs destroyed more eggs but fewer larvae and pupae than did adults. In fact, young nymphs were unable to feed on *T. castaneum* pupae and died of starvation when no alternative prey was offered. Predation on each stage was greater when only one stage was offered at a time, but the number of adults killed was still very low.

REGULATION OF PREY POPULATIONS: The importance of *X. flavipes* in regulating populations of storage pests and its potential as a biocontrol agent can be assessed on the basis of the results of several experiments in which the predator was either added to or excluded from infested commodities.

The impact of *X. flavipes* on populations of *T. castaneum* was demonstrated by Press et al. (16) in an experiment with infested lots of inshell peanuts (groundnuts). They placed each lot (ca. 210 liters) in a plywood bin with a capacity of about 1800 liters and then added adult beetles at a rate of 2.3 pairs per liter of peanuts. One week later, they added adult predators to all but one bin at rates of 0.3 to 2.3 pairs per liter.

Samples taken 15 weeks after the peanuts were infested showed that the predator had suppressed population growth of the beetle and had reduced the number of damaged peanut kernels by more than 66%. The beetle population had increased over 8X in the bin that received no predators but had decreased 20 to 80% in the others, depending on the initial density of the predators.

Xylocoris flavipes had an even greater impact on populations of *O. surinamensis* in small lots (ca. 32 liters) of shelled corn (maize) contained in fiber drums (ca. 98-liter capacity) (13). Suppression of the beetle ranged from 97 to 99%. Populations that were free from predation increased more than 1900X in 15 weeks from an initial density of 0.6 pair per liter of corn. When predators were added to the drums (1 week after the beetles) at a rate of 0.2 pair per liter, increase in the beetle population was reduced to 65X, and when predators were added at rates of 0.3, 0.6, or 0.9 pair per liter, increase was reduced to ca. 20X.

Lecato et al. (14) showed that *X. flavipes* can completely suppress populations of *T. castaneum*, *O. surinamensis*, and *E. cautella* in warehouses containing only grain debris. They introduced 15 pairs of each pest species into each of two rooms in a warehouse and then added 30 pairs of adult predators to one of the rooms a week later. (A small quantity of rolled oats had been scattered over the floor to simulate grain debris.) All three pest species increased steadily in the room that received no predators and reached population levels in excess of 2500 after 100 days. When predators were present, the pest populations increased over the first 25 or 50 days and then declined to levels below those at which they were introduced.

CHARACTERISTICS THAT DETERMINE EFFECTIVENESS AS A PREDATOR: The suppression of pest populations achieved by adding *X. flavipes* to infested commodities is evidence that the predator has a high searching capacity, that is, it is able to find prey when prey is scarce. A capacity to survive between contacts with suitable prey is an obvious and important element of this searching capacity. Although *X. flavipes* is not very resistant to starvation, it can survive and develop with relatively little food.

LeCato and Collins (20) found that some *X. flavipes* nymphs (65%) could complete development on as little as 1 egg, 1 larva, and 1 pupa of *T. castaneum* per week and that the rate of development was the same as in nymphs provided with an excess of the same prey. When only 6 eggs were provided each week, the time required for development more than doubled, but 79% still survived to adulthood. When the weekly ration was reduced to 1 larva, only 33% survived, and none survived on 3 eggs per week. Adult longevity also decreased as the weekly ration of prey was reduced. When weekly feedings consisted of 1 larva, 6 eggs, or a combination of 1 egg, 1 larva, and 1 pupa, adult lifespan averaged 12 days, 26 days, or 38 days, respectively.

Arbogast et al. (21) showed that 1st-instar *X. flavipes* nymphs are quite susceptible to starvation and can survive without prey for only about 3 days at 20° C or 2 days at 30° C. Late-stage nymphs (4th and 5th instars) can survive 3 or 4 times this long, and adults can live without prey for 1 or 2 weeks at 20° C or 4 to 6 days at 30° C. Females are more resistant to starvation than males, and virgin females are more resistant than mated females. In some mated females, eggs either fail to develop or are resorbed when no prey is available. In others, eggs develop and some oviposition occurs. About 60% of the starving females examined laid from 1 to 8 eggs before they died, but no partially or fully developed eggs remained in any starved females at the time of death.

This susceptibility of *X. flavipes* to starvation is compensated for, at least in part, by a pronounced cannibalistic nature (22). Nymphs as well as adults prey readily on members of their own species, and a small percentage of nymphs can complete development when no other prey is available. All nymphal instars are attacked, but the heaviest mortality is inflicted on the 1st. The eggs are apparently protected by a tough shell and are not vulnerable until they begin to hatch. No successful attacks on healthy adults have been observed, although both nymphs and adults will feed on dead adults and may also feed on those that have become moribund.

Cannibalism serves as a mechanism to reduce population density before starvation causes mortality or loss of reproductive ability; it also contributes to searching capacity by extending survival time when prey is scarce. The rate of cannibalism is influenced by hunger, and cannibalistic predation among nymphs intensifies as the population density, and hence competition for a limited supply of prey, increases.

In addition, *X. flavipes* has a high capacity to increase in numbers relative to its prey and a high capacity for prey consumption. Its maximum rate of increase is 72 per lunar month (10) compared with 50, 70, and 50 for *O. surinamensis*, *T. castaneum*, and *E. cautella*, respectively (23). Also, it destroys large quantities of prey when prey is abundant (20). When an excess of eggs, larvae, and pupae of *T. castaneum* was provided, each predator killed an average of 405 eggs, 4 larvae, and 8 pupae during its lifetime. When the various stages of prey were provided together, each predator killed an average of 405 eggs, 4 larvae, and 8 pupae during its lifetime. When the various stages of prey were provided separately, each predator destroyed an average of 539 eggs, 34 larvae, or 14 pupae.

The ability of *X. flavipes* to survive on relatively little prey, its cannibalistic behavior, its high capacity for increase in numbers, and its high capacity for prey consumption contribute to its effectiveness as a predator. Perhaps its most important limitation is its inability to gain access to certain species or stages of storage pests. Because its mouthparts are

incapable of penetrating seeds or any very hard substance, it is ineffective against most species that develop within seeds. For example, when it was tested against *Sitophilus oryzae* (L.) and *Callosobruchus maculatus* (F.), it did not suppress populations of either species (G. L. Lecato and J. W. Press, personal communication). When it was tested against *Sitotroga cerealella*, it achieved some suppression by destroying the exposed eggs and neonate larvae (G. L. LeCato, personal communication). However, the larvae bored into the kernels of grain soon after hatching and once inside they were protected from attack.

The effectiveness of *X. flavipes* is also limited by the texture of the commodity in which its prey occurs. The predator can move freely throughout material with large interstitial spaces, but in finely divided material its movements are restricted to a shallow layer near the surface. Thus the deeper layers provide a refuge for burrowing prey (24). The effect of commodity texture on the degree of suppression achieved was demonstrated by LeCato (17) who used *T. confusum* as the prey species. In rolled oats and whole wheat the predator had full access to all stages of the prey, and population growth was effectively suppressed. On cracked wheat, suppression was somewhat reduced, and there was no suppression of *T. confusum* on whole wheat flour.

CONCLUSION: Despite its limitations, *X. flavipes* possesses attributes that make it an effective predator of certain stored-product insects, and it can play a significant role in their natural regulation. Furthermore, in a relatively controlled storage environment it should be possible to achieve a high degree of control by augmenting natural populations. Whether this becomes acceptable and economically feasible will depend largely on future circumstances that could influence public attitudes and cost-benefit ratios relative to other control methods. Such circumstances could include: (1) development of pest resistance to chemicals, (2) increased costs of developing, producing, and applying pesticides, and (3) stricter regulations due to public concern about the health and environmental hazards of chemical pesticides (25).

Stored-product anthocorids other than *X. flavipes* remain poorly known. It seems likely on the basis of what we have learned about *X. flavipes* that they too play a significant role in natural regulation and may be useful as biocontrol agents. However, this supposition must be verified by detailed studies of their biology and prey relationships.

ACKNOWLEDGEMENT: I am indebted to Ruel Wilson, Richard Russell Research Center, SEA, USDA, Athens, Ga. for the response surface analysis of the population parameters.

REFERENCES:

(1) Hall, D. W., Observations on the distribution, habits and life history of the bug *Piezostethus galactinus* (Fieb.) (Hem., Anthocoridae). Entomologist's mon. Mag. 86 (1951) 45.

(2) Sinha, R. N., Insects and mites associated with hot spots in farm stored grain. Can. Ent. 93 (1961) 609.

(3) Champ, B. R., An investigation of peanut storage in Queensland. I. Introduction, species and pest status. Qd. agric. J. Anim. Sci. 22 (1965) 227.

(4) Peet, W. B., Jr., Biological studies on *Nidicola marginata* (Hemiptera: Anthocoridae). Ann. ent. Soc. Am. 66 (1973) 344.

(5) Carayon, J., Le genre *Xylocoris:* subdivision et espéces nouvelles (Hem. Anthocoridae). Ann. Soc. ent. Fr. (N.S.) 8 (1972) 579.

(6) Arbogast, R. T., et al., Developmental stages of *Xylocoris flavipes* (Hemiptera: Anthocoridae), a predator of stored-product insects. Ann. ent. Soc. Am. 64 (1971) 1131.

(7) Awadallah, K. T., Tawfik, M. F. S., The biology of *Xylocoris (=Piezostethus) flavipes* (Reut.) (Hemiptera: Anthocoridae). Bull. Soc. ent. Egypte 56 (1972) 177.

(8) Carayon, J., Action du sperme sur la maturation des ovaires chez les Hémiptères a insemination traumatique. Colloques int. Cent. natn. Rech. scient. 189 (1970) 215.

(9) Press, J. W. et al., The effect of low temperature on the egg hatch and subsequent nymphal survival of the predaceous bug *Xylocoris flavipes* (Hemiptera: Anthocoridae). J. Ga. ent. Soc. 11 (1976) 150.

(10) Arbogast, R. T., Population growth of *Xylocoris flavipes:* Influence of temperature and humidity. Environ. Ent. 4 (1975) 825.

(11) LeCato, G. L., Davis, R., Preferences of the predator *Xylocoris flavipes* (Hemiptera: Anthocoridae) for species and instars of stored-product insects. Fla. Ent. 56 (1973) 57.

(12) Jay, E., et al., Studies on the predacious habits of *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae). J. Ga. ent. Soc. 3 (1968) 126.

(13) Arbogast, R. T., Suppression of *Oryzaephilus surinamensis* (L.) (Coleoptera, Cucujidae) on shelled corn by the predator *Xylocoris flavipes* (Reuter) (Hemiptera, Anthocoridae). J. Ga. ent. Soc. 11 (1976) 67.

(14) LeCato, G. L., et al., Reduction of residual populations of stored-product insects by *Xylocoris flavipes* (Hemiptera: Anthocoridae). J. Kans. ent. Soc. 50 (1977) 84.

(15) LeCato, G. L., Predation by *Xylocoris flavipes* (Hem.: Anthocoridae): Influence of stage, species and density of prey and of starvation and density of predator. Entomophaga 21 (1976) 217.

(16) Press, J. W., et al., Control of the red flour beetle, *Tribolium castaneum* in a warehouse by a predaceous bug, *Xylocoris flavipes*. J. Ga. ent. Soc. 10 (1975) 76.
(17) LeCato, G. L., Habitat-influencing predation by *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae). Am. Midl. Nat. 93 (1975) 510.
(18) Press, J. W., et al., Interactions among *Tribolium castaneum* (Coleoptera: Tenebrionidae), *Cadra cautella* (Lepidoptera: Pyralidae), and *Xylocoris flavipes* (Hemiptera: Anthocoridae). J. Ga. ent. Soc. 9 (1974) 101.
(19) Press, J. W., et al., Interactions among *Plodia interpunctella*, [illegible], and *Xylocoris flavipes*: Environ. Ent. 3 (1974) 183.
(20) LeCato, G. L., Collins, J. M., *Xylocoris flavipes*: Maximum kill of *Tribolium castaneum* and minimum kill required for survival of the predator. Environ. Ent. 5 (1976) 1059.
(21) Arbogast, R. T., et al., Longevity of fed and starved *Xylocoris flavipes* (Reuter) (Hemiptera, Anthocoridae) under laboratory conditions. J. Ga. ent. Soc. 12.
(22) Arbogast, R. T., Cannibalism in *Xylocoris flavipes* (Hemiptera: Anthocoridae), a predator of stored-product insects. Entomologia exp. appl. In press.
(23) Howe, R. W., A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. J. stored Prod. Res. 1 (1965) 177.
(24) Press J. W. et al., Influence of media particle size on the distribution of the predaceous bug *Xylocoris flavipes*. J. Ga. ent. Soc. 13 (1978) 275.
(25) Starler, N. H., Ridgway, R. L., "Economic and social considerations for the utilization of augmentation of natural enemies," Ch. 15, Biological Control by Augmentation of Natural Enemies (Ridgway, R. L., Vinson, S. B., Eds.), Plenum Press, New York (1977).

A CONTROLLING EFFECT OF A JUVENILE HORMONE ANALOGUE ON *EPHESTIA CAUTELLA* (WLK.) BY NON-DIRECT APPLICATION

M. GONEN and A. SCHWARTZ
Division of Stored Products
Agricultural Research Organization
The Volcani Center, P.O. Box 6
Bet Dagan, ISRAEL

INTRODUCTION: The effects and feasibility of juvenile hormones (JH) and of juvenile hormones analogues (JHA) as control agents for stored product insects has been extensively studied and reviewed (3, 4, 5, 6, 15; for more references, see 13). The insect specificity revealed by these control agents, the non-toxicity to warm-blooded animals (1), and their non-toxic degradation products (12), offer some advantages especially where toxic insecticide residues are of great significance, e.g. in stored food. Some of the main difficulties in using JHA for the control of stored product insects stems from two facts:

(a) The insects comprising the multi-species community that is usually associated with stored products differ in their susceptibility (13, 14, 16);

(b) The different species differ also in their behaviour and distribution within a grain bulk or a stack of bags--a fact that complicates even more the logic of JHA application.

One of the most common stored product pests, against which some JHA have been shown to be effective, is the almond moth, *Ephestia cautella* (Wlk.). The efficiency of controlling *E. cautella*, as well as other stored product moths with JHA, has been demonstrated mainly by mixing the JHA with the food substrate (3, 4, 5, 14). Another possible approach could be to take advantage of a fundamental biological difference between *E. cautella* and most other stored product insects, i.e., the fact that the fully grown larvae, as well as the deposited eggs of *E. cautella*, come in contact with the surface of the infested bulk.

The purpose of these experiments was, therefore, to evaluate the effectiveness of a JHA for the control of *E. cautella* experimental populations that either received direct sprays or were brought into contact with previously treated surfaces.

MATERIALS AND METHODS: The insects were reared on ground wheat (12% m.c.) mixed with glycerin (12% w/w). Rearing and experimental conditions, unless otherwise specified, were 26±1°C and 70±5% R.H.

The JHA used was Altosid SR10 (Zoecon, Palo Alto, California). It contained 10% of the active ingredient isopropyl 11-methoxy-3,7,11 - trimethyl-2,4 dedecadienoate. Dilutions to desired concentrations were made in distilled water.

(a) Effect on eggs. Filter paper discs (Whatman No. 1) were sprayed with doses of 0.6-73.7 mg/m^2. After the paper discs dried out, each disc was placed in a petri dish which contained 10 g of rearing medium. To avoid contact between the treated filter paper and rearing medium, 20 polyethylene tubes (2 mm in diameter and 10 mm in length) were placed on top of the rearing medium. These tubes served later as pupation sites. Twenty 0-24 h-old eggs were placed on each filter paper disc. The discs were removed after completion of egg hatch. Five replicates were used for each tested dose. Emerging adults were counted.

(b) Effect of direct spraying on last instar larvae. Plastic vials of 250 ml each were lined with tissue paper. Ten last instar larvae were introduced into each of four vials for each tested dose. The tissue paper, with the larvae on it, was sprayed with doses ranging from 0 to 6.6 mg/m^2 of vial surface. Emerging adults were counted until emergence stopped.

(c) Effect of contact with a sprayed jute surface. Six small jute sacks were filled with unshelled peanuts - 100-115 g in each - and placed into each of twenty-eight 20-l metal containers. The external surfaces only of the jute sacks were sprayed with the JHA at rates ranging between 0.22 to 221.7 mg/m^2. Four replicates were used for each dose. One hundred *E. cautella* eggs, 0-24 h-old, were dispersed in each of the containers. Adult emergence was recorded from its onset until cessation.

(d) Persistence of the JHA activity on a sprayed surface under two temperature conditions. Vials lined as described above were sprayed with 6.6 mg/m^2 and kept at 18° and 26°C for periods ranging between 3 and 120 days. After the desired periods, ten last instar larvae were introduced into each of four replicate vials at each of the two temperatures. The vials with the larvae were returned to 26°C and adult emergence was recorded.

RESULTS:

(a) Effect on eggs. The effect of contact of *E. cautella* eggs with a JHA sprayed surface on the subsequent development of adults, is demonstrated in Table 1. No meaningful reduction in number of adults that developed from eggs that were in contact with a sprayed surface could be detected up to a dose of 14.7 mg/m^2. The higher doses tested reduced the number of developing adults by about 60%.

(b) Effect of direct spraying on last instar larvae. As shown in Figure 1, complete mortality at larval or pupal stages was induced by a dose of 6.6 mg/m^2. The treatment also caused a delay of up to 3 months in the pupation process, especially at the

Table I. *E. cautella* adult development (% of control±S.E.) from eggs in contact with a JHA-sprayed surface

Adult development	JHA dose (mg/m^2)						
	0.6	1.2	1.8	6.6	14.7	44.2	73.7
	97.9 ±1.5	97.[illegible] ±0.4	98.9 ±1.1	89.7 ±6,3	84.1 ±3.3	44.3 ±10.0	40.9 ±7.0

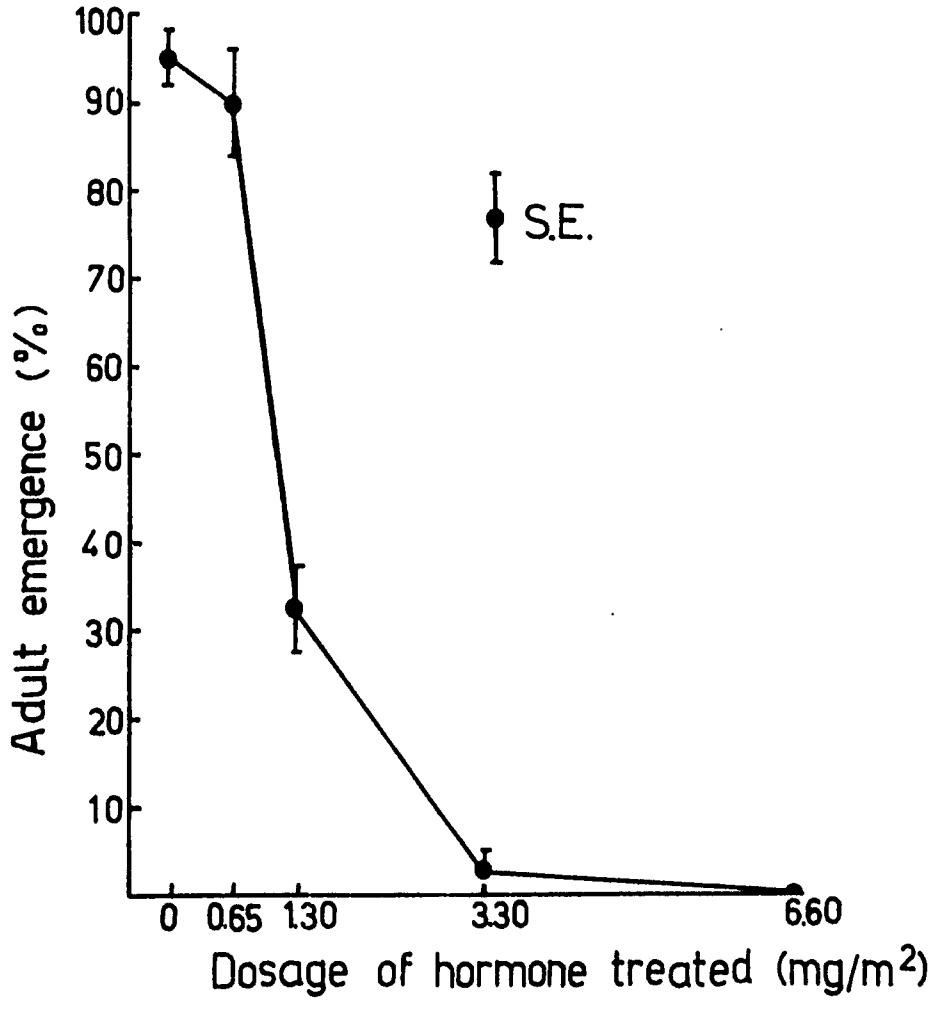


Figure 1. Emergence of *E. cautella* (%) from last instar larvae treated with juvenile hormone analogue.

three higher doses tested (Table II). The mortality of larvae treated with 1.3-6.6 mg/m^2 rose gradually over this extended period, starting 1-2 days after treatment (Table II).

Table II. Mortality of *E. cautella* last instar larvae treated with a JHA, and adult emergence (%)

JHA dose (mg/m^2	Mortality of larvae after		Mortality of pupae and intermediate forms (%)	Adult emergence (%)
	1-2 days (%)	2-3 months		
0	0	0	5.0	95.0
0.65	0	0	10.0	90.0
1.30	7.5	32.5	27.5	32.5
3.30	22.5	55.0	20.0	2.5
6.60	22.5	50.0	27.5	0

(c) Effect of contact with a sprayed jute surface. As the outer surface only of the jute sacks had been treated, the chances of the larvae coming into contact with it were limited. The effect of this limited contact on the proportion of insects reaching the adult stage, is recorded in Table III.

Table III. The effect of JHA spraying of the exterior of small jute sacks containing peanuts, on completion of the life cycle of *E. cautella* (% of control±S.E.)

	Dose of JHA (mg/m^2)						
	0.22	0.66	1.47	14.75	44.20	73.75	221.75
Insects completing life cycle	93.0 ±0	58.5 ±17.3	26.1 ±4.4	18.3 ±2.3	1.7 ±1.0	2.0 ±2.0	0

A dose of 44.2-73.7 mg/m^2 was required to achieve 96-98% control. The higher dose tested - 221.7 mg/m^2 - resulted in complete suppression of development to the adult stage. However, it is presumed that this result could be achieved with a lower dose.

d. Persistence of the JHA activity at two temperatures. The difference in the rate of loss of bioactivity at the two temperatures tested, is presented in Figure 2. The JHA retained its activity for a longer period at 18° than at 26°C. The selected dose - 6.6 mg/m^2 - retained its full activity for 3 and 5 days only at 26° and 18°C, respectively. At 18°C it retained 90% of its activity for 45 days, and at the end of 120 days it prevented 76% of adult development. At 26°C, the activity was reduced to 80% after three days only, and thereafter the reduction in activity was rapid and declined to 35% after 120 days.

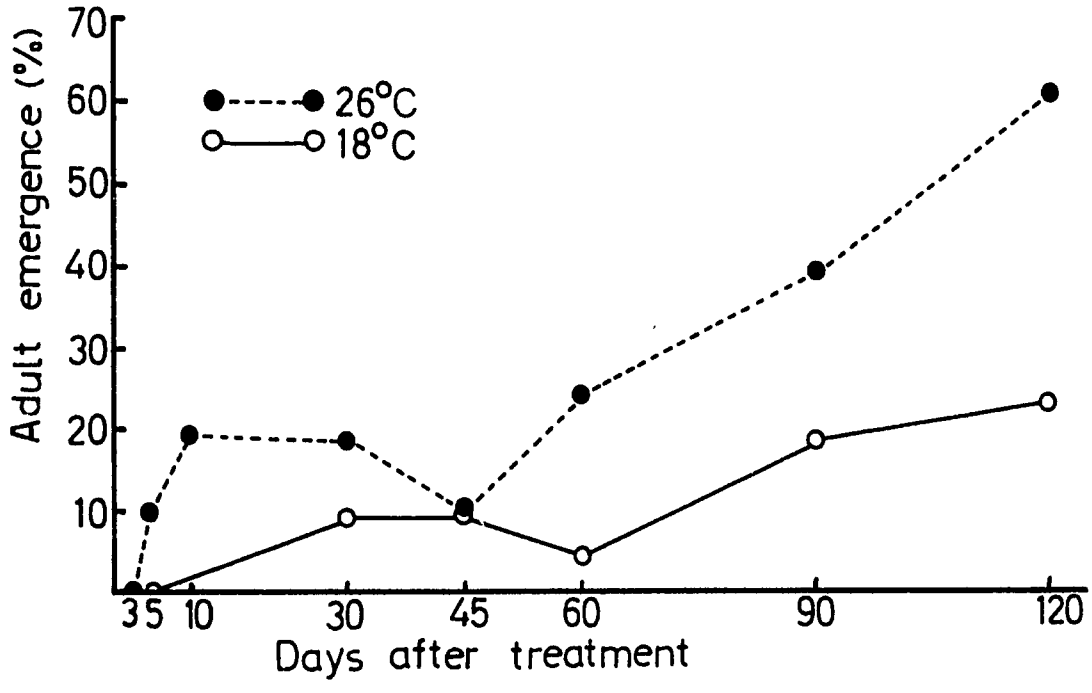


Figure 2: Biological activity persistence of an insect juvenile hormone which was sprayed on a paper surface and kept at two temperatures (at 6.6 mg/m^2)

DISCUSSION: A dose of 6.6 mg/m^2 was sufficient to prevent adult development not only in the case of direct application to last instar larvae (Figure 1), but also when contact between untreated larvae and a treated surface was formed within 3-5 days after application, depending on the temperature (Figure 2). Similar positive results were obtained by other workers (2, 15), who treated pupation sites only. This high sensitivity of the larvae

could not be reproduced in the small jute sacks experiment, in which the contact between the maturing larvae of the treated surfaces was formed 3-4 weeks after application of the JHA. A number of factors could contribute to the difference between these two sets of results. In the first experiment, the larvae were in constant contact with the treated surface and could not avoid it. In the jute sack experiment, the contact was probably not a constant one, as the larvae could move freely from treated surfaces--the jute sacks--to untreated places--the peanuts inside the sacks as well as the container's walls. The importance of such factors such as constant contact and the extent of contact with treated materials, in interfering with the normal course of development, has been demonstrated for *Plodia interpunctella* larvae (11). In addition, the reduction in bioactivity of the JHA contributed to the lower effectiveness of the treatment and to the need of much higher doses--73-221 mg/m^2--for achieving complete arrest of adult development. The rapid reduction in bioactivity is supported by similar published results on the compound's degradation when applied to wheat grains (9), although the main factors known to cause breakdown of such compounds (3) were not present.

The sensitivity of eggs was less than that of larvae and less than what could be expected on the basis of published results on insect egg sensitivity (7, 8, 10). However, the differences in the experimental conditions--mainly younger eggs and the direct application used by the above mentioned authors--as well as differences in species sensitivity, might account for these differences.

The results obtained in these experiments demonstrated that the concept of treating surfaces with which susceptible life stages of the insect come into contact, could be feasible. However, further experiments, probably with special formulations with a slower degradation rate, under warehouse conditions, are necessary.

REFERENCES:

(1) Antognini, J. (1972) Insect growth regulators and sex attractants in pest control. Proc. 56th Ann. Meeting Ent. Soc. Am.

(2) Bransby-Williams, W. R. (1972) Activity of two juvenile hormone analogues with *Heliothis armigera* (Hubner), *Sitophilus zeamais* Motshulsky and *Ephestia cautella* (Walker). E. Africa For. J. 38: 170-174.

(3) Hope, T. (1974) Effect of a juvenile hormone analogue on Mediterranean flour moth in stored grain. J. Econ. Ent. 67: 789.

(4) Hoppe, T., and Suchy, M. (1975) Present status of research on insect growth regulators for protection of stored grain. EPPO Bull. 5: 193-196.

(5) Loschiavo, S. R. (1975) Tests of four synthetic insect growth regulators with juvenile hormone activity against seven species of stored products insects. Manitoba Entomol. 9: 43-52.
(6) Loschiavo, S. R. (1976) Effects of the synthetic growth regulators Methoprene and Hydroprene on survival, development or reproduction of six species of stored-products insects. J. Econ. Ent. 69: 395-399.
(7) Riddiford, L. M. (1971) Juvenile hormone and insect embryogenesis. Mitteilungen Schweizerischen Entomologischen Gesellschaft. 44: 177-186.
(8) Riddiford, L. M., and Williams, C. M. (1967) The effect of juvenile hormone analogues on the embryonic development of silkworms. Proc. Natn. Acad. Sci. USA 57: 595-601.
(9) Rowlands, D. G. (1976) The uptake and metabolism by stored wheat grains of an insect juvenile hormone and two insect hormone mimics. J. Stored Prod. Res. 12: 35-41.
(10) Sehnal, F. (1975) Action of juvenoids on different groups of insects. in: Gilbert, L. T. (Ed.) The Juvenile Hormones. Pergamon Press, Lond. (1975) 572 pp.
(11) Silhacek, D. L., and Oberlander, H. (1975) Time-dosage studies of juvenile hormone action on the development of *Plodia interpunctella*. J. Insect Physiol. 21: 153-161.
(12) Slama, K. (1971) Insect juvenile hormone analogues. A. Rev. Biochem. 40: 1079-1102.
(13) Stall, G. B. (1975) Insect growth regulators with juvenile hormone activity. A. Rev. Ent. 20: 417-460.
(14) Strong, R. G., and Diekman, J. (1973) Comparative effectiveness of fifteen insect growth regulators against several pests of stored products. J. Econ. Ent. 66: 1167-1173.
(15) Tan Keng Hong (1975) Effects of a synthetic juvenile hormone and some analogues on *Ephestia* spp. (Lepidoptera: Phycitidae). Ann. Appl. Biol. 80: 137-145.
(16) Thomas, P. J., and Bhatnagar-Thomas, P. L. (1968) Use of juvenile hormone analogues as insecticide for pests of stored grain. Nature (Lond.) 219: 949.

PANEL SESSION ON BIOLOGY, ECOLOGY AND INTEGRATED CONTROL

Convener - DR. JAN BOCZEK
Agricultural University of Warsaw
02-766 Warszawa-Ursynow SGGW
POLAND

Group discussion led by:

Dr. Jan Boczek (Poland)

Dr. T. G. Amos (Australia)

Dr. W. E. Burkholder (U.S.A.)

Dr. R. Davis (U.S.A.)

Dr. S. C. Saxena (India)

SYMPOSIUM AND PANEL ON PESTICIDES, OTHER CHEMICAL, TOXICITY AND INSECT RESISTANCE

Convener - DR. B. R. CHAMP
Chairman - DR. J. M. DESMARCHELIER
Division of Entomology
C.S.I.R.O.
Canberra, AUSTRALIA

ATTITUDES AND PROSPECTS FOR USE OF CHEMICALS IN PROTECTING WORLD FOOD SUPPLIES

J. T. SNELSON
Pesticides Co-Ordinator
Pesticides Section
Department of Primary Industry
Canberra, A.C.T. 2600
AUSTRALIA

INTRODUCTION: The attention of the world was drawn to the problem of post-harvest food losses by the US Secretary of State, Dr. Henry Kissinger, at the World Food Conference that was held in November 1974 in Rome. In his key-note address at the opening session of the World Food Conference Secretary Kissinger said,

> "Another major priority must be to reduce losses from inadequate storage, transport and pest control. Tragically, as much as 15% of the countries' food production is often lost after harvesting because of pests that attack grains in sub-standard storage facilities. Better methods of safe storage must be taught and spread as widely as possible. Existing pesticides must be made more generally available. Many of these techniques are simple and inexpensive; investment in these areas could have a rapid, substantial impact on the world's food supply."

This challenge from Secretary Kissinger was taken up by the UN General Assembly on September 19, 1975 and one of the resolutions of the UN General Assembly was:

> "The further reduction of post-harvest food losses in developing countries should be undertaken as a matter of priority, with a view to reaching at least a 50% reduction by 1985. All countries and competent international organisations should cooperate financially and technically in the effort to achieve this objective."

This resolution has drawn the attention of the highest levels of government around the world to the problem of post-harvest food losses.

All those attending this Working Conference recognize the need to protect food. All are concerned to find the best ways of controlling insects in each of the many different situations. Especially are we looking for methods that can be adopted in the tropics and in developing countries.

WHERE DO CHEMICALS FIT: Notwithstanding advances in stored-product technology and advances that have been made in physical

and mechanical methods of destroying insects and protecting stored products from their attack, chemical methods including fumigants and grain protectant insecticides offer the major line of attack against insects.

Chemicals are not new. All of the fumigants available today have been available for many years. No new fumigants have been developed since the end of World War II. There has been considerable advance in the technology of fumigation and a significant increase in the use of fumigants which has brought with it a rising concern over the question of safety to operators and consumers.

Since the advent of DDT and BHC in the mid-1940's there has been an ever increasing development in pesticide science. We now have a wide range of potent and effective insecticides and a wealth of knowledge about their properties and use. Many of these insecticides have been evaluated against stored-product pests and some have been developed and approved for the treatment of structures. A few have been approved for incorporation into grain and other stored products.

The choice of insecticides which may be used for protecting commodities in storage is limited by the very strict requirements which must be enforced to ensure absolute safety for these important basic food commodities. To qualify for selection as a possible candidate insecticide for use on or around grain it must meet the following requirements:

(i) it must be effective at economic rates of use;
(ii) it must provide no hazard to consumers of grain and grain products;
(iii) it must be acceptable to health authorities;
(iv) it must be acceptable in international grain trade;
(v) it must not give rise to unacceptable residues;
(vi) it must not affect the quality, flavour, smell or handling of grain;
(vii) it must be capable of being used without hazard to operators;
(viii) it must be effective against a wide variety of insect pests;
(ix) it must not be flammable, explosive or corrosive;
(x) its method of use must be compatible with established grain handling procedures.

Insecticides meeting these specifications which have so far been cleared for use as grain protectants include:

- bioresmethrin
- bromophos
- carbaryl
- chlorpyrifos-methyl
- dichlorvos

- fenithrothion
- lindane
- malathion
- pirimiphos-methyl
- pyrethrins

The following potentially useful products are under consideration:

- decamethrin
- methacriphos
- phenothrin

ACCEPTANCE OF CHEMICAL TREATMENTS: Fumigants have been widely accepted on the assumption that they were volatile and thus disappeared completely from treated commodities. Modern analytical techniques are disturbing this blissful ignorance.

Current attitudes in some countries to the potential long-term effect of chemicals as measured by accelerated studies on susceptible laboratory animals is likely to cause an adverse reaction to traditional fumigants. Liquid grain fumigants are particularly vulnerable to criticism because, being halogenated derivatives, they all produce adverse reactions in the livers of certain strains of mice. The fact that significant residue can be detected in fumigated grain, oilseeds, and prepared foods is likely to bring liquid fumigants under critical review.

The value of pyrethrins has been exploited for many years but not to the extent that their properties justify. Lindane was first introduced almost thirty years ago. Malathion has been in world-wide use for almost twenty years. Dichlorvos has been used for more than ten years on a wide scale.

Along with the introduction of these potent and effective grain protectant insecticides has come improved understanding of the mode of action of these products, considerable advances in the technology for their application and monitoring, together with a considerable increase in the number of people trained in the proper use of these materials by grain handling authorities. All this has greatly contributed to the efficiency with which these materials are used.

Over recent years there has been a significant increase in the standards demanded by purchasers of grain and other stored products. This has been reflected in national and international trade by clauses in commercial contracts and in the various official grading regulations of exporting countries. These place limits on the amount of insect damage which will be accepted, and may or may not tolerate the presence of living insects or mites. Canadian and Australian regulations accept no tolerance for living insects in wheat for export. Similar official regulations apply to cocoa beans exported from Nigeria and Ghana and to groundnuts from South Africa and the USA. The mere presence of insects can result in severe financial loss if an importing

country imposes strict phytosanitary or quality standards. Freeman (1976) states that in the case of grain shipments to China, the discovery of one living insect in a cargo of wheat can result in the shipment being rejected or accepted only after expensive fumigation.

Freeman (1974) gave details showing that from 8 to 38% of almost five thousand cargoes examined in Great Britain in 1972 were found to be infested; cargoes from Africa, the Far East, and the Middle East being the most susceptible. Figure 1 from

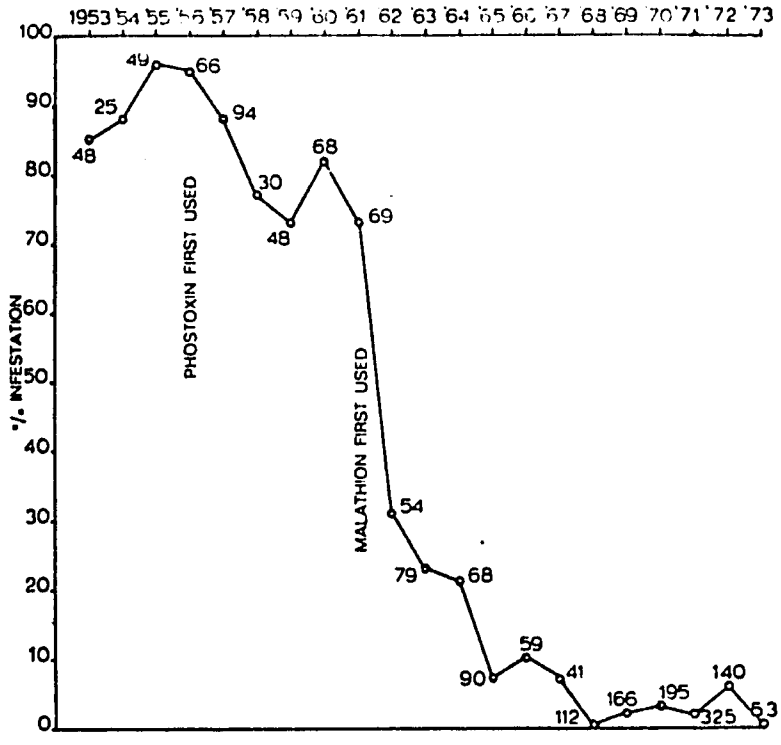


FIGURE 1. Infestation of Australian wheat imported into Great Britain (All cargoes are inspected either in the ships during discharge or in dry cargo containers. Any insects or mites found must either have been: a) introduced with cargo, b) acquired from other cargo or c) from the structure of the ship, being residual from a previous shipment. Skill and experience on the part of the inspector is sufficient to distinguish between a, b, or c in most instances. An infested cargo, for purposes of tables, etc., in this paper is one in which at least one living storage insect is found).

Freeman (1974a) shows that whereas cargoes of wheat from Australia prior to 1955 were infested with insects to the extent of 80 to 100%, following the use of malathion as a grain protectant insecticide in 1972 the incidence fell in one year from 80% to 30% and thereafter declined rapidly until in 1973 and later years no infestation was found. As indicated by Banks and Desmarchelier, (1978) Australian grain, once notorious for its high insect levels, now enjoys a reputation as one of the cleanest in the international market, a reputation achieved largely through the use of chemical insecticides, particularly malathion.

Tens of millions of tonnes of edible food grains have been treated successfully under a wide range of conditions with grain protectant insecticides. These grains have entered and have been accepted in international trade in spite of the enormous quantities of grain involved. Meticulous monitoring has revealed that it is possible to apply grain protectant insecticides to the extent necessary to virtually eliminate insects from commercial grain shipments whilst complying completely with the ridid legal limits for residues.

In several countries where grain protectant insecticides are used exclusively or extensively for the protection of grain, total diet studies have revealed that the intake of residues of these insecticides by consumers is well within the amount that is deemed to be without hazard if consumed daily for an entire lifetime.

BARRIERS TO ACCEPTANCE: It is a well known saying that "nothing succeeds like success." In spite of this outstanding achievement the use of chemical treatments for insect control in stored commodities has not been accepted universally. You may well wonder why. Let us look at some of the reasons.

(1) Failure by many people and national authorities to recognize the need to:

   (a) use chemicals to protect valuable food,

   (b) ensure the availability of staple commodities as a buffer against famine,

   (c) maintain economy of developing countries, and

   (d) provide for the increasing demand for food to feed the increasing population.

(2) General lack of understanding about the problem confronting tropical countries and countries which have not yet attained a high level of sophistication in the handling and storage of grain.

(3) Lack of knowledge about the limitations of non-chemical measures to control stored product pests.

(4) Inability to understand the significance of toxicology studies on laboratory animals, the dose-related effect and the concept of the no-toxic-effect level.

(5) Belief that man-made chemicals are somehow different to chemicals that occur in nature.

(6) Action by merchants, domestic producers and other self-interest groups to create misgivings in order to produce non-tariff barriers to trade.

(7) The development of the "natural food" cult and the attendant rackets in "health foods".

(8) The sensation-seeking news media.

(9) Fear of the unknown - what cannot be seen could well be dangerous.

You might well ask what has science done to break down these barriers to the acceptance of chemicals for protecting world food supplies. Science appears to have done sufficient to convince scientists of the safety and acceptability of these chemicals. It has:

(1) Generated a wealth of scientific fact about the nature, effect and fate of these chemicals.

(2) Provided results of extensive studies of their interaction with animal models to gauge the potential effect upon people.

(3) Studied the level and fate of residues in raw agricultural commodities, milled products, food and people.

(4) Provided scientific rationale for the interpretation of these data.

Whether science has done sufficient to convince the sceptics and the non-scientific segment is another question.

EFFORTS BY THE UNITED NATIONS ORGANIZATION: When the question of residues in raw agricultural commodities first began assuming significance as a barrier to free trade in essential raw agricultural commodities and foods and following the action by a few influential writers to create concern over the alleged danger of

residues to consumers, the United National Organisation began making a valuable contribution to a better understanding of these issues. Following international meetings in 1962 the Food and Agriculture Organisation and World Health Organisation set about the evaluation of pesticide residues as part of their Joint Food Standard Program.

The setting up of the Joint FAO/WHO Meeting of experts on Pesticide Residues, the Codex Committee on Pesticide Residues and the Codex Alimentarius Commission did not automatically resolve these difficulties. In fact it was many years before there was much semblance of agreement between Governments over the principles, let alone the practice of regulating residues in raw agricultural commodities at a level that would not inhibit the production and protection of food commodities.

You may well ask what these international agencies have done to bring about a better understanding and acceptance of the need to use chemicals in protecting world food supplies. Among many other achievements they have:

(1) Established and maintained standards as a basis for international agreement.

(2) Encouraged and stimulated research.

(3) Evaluated scientific data.

(4) Published reviews of this data and evaluations by experts.

(5) Encouraged and facilitated discussions between governments and other national and international organisations.

(6) Coordinated views of national authorities.

(7) Published international standards.

MAXIMUM RESIDUE LIMITS: Maximum residue limits, which when incorporated into national legislation, become legal limits for residues in raw agricultural commodities and food, have been recommended by the Joint FAO/WHO Meeting of Experts on Pesticide Residues and are currently under consideration by the Codex Committee on Pesticide Residues and national governments.

These maximum residue limits have been developed on the basis of "good agricultural practice" in the use of pesticides or, in other words, officially approved use patterns for the products in question. These use patterns are designed to effectively control the pest whilst leaving a residue which is the smallest practicable. Identical or similar maximum residue limits have already been incorporated into the legislation of many national governments. These maximum residue limits are at present under

discussion for acceptance as international standards. Attached as Annex I to this paper is a list of the maximum residue limits recommended for residues of grain protectant insecticides in raw grain milled cereal products and other stored commodities. The list also shows the status in the Codex Step Procedure for acceptance as international standards.

THE WORK OF THE CODEX COMMITTEE ON PESTICIDE RESIDUES: During the twelve and a half years since the Codex Committee on Pesticide Residues first met (January 1966) not only scientists but also officials of national governments have become better informed about residues. They still face considerable emotional and political pressures which often make it difficult for them to give immediate support to proposals for maximum residue limits. Sometimes they are expected to make decisions before the scientific data have been considered by them or their technical advisors. Sometimes the reviews of scientific data published in the monographs of the Joint FAO/WHO Meeting have been condensed to the point where it is more than a little difficult to see how the Joint Meeting derived its recommendations. Frequently the quantity of data available is just not sufficient to provide a completely credible basis for developing satisfactory recommendations. This is not the fault of the Joint Meeting but rather reflects the difficulty in locating and gaining access to the scientific data available in government archives, scientific institutions and open scientific literature.

During the eleven years that I have served as a delegate at the Codex Committee on Pesticide Residues I have noticed the steady evolution of an organisation which serves not only as forum for the exchange of views between governments but as a valuable piece of machinery for decision making. The democratic processes that are followed are slow and somewhat cumbersome but they do provide reassurance that the standard, in this case the maximum residue limit, when adopted, is not only politically acceptable but is scientifically sound.

Unfortunately for those of us who spend all our waking moments involved with some aspects of research, development and introduction of insecticides for controlling stored-product pests, the process of acceptance by international governments is painfully slow. It is bad enough that there are ten steps, (Annex 2) some involving a year or more, in the process of gaining acceptance by national governments, but some of the delegates at the meetings of the Codex Committee on Pesticide Residues are often not well informed on important technical aspects and are therefore understandably cautious when it comes to lending support to proposals.

The majority of delegations come from countries which are oriented towards import rather than production and export of food commodities so they naturally take the consumer's point of view which is that they would prefer to have no residues in food. Unfortunately, many delegations are not familiar with the problems

facing food producers in the semi-tropics and tropics and therefore it is understandable why they often appear unsympathetic to the need to use chemicals to protect crops and stored commodities. However, in the process of exchanging comment at the Codex Committee on Pesticide Residues a better understanding develops and in recent years there has been a softening of attitude towards the question of residues, particularly those in raw grain and similar stored products.

SAFETY TO CONSUMERS: Those who have accepted that grain protectant insecticides do not represent a hazard to consumers rely on the extensive studies which have demonstrated that there is a level of intake which is without effect on the most sensitive laboratory animals receiving the material in their rations every day of their lives. On the basis of extensive experience toxicologists have deduced that there is a level which is without potential harm to humans taking the material in their food every day for an entire lifetime. This is known as the acceptable daily intake (ADI). This is calculated from the no-effect-level in the most sensitive laboratory animal after applying an appropriately large safety factor.

During the research work leading to the acceptance of these insecticides for use on stored grain it was demonstrated by studies under laboratory and practical conditions that the amount of residue in food at the time of consumption is less than the amount of the acceptable daily intake.

Among those who have expressed concern over the addition of insecticides to grain there is one misconception that has been difficult to dislodge. This is the assumption that the intake of residues will be sufficient to cause a potential hazard, if not actual injury, to consumers. The misconception arises from the practice of assuming that the whole of the amount of insecticide applied to the raw grain is present in the food as consumed.

Apart from the significant loss and degradation which occurs while the treated grain is in storage, there are further losses during milling, processing and cooking that result in the amount of residue in the food as consumed being much less than 10% of the amount in the raw grain. This is the figure that should be used in calculating the theoretical consumption - not the level in the raw grain, and certainly not the legal maximum residue limit which is usually significantly higher still.

Unfortunately, some of the officials in developing countries, who do not have access to comprehensive technical information and advice, are seriously disturbed by the alarmist publicity in the news media about the alleged danger of chemicals, particularly pesticides. Since they take their responsibilities seriously they are reluctant to accept the use of grain protectants lest there should be adverse effects upon consumers, particularly in countries where raw grain is converted into food with a minimum of preparation and cooking.

The monographs of the Joint FAO/WHO Meeting of experts on pesticide residues contain extensive data and references to many studies which demonstrate that residues of each of the approved grain protectant insecticides are substantially removed before the food reaches the consumer. The loss is, to some extent, dependent upon the amount of processing. Because of this wholemeal bread will contain somewhat more than white bread because the bulk of the residue is removed with the bran during the preparation of white flour. However, the work of Lockwood et al (1974) shows that even when wheat, rice and sorghum were subjected to traditional preparation and wet methods of cooking such as are used in India, there was complete loss of malathion, fenitrothion and tetrachlorvinphos. Dry cooking methods used in preparing chapatties from wheat and sorghum resulted in losses of 51 to 75%. Further work along these lines is still required to demonstrate the fate under traditional methods of food preparation and cooking.

It is recognized that unsophisticated people, particularly small farmers and village store-keepers, might not be able to apply grain protectant insecticides safely as they are applied in industrialised countries with central grain storage facilities. However, experience has shown that provided the grain protectants are formulated as dilute dusts and that these dusts are pre-packed into small sachets, sufficient for one bag, basket or standard container, the least sophisticated can apply them safely and effectively.

Notwithstanding the long-standing and extensive use of malathion as grain protectant, the amount of scientific data on the nature, level and fate of the deposits on all types of grain and stored commodities in various types of storage is probably not yet adequate. The amount of data on the newer grain protectants under similar conditions is considerably less. It is therefore understandable why Government officials in some countries have appeared more than a little reluctant to embrace the idea of grain protectant insecticides under conditions which prevail in their country. More such data are surely needed. It is not particularly glamorous work and it certainly will not lead to many unique or novel discoveries but the work must be done and must be published if we are to make a worthwhile contribution to the reduction of loss of badly needed foodstuffs.

I am glad to see that the data developed by the group working under the aegis of the Australian Wheat Board, in the course of their investigations into grain protectant insecticides, is being submitted for publication. Some of the results were presented at the First Working Conference in Savannah; more will be referred to here in Ibadan. Attached as an Annex to this paper is a list of references to some of this Australian work and other important work carried out on grain protectants in recent years. This type of work needs to be repeated and extended under a wide variety of practical conditions to provide the experience and

reassurance that is so necessary to dispel any misgivings about the value, safety and acceptability of grain protectant treatments. Studies designed to demonstrate the fate of the deposit during storage, processing and cooking are particularly valuable, especially when they are carried out under conditions that are distinctly different to those prevailing in countries with a central grain handling system such as we have in Australia. The paper by Lockwood, Majumder and Lineback (1974) is typical of the type of work that I believe is badly needed. I hope that the work of LaHue (1978) will be extended with all speed so that the value of these tailor-made dusts to developing countries can be proven and exploited.

CONCLUSION: Chemicals including fumigants, but most particularly protectant insecticides, have a most important role in protecting world food supplies. They complement good management, supplement physical methods of insect control and greatly reduce the cost of protecting stored commodities from damage and destruction.

A great deal of scientific knowledge about their properties, use limitations and fate has accumulated over the last 20 years. Public concern having been provoked over alleged dangers from pesticides has generated increased political pressure for restrictions on their use.

This pressure has been relieved to some extent by the efforts of scientists and agencies of the United Nations. Further action is required to support these efforts and to supplement the scientific data on which decisions should be made.

Fear over cancer has evoked a critical attitude towards chemicals with the result that laboratory tests have been interpreted harshly. Liquid fumigants are likely to be condemned because of manifestations of tumours in the liver of inbred mice notwithstanding the views of a large body of expert opinion.

Greater efforts are required to inform national and international authorities of the importance and safety of chemicals needed for the protection of stored food products. Research and innovation is needed to further develop simple practical techniques by which protectant chemicals can be used by small farmers and village storekeepers to protect stored products in developing countries.

The process of education towards the acceptance of any new technology in agriculture is painfully slow and requires determination and effort by those who are convinced of its value. Unfortunately such worthy objectives as preventing famine, reducing malnutrition, saving waste and protecting food supplies are generally not considered newsworthy. The news media is therefore not likely to help gaining aceptance.

None the less I am confident that the attitude to chemicals is healthy and that the prospects for the general acceptance are good. They will remain thus only as long as professional entomologists, chemists and toxicologists continue their work. We must all increase our efforts to publicise the

need for a multi-disciplinary approach to protecting our scarse food supplies from the ravages of stored product pests.

SUMMARY: It is vital that everyone accepts a share of the responsibility for preventing avoidable losses of stored products. In doing so it must be recognised that technologies exist and that they have been thoroughly evaluated under a wide variety of conditions. Chemicals, including grain protectants and fumigants, currently offer the major line of attack against insects but must be recognised as adjuncts to good management, to re-enforce hygiene and sanitation and to enhance the effectiveness of suitable storage facilities.

Some of the reasons why chemical treatments for insect control have not been universally accepted are outlined. The efforts of the scientific community and the agencies of the United Nations to bring about a better understanding are reviewed as is the work of the Codex Committee on Pesticide Residues. The constraints on the CCPR are mentioned and an appeal is made for the publication of more data on the use and fate of grain protectant insecticides.

The prospects for the acceptance and adoption of chemical control methods remain good but progress will not be rapid. Greater effort is required to inform administrators, health officials and trade representatives of the advantages, limitations and safety of approved chemical treatments. Facilities must be provided to monitor and regulate residues to maintain the necessary assurance about the safety of chemical treatments to consumers.

REFERENCES:

(1) Anon., Report on a trial of bromophos on stored maize and sorghum. South African Department of Agricultural Technical Services, Pretoria, South Africa, (1975) Report 39/4/9 - (25-9-1975).

(2) Ardley, J. H., Further field evaluation of bioresmethrin as a potential replacement for malathion in grain protection. Wellcome Australia Ltd. (1973) Report TD/5/73/KI-36.

(3) Ardley, J. H., Synergised - bioresmethrin as a potential grain protectant. J. stored Prod. Res. 12 (1976) 253-259.

(4) Ardley, J. H., and J. M. Desmarchelier, Investigations into the use of resmethrin and bioresmethrin as potential grain protectants. Proc. 1st Internat. Working Conf. on Stored Product Entomology, Savannah, Ga. U.S.A. (1974) 511-516.

(5) Ardley, J. H. and J. M. Desmarchelier, Field trials of bioresmethrin and fenitrothion combinations as potential grain protectants. J. stored Prod. Res. 14 (1978) 65-67.

(6) Ardley, J. H., and R. Sticka, The effectiveness of fenitrothion and malathion as grain protectants under bulk storage conditions in Australia. J. stored Prod. Res. 10 (1974).

(7) Ardley, J. H., and R. Sticka, The effectiveness of fenitrothion and malathion as grain protectants under bulk storage conditions in New South Wales, Australia. J. stored Prod. Res. 13 (1977) 159-168.
(8) Banks, H. J., and J. M. Desmarchelier, New Chemical approaches to pest control in stored grain. Chemistry in Australia 45(6) (1978) 276-281.
(9) Bengston, M., L. M. Cooper, and F. J. Holton, A comparison of bioresmethrin, chlorpyrifos-methyl and pirimiphos-methyl as grain protectants against malathion-resistant insects in wheat. Qld. J. agric. anim. Sciences 32 (1975) 51-78.
(10) Bengston, M., Timed daily emmission of dichlorvos for control of *Ephestia cautella* infesting stored wheat. J. stored Prod. Res. 12 (1976) 157-164.
(11) Benston, M., M. Connell, R. Davies, J. M. Desmarchelier, B. Elder, R. Hart, M. Phillips, E. Ridley, E. Ripp, J. Snelson, and R. Sticka, Chlorpyrifos-methyl plus bioresmethrin, methacrifos, pirimiphos-methyl plus bioresmethrin and synergised bioresmethrin as grain protectants for wheat. Pesticide Science (1976a) (in press).
(12) Bengston, M., L. M. Cooper, R. Davies, J M. Desmarchelier, R. Hart, and M. Phillips, Grain protectants for the control of malathion-resistant insects in stored sorghum (1978b) (to be submitted for publication).
(13) Bengston, M., M. Connell, I. D. Crook, J. M. Desmarchelier, R. G. Hart, M. Phillips, J. T. Snelson, and R. Sticka, Field trials to compare chlorpyrifos-methyl, fenitrothion, pirimiphos-methyl, malathion and methacrifos for control of malathion-resistant insects infesting wheat in Australia. J. stored Prod. Res. (1978c) (in press).
(14) Bourne, M. C., Post-harvest food losses - the neglected dimension in increasing the world food supply. Cornell International Agriculture mimeograph 53. Pub. by New York State College of Agriculture and Life Sciences, April (1977).
(15) Carter, S. W., P. R. Chadwick, and J. C. Wickham, Comparative observations on the activity of pyrethroids against some susceptible and resistant stored products beetles. J. stored Prod. Res. 11 (1975) 135-142.
(16) Champ, B. R., R. W. Steele, B. G. Genn, and K. D. Elms, A comparison of malathion, diazinon, fenitrothion, and dichlorvos for the control of *S. oryzae* and *R. dominica* in wheat. J. stored Prod. Res. 5 (1969) 21-48.
(17) Desmarchelier, J. M., Analysis of pyrethroids on grains. J. stored Prod. Res. 12 (1976) 245-252.
(18) Desmarchelier, J. M., A model of the breakdown of dichlorvos on grain. J. Exp. Agric. Anim. Husb. 17 (1977a) 818-825.
(19) Desmarchelier, J. M., Selective treatments including combinations of pyrethroid and organophosphorus insecticides for control of stored product Coleoptera at two temperatures. J. stored Prod. Res. 13 (1977b) 129-137.

(20) Desmarchelier, J. M., Loss of fenitrothion on grains in storage. Pesticide Science 9 (1978a) 33-38.
(21) Desmarchelier, J. M., Application of protectants to bulk grain in Australia - some practical aspects (A summary of results of a field survey, October 1977 - January 1978) (1978b) (to be submitted for publication).
(22) Desmarchelier, J. M., H. J. Banks, P. Williams, and W. Minett, Toxicity of dichlorvos vapour to insects in aerated and non-aerated wheat and comparison of the vapour action of dichlorvos and malathion. J. stored Prod. Res. 13, (1977a) 1-12.
(23) Desmarchelier, J. M., M. Bengston, M. Connell, W. Minett, B. Moore, M. Phillips, J. Snelson, R. Sticka, and K. Tucker, A collaborative study of residues on wheat of methacriphos, chlorpyrifos-methyl, fenitrothion, malathion and pirimiphos-methyl. Part I. Method Development. Pesticide Sci. 8 (1977b) 475-483.
(24) Desmarchelier, J. M., M. Bengston, M. Connell, R. Henning, E. Ridley, E. Ripp, C. Sierakowski, R. Sticka, J. Snelson, and A. Wilson, Extensive pilot usage of the grain protectant combinations, fenitrothion plus bioresmethrin and pirimiphos-methyl plus bioresmethrin. Pesticide Sci. (1978a) (in press).
(25) Desmarchelier, J. M., M. Bengston, M. Connell, W. Minett, B. Moore, M. Phillips, J. Snelson, R. Sticka, and K. Tucker, Collaborative study of residues on wheat of methacriphos, chlorpyrifos-methyl, fenitrothion, malathion and pirmimiphos-methyl - II. Rates of decay. J. stored Prod. Res. (1978b) (submitted for publication).
(26) Desmarchelier, J. M., M. Bengston, R. Davies, R. Elder, R. Hart, R. Henning, W. Murray, E. Ridley, E. Ripp, C. Sierakowski, R. Sticka, J. Snelson, B. Wallbank, and A. Wilson, Extensive pilot usage of the grain protectants chlorpyrifos-methyl plus bioresmethrin, fenitrothion plus d-phenothrin, methacrifos and pirimiphos-methyl plus carbaryl. Pestic. Sci. (1978c) (to be submitted).
(27) Desmarchelier, J. M., M. Bengston, and R. Sticka, Efficacy of pyrethrins for control of *Rhyzopertha dominica*. Pyrethrum Post (1978d) (to be submitted).
(28) Eichler, D., Bromophos and bromophos-ethyl residues. Residue Reviews 41 (1972) 85-112. F. A. Gunther, (Ed.) Pub. by Springer-Verlag.
(29) Elms, K. D., J. D. Kerr, and B. R. Champ, Breakdown of malathion and dichlorvos mixtures applied to wheat. J. stored Prod. Res. 8 (1972) 55.
(30) FAO, Pesticide residues in food. Index of documentation and summary of recommendations of the FAO Panel of Experts on Pesticide Residues and the WHO Expert Committee on Pesticide Residues as at January 1978. AGP/1978/M/5. (1978) FAO, Rome.
(31) FAO/WHO, Fenitrothion. 1974 Evaluations of some pesticide residues in food. FAO/AGP/1974/M/11. (1974) 335-381. FAO, Rome.

(32) FAO/WHO, Bromophos. 1975 Evaluations of some pesticide residues in food. AGP/1975/M/13 (1977a) 41-50. FAO, Rome.
(33) FAO/WHO, Chlorpyrifos-methyl. 1975 Evaluations of some pesticide residues in food. AGP/1975/M/13 (1977b) 113-149. FAO, Rome.
(34) FAO/WHO, Bioresmethrin. 1976 Evaluations of some pesticide resiudes on food. AGP/1976/M/14 (1977c) 55-78. FAO, Rome.
(35) FAO/WHO, Carbaryl. 1976 Evaluations of some pesticide residues on food. AGP/1976/M/14 (1977d) 95-124. FAO, Rome.
(36) FAO/WHO, Fenitrothion. 1976 Evaluations of some pesticide residues in food. AGP/1976/M/14 (1977e) 361-376. FAO, Rome.
(37) FAO/WHO, Pirimiphos-methyl. 1977 Evaluation of some pesticide residues in food. FAO/AGP/1977/M/14 (1978).
(38) Freeman, J. A., A review of changes in the pattern of infestation in international trade. E.P.P.O. Bulletin 4 (1974a) 251.
(39) Freeman, J. A., Infestation of stored food in temperate countries with special reference to Great Britain. Outlook on Agriculture 8(1) (1974b) 34-41.
(40) Freeman, J. A., Food in Store - IN Pesticides and Human Welfare edited by D. L. Gunn and J. G. R. Stevens, pub. by Oxford University Press (1976) 169-178.
(41) Harein, P. K., and E. De Las Casas, Chemical control of stored-grain insects and associated organisms - IN Storage of Cereal Grains and their Products - 2nd Edition - C. M. Christensen (Ed.), pub. by American Assoc. of Cereal Chemists Inc., St. Paul, Minnesota (1974) 232-291.
(42) Goubert, P. C., and P. R. De Beer, The toxicity of contact insecticides to seed-infesting insects. Republic of South Africa, Department of Agriculture Technical Series No. 4 (1968a).
(43) Goubert, P. C., and P. R. De Beer, The toxicity of contact insecticides to seed-infesting insects. Republic of South Africa. Department of Agriculture Technical Series No. 6 (1968b).
(44) Kane, J., and A. A. Green, The protection of bagged grain from insect infestation using fenitrothion. J. stored Prod. Res. 4 (1968) 59-68.
(45) Kashi, K. P., An appraisal of fenitrothion as a promising grain protectant. Internat. Pest Control 14 (1972) 20-22.
(46) La Hue, D. W., Evaluation of malathion, synergised pyrethrum, and a diatomaceous earth as protectants against insects in sorghum grain in small bins. USDA Marketing Research Report No. 781 (1967).
(47) La Hue, D. W., Pirimiphos-methyl as a short-term protectant of grain against stored-product insects. J. Econ. Entom. 68 (1975) 235.
(48) La Hue, D. W., Grain protectants for seed corn. J. Econ. Entom. 69(5) (1976) 652-654.

without any selection pressure. Dilution with susceptible insects may depress frequencies of resistant insects but resistance reappears quickly when selection pressure is applied.

Resistance to certain pesticides is so common in some species, as for example in *Tribolium castaneum*, that it can be regarded as a normal attribute of the species. This acquired state requires that resistance be an integral consideration of basic biological studies through to planning of control programmes. Despite their significance, little is known of the basic mechanisms involved in resistance. Major controlling factors have been isolated, explaining simplistically, the spread of resistance into and through populations. The less obvious factors which are correlated with or intrinsically part of the resistance, however, are not understood or amenable to descriptive analysis. The fitness for survival of resistant strains, in the absence of selection pressure from pesticides, is indisputable, as must be the role of minor factors in maintaining this fitness, and so stability of the resistance. The effects of the minor factors, or indeed the major factors, on biological and behavioural characteristics of species are not known, although scattered observations in the literature attest to their existence. Whether changes in these characteristics occur within the limits of normal variability is obscure, although significant shifts in their distributions seem probable. Associations between changes in biological and behavioural characteristics and resistance may be fortuitous in some instances but nevertheless it cannot be assumed that data derived from susceptible strains of pests in the laboratory, can be extrapolated to resistant populations in the field. This implies, firstly, that appropriately resistant strains should be included in local evaluations of biological and hence ecological characteristics of particular species. Secondly, as behavioural studies with stored product species are a largely untouched field, and the effects of pesticides on behaviour even less known, there is a valid case to determine the significance of behaviour patterns in storage pests particularly as they are influenced by a pesticide-loaded environment. The interactions of these patterns with resistance may assist in an understanding of the development of resistances, and may allow more effective use for longer periods, of the pesticides available, before resistance nullifies their practical value. Finally in this context, it is essential that evaluations of new pesticides include consideration of resistant strains from the earliest stage of their testing, and that this be continued through laboratory studies to field testing. If appropriately resistant strains do not appear in field tests, the commodities should be infested artificially. Similarly resistant strains should be included in the evaluation of control methods not involving chemicals, if these strains are normal for the area of application of the control method.

CONCLUSIONS: Resistance is widespread involving all major pesticides and most of the important pests of cereal and cereal product storage. Control failures in the field have been unequivocally associated with resistance and have forced use of materials such as malathion to be abandoned in some areas.

FAO has provided test methods for detecting resistance to contact insecticides and fumigants in the major beetle and moth pests of stored cereals. These tests enable resistance to be detected before control failure is apparent and provide a convenient method for continuous monitoring of the resistance status of field populations. Their use is commended to enable rational planning of pest control programmes and the countermeasures for resistance that must be a feature of these programmes today.

In general, pest controls with chemicals should aim for complete kills. The alternative will usually be resistance. If less than complete kills are required, methods not using chemicals should be sought. Irrespective there is need for all concerned to adopt a rational approach to storage pest control. Safe storage can only be based on the well-tried and proven principles of sound storage practice if long-term efficacy is to be achieved. These principles have been clearly understood for a very long time and it is mandatory that all controls be based on them. They require:

1. An adequate drying of the commodity before or during storage. 2. A high standard of hygiene, that is storage of grain and other infestable commodities under circumstances where applied control measures are expedited, and removal of any spillage, residues or other materials that provide harbourage for pests or otherwise reduce the effectiveness of applied measures. 3. Use of suitable storage and transport facilities and if necessary their improvement to an acceptable standard. 4. Regular inspection of the commodity and storage for infestations or other causes of deterioration to allow prompt remedial action in the early stages of their development. 5. Mimimum use of chemicals to reduce incidence of residues, selection for resistance, environmental hazards, and general overhead costs. Whilst this should come primarily from hygiene and good warehousekeeping, aeration, refrigeration and other physical control methods should be used if practicable and economical. 6. Use of chemical methods that give as complete a kill as possible to delay population build-up and reduce rate of selection for resistance. Wherever possible, fumigants should be used for control of established infestations and physical and/or contact insecticides to prevent reinfestation. Additionally, where appropriate. 7. Use of varieties of grain that have resistance to insect attack, and harvesting techniques that reduce liability to field infestation and damage to the grain that increases susceptibility to insect attack.

Current knowledge of the control of grain pests is more than adequate if properly used to contain the problem.

REFERENCES:

(1) Anon. (1959) Variation in insect resistance. Pest Infest. Res. 1958: 25,26.

(2) Anon. (1974) Fumigants - Mode of action, use and residue and analysis. Res. Inst. London, Ont., Res. Branch Rep. 1973, p. 186.

(3) Attia, F.I. (1976) Insecticide resistance in *Cadra cautella* in New South Wales, Australia, J. Econ. Ent. 69: 773-774.

(4) Attia, F.I. (1977a) Insecticide resistance in *Plodia interpunctella* (Hübner) (Lepiodptera: Pyralidae) in New South Wales, Australia. J. Aust. Ent. Soc. 16: 149-152.

(5) Attia, F.I. (1977b) In Kerr, R.W. (1977) Resistance to control chemicals in Australian arthropod pests. J. Aust. Ent. Soc. 16: 327-334.

(6) Bansode, P.C. (1974) Studies on the development of resistance to malathion in *Sitophilus oryzae* (L.) Ent. Newsl. (Indian Agric. Res. Inst.) 4: 8.

(7) Bell, C.H., Hole, B.D. and Evans, P.H. (1977) The occurrence of resistance to phosphine in adult and egg stages of strains of *Rhyzopertha dominica* (F.) (Coleoptera:Bostrychidae) J. Stored Prod. Res. 13: 91-94.

(8) Bhatia, S.K. and Pradhan, S. (1968) Studies on resistance to insecticides in *Tribolium castaneum* (Herbst). I. Selection of a strain resistant to p,p^1-DDT and its biological characteristics. Indian J. Ent. 30: 13-32.

(9) Bhatia, S.K. and Pradhan, S. (1970) Studies on resistance to insecticides in *Tribolium castaneum* (Herbst). II. Cross-resistance characteristics of the p,p^1-DDT-resistant strain. Indian J. Ent. 32: 32-38.

(10) Bhatia, S.K. and Pradhan, S. (1972) Studies on resistance to insecticides in *Tribolium castaneum* (Herbst). V. Cross-resistance characteristics of a lindane-resistant strain. J. Stored Prod. Res. 8: 89-93.

(11) Bhatia, S.K., Yadav, T.D. and Mookherjee, P.B. (1971) Malathion resistance in *T. castaneum* in India. J. Stored Prod. Res. 7: 227-230.

(12) Binns, T.J. and Tyler, P.S. (1978) Lindane resistance in *Dermestes maculatus* Deg. (Coleoptera: Dermestidae). J. Stored Prod. Res. 14: 19-23.

(13) Blackith, R.E. and Gorringe, B.S. (1953) Response of pests to fumigation. I. Toxicity of mercury vapour to the eggs of *Calandra granaria* (L.) Bull. Ent. Res. 44: 217-224.

(14) Blackman, D.G. and Peckover, J.I. (1976) Incidence or resistance in the United Kingdom. Other beetles. The long-headed flour beetle. Pest Infest. Control 1971-73: 84.

(15) Bond, E.J. (1973) Increased tolerance to ethylene dibromide in a field population of *Tribolium castaneum* (Herbst). J. Stored Prod. Res. 9: 61-63.

(16) Bond, E.J. and Upitis, E. (1972) Persistence of tolerance to methyl bromide in *Sitophilus granarius* after cessation of selection. J. Stored Prod. Res. 8: 221, 222.

(17) Carter, S.W. (1975) Laboratory evaluation of three novel insecticides inhibiting cuticle formation against some susceptible and resistant stored products beetles. J. Stored Prod. Res. 11: 187-193.

(18) Carter, S.W., Chadwick, P.R. and Wickham, J.C. (1975) Comparative observations on the activity of pyrethroids against some susceptible and resistant stored product beetles. J. Stored Prod. Res. 11: 135-142.

(19) Champ, B.R. and Campbell-Brown, M.J. (1970) Insecticide resistance in Australian *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). II. Malathion resistance in eastern Australia. J. Stored Prod. Res. 6: 111-131.

(20) Champ, B.R. and Cribb, J.N. (1965) Lindane resistance in *Sitophilus oryzae* (L.) and *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae) in Queensland. J. Stored Prod. Res. 1: 9-24.

(21) Cichy, D. (1971) The role of some ecological factors in the development of pesticide resistance in *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst). Ekol. Pol. (A) 19: 563-616.

(22) Dal Monte, G. (1969) World survey for resistance. Item 5/10/5. Rep 4th Session FAO Working Party of Experts on Resistance of Pests to Pesticides, Meeting Rep. PL/1968/m/10. (FAO: Rome). p. 31.

(23) Dyte, C.E. (1974) Problems arising from insecticide resistance in storage pests. Europ. Pl. Prot. Org. Bull. 4: 275-289.

(24) Dyte, C.E. (1976) In Champ, B.R. and Dyte, C.E. (1976) Report of the FAO Global Survey of Pesticide Susceptibility of Stored Grain Pests. FAO Plant Prod. & Prot. Ser. No. 5, FAO, Rome.

(25) Dyte, C.E. and Blackman, D.G. (1967) Selection of a DDT-resistant strain of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) J.Stored Prod. Res. 2: 211-228.

(26) Dyte, C.E. and Blackman, D.G. (1972) Laboratory evaluation of organophosphorus insecticides against susceptible and malathion-resistant strains of *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae) J. Stored Prod. Res. 8: 103-109.

(27) Dyte, C.E. and Forster, R. (1970) Insecticide resistance. Lindane resistance in the groundnut borer. Pest. Infest Res. 1969: 43.

(28) Dyte, C.E. and Forster, R. (1973) Studies on insecticide resistance in *Oryzaephilus mercator* (Fauv.) (Coleoptera: Silvanidae). J. Stored Prod. Res. 9: 159-164.

(29) Dyte, C.E., Forster, R. and Aggarwal, S. (1976a) The rust-red flour beetle. Resistance to juvenile hormone mimics. Pest Infest. Control 1971-73: 79,80.

(30) Dyte, C.E., Rowlands, D.G. and Edwards, J.P. (1976b) Incidence of resistance in the United Kingdom. The rust-red flour beetle. Resistance to piperonyl butoxide. Pest Infest. Control 1971-73: 82,83.

(31) Dyte, C.E., Tyler, P.S., Blackman, D.G., Forster, R., Cogan, P.M., Binns, T.J.and Peckover, J. (1976c) Incidence of resistance in the United Kingdom. The saw-toothed grain beetle. Cross-resistance studies. Pest Infest. Control 1971-73: 74.

(32) Dyte, C.E. and Wilkin, D.R. (1965) Increased resistance of stored-product insects to insecticides. The saw-toothed grain beetle and carbaryl. Pest Infest. Res. 1964: 34.

(33) FAO Survey, 1972-73 In Champ, B.R. and Dyte, C.E. (1976) Report of the FAO Global Survey of Pesticide Susceptibility of Stored Grain Pests. FAO Plant Prod. & Prot. Ser. No. 5. FAO, Rome.

(34) Fernando, H.E. (1967) Summary of cases of resistance to pesticides in agricultural pests. Item 7/16/21. Rep. 1st Session FAO Working Party of Experts on Resistance of Pests to Pesticides, Meeting Rep. PL/1965/18. (FAO: Rome). P. 78.

(35) Godavaribai, S., Krishnamurthy, K. and Majumder, S.K. (1962) Bacterial spores with malathion for controlling *Ephestia cautella*. Pest Technol. 4: 155-158.

(36) Gough, H.C. (1939) Factors affecting the resistance of the flour beetle *Tribolium confusum* Duv., to hydrogen cyanide. Ann. Appl. Biol. 26: 533-571.

(37) Hashimoto, Y. and Fukami, J. (1964) Resistance to insecticides in almond moth, *Ephestia cautella* Walker. I. Development of methyl-parathion resistance. Jap. J. Appl. Ent. Zool. 8: 62-67.

(38) Holborn, J.M. (1957) The susceptibility to insecticides of laboratory cultures of an insect species. J. Sci. Fd. Agric. 8: 182-188.

(39) Howe, R.W. (1962) The entomological problems of assessing the success of a fumigation of stored produce. Proc. 11th Int. Congr. Ent., Vienna, 1960. 2: 288-290.

(40) Joubert, P.C. and de Beer, P.R. (1968) The toxicity of contact insecticides to seed infesting insects. No. 6. Tests with bromophos on maize. Dept. Agric. Techn. Serv., S. Africa, Tech. Comm. No. 84, 9 pp.

(41) Kem, T.R. (1975) Studies on the development of resistance to phosphine in *Tribolium castaneum* (Herbst). Ent. Newsl. (Indian Agric. Res. Inst.) 5: 6,7.

(42) Kisiedu, E.W. and Ntifo, S.E.A. (1975) Problems of cocoa storage and shipment in Ghana. Proc. 4th Conf. W. Afr. Cocoa Entomologists. Zool. Dept., Univ. of Ghana. pp. 104-112.

(43) Kühne, H. (1967) Co-resistenz und Resistenz-Vererbung eines gegen Dieldrin resistenten Laboratorium Stammes der Kleidermotte (*Tineola bisselliella* (Hum.), (Lep.)) Zool. Beitr. 13: 397-407.

(44) Kühne, H. and Becker, G. (1965) Zuchtung giftresistenter Kleidermotten (*Tineola bisselliella* (Hum.), Lep.) Z. Angew Ent. 56: 61-89.

(45) Kumar, V. and Morrison, F.O. (1965) Recording the susceptibility levels of current stored product pest populations to current insecticides. Proc. 12th Int. Congr. Ent., London, 1964, pp. 656, 657.

(46) Kumar, V. and Morrison, F.O. (1967) Carbamate and phosphate resistance in adult granary weevils. J. Econ. Ent. 60: 1430-1434.

(47) Lakocy, A. (1970) Actual problems of the resistance of agricultural pests to pesticides in Poland. Bull. Inst. Ochrony Roslin 47: 89-103.

(48) Lindgren, D.L. and Vincent, L.E. (1965) The susceptibility of laboratory-reared and field-collected cultures of *Tribolium confusum* and *T. castaneum* to ethylene dibromide, hydrocyanic acid and methyl bromide. J. Econ. Ent. 58: 551-555.

(49) Lloyd, C.J. (1969) Studies on the cross-tolerance to DDT-related compounds of a pyrethrin-resistant strain of *Sitophilus granarius* (L.) (Coleoptera, Curculionidae). J. Stored Prod. Res. 5: 337-356.

(50) Lloyd, C.J. (1973) The toxicity of pyrethrins and five synthetic pyrethroids, to *Tribolium castaneum* (Herbst), and susceptible and pyrethrin-resistant *Sitophilus granarius* (L.) J. Stored Prod. Res. 9: 77-92.

(51) Lloyd, C.J. and Parkin, E.A. (1963) Further studies on a pyrethrin-resistant strain of the granary weevil, *Sitophilus granarius* (L.). J. Sci. Fd Agric. 14: 655-663.

(52) Lloyd, C.J., Rowlands, D.G. and Ruczkowski, G. (1976) Incidence of resistance in the United Kingdom. The rust-red flour beetle. Resistance to synthetic pyrethroids. Pest Infest. Control 1971-73: 81,82.

(53) Maeda, O. (1958) Development of DDT resistance in the flour beetle *Tribolium confusum* Duv. Botyu-Kagaku 23: 66-74.

(54) Mathlein, R. (1952) Undersökningar över uppkomst av DDT-resistens hos kornvivel, *Calandra granaria* L. Meddn St. Växsk. Anst. No. 62, 20 pp.

(55) Mello, E.J.R. (1972) Constatacao de resistencia ao DDT e lindane em *Sitophilus oryzae* (L.) em milho armazenado, na localidade de Capinipolis, Minas Gerais. Rep. Instituto Biologico de Sao Paulo, Brazil.

(56) Monro, H.A.U., Musgrave, A.J. and Upitis, E. (1961) Induced tolerance of stored product beetles to methyl bromide. Ann. Appl. Biol. 49: 373-377.

(57) Monro, H.A.U., Upitis, E. and Bond, E.J. (1972) Resistance of a laboratory strain of *S. granarius* (L.) (Coleoptera: Cuculionidae) to phosphine. J. Stored Prod. Res. 8: 199-207.

(58) Morallo-Rejesus, B. (1972) Survey of Philippine populations of rice weevil (*Sitophilus oryzae* (L.)) for resistance to insecticides. 3rd Ann. Intensified Corn Prod. Conf., U.P. College of Agriculture, Philippines, 1972.

(59) Odeneal, J.F. (1961) Insect resistance survey II. Soap and Chem. Spec. 37: 103-107.

(60) Parkin, E.A. and Bright, P.E. (1965) Increased resistance of stored product insects to insecticides. Cross-resistance of malathion-resistant flour beetles. Pest Infest. Res. 1964: 34.

(61) Parkin, E.A. and Forster, R. (1968c) Increased resistance of stored-product insects to insecticides. The groundnut borer and dieldrin. Pest Infest. Res. 1967: 34.

(62) Pasalu, I.C. and Bhatia, S.K. (1974) Specific nature of malathion resistance in *Tribolium castaneum* in India. Bull. Grain Technol. India. 12: 229.

(63) Rajak, R.L. and Hewlett, P.S. (1971) Effects of some synergists on the insecticide potency of phosphine. J. Stored Prod. Res. 7: 15-19.

(64) Sevintuna, C. and Musgrave, A.J. (1961) Observations on males and females of *Sitophilus granarius* (L.) the granary weevil, GC Strain, exposed for 6 generations to allethrin and piperonyl butoxide. Can. Ent. 93: 545-552.

(65) Speirs, R.D., Redlinger, L.M. and Jones, R. (1971) DDT-resistant red flour beetle from a Georgia peanut sheller. J. Econ. Ent. 64: 1328, 1329.

(66) Speirs, R.D. and Zettler, J.L. (1969) Toxicity of three organophosphorus compounds and pyrethrins to malathion-resistant *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). J. Stored Prod. Res. 4: 279-283.

(67) Tyler, P.S. and Binns, T.J. (1976a) Incidence of resistance in the United Kingdom. Other beetles. The hide beetle. Pest Infest. Control. 1971-73: 84,85.

(68) Tyler, P.S. and Binns, T.J. (1976b) In Champ, B.R. and Dyte, C.E. (1976) Report of the FAO Global Survey of Pesticide Susceptibility of Stored Grain Pests. FAO Plant Prod. & Prot. Ser. No. 5 FAO, Rome.

(69) Upitis, E., Monro, H.A.U. and Bond, E.J. (1973) Some aspects of inheritance of tolerance to methyl bromide by *Sitophilus granarius* (L.) J. Stored Prod. Res. 9: 13-17.

(70) Vincent, L.E. and Lindgren, D.L. (1967) Susceptibility of laboratory and field collected cultures of the confused flour beetle and red flour beetle to malathion and pyrethrins. J. Econ. Ent. 60: 1763-1764.

(71) Wilkin, D.R. (1973) Resistance to lindane in *Acarus siro* from an English cheese stores. J. Stored Prod. Res. 9: 101-104.

(72) Wilkin, D.R., Pragnell, L. et al. (1976) Incidence of resistance in the United Kingdom. Mites. *Glycyphagus destructor*. Pest Infest. Control 1971-73: 86.

(73) Winks, R.G. (1969) Resistance to the fumigant phosphine in a strain of *Tribolium castaneum* (Herbst). M.Sc. Thesis, University of Queensland, 145 pp.

(74) Yana, A. (1967) Note sur l'efficacité d'un insecticide de la série des organophosphorés: le sumithion (fenitrothion) sur quelques souches Tunisiennes d'insectes des grains. Doc. tech. Inst. Nat. Rech. Agron. Tunisie. 25: 1-15.

(75) Zettler, J.L., McDonald, L.L., Redlinger, L.M. and Jones, R.D. (1973) *Plodia interpunctella* and *Cadra cautella* resistance in strains to malathion and synergised pyrethrins. J. Econ. Ent. 66: 1049,1050.

APPENDIX I

TABLE 1 OCCURRENCE OF INSECTICIDE RESISTANCE IN PESTS OF STORED PRODUCTS

Lab-selections with same material unless specified.
Adult stage examined unless specified otherwise.
Type of test - F, film; T, topical; Am, admixture.
Maximum resistance factors given at LD_{50} level.

Insecticide and Species	Distribution and Notes	Reference
	CHLORINATED HYDROCARBONS	
DDT		
S. oryzae	Poland, lab-selected (F,x40)	Cichy 1971
	India, lab-selected malathion (x11)	Bansode 1974
	Australia (F,x14)	FAO Survey 1972-73
S. zeamais	Brazil (Am,>x25)	Mello 1972
	Philippines (F,x18)	Morallo-Rejesus 1972
S. granarius	Sweden, lab-selected (low level)	Mathlein 1952
	U.K., lab-selected pyrethrins (T,x29.5, also deutero DDTx30, Bulan x22, Prolan x14, fluoro DDTx37)	Lloyd 1969
	Poland, lab-selected	Lakocy 1970
	Canada (F,x5)	Kumar & Morrison 1965
T. castaneum	Nigeria (low level)	Parkin & Bright 1965
	South Africa (T,x2),lab-selected (T,x166)	Dyte & Blackman 1967
	India, lab-selected (Am,x95)	Bhatia & Pradhan 1968
	India (F,x2.3)	Bhatia et al. 1971
	Poland, lab-selected (F,x4)	Cichy 1971
	U.S.A. (T,x82)	Speirs et al. 1971
	Australia (F,x2.2)	Champ & Campbell-Brown 1970
T. confusum	Japan, lab-selected (x8)	Maeda 1958
	Canada (F,x25)	Kumar & Morrison 1965
O. surinamensis	Australia (F,x2)	FAO Survey 1972-73
E. cautella	Australia (Larvae, T,>x52)	Attia 1976
E. kuehniella	Australia (Larvae, T)	Attia 1977b
P. interpunctella	Australia (Larvae,T,>x42)	Attia 1977a
LINDANE		
S. oryzae	World-wide, 53/58 countries (Am,x72)	FAO Survey 1972-73
S. zeamais	World-wide, 46/48 countries (Am,x32)	FAO Survey 1972-73
S. granarius	Warmer areas of occurrence only, Canada, Brazil, Argentina, Chile, U.K., Mediterranean, South Africa, Australia (T,x7)	FAO Survey 1972-73
R. dominica	World-wide, 41/51 countries (F,x3)	FAO Survey 1972-73

Insecticide and Species	Distribution and Notes	Reference
LINDANE (cont.)		
T. castaneum	World-wide, 75/76 countries (F,x240)	FAO Survey 1972-73
T. confusum	World-wide, 23/34 countries (F,x2)	FAO Survey 1972-73
O. surinamensis	World-wide, 46/56 countries (F,x20)	FAO Survey 1972-73
O. mercator	U.S.A., Caribbean, Sardinia, U.K., Gambia, Senegal, Kenya Mozambique, Botswana, Swaziland, Burma (F,>x89)	FAO Survey 1972-73
C. serratus	Gambia (T,x3)	Dyte & Forster 1970
D. maculatus	U.K., lab-selected (T,x26); U.S.A., U.K., Gambia, Ghana, Nigeria, Lebanon, Pakistan, India, Hong Kong, Australia (F,x2)	Binns & Tyler 1978
S. cerealella	Sri Lanka	Fernando 1967
E. kuehniella	Australia (Larvae,T)	Attia 1977b
P. interpunctella	Australia (Larvae,T,x14)	Attia 1977a
A. siro	U.K.	Wilkin 1973
G. destructor	U.K.	Wilken *et al.* 1976
CYCLODIENES		
S. oryzae	India, lab-selected malathion (dieldrin x4, endrin x3)	Bansode 1974
	Australia (dieldrin,F,x600)	Champ & Cribb 1965
S. granarius	U.K., lab-selected (T,dieldrin x2, aldrin x 3)	Lloyd 1969
	Canada (dieldrin,F,x2)	Kumar & Morrison 1965
T. castaneum	Nigeria (dieldrin,low level)	Parkin & Bright 1965
	India, lab-selected DDT (F, heptachlor x3, dieldrin x2, endrin x2, chlordane x2, endosulphan x2)	Bhatia & Pradhan 1970
	India, lab-selected lindane (F, dieldrin >x291, heptachlor >x232, endrin > x165, aldrin >x100, chlordane >x34, toxaphene >x9, endosulphan >x7)	Bhatia & Pradhan 1972
	Australia (T,aldrin,x3)	Dyte 1976
C. serratus	Gambia (dieldrin,Am,x15)	Parkin & Forster 1968
A. megatoma	Australia (dieldrin)	FAO Survey 1972-73
E. cautella	Australia (Larvae,T,endrin x62, dieldrin >x49)	Attia 1976
E. kuehniella	Australia (Larvae,T,endrin)	Attia 1977b
P. interpunctella	Australia (Larvae,T,endrin x74, dieldrin >x53)	Attia 1977a
T. bisselliella	Germany F.R., lab-selected (dieldrin x70)	Kühne & Becker 1965
	Germany, lab-selected (endrin, chlordane)	Kühne 1967
T. pellionella	Australia (dieldrin x100)	FAO Survey 1972-73
Clothes moths and fur beetles	U.S.A., chlorinated hydrocarbons	Odeneal 1961

PYRETHROIDS

PYRETHRINS		
S. oryzae	Poland, lab-selected* (F,x6*)	Cichy 1971
	India, lab-selected malathion (x4)	Bansode 1974
	Australia (F,x7,x4*)	FAO Survey 1972-73
S. granarius	Sweden, lab-selected DDT	Malthlein 1952
	U.K., lab-selected (F,x3.5)	Blackith 1953
	U.K. (Am,x3.5)	Holborn 1957
	U.K., lab-selected (T,x148,x8*)	Lloyd 1973
T. castaneum	U.K. (Am,x3.5)	Holborn 1957
	U.S.A. (T,5.7)	Vincent & Lindgren 1967
	U.S.A., lab-selected malathion (T,x13)	Speirs & Zettler 1969
	India, lab-selected DDT (F,x2)	Bhatia & Pradhan 1970
	India, lab-selected lindane (F,x2)	Bhatia & Pradhan 1972
	India, lab-selected malathion (F,x5)	Pasalu & Bhatia 1974
	Poland, lab-selected* (F,x8*)	Cichy 1971
	Australia (T,x15,x5*)	Lloyd *et al.* 1976
O. surinamensis	Australia (F,x3,x4*)	FAO Survey 1972-73
E. cautella	U.S.A. (Larvae,T,x3.3*)	Zettler *et al.* 1973
P. interpunctella	U.S.A. (Larvae,T,x2.5*)	Zettler *et al.* 1973
ALLETHRIN		
S. granarius	Canada, lab-selected (x2)	Sevintuna & Musgrave 1961
	U.K., lab-selected pyrethrins (T,x28,14*)	Lloyd 1973
BIOALLETHRIN		
S. granarius	U.K. lab-selected pyrethrins (T,x39,x9*)	Lloyd 1973
T. castaneum	Australia (T,x16,x71*)	Lloyd *et al.* 1976
BIORESMETHRIN		
S. oryzae	Australia (F,x7)	FAO Survey 1972-73
S. granarius	U.K., lab-selected pyrethrins (T,x79,x8*)	Lloyd 1973
	Australia (F,x2)	FAO Survey 1972-73
R. dominica	Australia (F,x1.7)	
T. castaneum	Australia (Am,x4.3,x6.4*)	Carter *et al.* 1975
	Malaysia (Am,x2.9,x1.6*)	Carter *et al.* 1975
T. confusum	Australia (F,x2)	FAO Survey 19. .-73
O. surinamensis	Australia (F,x8)	FAO Survey 1972-73
CISMETHRIN		
T. castaneum	Malaysia (Am,x1.3,0.6*)	Carter *et al.* 1975
FENOXYTHRIN		
S. oryzae	Australia (F,x3)	FAO Survey 1972-73
T. castaneum	Australia, lab-selected malathion (F,x2)	FAO Survey 1972-73
T. confusum	Australia (F,x2)	FAO Survey 1972-73
O. surinamensis	Australia (F,x5)	FAO Survey 1972-73

* Synergised with piperonyl butoxide

KIKUTHRIN		
T. castaneum	Australia (T,x120,x27*)	Lloyd *et al.* 1976
PHENOTHRIN		
T. castaneum	Australia (T,x6,x20*)	Lloyd *et al.* 1976
PROTHRIN		
T. castaneum	Australia (T,x25,x27*)	Lloyd *et al.* 1976
RESMETHRIN		
S. granarius	U.K., lab-selected pyrethrins (T,x207,x8*)	Lloyd 1973
T. castaneum	Australia (T,x2.2,x0.9*)	lloyd *et al.* 1976
TETRAMETHRIN		
S. granarius	U.K., lab-selected pyrethrins (T,>x10,x8*)	Lloyd 1973
T. castaneum	Malaysia (Am,x8.9*) Australia (T,x9,x97*)	Carter *et al.* 1975 Lloyd *et al.* 1976
	ORGANOPHOSPHORUS COMPOUNDS	
MALATHION		
S. oryzae	Columbia, Peru, U.K., Cent. Afr. Emp., Mozambique, Pakistan, India, Nepal, China (Taiwan), Papua New Guinea, Australia (Am,x22)	FAO Survey 1972-73
S. zeamais	Brazil, El Salvador, Guatemala, U.K., China, Papua New Guinea, Australia (Am,x2)	FAO Survey 1972-73
S. granarius	Argentina, U.K., Greece, Australia (T,x6)	FAO Survey 1972-73
R. dominica	23/50 countries, U.S.A., Caribbean, Argentina, Brazil, U.K., Portugal, Libya, Cent. Afr. Emp., Nigeria, Mozambique, South Africa*, Middle East, India, Indonesia, Philippines, Australia* (F,>x100)	FAO Survey 1972-73
T. castaneum	World-wide, 75/78 countries (Am,x52)	FAO Survey 1972-73
T. confusum	World-wide, 27/33 countries (F,x18)	FAO Survey 1972-73
O. surinamensis	Central U.S.A., El Salvador, Guadeloupe, Brazil, Cyprus, Israel, India, China (Taiwan), Japan, Australia (F,x40)	FAO Survey 1972-73
O. mercator	U.S.A., Jamaica, Trinidad, Sardinia, Gambia, Senegal, Swaziland (F,x1.9)	FAO Survey 1972-73
T. granarium	Tunisia	Yana 1967
L. oryzae	-	Blackman & Peckover 1976
D. maculatus	U.K.	Tyler & Binns 1976a
E. cautella	India (Am,x5)	Godavaribai *et al.* 1962
	Japan, lab-selected methyl parathion (F,x3)	Hashimoto & Fukami 1964
	South Africa	Joubert & de Beer 1968
	U.S.A. (Larvae, F,x7.2)	Zettler *et al.* 1973
	Australia (Larvae, F,>x259)	Attia 1976
E. kuehniella	Australia (Larva,T)	Attia 1977b

* Only countries where *R. dominica* resistant to malathion synergised with triphenyl phosphate. See Report FAO Survey 1972-73 for other species.

ACETHION		
T. castaneum	Nigeria, lab-selected malathion (T,x2)	Dyte & Blackman 1972
BENOXAFOS		
T. castaneum	Australia (F,x6)	Champ & Campbell-Brown 1970
BROMOPHOS		
S. zeamais	Brazil (Am,x2)	Mello 1972
R. dominica	Australia (F,x15)	FAO Survey 1972-73
T. castaneum	Australia (T,x6)	Dyte 1974
T. confusum	Australia (F,x2)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x19) Australia (F,x9) Various countries (F,x17)	Tyler & Binns 1976b FAO Survey 1972-73 Dyte *et al.* 1976c
O. mercator	Senegal, lab-selected malathion (F,x158)	Dyte & Forster 1973
CHLORPHOXIM		
T. castaneum	U.S.A., lab-selected malathion (T,x20)	Speirs & Zettler 1969
CHLORPYRIPHOS		
T. castaneum	Australia (F,x5)	Champ & Campbell-Brown 1970
E. cautella	Australia (Larvae, T,x1.7)	Attia 1976
CHLORPYRIPHOS METHYL		
S. oryzae	Australia (F,x2)	FAO Survey 1972-73
R. dominica	Australia (F,x33)	FAO Survey 1972-73
T. castaneum	Australia (F,x4)	Champ & Campbell-Brown 1970
T. confusum	Australia (F,x3)	FAO Survey 1972-73
O. surinamensis	Unspecified localities (F,x2)	Dyte *et al.* 1976c
CHLORTHION		
O. surinamensis	Israel, lab-selected malathion (F,x2)	Tyler & Binns 1976b
CYANOLATE		
T. castaneum	Australia (T,x37)	Dyte 1976
CYANOPHOS		
R. dominica	Australia (F,>x100)	FAO Survey 1972-73
T. castaneum	Australia (F,x3)	Champ & Campbell-Brown 1970
T. confusum	Australia (F,x4)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x3)	Tyler & Binns 1976b
DEMETON METHYL		
S. oryzae	Poland, lab-selected (F,x28)	Cichy 1971
T. castaneum	Poland, lab-selected (F, 434)	Cichy 1971

DIAZINON		
S. oryzae	India, lab-selected malathion (x18) Australia (F,x10)	Bansode 1974 FAO Survey 1972-73
S. zeamais	Brazil (Am,x7)	Mello 1972
S. granarius	Australia (F,x2)	FAO Survey 1972-73
R. dominica	Australia (F,x3)	FAO Survey 1972-73
T. castaneum	U.S.A., lab-selected malathion (T,x8) India, lab-selected DDT (F,x9) India, lab-selected malathion (F,x2) Australia (F,x11)	Speirs & Zettler 1969 Bhatia & Pradhan 1970 Pasalu & Bhatia 1974 Champ & Campbell-Brown 1970
T. confusum	Australia (F,x17)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x7) Australia (F,x11)	Tyler & Binns 1976b FAO Survey 1972-73
O. mercator	Senegal, lab-selected malathion (F,x4)	Dyte & Forster 1973
E. cautella	Australia (Larvae, T,x15)	Attia 1976
P. interpunctella	Australia (Larvae, T,x9.7)	Attia 1977a
DICAPTHON		
O. surinamensis	Israel, lab-selected malathion (F,x2)	Tyler & Binns 1976b
DICHLORVOS		
S. oryzae	India, lab-selected malathion (x7) Australia (F,x6)	Bansode 1974 FAO Survey 1972-73
R. dominica	Australia (F,x16)	FAO Survey 1972-73
T. castaneum	Australia (F,x3)	Champ & Campbell-Brown 1970
T. confusum	Australia (F,x15)	FAO Survey 1972-73
O. surinamensis	Australia (F,x2)	FAO Survey 1972-73
E. cautella	Australia (Larvae,T,x2.5)	Attia 1976
P. interpunctella	Australia (Larvae,T,x3.6)	Attia 1977a
DICROTOPHOS		
T. castaneum	Australia (T,x11)	Dyte 1974
FENCHLORPHOS		
S. oryzae	Australia (F,x4)	Champ & Cribb 1965
FENITROTHION		
S. oryzae	India, lab-selected malathion (x39) Australia (F,x6)	Bansode 1974 FAO Survey 1972-73
R. dominica	Australia (F,x3)	FAO Survey 1972-73
T. castaneum	Malaysia (Am,x1.6) Australia (Am,x6)	Carter *et al.* 1975 Carter *et al.* 1975
T. confusum	Australia (F,x3)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x11) Australia (F,x20) Various countries (F,x109)	Tyler & Binns 1976b FAO Survey 1972-73 Dyte *et al.* 1976c
O. mercator	Senegal, lab-selected malathion (F,x2)	Dyte & Forster 1973
E. cautella	Japan, lab-selected methyl parathion (F,x3) Australia (Larvae,T,x9)	Hashimoto & Fukami 1964 Attia 1976
P. interpunctella	Australia (Larvae,T,x8.6)	Attia 1977a

FENTHION		
S. granarius	Canada, lab-selected	Kumar & Morrison 1967
E. cautella	Japan, lab-selected methyl parathion (F,x2)	Hashimoto & Fukami 1964
FOSPIRATE		
S. oryzae	Australia (F,x3)	FAO Survey 1972-73
R.dominica	Australia (F,x43)	FAO Survey 1972-73
T. castaneum	Australia, lab-selected malathion (F,x4)	FAO Survey 1972-73
O. surinamensis	Australia (F,x2)	FAO Survey 1972-73
JODFENPHOS		
S. oryzae	India, lab-selected malathion (x9)	Bansode 1974
S. granarius	Australia (F,x21)	FAO Survey 1972-73
R. dominica	Australia (F,x16)	FAO Survey 1972-73
T. castaneum	Australia (T,x4)	Dyte 1974
T. confusum	Australia (F,x3)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x35)	Tyler & Binns 1976b
	Australia (F,x9)	FAO Survey 1972-73
	Various countries (F,x30)	Dyte *et al.* 1976c
O. mercator	Senegal, lab-selected malathion (F.x28)	Dyte & Forster 1973
K37		
T. castaneum	Australia (T,x3)	Dyte 1976
METHACRIFOS		
R. dominica	Australia (F,x13)	FAO Survey 1972-73
T. confusum	Australia (F,x2)	FAO Survey 1972-73
MONOCROTOPHOS		
E. cautella	Australia (Larvae,T,x2.3)	Attia 1976
PARATHION		
T. castaneum	India, lab-selected DDT (F,x9)	Bhatia & Pradhan 1970
	India, lab-selected lindane (F,x2)	Bhatia & Pradhan 1972
	India, lab-selected malathion (F,x2)	Pasalu & Bhatia 1974
PARATHION METHYL		
E. cautella	Japan, lab-selected (F,x7)	Hashimoto & Fukami 1964
	Australia (Larvae,T,x3)	Attia 1976
P. interpunctella	Australia (Larvae,T,x2)	Attia 1977a
PHENOTHOATE		
T. castaneum	Nigeria, lab-selected malathion (T,x25)	Dyte & Blackman 1972
	Australia (T,x7)	Dyte 1974
O. surinamensis	Israel, lab-selected malathion (F,x7)	Tyler & Binns 1976b
PHOXIM		
T. castaneum	U.S.A., lab-selected (T,x5)	Speirs & Zettler 1969
	Australia (F,x10)	Champ & Campbell-Brown 1970
O. surinamensis	Israel, lab-selected malathion (F,x6)	Tyler & Binns 1976b
PIRIMIPHOS ETHYL		
T. castaneum	Australia (T,x4)	Dyte 1976

PIRIMIPHOS METHYL		
S. oryzae	Australia (F,x5)	FAO Survey 1972-73
S. granarius	Australia (F,x2)	FAO Survey 1972-73
T. castaneum	Australia (T,x6)	Dyte 1974
T. confusum	Australia (F,x4)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x8) Australia (T,x8) Unspecified localities (F,x5)	Tyler & Binns 1976b FAO Survey 1972-73 Dyte *et al.* 1976c
E. cautella	Australia (Larvae,T,x13)	Attia 1976
P. interpunctella	Australia (Larvae,T,x4.8)	Attia 1977a
TEMEPHOS		
T. castaneum	Australia (F,>x9)	Champ & Campbell-Brown 1970
TETRACHLORVINPHOS		
S. oryzae	Australia (F,x7)	FAO Survey 1972-73
S. zeamais	Brazil (Am,x3)	Mello 1972
S. granarius	Australia (F,x2)	FAO Survey 1972-73
R. dominica	Australia (F,x5)	FAO Survey 1972-73
T. castaneum	Australia (F,>x227)	Champ & Campbell-Brown 1970
T. confusum	Australia (F,x4)	FAO Survey 1972-73
O. surinamensis	Israel, lab-selected malathion (F,x7) Australia (F,x12)	Tyler & Binns 1976 FAO Survey 1972-73
O. mercator	Senegal, lab-selected malathion (F,>x64)	Dyte & Forster 1973
TETRACHLORVINPHOS ETHYL		
T. castaneum	Australia (T,>x20)	Dyte 1976

CARBAMATES

ARPROCARB		
T. castaneum	Australia (F,25)	Champ & Campbell-Brown 1970
CARBARYL		
S. oryzae	India, lab-selected malathion (x5) Australia (F,x3)	Bansode 1974 FAO Survey 1972-73
S. zeamais	Philippines (F,x4)	Morallo-Rejesus 1972
S. granarius	U.K., lab-selected pyrethrins (T,x3)	Lloyd & Parkin 1963
T. castaneum	India, lab-selected DDT (F,>x12) India, lab-selected lindane (F,>x12) India, lab-selected malathion (F,x2) Australia (F,x13) Malawi, Senegal	Bhatia & Pradhan 1970 Bhatia & Pradhan 1972 Pasalu & Bhatia 1974 Champ & Campbell-Brown 1970 Dyte *et al.* 1973
T. confusum	Australia (F,x9)	FAO Survey 1972-73
O. surinamensis	U.K., lab-selected (Am,x120) Australia (F,x12)	Dyte & Wilkin 1965 FAO Survey 1972-73
PROMECARB		
T. castaneum	Australia (F,x3)	Champ & Campbell-Brown 1970
PROPOXUR		
S. granarius	Canada, lab-selected	Kumar & Morrison 1967

MISCELLANEOUS COMPOUNDS

DINOSEB		
S. granarius	U.K., lab-selected pyrethrins (T,x6)	Lloyd & Parkin 1963
JUVENILE HORMONE MIMICS (JH-1, Altozar, Altosid, DMF, Bowers'2B)		
T. castaneum	Australia	Dyte *et al.* 1976a Forster, unpublished data
MITIN FF		
T. bisselliella	Germany FR (x2)	Kühne & Becker 1965
PIPERONYL BUTOXIDE		
T. castaneum	Australia	Dyte *et al.* 1976b
TRIBUTYLTIN ACETATE, PH-60-40		
T. castaneum	Australia	Carter 1975

TABLE 2 OCCURRENCE OF FUMIGANT RESISTANCE IN PESTS OF STORED PRODUCTS

Stage examined - E, eggs; L, larvae; P, pupae; A, adults. Resistance factors at LD_{50} level.

Fumigant and Species	Distribution and Notes	Reference
METHYL BROMIDE		
S. zeamais	China (A,x1.4)	FAO Survey 1972-73
S. granarius	Canada, lab-selected MeBr(A,x17)	Anon. 1974b
	Canada, lab-selected MeBr(A,F_{50},x7.8)	Bond & Upitis 1972
	Canada, lab-selected MeBr(F_{50},E-x1, L-x1.2-2.7,P-x2.4,A-x4.7)*	Upitis *et al.* 1973
	Malta (E,L,x1.6)	Howe 1962
T. castaneum	Malawi†; Bahrain, Canada, China, U.K., Ethiopia, U.S.A. (A,<x1.5)	FAO Survey 1972-73
	China, lab-selected ex FAO Survey (A,F_3x1.6)	Winks (pers. comm)
	Australia	Winks (pers. comm)
T. confusum	Argentina, Canada, China, Cyprus, U.K., Ethiopia, Finland, Germany F.R., Greece, Iran, Iraq, Japan, Spain, U.S.A. (A,<1.5)	FAO Survey 1972-73
	Australia	Winks (pers. comm)
Bruchidae	Malawi†	FAO Survey 1972-73
Stored cocoa beans	Ghana†	Kisiedu & Ntifo 1975
PHOSPHINE **		
S. oryzae	India (A,x2.5); Guyana, Kenya, Portugal (A,<x2)	FAO Survey 1972-73
S. granarius	Canada, lab-selected MeBr(A,F_{12},x13)	Monro *et al.* 1961
	Canada, lab-selected PH_3(A,F_{28},x3)	Monro *et al.* 1972
	U.K., lab-selected pyrethrins (A,x2)	Rajak & Hewlett 1971
	Argentina (A,x2.4)	FAO Survey 1972-73
R. dominica	Guyana (A,x12); India, Libya (A,x7); Argentina, Cent. Afr. Emp., Greece (A,x4); Australia, China (Taiwan), Guadeloupe, Jamaica (A,<x2)	FAO Survey 1972-73
	Egypt (E,A)	Bell *et al.* 1977
T. castaneum	Australia, lab-selected PH_3(A,F_2,x6.5)	Winks 1969
	India, lab-selected PH_3(A,F_{10},x12)	Kem 1975
	Australia, Cent. Afr. Emp., China, Greece, Guyana, India, Japan, Malawi, Montserrat, Nepal, Somalia, Syria, U.S.A. (A,<x1.5); Guyana, lab-selected PH_3(A,F_2,x6); India, Japan, Nepal, Syria, lab-selected PH_3(A,F_1,x5)	FAO Survey 1972-73
T. confusum	U.S.A. (A,x3); Argentina, Australia, Canada, Cyprus, U.K., Finland, Germany F.R., Greece, Iran, Iraq, Jamaica, Japan, Spain (A,<x2)	FAO Survey 1972-73

* Resistance factors referred to susceptible adult stage.

** Resistance factors at the $LD_{99.9}$ were higher than at the LD_{50} for the less-resistant strains, usually >x5.

† Not known to be confirmed with laboratory tests.

HYDROGEN CYANIDE		
S. oryzae	U.S.A., lab-selected HCN(A,F_{36},x2.5)	Lindgren & Vincent 1965
S. granarius	Canada, lab-selected MeBr(A,F_{27},x2)	Monro *et al.* 1961
	U.S.A., lab-selected HCN(A,F_{25},x3)	Lindgren & Vincent 1965
T. castaneum	U.S.A.(A,x1.4)	Lindgren & Vincent 1965
T. confusum	U.K., lab-selected HCN(A,F_7,x1.7)	Gough 1939
	U.S.A.(A,x1.4)	Lindgren & Vincent 1965
	Australia (A)	Winks (pers. comm.)
ETHYLENE DIBROMIDE		
S. granarius	Canada, lab-selected MeBr(A,F_{27},x3)	Monro *et al.* 1961
T. castaneum	Canada (A,x2)	Bond 1973
	Canada, lab-selected EDB ex above strain (A,F_6,x4)	Anon. 1974b
	U.S.A. (A,x1.8)	Lindgren & Vincent 1965
CHLOROPICRIN		
S. granarius	Canada, lab-selected MeBr(A,F_{12},x2.2)	Monro *et al.* 1961
	Canada, lab-selected PH_3(A,F_{18},x2.7)	Monro *et al.* 1972
ACRYLONITRILE		
S. granarius	Canada, lab-selected MeBr(A,F_{27},x4.7)	Monro *et al.* 1961
ETHYLENE OXIDE		
S. granarius	Canada, lab-selected MeBr(A,F_{27},x4.8)	Monro *et al.* 1961
METHYL FORMATE		
T. confusum	U.K., lab-selected Me formate (A,F_{35},x3)	Anon. 1959
MERCURY		
S. granarius	U.K., lab-selected Hg(A,F_{10},x350)	Blackith & Gorringe 1953
MIXTURES		
EDB-MeBr		
T. castaneum	Canada, EDB component only, see EDB	
EDC-CCl_4		
O. surinamensis	Italy (all life-history stages)	Dal Monte 1969
CARBON DIOXIDE		
S. granarius	Canada (A,F_7,x3)	Bond (pers. comm.)

LIMITING CONCENTRATIONS FOR FUMIGATION EFFICIENCY IN THE CONTROL OF INSECT PESTS

C. H. BELL
Pest Infestation Control Laboratory, London Road, Slough, Berks., ENGLAND

INTRODUCTION: Fumigation is a control method often carried out at short notice in an emergency when a heavy infestation is noticed or when quarantine regulations demand during transit in or out of ports. It is an expensive method of control, largely because of the cost of immobilising transport or working machinery at factories, mills, docks, etc. The event of a fumigation failure may therefore be financially no less than catastrophic and over the years this has justified a high input on research into improving fumigation efficacy, i.e., keeping an infested commodity in a toxic atmosphere for long enough to kill all pests present. This paper investigates what constitutes a toxic atmosphere for two fumigants, methyl bromide and phosphine, and how to estimate the time required for action. Fumigation efficiency is here defined as an economy of dosage, measured as a product of concentration and time, in achieving control.

For most fumigants, the concentration-time (CT) product has proved a useful expression of dosage as usually long exposures at low concentrations give comparable results to shorter exposures at higher concentrations, i.e., mg/l x hr (combined units mg hr/l) approximates to k, a constant for mortality. With phosphine, this principle is not expressed clearly because of the enormous variations in insect tolerance as development proceeds from egg to adult (Table I), some stages appearing to be immune for short

Table I
CT PRODUCTS (mg h/l) for 100% KILL OF LIFE STAGES OF E.*cautella* (2-DAY EXPOSURES FOR PH_3)

	EGG	LARVA	PUPA	ADULT
CH_3Br	26	31	50	< 15
PH_3	77	1.4	2.6	< 0.7

periods. These stages can be killed only if the exposure time is long enough to allow them to develop to a stage of susceptibility (1). Hence for phosphine mortality is often related more closely to exposure time than to CT product when a mixture of stages or a natural population is fumigated. If the variations due to insect

development can be eliminated, however, by choosing a stage not undergoing rapid change, then, even for phosphine, a relationship of C x T approximating to k can be discerned and fumigant efficiency assessed. The test insect chosen for this study was the diapausing larva of the warehouse moth *Ephestia elutella*, a stage persisting for months in nature and with a low metabolic rate at moderate temperatures.

For all fumigants, the CT principle breaks down for very low concentrations or too short exposure periods because at these levels some individuals survive CT products normally lethal to them. The present work investigates such limits for methyl bromide and phosphine and describes some factors influencing them. All tests were conducted in 1700l. steel fumigation chambers fitted with ports for the transfer of insect material, and gas samples were taken using evacuated glass flasks at intervals throughout each experiment (2).

LIMITING CONCENTRATIONS FOR EFFICIENT ACTION OF METHYL BROMIDE

A pilot series of tests over the concentration range of 0.6 to 20 mg/l at 20°C subjected diapausing larvae to three standard CT products which at non-extreme concentrations were expected to give about 25%, 50%, and 70% kill. Estimated CT products for 50% kill (LD 50) indicated that maximum efficiency was obtained with concentrations of 3-15 mg/l and that outside this range LD 50 values increased (2). At 20 mg/l and an exposure range of 2-4 2-4-1/2 hr the loss of efficiency was small but at 14.6 mg/l kill was recorded at all. It was decided to investigate the effect of temperature on the concentration threshold, a factor heretofore largely ignored, and six concentrations between 0.9 and 6.0 mg/l were tested at 15 and 25°C.

Some lower concentrations proved less toxic at 25° than at 15°C (Figure 1). The reason for this reversal of the usual order of tolerance was twofold. Firstly there was a higher threshold for efficient action at 25° than at 15°C, some individuals at 25°C surviving higher than expected CT products at 2.7 and 1.9 mg/l. Secondly at and below the threshold, the rate of loss of efficiency (i.e. rate of increase in LD values) as concentration was lowered was not constant at 25°C, being at first gradual (4.0 - 1.9 mg/l) and then rapid (<1.9 mg/l). In general, observations at the LD 50 revealed smaller changes and at 25°C indicated a somewhat lower threshold level than at the LD 99. This was because although 2.7 mg/l was too low to be effective against a few individuals, for most individuals both 2.7 and 1.9 mg/l were still effective. Thus in Figure 1 the 15 and 25 C lines cross between 2.7 and 1.9 mg/l at the LD 99 and between 1.9 and 1.3 mg/l at the LD 50. For practical purposes the threshold identified at the LD 50 is an underestimate of the lowest concentration for efficient action, and better results are obtained by consideration of an extreme mortality level. All members of a population need to be controlled for fumigation to be viable.

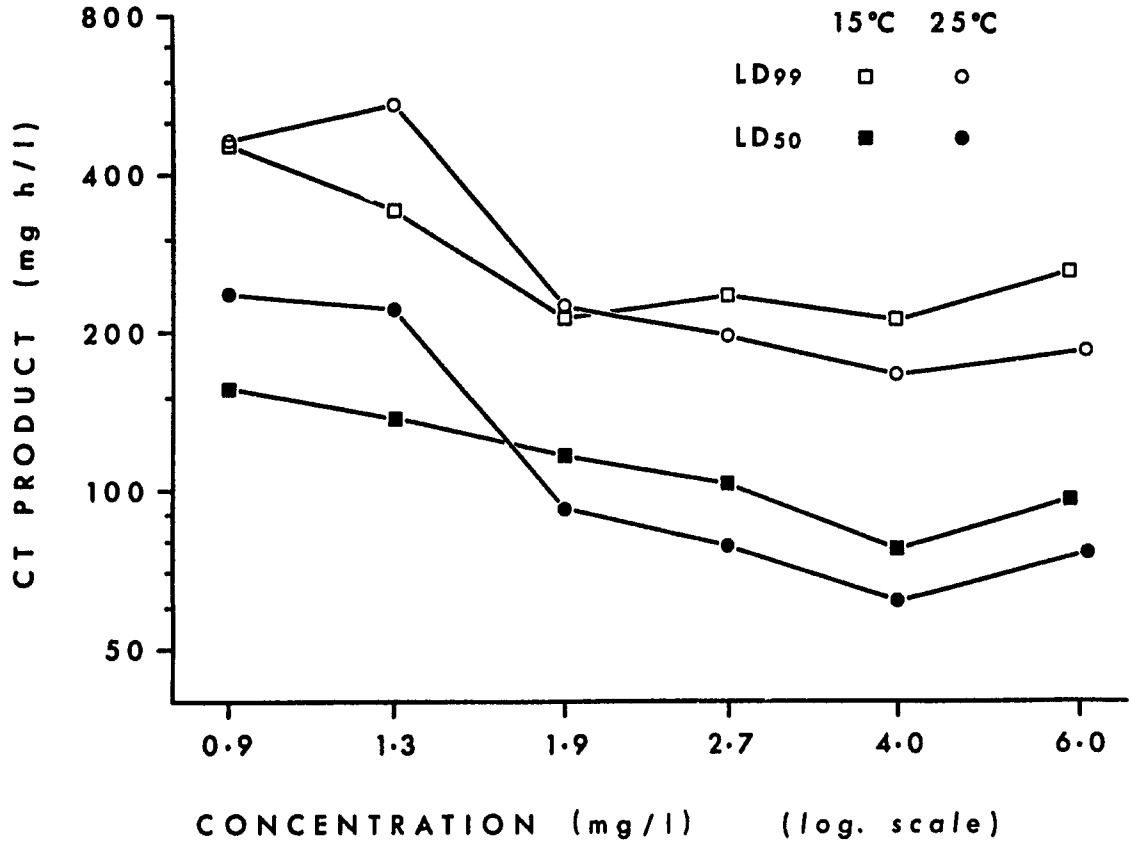


Figure 1 Variation of LD 50 and LD 99 values with temperature, testing six low methyl bromide concentrations against diapausing larvae of *Ephestia elutella*.

Another aspect which has received little attention is the effect of exposure to a high (well above threshold) concentration on the subsequent tolerance to low concentration, i.e., a fumigation with a fall in concentration. This is, of course, the form of the exposure in most practical fumigations, and knowledge of the efficiency threshold for the 'tail' of the concentration curve is necessary for meaningful decisions on their proposed duration. The recommendation to extend a fumigation without regassing would thus depend on the concentration level and its rate of fall-off, with a defined terminal concentration in mind.

In laboratory tests, two concentrations were established in separate chambers at 25°C. Larvae were exposed firstly at 12 mg/l, a concentration well above the threshold range but lower than many occurring in practice, and were then quickly transferred to a selected low concentration in the second chamber. The exposure at high concentration was initially set at a length expected to achieve no more than 10-20% kill. A slight depression of the concentration threshold was discernible, concentrations down to 2.8 mg/l retaining full efficiency (Table II). More recently a

TABLE II
CT PRODUCTS FOR LD 50 and LD 99 OF DIAPAUSE LARVAE EXPOSED AT 25°C TO LOW CH_3Br CONCENTRATIONS AFTER 12 mg/l for 3-1/2 HOURS

	CONC. (mg/l):	4.1 ± 0.1	2.8	1.9	1.2 ± 0.1
EXPOSED 3½ hr AT 12 mg/l	LD 50	62	74	100	147
	LD 99	144	151	275	431
EXPOSED AT LOW CONCENTRATION ONLY	LD 50	62	79	92	220
	LD 99	160	199	225	541

second series of fumigations has been conducted in which exposure at 12 mg/l was extended to give an expected kill of about 70% (CT product 90 mg hr/l). The latest results from this series indicate a concentration threshold of about half the value obtained at 25°C without exposure to high concentration. Thus the higher the level of kill, the lower the concentration that can be tolerated by survivors.

THE EFFICIENCY OF PHOSPHINE OVER A WIDE RANGE OF CONCENTRATIONS at 20°C. In the first series of tests a concentration range of 0.02 to 1.4 mg/l was examined using three standard CT products as described for methyl bromide (2). Estimates of LD 50 gave no evidence of a fall-off in efficiency at the lower concentrations tested; indeed the lowest concentration of all gave the lowest LD 50. At higher concentrations it was clear that efficiency decreased markedly, the LD 50 at 0.75 mg/l being much higher than at 0.27 mg/l. However LD 50 values for 0.75 and 1.0 mg/l were obtained only by extrapolation and no significant kill at all was obtained at 1.4 mg/l at which all exposures were less than 6 hr. Additional data were thus needed to clarify results. Further examination of the effect of low concentrations was also needed because a previous test with a gradually falling concentration had identified a threshold near 0.03 mg/l. In this test, very little increase in kill was obtained after the concentration fell to this level (Figure 2).

To obtain a more complete picture of the concentration limits for efficient action of phosphine, larvae were fumigated at 20°C at concentrations of 0.014-4.0 mg/l and exposure periods of 3-1/2 hr to 43 days, giving a CT product range of 3.5-56 mg h/l. Examining firstly the effect of low concentrations it is evident that a loss of fumigant efficiency occurs below 0.04 mg/l, as judged by an increase in the CT product for 90 and 99% kill (Figure 3, Table III). However, this loss of efficiency is not evident at the LD 50 and hence remained undetected in the pilot test series. At higher concentrations (0.5 mg/l and above) fumigant efficiency declined to such a marked extent that LD 99 values had to be calculated by extrapolation beyond the tested exposure ranges. This deterioration in fumigant efficiency was also evident at the LD 90, but not at the LD 50 at 0.7 mg/l and below. Concentrations of 0.5 mg/l and above are described by Winks (3) as narcotic and it is possible that from this level upwards a few individuals become narcotised and survive for longer than expected, causing curvature of probit lines and increasing the LD 99 rather than the LD 50 in a linear fit.

A further series of six tests was conducted at 1.5-6 mg/l, each test having eight exposures from 3-1/2 hr to 40 hr. Single larvae survived the 40 hr exposure at 1.5 and 2.0 mg/l, but in the other four tests complete kill was obtained in both 40 and 28 hr exposures. The LD 99 values calculated were similar to their projected counterparts in the earlier series, but indicated that above 2 mg/l the whole population was narcotised and mortality was dependent solely on duration of exposure (Table IV). The time for 50% kill (LT 50) at these concentrations was about 9 hr and the LT 99 about 29 hr.

For phosphine, then, four phases of efficiency can be distinguished as concentration is increased from very low to very high levels. Firstly, there is the below-threshold region up to

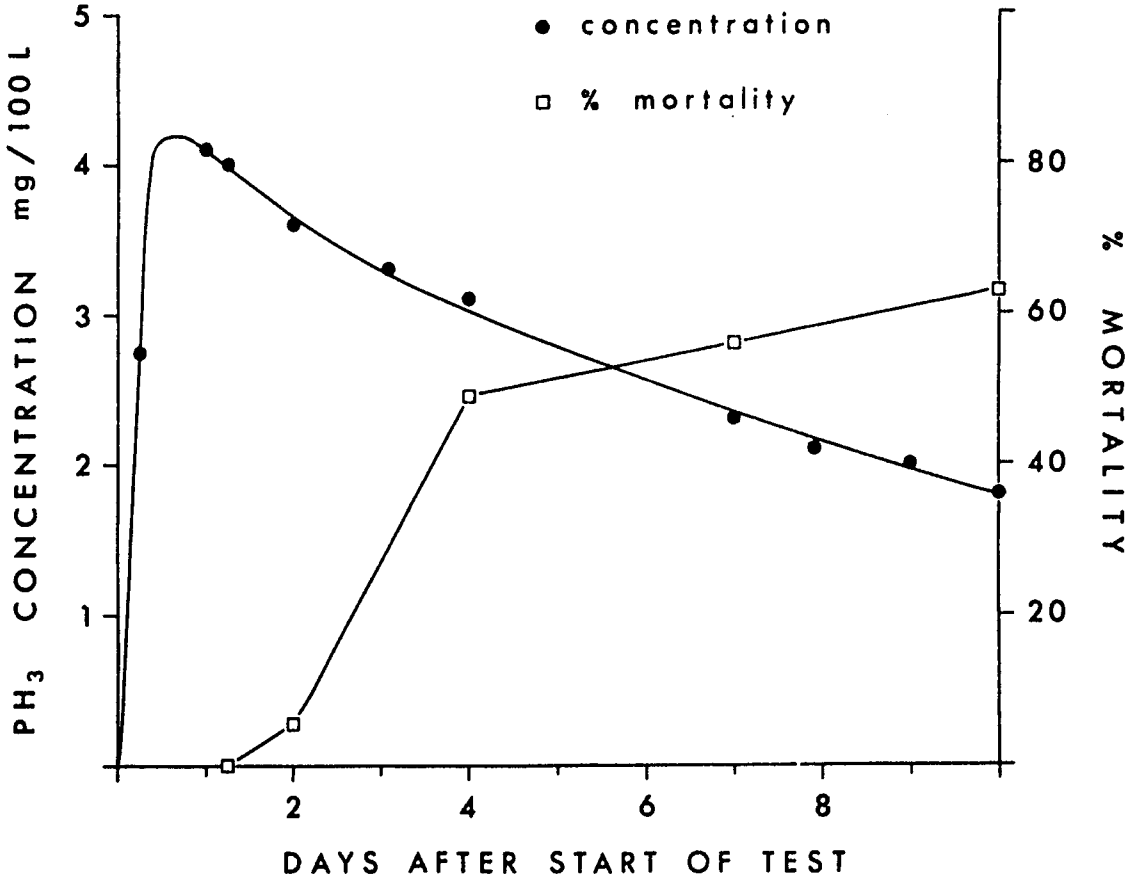


Figure 2. Effect of a low and falling concentration of phosphine on the mortality of diapausing larvae of *Ephestia elutella* at 25°C

0.04 mg/l with some individuals surviving disproportionally long periods and reducing efficiency. Between 0.04 and 0.35 mg/l the action of phosphine is highly efficient and the CT principle holds as shown by the linear portion of Fig. 3. The slope of this

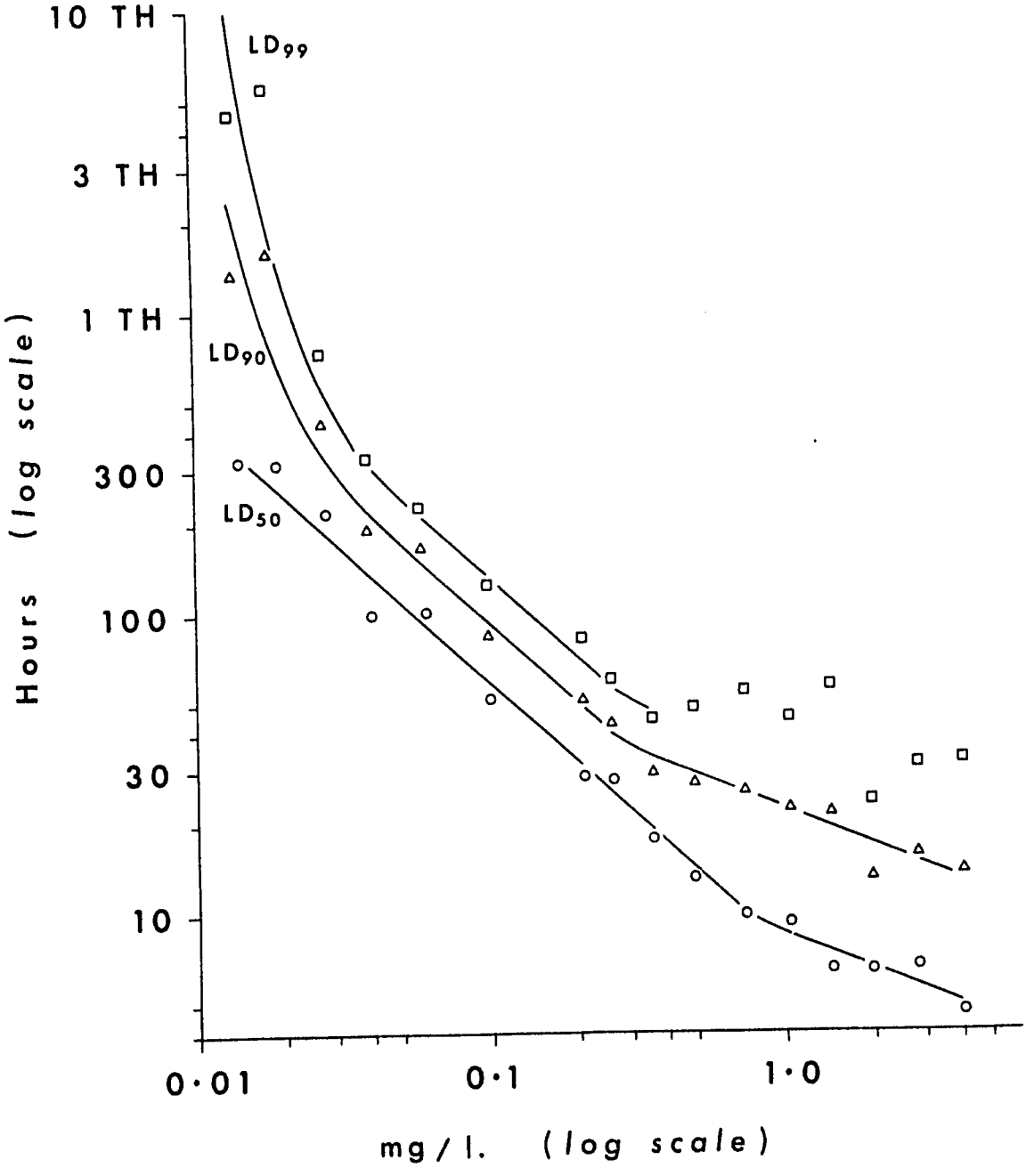


Figure 3. The relationship between time and concentration of phosphine for mortality of *Ephestia elutella* diapausing larvae fumigated at 20°C

TABLE III. TOXICITY OF LOW CONCENTRATIONS OF PHOSPHINE TO *E. elutella* DIAPAUSE LARVAE (AT 20°C)

CONCN. (mg/l)	LD 50 (mg h/l)	LD 99 (mg h/l)
0.014	4.5	65
0.018	6.1	103
0.027	6.1	20
0.039	4.0	1[illegible]
0.058	6.0	1[illegible]

TABLE IV. EXPOSURE TIME FOR LD 50 and LD 99 of DIAPAUSE LARVAE IN HIGH DOSE PHOSPHINE TESTS AT 20°C

CONCENTRATION mg/l	LD 50 (hr)	LD 99 (hr)
5.8	9	29
4.1	9	29
2.8	8	25
2.3	9	29
2.0	16	50
1.5	13	44

linear portion is -0.9, indicating a slight time bias in the CT relationship ($C^{0.9}T = K$). At 0.04-0.10 mg/l, a CT product of 14 mg h/l is adequate for 100% kill of the test insects.

Above 0.35 mg/l the efficiency of phosphine declines, but increases in concentration up to 2 mg/l continue to shorten the exposure required for 100% kill. A heavily time-biased CT relationship (approximately to $C^{0.4}T = K$) may still operate over this concentration range. Lastly, for concentrations above 2 mg/l, mortality is determined by time of exposure only, individuals varying in their capacity to survive in a narcotised state.

As temperature has already been shown to influence the minimum effective concentration with methyl bromide, some pilot tests have been conducted on the effect of temperature on the minimum exposure for 99% kill with phosphine. Again (Table V)

TABLE V PERCENTAGE KILL OF *Ephestia elutella* DIAPAUSING LARVAE IN HIGH DOSE PHOSPHINE TESTS

EXPOSURE (HOURS)	2.0 mg/l		4.1 mg/l	
	15°C	20°C	15°C	20°C
3.5	37	23	63	33
5	56	46	80	68
7	89	50	79	79
10	89	54	89	75
14	93	78	98	95
20	98	90	100	98
28	100	93	100	100
40	100	98	100	100

a reversal is seen in the order of tolerance at higher and lower temperatures, tests at 2 and 4 mg/l proving more toxic at 15°C than at 20°C. LT 99 values calculated for the two concentrations at 15°C are similar (22-23 hr) indicating that time alone was governing mortality. The minimum effective exposure period for complete control, like the LT 99, is likely to be shorter at 15°C than at 20°C.

DISCUSSION AND CONCLUSIONS: For methyl bromide the maximum concentration range for high fumigation efficiency in normal practice is about 2-20 mg/l, but concentrations up to 4 mg/l may prove ineffective against certain species in warm conditions. Very low concentrations are more toxic at low temperatures than at higher ones, and are more effective when following exposure to higher concentrations.

For phosphine, a CT relationship exists over a restricted concentration range but is usually observed by insect development. In general, all concentrations above a very low minimum (0.03 mg/l for *Ephestia elutella* diapausing larvae at 20°C) are effective, but no advantage is gained in terms of extra kill by increases above 2 mg/l. However, because insect development largely controls mortality, with phosphine long exposures are always required to span tolerant stages and achieve control, especially at lower temperatures, and high initial doses may be required to ensure that gas is present at the end of the exposure. High concentrations may induce a state of narcosis in insects exposed but the period so survived is relatively short, especially at lower temperatures.

Against this background, factors contributing to the development of resistance can be viewed more clearly. The worst situation for long term efficacy is persistent exposure of an insect population to low concentrations at high temperature. With methyl bromide the biggest danger is when highly sorptive commodities such as oilseed cakes and fishmeal are treated as these can lower the free-space concentration to threshold levels. The minimum effective concentration increases with temperature, implying that for a given temperature rise the rate of detoxification increases more rapidly than the rate of uptake. This being so, individuals surviving marginal treatments at higher temperatures will be the fastest detoxifiers. At lower temperatures, individuals with slow rates of uptake may prevail equally well. Hence the danger of low dosage levels at high temperature is the rapid selection for resistance based on detoxification. It is fortuitous, perhaps, that warm rearing conditions have been used in laboratory selection studies on resistance. For resistance based on slow uptake, however, a different approach may be required.

Because of the temperature effect, it can be seen that fumigant resistance is more likely to appear and cause problems in tropical rather than temperate zones. With a fumigant like phosphine the possibility of narcosis provides an additional resistance mechanism. Selection for this type of resistance is most likely to occur by repeated exposure of a population to high dosages for short periods, again at high temperature. Fumigation of leaky containers or railway trucks in the propics provide examples of how this combination of conditions can occur in practice.

At present resistance to fumigants has not become a serious economic problem. Some resistance to phosphine in short exposures was reported in the 1973 Global Survey (4) but all strains that have been tested with longer exposure periods have shown more normal tolerance. The threat of future increases in tolerance cannot, however, be ignored.

REFERENCES:

(1) Howe, R. W., J. stored Prod. Res. 8 4 (1973) 241.

(2) Bell, C. H., Glanville, V., J. stored Prod. Res. 9 4 (1973) 165.

(3) Winks, R. G., Phostoxin Technical Conference, Phostoxin Sales, Inc., (Proceedings Alhambra, Calif. 1974) 83.

(4) Champ, B. R., Dyte, C. E., Report of the FAO Global Survey of Pesticide Susceptibility of Stored Grain Pests. U.N. Fd. Afric. Org., Rome (1976).

ANALYSIS OF FORMULATIONS AND RESIDUES - SOME CURRENT CONSIDERATIONS

J. M. DESMARCHELIER
CSIRO, Division of Entomology,
P.O. Box 1700,
ACT, 2601, Australia

I will give a very brief outline of recent Australian work on analysis of formulations and residues with emphasis on determination of amounts of chemicals as a tool for improving usage of chemicals. I feel sure that my comments on Australia will apply to other countries and I will be brief because I think the discussion will prove more useful than my talk.

FORMULATIONS: The following faults with formulations have been observed.

1) Some formulations were supplied by manufacturer at less than stated strength.
2) Some formulations broke down in containers - i.e. lost chemical strength.
3) Some formulations congealed in containers - i.e. lost physical properties.
4) Some formulations were delivered with added noxious compounds (solvents).
5) Some formulations, when diluted with water, became heterogeneous (i.e. settling occurred).
6) Some formulations, when diluted with hard but not soft water, became heterogeneous.

There is therefore a need to determine chemical and physical properties of formulations under conditions of use. If a new chemical is to be used, such determinations should be carried out, as a precaution, in extensive trials before full introduction. In all cases, sampling is required to determine concentrations. Therefore there is a need for rapid and cheap methods of analysis.

A cheap analysis usually means analysis by color, or a titrimetric analysis. Such methods of analyses are declining in highly developed countries. This is a pity, for two reasons:

1) Such methods are cheaper than electronic methods and therefore more universally applicable.
2) Such methods usually have constant machine response and primary analytical standards, and are therefore less prone to the gross errors that can occur in electronic analyses.

RESIDUES ON GRAINS: From analyses of residues on grains we have found, in Australia:

1) The average residue is predictable.
2) A small area of grain, e.g. 100 tonnes, in a large well-treated storage can contain no insecticide at

all because, for example, the insecticide pump was turned off for an hour during receival of grain.

3) Experimental treatments can be mislabelled.
4) Some storages can receive erratic application of insecticides because of the position of the spray.
5) Marked improvements in effectiveness of protectants can be achieved by even small changes in temperature (a few degrees is important) or by partial turning of bins to even out residues.

The value of determination of residues, in this context, is that they point to areas where improvements can be made. They result in better control of insects, at little extra cost and sometimes at reduced cost. However, the value of such work is usually only of local benefit - e.g. this spray is wrongly placed, that water is too hard, etc. Therefore each country and each district must determine its own residues.

Therefore we need cheap, rapid methods to analyze residues.

In my experience, small differences in residues between storages usually lead to no practical improvement. For example, if residues in two storages are 4 and 5 g/t respectively, one cannot draw conclusions about application in either storage. If, however, residues are 0.5 and 5 g/t, one can draw conclusions and often the source of error can be detected, and corrected. For such purposes, there is need for many analyses, but they do not have to be precise. In Australia, we have found semiquantitative methods of analysis to be very useful, for example analysis of bioresmethrin or carbaryl by a color reaction on a plate for Thin-Layer Chromatography. Such methods are very rapid, inexpensive and sufficiently precise (±20%) for most purposes.

COLLABORATIVE ANALYTICAL PROGRAMS: Such programs, where several analysts analyze a given sample, are excellent checks on reliability of procedures and help to detect, and therefore correct, errors made by a particular analyst.

SUGGESTIONS FOR INTERNATIONAL COOPERATION ON METHODS OF ANALYSIS SUITABLE FOR LABORATORIES WITH LIMITED FINANCES: There are two major objections to the use of determination of chemical residues as a tool for improving the benefits of chemical usage. These objections are the cost of chemical laboratories, and the reliability of results from one laboratory. I put forward for your consideration some proposals to reduce cost and increase reliability.

1) A list should be collected of regional and international laboratories prepared to check suitable methods of analysis. Such collaborative programs are the best test of reliability. For most purposes regional programs are adequate.

2) Residue chemists could develop methods of analysis suitable for a given type of equipment if laboratories with limited resources could standardize on a given type of equipment.
3) Emphasis should be placed on volumetric and color methods of analysis, where possible (e.g. malathion, pyrethrins, fenitrothion, carbaryl).
4) Regional organizations should ensure that suitable methods of analysis are evaluated before the introduction of new insecticides. Such organizations could request developmental work from laboratories outside the region.
5) Analytical procedures suitable for developing country would be evaluated more frequently in developed countries if they were more aware of the analytical requirements and analytical equipment of developing countries. Would it be worthwhile to exchange such information within regions, and between regions?
6) Might it be useful, at the next Conference, and informally at this Conference, to have one period devoted to sub-programs, for example, a program on analysis of residues?

SYMPOSIUM ON RADIATION AND OTHER NON-CHEMICAL
MEANS OF INSECT CONTROL

Convener - DR. ROBERT DAVIS
Stored-Product Insects Research and Development Laboratory
Agricultural Research-SEA-USDA
P.O. Box 22909
Savannah, Georgia 31403
U.S.A.

RECENT ADVANCES IN THE USE OF MODIFIED ATMOSPHERES FOR STORED PRODUCT PEST CONTROL

H. J. BANKS
CSIRO, Division of Entomology, P.O. Box 1700
Canberra, A.C.T., 2601, Australia

Modified or controlled atmosphere (CA) storage of grain involves alteration of the proportions of the normal gaseous constituents of the storage environment, oxygen, nitrogen and carbon dioxide to provide an insecticidal atmosphere. This paper reviews experimental approaches made over the years directed towards the development of full commercial utilisation of this residue-free method of insect control in stored dry durable commodities, such as grain or pulses. Although working on a similar biological principle, hermetic and pit storage systems are specifically excluded from this review and only atmospheres created by external addition of gases to give the altered composition will be considered.

There are several questions which must be answered before controlled atmosphere storage can be used successfully, efficiently and routinely.

They can be summarised as:

(a) How well sealed must the storage be?
(b) What quantity of gas is required to create the desired atmosphere in this storage?
(c) How much gas will be required to maintain the correct gaseous composition for a set exposure period?
(d) What is the correct exposure period?

Two publications in 1971 (1) and 1977 (2) have set out 'state of the art' practical instructions for controlled atmosphere storage of grain. Both were based on field experience of the method and gave answers to these questions as then known. However, practical experience in the use of this technique is rapidly being amassed and it is time to review the information available and see where there are still problems to be solved.

REQUIREMENTS FOR APPLICATION OF MODIFIED ATMOSPHERES: The atmospheric composition and its biological effect - Two main types of modified atmospheres are insecticidal, both of which have been investigated under full scale field conditions: - low oxygen atmospheres and CO_2-rich atmospheres. The low oxygen atmospheres have been found to be insecticidal below about 2% oxygen to all species and stages of stored product pests so far tested (3). Some species are more susceptible and may be killed at 3% O_2 or more (e.g. *Cryptolestes ferrugineus* adults (4)). An atmosphere containing 1% oxygen appears to be the best compromise between increased speed of action at lower oxygen levels (5) and the increased difficulty of maintaining low O_2 levels.

The low oxygen atmospheres have been generated under field comditions either by purging the storage with nitrogen, supplied by tanker as a liquid, or by burning hydrocarbons in air and using the exhaust from the burner as a purge.

CO_2 rich atmospheres have been generated from CO_2 supplied in tanker as a liquid, as compressed gas in cylinders or as dry ice. It has long been recognized (6) that high levels of CO_2 give control in the presence of substantial quantities of oxygen and therefore that CO_2 acts as a toxic fumigant rather than merely displacing oxygen. The optimum level appears to be about 60% CO_2 in air, i.e. 8% O_2, 60% CO_2, balance N_2 and rare gases. Below 60%, the action of the gas mixture against several species (e.g. *S. granarius* declines (4) (7)). Between 60 and 98% it is approximately constant (8) and then declines slightly for still higher CO_2 levels.

The time taken to achieve a certain level of insect kill is dependent not only on the composition of the atmosphere but also on the temperature of the environment. With low oxygen atmospheres the temperature effect is substantial; the period required for complete insect kill at high storage temperatures, e.g. 35°C, is only a few days but may be many weeks below 15°C. Exposure times required for complete disinfestation at various temperatures have been published (2). Where only susceptible species such as *Oryzaephilus surinamensis* are present or a lower level of mortality is acceptable, these periods may be substantially reduced. There is insufficient data available to assess accurately the influence of temperature upon the effectiveness of carbon dioxide-rich atmospheres. However, it appears that there is a similar but less pronounced temperature dependence than for low oxygen systems. Generally, the speeds of action of the two systems are similar but there is some variation between species and stages.

The requirement for an exposure period of several days or even some weeks, to the modified atmosphere, means that the atmosphere of the correct composition must be maintained under conditions where some leakage is inevitable. During this period, the 'maintenance phase,' it has been found necessary with low oxygen atmospheres to add further gas to counteract leakage. This may also be the case with CO_2-rich atmospheres, although because they are effective over a wide range of CO_2 levels, this is not always necessary.

The effects of sealing - Before considering the results of the various field trials in detail it is necessary to explain the relevance of the sealing level of the enclosure to the general technique of modified atmosphere storage. It is obvious that given an inexhaustable supply of gas available at any rate on demand, it would be possible to create a specified atmosphere in almost any storage enclosure. Such a situation would clearly be uneconomic. Gas usage must thus be reduced by sealing. This

may sometimes be expensive, but the cost can be offset against the saving of gas.

There are a number of forces which cause gas losses from enclosures. These have been summarized for freight containers (9) and their various contributions investigated under practical conditions (10) (11). The influence of some forces, such as wind, may be reduced by increased level of sealing. Others, particularly those generated by temperature cycling in the headspace, are substantially decreased only by having very high levels of sealing. The optimal standard of sealing for storages for controlled atmosphere use is that where the gas loss caused by the forces in the former category is negligible compared with that caused by the latter. This standard can be predicted mathematically and has been published for storages of 300-10000 tonnes (2). The predicted gas interchange rate of such sealed stored with atmosphere is less than 5%/day. The setting of such a standard is important as it prevents the expenditure of unnecessary effort in attaining higher levels of sealing which do not result in reduced leakage. When because of practical difficulties, this sealing level cannot be achieved, a higher rate of gas usage can be expected to maintain a set atmospheric composition. For ISO IC freight containers, a leakage standard of <20 m3/hr at 250 Pa excess pressure seems appropriate on present data (12).

The sealing of a storage also provides an insect-proof barrier. Thus, unless required for quality preservation, the maintenance of modified atmosphere is required only for as long as required for complete insect kill within the store.

It is unfortunate that an objective measurement of gastightness, such as a pressure test, is seldom given in reports of modified atmosphere trials. This prevents conclusive analysis of the reasons for the differing efficiencies attained in the different trials. However where a large maintenance rate is required, it is likely that the standard of sealing was low.

FIELD TRIALS: Atmospheres generated with nitrogen - There have been a number of field trials conducted with low oxygen atmospheres generated by introduction of nitrogen gas. Table I gives a summary of the trials carried out in Australia over the past few years. This table is an expanded version of that presented (3) to the First International Working Conference on Stored Product Entomology. Details of the pressure tests and duct work of the bins used are given in Table II.

Despite the wide range of gastightness, rates of gas input, configuration of gas introduction system and bin capacity and degree of filling, there was no difficulty in creating a sufficiently low oxygen atmosphere throughout the grain mass in the structures. In three of the trials, purging was terminated before the headspace was below 1.5% oxygen. In two of these, the addition of gas during the maintenance phase lowered the oxygen level below this. In the third, Cunnigar I, the oxygen level

TABLE I. Nitrogen usages and efficiencies for trials using liquid nitrogen carried out by CSIRO (13).

Trial (Site)	Date of Trial	Storage capacity m^3	Load (tonnes)	Filling ratio	Nitrogen used for purge (m^3)	Headspace % O_2 at termination	Efficiency (E_3 %)*
Bordertown I	1972	9049	7035 wheat	0.92	7306	1.1	76
Bordertown II	1972	9049	5220 wheat	0.74	9622	3.2	73
Cunningar I	1973	2930	2040 wheat	0.85	1990	3.9	84
Cunningar II	1973	2930	2040 wheat	0.85	2467	1.0	92
Sunshine	1974	3055	1809 barley	0.71	3300	1.2	89
Newcastle	1975	421	294 wheat	0.83	430	0.7	88
Balaklava	1976	9049	6474 wheat	0.91	7072	2.1	75
Bungunya	1976	2330	1780 wheat	0.91	2095	0.8	79

* Efficiency calculated according to formula in Appendix I.

TABLE II. Summary of purging and pressure tests for CSIRO nitrogen trials (13).

Trial	Inlet system	Average purge rate (m^3/min)	Calculated equivalent rise rate m/hr	Pressure test	
				Decay 250-125 Pa (filled) (secs)	Flow giving 250 Pa (l/sec)
Bordertown I	Annular perforated duct close to wall and central input point	4.9	1.8	100	-
Bordertown II	Shielded input on base on wall	9.4	3.5	1600	-
Cunningar I	Directly into base of cone	2.2	1.5	100	-
Cunningar II	Directly into base of cone	3.2	2.1	80	-
Sunshine	Y-shaped perforated aeration duct on floor	2.7	2.1	780	4
Newcastle	Perforated duct along diameter of bin	0.77	2.2	-	6
Balaklava	3 symmetrically placed shielded inputs around base of wall	1.7	0.6	960	1
Bungunya	Radial perforated duct	1.35	1.8	240	5

rose, as an inadequate level of sealing had been achieved and air was forced in by wind at a rate greater than could be counteracted by the gas input rate available.

In small scale trials in bins of 30-150 m^3 capacity by Shejbal et al. (5) (14) (15), nitrogen was introduced for purging directly into the headspace of the storage. Two to three times the interstitial volume was said (4) to reduce the oxygen tension in the bin to that of the purge nitrogen. Assuming a 95% full bin and an attained O_2 proportion of 0.5%, the usage of two and three nitrogen volumes (with 0.5% O_2 content) corresponds to efficiencies of 81 and 54% respectively (formulae for calculation of efficiencies are given in Appendix I). Because nitrogen is less dense than air, purging down through the grain may reduce density-related mixing and give a higher efficiency. There is no evidence for this as the efficiencies obtained by Shejbal et al. (14) are similar to those in the CSIRO trials (Table I) (13) where upward flow was used.

It can be seen that the creation of low oxygen atmospheres is a reasonably efficient process even in storages whose gasetightness is less than desirable to give an economic maintenance rate. The wide variety of systems found to be suitable show that the efficiency of creation of low oxygen atmospheres is not very sensitive to the ductwork design and introduction rates. It seems that the advantage of any increase effecting more complex introduction systems would be offset by their cost and inconvenience.

In most of the trials where maintenance of the atmosphere was attempted, the maintenance gas was added into the headspace. The minimum requirement was specifically investigated in three trials by progressively decreasing the input rate until maintenance was just achieved. Table III compares the observed

TABLE III. Minimum maintenance flow compared with air ingress due to head space treatment (12).

	Nitrogen flow to maintain low oxygen concentration	Maximum possible air ingress due to temperature cycle (E_1)	Calculated nitrogen requirement (E_2) dilute this ingress to 1% O_2
	m^3 day^{-1}	m^3 day^{-1}	m^3 day^{-1}
Newcastle	15	4.3	13
Bungunya	37	8.4	26
Balaklava	69	55	169

and calculated requirements. It is assumed that there is direct displacement of the air coming in and free mixing with displacement of the diluted gas. In two cases the requirement was similar to that expected from free mixing. In the third it was close to that expected from displacement. This difference may partly be attributable to differences in the location of leaks, as well as to difference in total sealing level. Based on the experience obtained with these and other trials, a table of expected maintenance usages, with various bin sizes and fillings, has been published (2).

In two trials, Cunnigar I and II, the maintenance nitrogen was introduced at the base. In Cunningar II, there was a very high maintenance requirement of about 850 m^3/day. This high rate resulted partly from high general interchange rate as the storage was not sealed to a high standard, but also because the air, entering principally at the base of the bin, was forced into the grain mass, instead of, at least in part, being expelled through the leak where it entered. Admission of the nitrogen into the headspace would have substantially reduced the maintenance requirement by allowing this to occur.

In experimental treatments by Shejbal et al. (14) nitrogen was introduced at a continuous rate to give a perceptable outflow of gas at the base of the storage. The requirement ranged from 0.2 to 1.5 litres N_2/hr/100 kg wheat or barley. In commercial usage in Italy the requirement is 0.008-0.02 litres N_2/hr/100 kg grain (16). A demand system is used which maintains a slight positive pressure in the structure at all times. These rates correspond to usages of 96 to 720 and 29-72 m^3/day respectively. The latter rate is similar to that observed in the CSIRO trials (Table IV) using a continuous nitrogen input.

The biological effectiveness of the experimental trials using nitrogen has been high but not always complete. Shejbal et al. (5) (14) apparently obtained survival of eggs of *S. granarius* after 10 days at 22°C in their trials with 0.5% O_2 in nitrogen. In CSIRO trials, where short exposures have been used, some survival has been found. In the Sunshine trial, a mortality of 99.3% of mixed stages of *S. oryzae* was obtained, with only early stages and pupae surviving after 31 days at 14-20°C at <1% oxygen.

No infestation was recorded in the Bungunya and Balaklava trials, which remained sealed for a further five and eight months respectively after termination of maintenance of nitrogen despite infestations in the adjacent bins. The bins had been under low oxygen for more than 195 days. The grain from the Newcastle trial was also free of insects but had previously been disinfested with phosphine, and thus the effect of the nitrogen exposure could not be assessed. In these cases the insect proofing from the sealing was clearly demonstrated.

Recently, commercial pilot trials have been carried out in Victoria and Queensland with nitrogen-generated low oxygen

TABLE IV. Summary of trials conducted using CO_2 by CSIRO.

Trial	Enclosure	Load (tonnes)	Average CO_2 level achieved %	Initial charge	Purging efficiency E_1	Purging efficiency E_2	Decay 250-125 Pa (filled) (secs)	Flow giving 250 Pa (l/sec)	Reference
Bordertown III	welded steel bin	6600 wheat	97†	10.4 tonnes	76†	-	450	-	[33]
Bordertown IV	welded steel bin	6600 wheat	73†	6.9 tonnes	79†	-	450	-	[33]
Sydney I	PVC sheet	2.7 wheat & rye	60	11 kg	-	60	-	2.5	[34]
Boggabri	freight container	18-22 wheat	45-70	20-40 kg	-	81-93	-	0.1-9.4	[35]
Sydney II	freight container	18 wheat	45	31 kg	-	71	-	2.5	[36]
Rabaul I	freight container	8 copra	74	75 kg	-	69	10	-	[35]
Rabaul II	LASH barge	135 cocoa*	53	851 kg	-	92	96†	-	[35]
Harden	grain storage	13600*	55†	33 tonnes	73†	-	470**	-	[33]

* Part load
** 125-62.5 Pa decay
† Provisional figures

atmospheres. These have been based on the trials reported here. No insects were present at outturn in either series, although infestation, largely *T. castaneum* and *R. dominica*, were present at the start. In both cases the exposure to low oxygen exceed two months.

Atmospheres generated by burning hydrocarbons - The use of liquid nitrogen as a source of atmosphere may often be expensive, particularly where long transport distances are involved between the production site and the storage. This can be avoided if a method of on-site generation of suitable atmosphere is available.

The first record (1918) (17) (18) of a process of this kind is of the treatment of 230 tonnes of "very weevilly" wheat enclosed in malthoid with the exhaust gases from burning coke. An atmosphere of 10-15% CO_2 and presumably low oxygen was generated and maintained by passing the combustion gases from a furnace into the enclosure. The exhaust was said to be 80% nitrogen, 20% CO_2 and "no free oxygen." No live weevils were found after treatment. The process was extensively used in 1918 and 1919 (18). The only on-site method tested to modern standards consists of burning hydrocarbons in air, thus producing a low oxygen exhaust, with conditioning to remove excess moisture. The technique is widely used (19) in apple stores and in the storage of oxygen sensitive commodities such as alfalfa pellets.

Storey (20) used gas from two exothermic generators, output capacity 850 m^3/hr each, for the purging of 543 tonnes of wheat in a cell of 937 m^3 capacity (assuming flat roof and floor). The gas produced was <1% O_2, 8.5-11.5% CO_2 1-2% CO and balance nitrogen. In one experiment the gas was introduced with the grain in situ. The inert atmosphere front rose through the bulk at 2.4 m/hr corresponding to an input rate of 22 m^3/hr (actual rate not given) with an atmosphere of <1.0% O_2 being achieved at all points after 48 hours of purging. In a second experiment, the empty bin was partly purged to 8.5% O_2, and then inloaded with 543 tonnes wheat. The oxygen level in the bin rose to an average of 14.1% O_2. It was then purged at a slower but unspecified rate than in the first test giving concentrations from 0.3-1.7% O_2 after 72 hours. In the third test, levels were 3.8% before loading, 9.0% after loading with 0.1-0.9% O_2 after 20 hours at a purge rate as in the first experiment. In the first trial, complete mortality of adult *T. confusum* test insects was observed after 72 and 96 hours respectively. In all trials, immature stages of *S. oryzae* survived. The survival of adult *T. confusum* in the third trial was attributed to air ingress from wind, demonstrating that the cells were not adequately sealed.

An exothermic generator has been used in the USSR (2) for experimental storage of high moisture paddy rice (20-21%) and suggested (22) for storage of flour and grain. No details of tests on dry commodities are available, but the system produces a gas mixture similar to that used by Storey (20) and thus could be

useful for insect control. Sixteen and eight-tenths cubic meters of natural gas were used per day to maintain the atmosphere over 24,000 tonnes rice in four storages for four months.

A catalytic burner using propane was used to reduce oxygen levels in a 1268 tonne capacity metal bin in Israel. The results of operations over two seasons have been reported (23) (24). In the first season the level in the bin was reduced from 16% to 1.2% in 49.5 hours using propane at 1.2 kg/hr. In the next season, the burner reduced the oxygen level from 21% to 0.2% in 60.3 hours using 67 kg propane in a load of 1208 tonnes wheat. Subsequent intermittent operation of the burner for a total of 19.5 hours maintained the oxygen level below 2% for 20 days, using 23.6 kg propane. The usage corresponds to an air leakage rate of 16.4 m^3 or about 2.6%/day. The storage was tested by pressure testing in both seasons giving decay times of [illegible] and 115 secs for a 500-250 Pa pressure drop. The air interchange rate calculated from the published graphs (23) (24) were 2.0 and 1.2%/day respectively. These rates show a satisfactory standard of sealing for efficient operation although the pressure test results were lower than the proposed standard (2).

High but incomplete insect mortality was observed in all trials. Even when a low oxygen atmosphere (<2%) was maintained for 20 days, there was survival at the base of the bin (*R. dominica* adults (1%), *T. castaneum* larvae (8%) and adults (4%)) and on the grain surface (*T. castaneum* larvae (4%) and *O. surinamensis* larvae (15%)). Surprisingly, there was complete mortality of *S. oryzae* adults and larvae. This species is often regarded as that most tolerant to low oxygen atmospheres. The temperatures at the sites for the test cases were not given but may have been low as the experiment was carried out in January.

Atmospheres generated with carbon dioxide - The possibility of using CO_2 for control of stored product insects has been recognized for many years. In Australia, a dosage of 0.72 kg CO_2 per tonne of grain in an airtight silo was said in 1917 to be the "most effective" fumigant then available (25), when compared with CS_2 and HCN. Later (1921) (26), a rate equivalent to 1.4 kg/tonne was recommended for maize in galvanized iron tanks. Despite these early uses, CO_2 was either superseded by other fumigants or never became generally used.

Since then a number of trials have been carried out to develop the use of CO_2 for insect control in stored products. Oosthuizen and Schmidt (27) in 1942 tested the use of CO_2 against *Callosobruchus chinensis* in old and new galvanized tanks of 1.2 m^3 capacity. Carbon dioxide was introduced into the base of the tank filled with cowpeas, with 0.55-0.70 kg of CO_2 giving an atmosphere of about 70% (by extrapolation of observed concentration decay with time, no initial reading taken) in the new bins. The CO_2 levels in the new bins decayed slowly, averaging 41%, in one case, after 14 days. The old bins leaked badly and the effectiveness of the treatment was low.

Mansour in 1955 (28) treated 180 tonnes of wheat in a bin (capacity 240 m^3) with the quantity of dry ice, 160 kg or 0.89 kg/tonne, calculated to give 100% CO_2 by displacement in the full bin at a porosity of 30% and an apparent CO_2 density of 2 kg/m^3. The CO_2 level achieved was not given but when the cell was outloaded after 25 days the cell was the 90% mortality of the weevils present at a temperature of 11-15°C.

Le Du (29) stored 11 tonnes of wheat of 16% m.c. under CO_2 in a small metal bin for two years. Carbon dioxide was added automatically from cylinders to keep an internal pressure exess of 250 Pa. Actual usage rates were not given. The experiment was designed for quality preservation not insect control but it is relevant to note it here as the system could have been used for the latter purpose.

Jay et al. (30) purged a silo bin of 2262 m^3 capacity containing 2203 m^3 (~490 tonnes) of undercorticated groundnuts with 1.49, 1.54 and 1.50 tonnes CO_2 in three separate trials. The gas was admitted into the top of the bin and the purge was terminated when the CO_2 level rose to about 35%. Gas was circulated through a small blower from the bottom to the top of the bin during the trials. At a solid density of 1.1 tonnes/m^3, the total void space is 1810 m^3, equivalent to 1.17 tonnes CO_2 at 35% CO_2 (15°C, 100 kPa). For free mixing (E_2) to 35%, the theoretical requirement on this basis is 1.44 tonnes, which is close to the observed usage. Additional CO_2 was put in to maintain the 35% level for periods of 2, 4 and 7 days. This averaged 0.34, 0.45 and 0.47 tonnes/day or about 180, 240 and 250 m^3/day.

Jay and Pearman (31) treated 647 tonnes of maize in a concrete vertical cell of 1102 m^3 capacity with 1.15 tonnes of CO_2 applied into the headspace over 8 hours. This gave an atmosphere of >50% CO_2 at all but one point, where penetration was slowed by dust in the load. The atmosphere was then maintained between 55-65% CO_2 with an automatic injection system for 91 hours using an average maintenance rate of 425 m^3 CO_2/day. The theoretical requirement for 55% CO_2 is about 0.92 tonnes on the basis of free mixing. There was a low level of survival of immature stages of *Sitophilus* spp. but *Sitotroga cerealella* was eliminated.

Jay et al. (32) treated loads of comb honey in 12 insulated semi-trailer units, each of a size similar to a 1A ISO freight container (40x8x8 ft; 72.5m^3 capacity). The CO_2 was introduced through ductwork laid along the floor of the unit. After purging to give CO_2 >95%, the units were sealed. Carbon dioxide levels were maintained automatically by a servo system with CO_2 added whenever the level dropped below 96%. For an average total usage of 606 kg CO_2/unit, the atmosphere was maintained for 10-12 hours at an average of 98.6% CO_2. Since complete displacement of the gas with no allowance for the volume occupied by the load would take about 100 kg CO_2, the process was

clearly an inefficient one, presumably because of a high rate of leakage from the unit.

There have been a number of trials carried out in Australia recently (33) (34) in partially sealed structures with carbon dioxide applied to give an insecticidal atmosphere. Two were also carried out (35) in Papua, New Guinea, in order to show that the method could be used under tropical conditions. The trials conducted by CSIRO are summarized in Table IV.

The large scale trials with wheat were carried out in structures exceeding the proposed gastightness standard (2). Bordertown III was carried out to demonstrate that a high CO_2 level could be easily achieved in a grain storage under commercial conditions in Australia. In this trial CO_2, supplied by tanker as a liquid, was vaporized and introduced through shielded inlets in the bin wall directly into the grain mass, with the displaced air vented through a hatch in the roof. A narrow and discrete CO_2 front was observed in the grain mass during purging. After usage of 10.4 tonnes of CO_2, the purge was terminated and the bin sealed. The natural decay of the CO_2 levels was observed. As had been found elsewhere (1), the headspace concentration dropped with air ingress, with the zone of low CO_2 concentration descending slowly through the bin. This tendency to 'drop out' was counteracted by mixing the bin atmosphere by recirculation from the base to the headspace by means of a small fan. A recirculation rate of 0.084 air change/day was almost sufficient to prevent this 'drop out.'

The test was repeated, but using a purge of 75% CO_2 rather than pure CO_2 since the available literature (e.g. 4, 7, 8) suggests that it is unnecessary to levels higher than this in order to achieve insect control. The atmosphere was recirculated as previously. The average CO_2 level decayed from 73 to 45% in the 10 days before venting of the bin.

In the most recent trial, Harden, a large grain storage shed was sealed and treated with 33 tonnes of pure CO_2, generated from tanker supplied liquid. The purge was terminated before the whole of the gas space was filled with CO_2 and the atmosphere was then recirculated through a small external fan at a rate of 0.11 air changes/day. The CO_2 level, initially ranging from 18-99% CO_2, ranged from 37-86% after 30 hours of recirculation and 51-66% (mean 52%), after 72 hours. At termination of the trial, after 20 days, the atmosphere was still at an average of 25% CO_2. Initially the insecticide-free wheat was substantially infested but no live insects were detected on detailed inspection 12 days after termination. However a resurgence of infestation was noted after 50 days in one area only where a 'hot spot' had developed before treatment. Grain temperatures ranged from 11-37°C after treatment.

To demonstrate small scale use of CO_2, a small load of bagged grain was treated in a PVC enclosure with CO_2 as dry ice (34). Because of leakage, several additions of dry ice were

required during the 22 day exposure period in order to maintain the CO_2 concentration above 35%. A high mortality of the predominant pest species, *R. dominica*, was obtained with survival amongst the earlier developed stages only. Some of the parasitoids *Anisopteromalus calandrae* and *Choetospila elegans* present survived too, apparently as pupae. The grain temperature was from 10-14°C.

A series of trials (35) has been undertaken to develop the use of CO_2 as an in-transit treatment against insects in commodities in freight containers. In one experiment, the Boggabri trial, 10 freight containers selected for gastightness were loaded with wheat, and treated with 20-40 kg CO_2 as dry ice applied directly to the grain surface. In some containers, an additional charge of 30 kg CO_2 was added in an insulated box giving a controlled release of 3 kg CO_2/day. Caged mixed age cultures of *S. oryzae* were added as test insects to two containers. The container with the box maintained levels between 50-72% CO_2 over 16 days at 23°C. This gave complete mortality of the test insects. In the other, the CO_2 level fell from a maximum of 89% to 26% CO_2 at 10 days and a low level of survival of some early stages was observed (overall mortality >96%). A light natural infestation of *T. castaneum* was eliminated in both cases. In a further trial (36) bagged wheat in an ISO general purpose freight container with 30 kg of dry ice with 30 kg additionally in an insulated box was exported to West Germany after an 11 day holding period in Australia. During the holding period the CO_2 level remained at about 45% and was still 7.5% after the 6 week sea voyage. At outturn, the added test insects (all stages of *S. oryzae*, 36,000 insects in total) were all dead. A very light infestation of *R. dominica* present on stuffing was not detected at outturn.

Under static, tropical conditions in Rabaul, New Britain, a load of bagged copra in a container (35), selected to meet a gastightness standard, was treated with 75 kg CO_2 added into the headspace through the ventilators from cylinders. The initial CO_2 level of 74% fell to 45% after 6 days. After 9 days the exposure was terminated. There was no survival found in the heavy infestation of *Necrobia rufipes* and *Oryzaephilus mercator* originally present, either at outturn or upon incubation of the sievings taken during the inspection.

CO_2 has also been used (35) to treat cocoa beans in a LASH barge at Rabaul. CO_2 was added to the headspace of the barge from cylinders, over about 30 hours. The rate was limited by freezing of lines or cylinder contents. The increase in CO_2 concentration in the barge closely followed the trend expected from free mixing. The CO_2 level fell from a maximum of 53% to 28% at 9 1/2 days. The barge was then aired and shipped to the west coast of the U.S.A. No live specimens of the added test insects, largely *Tribolium castaneum* and *Oryzaephilus mercator*, were found at outturn but, on incubation, a small number of *T. castaneum* were detected.

The general usage rates and calculated purging efficiencies are given for the CSIRO trials in Table V. The efficiencies do not include allowances for sorption which may be substantial (37). The insect mortalities for those CO_2 trials in which detailed observations were made are summarized in Table V.

GENERAL OBSERVATIONS: From the field trials reviewed above it is clear that it is possible to generate and maintain an insecticidal concentration of oxygen or carbon dioxide under a variety of field conditions. Nitrogen purging efficiencies were high. In CSIRO trials they exceeded 70%, (Table I), giving a usage of not more than 40% more than expected theoretically. For CO_2, those enclosures purged from below gave efficiencies of greater than 70% on the basis of direct displacement. Where a calculation based on free mixing was appropriate, as in addition of CO_2 into the top of an enclosure, efficiencies ranged from 60-93% (Table IV). With CO_2, maintenance was often unnecessary as the natural leakage was sufficiently restricted by a feasible standard of sealing to give an adequate time of retention of high CO_2 levels for insect control. As this standard of sealing the interchange rate of the atmosphere with air in bulk storages was less than 5%, typically 2-3%. The expected requirement of maintenance gas, nitrogen, CO_2 or gases from propane burning, can be calculated directly from this. With this information, the total gas requirements of a particular treatment can be predicted and economic comparisons can then be made with other pest control measures.

While efficiencies have been found to be high there is scope for some improvement particularly with nitrogen. It may be that this can be achieved by altering the purging rate, but the effects of this have not been studied. In trials so far with nitrogen though widely different introduction rates have been used, the range of rates of travel of the purge front has been small (see Table II) and thus there is no firm evidence on the effect of varying this on efficiencies.

The extension of modified atmosphere technology into use in tropical conditions is important. Both carbon dioxide and nitrogen can be produced locally and are usually more easily procurable than the toxic fumigants such as methyl bromide. The two trials outlined here, Rabaul I and II, were carried out under conditions similar to that to be expected in commercial use. The trial in the LASH barge gave a high degree of insect control. The CO_2 level achieved in the barge was limited by available gas supplies, not by leakage. With a higher initial level it is likely that total insect control would have been attained. In the other trial, in a container selected for gastightness, there was complete insect mortality, to our level of assessment, in a shorter period than used in the barge. Presumably the insect species present were more susceptible to CO_2 than is *T. castaneum*. This disinfestation was carried out on bagged copra, a notoriously difficult commodity to disinfest by fumigation.

TABLE V. Summary of mortality data obtained in the course of field trials utilizing CO_2.

Test Insect	Exposure period (days)	Temp. °C	Concentration range % CO_2	Mortality	Reference
Callosobruchus chinensis all stages	14	26.7	70-41	98.8†	[27]
Galleria mellonella larvae	0.5	25-40	96	97.8	[32]
Necrobia rufipes all stages	6	25	74-45	100	[35]
Oryzaephilus mercator all stages	9.5	30	53-28	100	[35]
Oryzaephilus mercator all stages	6	25	74-45	100	[35]
Rhyzopertha dominica all stages	22	11-14	25-90*	97	[34]
Sitophilus oryzae all stages	16	23	50-72	100	[35]
Sitophilus oryzae all stages	10	23	59-26	96	[35]
Sitophilus oryzae eggs, young larvae and adults	10	31	73-47	100	[33]
Sitophilus oryzae old larvae, pupae and adults	10	31	73-47	99.2	[33]
Sitophilus oryzae eggs, young larvae and adults	10	13.5	68-47	77	[33]
Sitophilus oryzae old larvae, pupae and adults	10	13.5	68-47	79	[33]
Sitophilus oryzae all stages	11	26	80-45**	100	[36]
Sitophilus spp. immature stages	3.75	14-25	55-65	99.9	[31]
Tribolium castaneum adults	4	18-32	35	93	[30]
Tribolium castaneum all stages	9.5	30	52-38	98.6	[35]

† Detailed series of results given under different conditions (27).

* Concentration variable.

** With a further 4-1/2 weeks for decay from 45-8% CO_2.

It will be noted that many of the modified atmosphere trials reviewed here have achieved high (>95%) insect mortality of test insects or natural infestations but have fallen short of complete insect kill. The levels achieved under these circumstances may be higher than that required to meet various inspection standards, except when heavy infestations were present before treatment. The survival of early developmental stages means that infestation will not be detected if the commodity is presented soon after treatment. However, if long term storage is required without risk of resurgence of infestation, a mortality of 99.5% must be regarded as a control failure, since it will not take many generations of the pests before they again become noticeable and possibly damaging. The laboratory data available have given an over-optimistic view of the speed of action of modified atmospheres, particularly at lower CO_2 concentrations (e.g. 35%). A 7-day exposure at 35% CO_2 has been suggested for practical use (1), but with tropical conditions and under somewhat higher levels, as in the Rabaul I trial, some survival has been noted. It appears from the limited data in Table V that an initial level exceeding 70% and an exposure time of 10 days under high CO_2 (>35%) is an appropriate dosage regime for CO_2 for complete insect control at temperatures >20°C. This can clearly be modified if susceptible species only are present, e.g. *Galleria mellonella*. The limits of use at lower temperatures have not been determined but substantially larger exposures may be required.

OUTLOOK: The development of nitrogen and CO_2-generated controlled atmospheres is now at a stage where they are ready for commercial evaluation for disinfestation and storage of durable products. There are several remaining problems. On the scientific side much more data is needed on the response of stored product insects to differing atmospheric compositions and particularly on the effect of a varying concentration. The effectiveness of modified atmospheres at temperatures below 20°C is inadequately researched. Evaluation is required on the effect of a decaying concentration of CO_2 as would be observed in a partially sealed structure with an initial charge of gas which received no maintenance doses.

Despite these inadequacies in our basic knowledge, field trials have been sufficiently successful to show that the general technique has a wide range of possible application now. The problems in application are technical and economic. The provision of a suitably gastight system to give gas usages which are competitive in cost with other pest control methods, is a major problem. In Australia there are now techniques available for sealing of all our major types of grain storage. Clearly such sealing must be done at an acceptable cost. Various sealing systems are being investigated at present, but in welded steel structures, sealing costs will be one of the major components of

the overall cost of the method. Many general purpose dry containers can be made adequately gastight with minimal effort and are thus suitable for use with modified atmospheres for insect control.

One important pest control system in widespread use, fumigation in stacks under gasproof sheets, has not yet been directly tested to determine whether modified atmosphere storage is economically possible in it. However, ethylene oxide is often added with CO_2 to commodities under sheets for fumigation. The high rate of CO_2 loss observed under such conditions (38) shows that some modification of the technique will be required before efficient CO_2 use will be possible in such circumstances.

Despite these current limitations, there are mary advantages of modified atmosphere storage. These include absence of chemical residues from the treatment, absence of effects on germination and many other parameters important in the quality of different commodities and decreased hazard of leakage into workspace of toxic material. These advantages, together with cost competitiveness against many existing practices, ensure that modified atmospheres will be used on a routine basis as a method of insect control in stored products in the future.

ACKNOWLEDGEMENTS: My attendance at this conference was financed by a grant from the Commonwealth Industrial Gases Ltd.

The Australian trials reported here are the work of a large number of people and have been supported by several different bodies who will be acknowledged fully with the formal detailed publication of the results. I am particularly indebted to the Australian Wheat Board for their financial support and to Mr. P. C. Annis, CSIRO Divsion of Entomology and to Dr. A. K. Sharp, CSIRO Division of Food Research who were involved in many of the experiments.

REFERENCES:

(1) Jay, E. G., Suggested conditions and procedures for using carbon dioxide to control insects in grain storage facilities. USDA-ARS, Sept (1971) 51-46.

(2) Banks, H. J., and P. C. Annis, Suggested procedures for controlled atmosphere storage of dry grain. CSIRO, Div. of Entomology Technical Paper No. 13 23 pp (1977).

(3) Bailey, S. W. and H. J. Banks, The use of controlled atmospheres for the storage of grain. Proc. 1st Internat. Working Conf. Stored-Prod. Entomol. Savannah (1974) p. 362.

(4) Bailey, S. W., Air-tight storage of grain: its effect on insect pests - IV. *Rhyzopertha dominica* (F.) and some other Coleoptera that infest stored grain. J. stored Prod. Res. 1 (1965) 25.

(5) Shejbal, J., A. Tonolo, and G. Careri, Conservation of cereals under nitrogen. Med. Fac. Landbouww. Rijksuniv. Gent 38 (1973) 1133.

(6) Dendy, A., The conservation of our cereal reserves. Nature (Lond.) 53 (1919) 55.
(7) Harein, P. K., and A. F. Press, Mortality of stored-peanut insects exposed to mixtures of atmospheric gases at various temperatures. J. stored Prod. Res. 4 (1968) 77.
(8) Lindgren, D. L., and L. E. Vincent, Effect of atmospheric gases alone or in combination on the mortality of granary and rice weevils. J. econ. Entomol. 63 (1970) 1926.
(9) Banks, H. J., A. K. Sharp, and A. R. Irving, Gas interchange in freight containers. Proc. 1st Internat. Working Conf. Stored-Prod. Entomol. Savannah (1974) p. 519.
(10) Sharp, A. K., A. R. Irving, and H. J. Banks, Leakage of air into ISO insulated containers. Bull. Iir. Annex 1976-1 (1977) 501.
(11) Sharp, A. K., C. Myers, A. R. Irving, and H. J. Banks, Gas loss from moving containers: a report of an experimental investigation. CSIRO Food Research Report No. 123 (1977) 36.
(12) CSIRO, Freighting pest-free grain. CSIRO Ind. Res. News 127 (1978) 4.
(13) Banks, H. J., S. W. Bailey, P. C. Annis, J. H. O'Keefe, and G. Smith, Unpublished results on trials with nitrogen.
(14) Shejbal, J., A. Tonolo, and G. Carteri, Conservation of wheat in silos under nitrogen. Ann. Technol. agric. 22 (1973) 773.
(15) Shejbal, J., and D. Di Maggio, Preservation of wheat and barley in nitrogen. Med. Fac. Landbouww. Rijksuniv. Gent. 41 (1976) 595.
(16) Tranchino, L., Personal communication.
(17) Anon., The weevil pest of grain. J. Agric. Vic. 16 (1918) 695.
(18) Winterbottom, D. C., Weevil in wheat and storage of grain in bags: A record of Australian Experience during the War Period (1915 to 1919). Government Printer, Adelaide (1922) 122 pp.
(19) Kader, A. A., and C. L. Morris, Modified atmospheres. An indexed reference list with emphasis on horticultural commodities. Supplement No. 2 University of California. Vegetable Crops Series 187, March (1977) 29 pp.
(20) Storey, C. L., Exothermic inert-atmosphere generators for control of insects in stored wheat. J. econ. Entomol. 66 (1973) 511.
(21) Golik, M., R. Averina, and I. Zhuk, Effectiveness of use of an inert gas atmosphere for the storage of high moisture rice. Mukmolno-Elevat. Prom. 39 (1973) 10.
(22) Anon., The inert gas atmosphere generator. Ministry of Gas Industry. Information Leaflet, No. 34-74 (1974).

(23) Navarro, S., Y. Kashanchi, and H. Franji, Alteration of atmospheric gas composition in grain storage bins as a method of controlling stored-product insects. Ministry of Agriculture, Division of Stored Products, Yafo. Progress Report for the year 1974/75. ix, 61.
(24) Navarro, S., M. Gonen, Y. Kashanchi, and H. Franji, The use of a controlled atmosphere for the control of stored product insects: I. Experiments in a flat metal bin. Ministry of Agriculture. Progress Report for the year 1975/76 of the Stored Products Division, Yafo. Special Publication No. 73 Division of Scientific Publications, Bet Dagan, (1977) xiv, 85.
(25) Anon., Grain weevils - a menace to the wheat stacks. J. Dept. Agric. S. Aust. 20 (1917) 977.
(26) Froggatt, W. W., Fumigating maize with carbon dioxide, Agric. Gaz. N. W. Wales 32 (1921) 472.
(27) Oosthuizen, M. J., and U. W. Schmidt, The toxicity of carbon dioxide to the cowpea weevil. J. ent. Soc. S. Afr. 5 (1942) 99.
(28) Mansour, A. H., Contribution à l'étude de la conservation des graines dans une atmosphère de CO_2. Ann Éc. Nat. Sup. Agron. 3 (1955) 109.
(29) Le Du, J., Conservatior de blé sous vide, sous atmosphère confinéee, sous atmosphère de gaz carbonqiue. Conservation d'orge de brasserie sous atmosphère confinée. Industr. alim. agric. 85 (1968) 811.
(30) Jay, E. G., L. M. Redlinger, and H. Laudani, The application and distribution of carbon dioxide in a peanut (groundnut) silo for insect control. J. stored Prod. Res. 6 (1970) 247.
(31) Jay, E. G., and G. C. Pearman, Jr., Carbon dioxide for control of an insect infestation in stored corn (Maize). J. stored Prod. Res. 9 (1973) 25.
(32) Jay, E. G., G. E. Cantwell, G. C. Pearman, Jr., and J. V. Thompson, Control of the greater wax moth, *Galleria mellonella* (Linnaeus). Am. Bee J. 112 (1972) 342.
(33) Banks, H. J., P. C. Annis, R. Bell, and J. R. Wiseman, Unpublished results on use of CO_2 in grain storages.
(34) Banks, H. J., and A. K. Sharp, Insect control with CO_2 in a small stack of bagged grain in a plastic film enclosure. J. exp. Agric. Anim. Husb. (in press).
(35) Banks, H. J., P. C. Annis, A. K. Sharp, and A. R. Irving, Unpublished results on use of CO_2 in transport systems.
(36) Banks, H. J., and A. K. Sharp, Export of containerized bagged wheat under CO_2 for insect control. CSIRO Div. of Entomology Tech. Rep. (in press).
(37) Yamamoto, A., Studies on the carbon dioxide gas adsorption by cereal grains. J. Jap. Soc. Food Nutr. 29 (1976) 417.
(38) Thompson, R. H., and E. E. Turtle, Some recent developments in fumigating under gas-proof sheets, Chem. and Ind. 1953 365.

APPENDIX I.

Formulae used:

Efficiency of purging for displacement of gas (E_1)

$$E_1 = C_c \left[\frac{nV_B + V_{HS}}{V_G} \right]$$

Efficiency of purging assuming free mixing throughout the storage atmosphere (E_2)

$$E_2 = -100 \left[\frac{(nV_B + V_{HS}) \ln \left(1 - \frac{C_c}{100}\right)}{V_G} \right]$$

or

$$= 100 \left[\frac{nV_B + V_{HS}}{V_G} \right] \ln \frac{(21)}{(C_o)}$$

Efficiency of purging assuming complete displacement in the loadspace with free mixing in the headspace of the storage (E_3)

$$E_3 = 100 \left[\frac{nV_B + V_{HS} \ln \frac{(21)}{(C_o)}}{V_G} \right]$$

C_o = Concentration of oxygen at termination (%).

C_c = Concentration of CO_2 at termination (%).

n = Commodity porosity.

V_B = Volume of stored commodity (loadspace).

V_{HS} = Volume of headspace.

V_G = Volume of purge gas added.

CURRENT STATUS OF IRRADIATION FOR USE IN INSECT CONTROL

E. W. TILTON
Stored-Product Insects Research and Development Laboratory
Agricultural Research, Sci. and Educ. Admin., USDA.
Savannah, GA. 31403 U.S.A.

At the 1974 meeting of this group I reported that the reasons why ionizing radiation had not been adopted generally for control of stored-product insects appeared to be wholly economic (1). Although some engineering studies had indicated that on a per ton basis radiation disinfestation had a favorable cost relationship to fumigation, these studies were based on the assumption that all the product handled by a facility would be treated and that the product would be continuously and uniformly available for treatment. In fact, neither of these assumptions is correct. Fumigation of commodities is usually done only when necessary, and the amount of most products that move through collection or shipping points fluctuates greatly. In addition, the initial cost of an irradiator is high, which means that most of the cost for several years of disinfestation would have to be paid at the beginning of the operation.

Even if these cost factors could be overcome, there would be (and has been) considerable delay in the legal acceptance of food irradiation. The national health agencies in many countries have ruled that irradiation constitutes a food additive and therefore is subject to evaluation by long-term animal feeding studies. Further, radiation is considered a different additive to each food, so proven safety with wheat, for example, does not give automatic clearance to any other cereal grain or even to processed wheat products. This is true even though very low levels of radiation are necessary for the insect disinfestation compared with the levels needed for bacterial pasteurization of seafood or chicken (200 krad and up) and the much higher doses (in the Mrad range) necessary for complete microbial sterilization of beef and other meats. Just how time consuming and expensive a procedure is involved is shown by the U. S. Army's program of wholesomeness testing of radappertized beef: it has required 5 years and $5 million (2).

In an attempt to satisfy the extensive testing now required by health authorities and to stay within national budget limitations, 23 countries joined with the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture in the International Program in the Field of Food Irradiation (IFIP). The group has its headquarters at the Federal Research Center for Nutrition, Karlsruhe, Federal Republic of Germany. IFIP has conducted extensive tests of several foodstuffs for wholesomeness for human consumption. Largely as a result of the data produced, the Joint FAO/IAEA/WHO

Expert Committee at its meeting in 1976 recommended clearances on several foodstuffs (3). The stored products that have been cleared for insect disinfestation are listed in Table 1.

Table 1. World Health Organization (FAO/IAEA/WHO Expert Committee) clearances for insect disinfestation.

Product	Type and source of radiation			Dose (krad)	Date of approval
	^{60}Co	^{137}Cs	10 mev max. electrons		
Papaya	x	x	x	50-100	7 September 1976
Wheat and ground wheat products*	x	x	x	75 max	12 April 1969
Wheat and ground wheat products**	x	x	x	15-100	7 September 1976
Rice***	x	x	x	10-100	7 September 1976

* Temporary acceptance.

** Unlimited clearance (unconditional acceptance: WHO).

*** Provisional.

Also, the Codex Committee on Food Additives of the Codex Alimentarius Commission, which had included the irradiation process within its terms of reference in 1969, adopted, at its 1977 meeting a Draft Standard on Irradiated Food and a Code of Practice for the Operation of Radiation Facilities Used in the Treatment of Foods. The Joint FAO/IAEA/WHO Expert Committee submitted these drafts to the Codex Commission at Step 5 of the Codex Procedure. The Codex Alimentarius Commission meeting in Rome, Italy, 17-18 April, 1978, decided to advance the Draft Standard and the Code of Practices from Step 5 to Step 6. This enabled the Codex Secretariat to submit the Standard and the Code of Practice to all 116 member countries of the Codex for comments and to plan to evaluate these comments at the next session of the Codex Committee on Food Additives (October, 1978) with a view to elevating the proposals to the next step in the Codex Procedure (4). This is probably one of the most

important advances made in food irradiation in several years.

However, at the present time, IFIP is scheduled for termination in 1980. Unless there is a fundamental change in the evaluation of wholesomeness of irradiated foods by that time, the participating countries may lose interest (2).

Finally, active research programs on stored-product disinfestation are underway in a number of countries and at a number of institutions in some countries. There are also several international programs having to do with food irradiation, some of which include research on stored-product disinfestation. In addition, the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture oversees several coordinated research programs on various phases of food irradiation. Some of these programs deal specifically with stored-product disinfestation, and most of them involve one or more of the cereal grains and pulses. However, some programs involve disinfestation of products such as dried fish in the Philippines, Indonesia, and Bangladesh (5); dried dates in Iraq; cocoa beans in The Netherlands and Ghana; and coffee beans in Brazil (6).

It is thus easy to think and say that the reason for the current lack of practical use of radiation in food processing is the difficulty in obtaining clearances from health agencies and the nonuniformity of regulations between countries, but this is only part of the difficulty. For example, in the U.S.S.R. irradiation of grain at 30 krad has been permitted since 1959, and irradiation of dried fruits at 100 krad and dried food concentrates at 70 krad has been permitted since 1966. In the U.S.A., regulations have permitted irradiation of wheat and wheat flour since 1963. Canada has permitted irradiation of wheat and whole wheat flour at 75 krad since 1969, and Bulgaria has permitted grain irradiation at 30 krad and irradiation of dry food concentrates and dried fruits at 100 krad since 1972 (3). Nevertheless, no large-scale use has been made of the process. The primary reason why radiation is not being used is therefore still economic.

It is because of the importance of economic considerations to the acceptance of radiation in food processing that recent developments in the cost and operation of accelerators are so noteworthy. One firm in the U.S.A. now claims to be able to provide an electron accelerator that will treat grain with a dose in the 50 krad range for about $0.118 to $0.20 U.S.dollars/metric tonne. This figure is predicated on a flow rate of about 400 metric tonnes/hour; with an increased flow rate, the cost per unit treated would decrease (7).

At least two electron accelerators for grain irradiation are being built or are in the process of being built. The Instituto de Fisica. Univerisidad Nacional Antonoma de Mexico and the Programa de Technologia, Instituto Nacional de Energia Nuclear are jointly building an irradiator for maize irradiation. This facility will make use of a rebuilt Dynamitron(R) accelerator. Maize will move through the radiation field in an airstream. This unit, while not of a commercial size, will treat sufficient maize so consumer acceptance data can be evaluated and will provide reliable cost

estimates (8). Also, there are plans to build an electron irradiator for grain irradiation at the Port of Odessa, U.S.S.R. (9).

Several additional factors may interact to give added impetus to the adoption of ionizing radiation disinfestation of grain and other stored products. For example, the increasing problem of insecticide resistance, the problem of chemical contaminants, and the difficulty of fumigation at export may all contribute. However, the increasing demand by buyers for insect-free products probably will be the major reason for adopting such new and more effective insect control methods. This demand is certain to be increased with the new generation of insect detection devices that are about to be marketed.

REFERENCES:

(1) Tilton, E. W., Achievements and limitations of ionizing radiation for stored-product insect control. p.354-61. Proc. First Int. Work. Conf. on Stored Prod. Entomol. Savannah, GA (1974) 703.

(2) Diehl, J. F., Food Irradiation, Part 2 - Some proven applications. Food Engineer Int. 49 7 (1977) 45-51.

(3) Anon. List of Clearances. General Survey of Irradiated Food Products Cleared for Human Consumption in Different Countries. Food Irradiation Newsletter 1 3 (1977) 34-48.

(4) Anon. Towards an International Standard and of a Code of Practice on Food Irradiation. XII Session of the Joint FAO/WHO Codex Alimentarius Commission, 17-28 April; Rome, Italy. Food Irradiation Newsletter 2 2 (1978) 38-41.

(5) Anon. Report of a Research Coordination Meeting of Radiation Preservation of Asian Fish and Fishery Products. Bombay, India, 7-11 February, 1977. Food Irradiation Newsletter 1 3 (1977) 3-14.

(6) Anon. Report of an FAO/IAEA Research Coordination Meeting on Technological and Economic Feasibility of Food Irradiation. 20-24 February, 1978, Accra, Ghana. Food Irradiation Newsletter 2 2 (1978) 3-23.

(7) Morganstern, K. H., The economics of electron accelerators in the preservation of food by irradiation. v. 2. p.267-38. Symposium Proc. Food Preservation by Irradiation. Wageningen, The Netherlands, 21-25 November, 1977. IAEA, (1978) 429.

(8) Tilton, E. W., Disinfestation of Maize by Irradiation. Report to the Government of Mexico. TA Report No. 1085. IAEA (1975) 10p.

(9) Davis, R., USDA-SEA-AR, Savannah, GA. U.S.A., Personal communication. 1978.

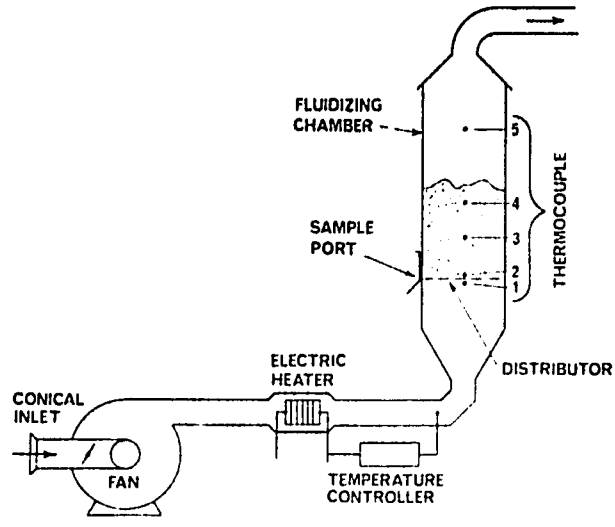
THE POTENTIAL OF FLUIDIZED-BED TECHNIQUES IN INSECT CONTROL

D. E. EVANS and T. DERMOTT
CSIRO Division of Entomology, Canberra, A.C.T.
CSIRO Division of Mechanical Engineering, Highett, Victoria

INTRODUCTION: In Australia, the growing resistance of stored grain insects to insecticides and increased social pressures against the use of potentially hazardous chemical treatments have led to increased interest in the development of physical methods of pest control. One of the physical methods being investigated is the use of high temperatures, which is regarded as a potential alternative to fumigation with, for example, methyl bromide.

Recent work (1 to 8) on the use of elevated temperatures to disinfest grain and cereal products has been largely concerned with infra-red, microwave, and dielectric heating. These studies have investigated the effectiveness of rapid heating followed by passive cooling, typically over several hours. Disinfestation processes that depend on the retention of heat for long periods have little potential in Australia where a continuous flow in-line system capable of matching shipping rates approaching 2000 tonnes h^{-1} is considered essential. Further requirements of a disinfestation process are that all developmental stages of the major pests must be killed, grain moisture content must not be appreciably changed, grain quality must not be affected and the method must be economically competitive and compatible with working conditions in a grain handling terminal. These criteria are likely to be met only in a process that exposes individual grains to the same temperature:time regime. Hot-air heating in a fluidized-bed appears to be a means of meeting the desired criteria because fluidized-bed heating offers high rates of heat transfer with accurate temperature control and has the potential for scale-up to high throughputs with relatively few engineering problems.

EXPERIMENTS WITH A BATCH-HEATING SYSTEM: A 340 mm diameter fluidized-bed capable of heating 10 kg of wheat was constructed (Figure 1) and batches of wheat infested with the immature stages of *Sitophilus oryzae*, *Rhyxopertha dominica*, and *Sitotroga cerealella* were subjected to a range of heat treatments (9). To assess insect mortality, samples of 500 g wheat were drawn off the bed at predetermined times and then cooled rapidly in a small fluidized-bed. Temperatures in the heating and cooling beds were measured continuously. Constant air temperatures of 60, 70, or 80° were used with an air-flow of 14.5 l kg^{-1} s^{-1} at 1.6 m s^{-1}. The samples were incubated for 6 weeks after treatment and the numbers of F_1 adults that emerged compared with the numbers emerging from un-heated but fluidized control samples. Drying curves were established in a similar manner for Olympid wheat of 11.5% m.c.



FLUIDIZED - BED HEAT TREATMENT APPARATUS

Figure 1. Fluidized-bed heating system

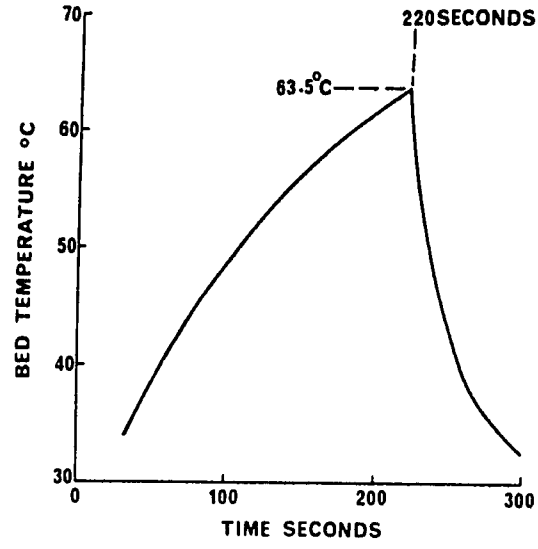
exposed to 60, 70, or 80°C air for up to 30 min. High and low protein wheats were checked for heat sensitivity using air inlet temperatures of 60 to 100°C and exposures of up to 30 min followed by dough characteristic and baking tests.

A typical heating and cooling curve is shown in Figure 2 for wheat exposed to 80°C air for 3 min 40 sec with an air flow of 14.5 l kg^{-1} sec^{-1} at 1.6 m s^{-1}. The heating and cooling curves were readily described by a perfect mixing model (9).

Exposures of 12, 6, and 4 min respectively to air at 60, 70, and 80°C produced grain surface temperatures of 59, 62, and 65°C respectively and gave complete disinfestation. The heat tolerance of *R. dominica* was greater than that of the other species. Additional experiments showed that these treatments gave complete kills of the adults of all three species.

Drying curves for Olympic wheat of 11.5% m.c. exposed to air of 60 to 80°C for up to 30 min are shown in Figure 3. The reduction in moisture content of wheat heated at 60°C for 12 min, at 70°C for 6 min and at 80°C for 4 min was respectively 0.8, 0.6, and 0.6%.

Baking and dough characteristic tests on flour milled from heated and unheated wheat showed that heating with 80°C air



Batch heating and cooling of wheat to kill all stages of *Rhyzopertha dominica.*
Air inlet temperature – 80°C
Air flow rate – 14.5 ℓ $kg^{-1}s^{-1}$

FIGURE 2. Heating and cooling curve for wheat exposed to 80°C for 220 seconds

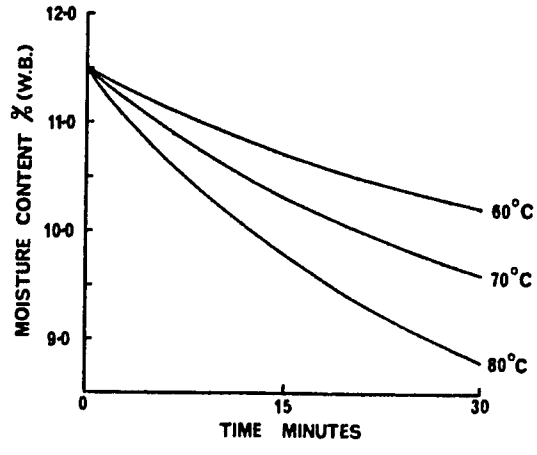


FIGURE 3. Drying curves for Olympic wheat of 11.5% m.c. exposed to air at 60, 70, and 80°C

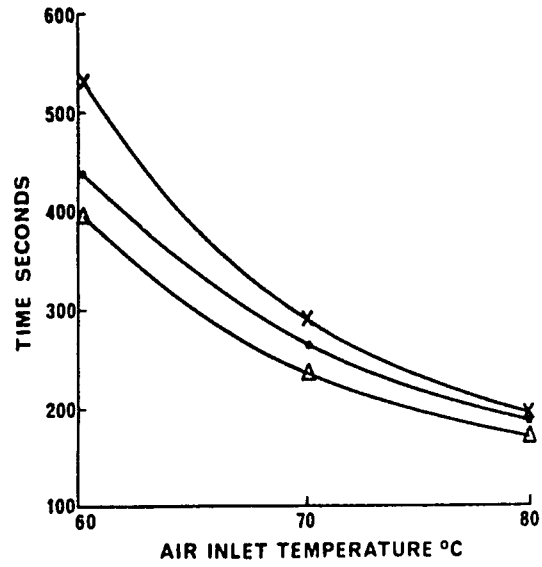
for up to 30 min did not adversely affect baking quality whereas heating with 100°C air for longer than 5 min did. At 90°C, heating for 15 min did not significantly alter baking quality although Extensograph and Viscograph data indicated some heat damage (9).

It was concluded that fluidized-bed heating gave good kills of insect infestations in relatively short periods of time without significantly affecting grain moisture content or baking quality.

The two main components of operating cost are the energy needed to heat the wheat and the power required for fluidization. Assuming that a 4 min exposure to 80°C is required for complete disinfestation in a continuous-flow system with recirculation, 90% thermal efficiency, and no heat recovery from the grain, the energy required to raise one tonne of wheat from 25 to 65°C would be 69 MJ. The power required to supply fluidizing air at 14.5 l kg^{-1} s^{-1} at 5 kPa with typical fin and motor efficiencies would be 8 kWh $tonne^{-1}$. On present prices in Victoria, the cost of the heating cycle would be about 34c $tonne^{-1}$. Cooling would be required and, when aided by water injection evaporation would cost, say, 10c $tonne^{-1}$ to give a total of about 44 c $tonne^{-1}$. This compares favourably with a labour + materials cost of about 40c $tonne^{-1}$ for a 24 h recirculated fumigation with methyl bromide at 24 g m^{-3} in 2000 tonne vertical cells.

MORTALITY:DOSAGE RELATIONSHIPS: An understanding of the relationship between insect mortality and the two dosage variables, temperature and time, would clearly be useful in planning heating strategies and in designing disinfestation equipment. Dermott and Evans (9) showed that for a given level of mortality, the LT99.9 for instance, the relationship between exposure time and air temperature was described by a hyperbola i.e. $\underline{T}$ ($\underline{t}$-$\underline{c}$) = $\underline{K}$ where $\underline{T}$ and $\underline{t}$ represent exposure time and air temperature respectively and $\underline{c}$ and $\underline{K}$ are constants (Figure 4).

To examine further the mortality-heat dosage relationship, a small-scale fluidized-bed has been built which can fluidize up to 2 kg wheat and can be switched instantaneously from heating to cooling. Experiments have been designed to examine the relationships at two rates of heating achieved by varying the load of grain rather than the airflow. Results with 1 kg loads fluidized in air of 60-80°C confirm previous findings. Experiments with 0.5 kg loads have not been completed but have given gratifying results in that treatment times have been greatly reduced. Thus, the respective LT99.9s for *R. dominica* immatures exposed to 80°C air in loads of 1 kg and 500 g were 2.98 and 1.70 min. If final results with 0.5 kg loads follow the same trend as those with 1 kg loads, it will be clear that, for a given rate of heating a simple hyperbolic relationship exists between exposure time and air temperature. Thermal summations can then be used to consider the relative merits of different temperature-time regimes during fluidization and of heat soaking - i.e. leaving the grain at the same temperature for a period before cooling.



Temperature-time regimes for 99% mortality
× *Rhyzopertha dominica*
• *Sitotroga cerealella*
△ *Sitophilus oryzae*

Figure 4. The relationship between insect mortality (LT99) and air inlet temperature

The small scale apparatus is also being used to explore some of the biological and physical variables that may affect heat-tolerance. Previous acclimation, population age-structure and between population differences in heat-tolerance could perhaps have some effect on heat-tolerance and hence the temperature-time regimes to be recommended for use by the grain industry. The initial temperature and moisture content of the grain may also alter apparent tolerances.

Although current experiments are based on *R. dominica*, the most heat tolerant of the primary pests, additional work is being done to ensure that regimes recommended for *Rhyzopertha* will deal also with other pests such as *Cryptolestes*, *Oryzaephilus*, and *Tribolium*. Results to date indicate that these pests, as is to be expected from their biology, are easier to kill than *Rhyzopertha*.

EXPERIMENTS WITH A CONTINUOUS-FLOW SYSTEM: A pilot plant with a design capacity of 1 tonne/h^{-1} has been constructed (Figure 5) to demonstrate that thermal disinfestation can be carried out in a continuous-flow system. The heating chamber has an area of 200 x 800 mm and up to seven vertical baffles can be installed. The cooling chamber is 100 x 200 mm in area and is fitted with water

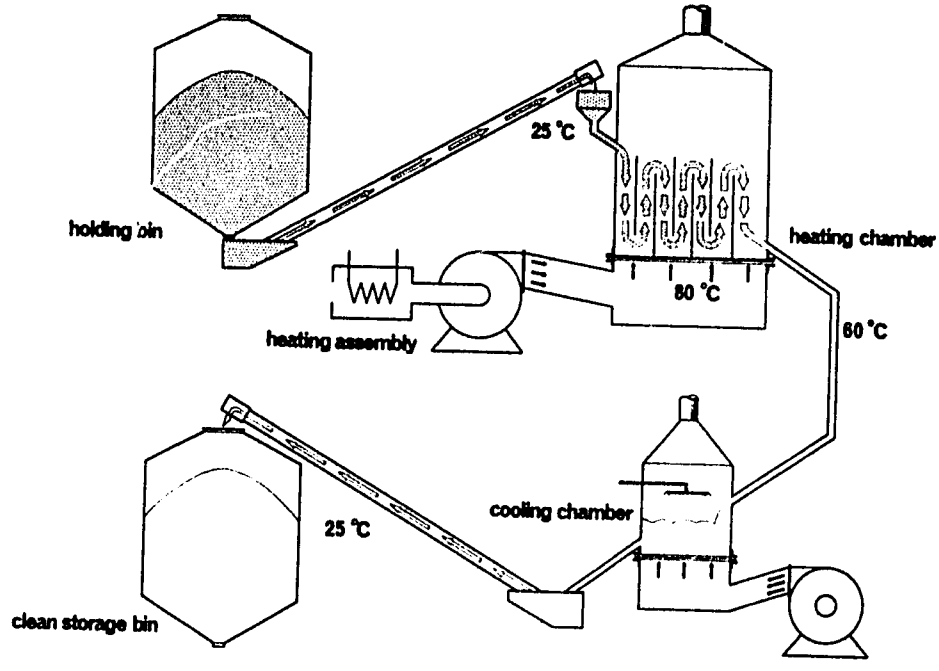


FIGURE 5: Flow chart for experimental continuous flow fluidized-bed heating plant

sprays for evaporative cooling. Air-inlet temperature, air and grain flow rates and bed-depth can be varied to change the heat dosage applied. Heat is provided by a natural gas burner on the air inlet and air inlet temperature is regulated by a modulating controller on the gas line.

Preliminary experiments using overall (both heating and cooling) mean residence times of 4 and 5 min and an air inlet temperature of 80°C have given good kills (up to 99.6%) of immature *R. dominica*. Mortality should be increased as the variance about mean residence time is reduced by changed baffle configuration.

CONCLUSIONS: It appears that wheat can be rapidly disinfested in both batch- and continuous-flow fluidized-bed heating systems. The moisture content of the grain is little changed by the heating process and any loss can be restored in a continuous flow system by evaporative cooling. There appears to be an adequate safety margin between the heat dose that will kill the pests within the grain and the dose that will cause detectable deterioration of baking properties. Cost estimates based on batch-heating suggest that fluidized-bed heating will be cost competitive with chemical fumigation. It is expected that, in practice, a continuous flow

disinfestation unit will give higher rates of heating than batch systems since, under steady-state conditions, the wheat will be added to a bed of wheat with a considerable thermal capacity. Thus shorter exposure times could be expected to be effective with a continuous flow process than with batch heating. Our running cost estimates may be somewhat pessimistic and this reinforces our conclusion regarding the likely competitiveness of continuous flow high temperature disinfestation.

The procedure uses existing technology which the Australian grain industry is capable of operating: equipment is currently commercially available in Europe that would suit the needs of food packers wishing to disinfest relatively small quantities of cereals and legumes. Fluidized-bed heating systems can utilize any suitable energy source and can be made inherently safe by fluidizing with recirculated inert combustion gases.

The use of fluidized-beds has ancillary potential in that aspiration allows dust removal and evaporative cooling permits the moisture content of the grain to be increased if so desired. Such procedures could be used to give a clean, safe and uniform product.

The procedures developed for a fluidized-bed heater could be modified for application to other heat transfer systems, such as a rotating drum or pneumatic conveyor. Alternative systems should ensure that, as with a fluidized-bed, all the particles receive a minimum heat dosage sufficient to give disinfestation.

Fluidized-bed technology is available to developing countries, but its implementation in rural areas may present insurmountable problems. Economical implementation of fluidized-bed disinfestation requires plentiful supplies of electrical energy or oil; both of these are relatively low cost in Australia but are usually at a premium in developing countries. Furthermore, the fine control and high throughputs required in the export oriented Australian grain industry may not be justified in consumer countries. Alternative systems using low level technology with manual control and perhaps utilizing animal or human power could be attractive in many rural economies.

Heat could be supplied by burning crop residues or from simple solar collectors. Mixing the grain to ensure uniform heat dosage could take place in locally manufactured drums rotated by a small petrol engine, or say animal or human power. In this way batches of 50 to 100 kg could be disinfested quite rapidly. Instrumentation and control could be as simple as maintaining an air inlet temperature between the melting points of two waxes. Air flow could be supplied by a bellows or chimney. Obviously a low air pressure drop system would be preferable for very simple systems.

Although completely different systems to those in Australia would have to be developed to meet the needs of developing countries, these systems could be designed by interpretation of the data presented in this paper.

REFERENCES:

(1) Boulanger, R. J., Boerner, W. M., Hamid, M. A. K., Microwave and dielectric heating systems, Milling 153 2 (1971) 18 and 24.

(2) Kirkpatrick, R. L., Infra-red radiation for control of lesser grain borers and rice weevils in bulk wheat (Coleoptera: Bostrichidae and Curculionidae), J. Kans. ent. Soc. 48 1 (1975) 101.

(3) Kirkpatrick, R. L., The use of infra-red and microwave radiation for control of stored-product insects, Proc. 1st Int. Conf. Stored-Product Ent. Savannah, 1974 (1975) 431.

(4) Kirkpatrick, R. L., Brower, J. H., and Tilton, E. W., A comparison of microwave and infra-red radiation to control rice weevils (Coleoptera: Curculionidae) in wheat, J. Kans. ent. Soc. 45 4 (1972) 434.

(5) Kirkpatrick, R. L., Tilton, E. W., Infra-red radiation to control adult stored product Coleoptera, J. Ga. ent. Soc. 7 1 (1972) 73.

(6) Nelson, S. O., Possibilities for controlling stored-grain insects with RF energy, J. Microwave Power 7 3 (1972) 231.

(7) Nelson, S. O., Insect-control studies with microwave and other radio-frequency energy, Bull., ent. Soc. Am. 19 (1973) 157.

(8) Watters, F. L., Microwave radiation for control of *Tribolium castaneum* in wheat and flour, J. stored Prod. Res. 12 1 (1976) 19.

(9) Dermott, T., Evans, D. E., An evaluation of fluidized-bed heating as a means of disinfesting wheat, J. stored Prod. Res. 14 1 (1978) 1.

THE USE OF ELECTROMAGNETIC ENERGY TO DETECT HIDDEN INSECT INFESTATION

W. A. BRUCE and M. W. STREET
Stored-Product Insects Research and Development Laboratory,
SEA, USDA
Savannah, Georgia, 31403
U. S. A.

INTRODUCTION: Historically, the detection of hidden insects in stored products has been accomplished by using a wide variety of methodologies such as chemical, flotation, aural, and, as a last resort, visual counts of penetration or emergence holes. As the world demand for food increases, the need to detect hidden insects accurately, quickly, and with a high degree of sensitivity becomes more urgent. The challenge will be met successfully only by reevaluating old methods and by incorporating new technologies into usable systems.

Electromagnetic energy, in the broad sense, appears capable of providing us with a variety of sophisticated methods or technologies for immediate use and also for future consideration (1). Recent developments in infrared CO_2 analysis have already provided regulatory agencies and private industry with a powerful tool for detecting insects and are thereby aiding us in our efforts to protect both the quality and quantity of our food, feed, seed, and fiber throughout the marketing channel.

Further developments in the areas of closed loop CO_2 sampling. IR CO_2 pyroelectric detectors, and large volume sampling (e.g. grain silo) could also be significant. Techniques that may be applicable and appear to offer great potential include thermal measurement, thermal imaging, and the pyroelectric vidicon. Photo-electron spectroscopy, nuclear magnetic resonance (NMR) imaging, far infrared imaging, and photoacoustic spectroscopy should be investigated and considered.

It is the intention of the authors to discuss the merits and/or potential of each of the aforementioned techniques as they relate to the detection of hidden insects. Also, a brief overview of detection methodologies is presented.

DETECTION TECHNIQUES: Detection techniques may be arbitrarily divided into two broad categories, active and passive. Active techniques involve the input of either external physical energy or a chemical reagent and require that the insects modify or otherwise react with the input to produce either meaningful visual information (a film image or colorimetric change in an indicator material) or an electronically measurable change (resistance, complex impedance, or proton spin). However, active techniques such as x-rays or chemical reagents, although generally reliable, could create personnel hazards, cause environmental pollution, or alter or destroy the sample. Passive techniques,

on the other hand, simply monitor the presence of some type of "signal" produced by the insects; they do not introduce external physical energy or chemical inputs, but instead rely solely on the detection of outputs generated by the insect (e.g. IR energy given off by the insects, sounds produced by feeding, or vapor or gas produced by metabolism or respiration).

For these reasons, passive detection is more desirable than active detection, and efforts to develop methods using insect-produced data are continuing.

Present

X-ray - X-rays, though not a passive technique, certainly qualify as electromagnetic radiation. The method is included here primarily because it once enjoyed rather wide acceptance and because the instrumentation is both current and readily available.

The Hewlett-Packard Faxitron(R) x-ray unit will serve as a model. These units are especially suitable for observation of seeds, grains, and other small objects and are self-contained, radiation-shielded systems designed to give high resolution radiographs. In addition, they are simple to operate and are convenient and generally hazard-free. The simplicity of operation has been enhanced by the inclusion of an automatic exposure control and by making available various types of film such as self processing (Polaroid(R)) and cassettes. However, to achieve the necessary detail required for radiographs that permit critical inspection for insects, extra fine grain films are essential (2). This necessitates more complex and time-consuming film developing and processing. However, regardless of the time involved in obtaining an acceptable radiograph, it is the interpretation of that radiograph which makes the x-ray technique so difficult to use for routine, rapid inspections. In fact, the interpretation of radiographs is so difficult and time consuming that the United States Department of Agriculture's Federal Grain Inspection Service no longer uses this technique in inspection operations. Moreover, even with correct interpretation, there is little or no information as to whether the infestation is live.

Radiography, however, should not be ruled entirely out as a viable procedure. The recent announcement of the Lixiscope (low intensity x-ray imaging scope) developed in the U.S. at NASA's Goddard Space Flight Center reflects the rapid changes in the technology. This instrument is a small hand-held unit powered by a penlight battery. It uses a 10-20 millicurie radiation source and a high vacuum night vision image intensifier tube that enhances light intensity 40,000-fold. Fiber optics are used to carry the visible image to a viewing plate. Nevertheless the problem of image interpretation remains.

Acoustic Inspection - Brief mention should be made of acoustical technology because the equipment is extremely sophisticated and readily available. The basic objections to the use of

this technology for inspection stated by Street (3) are still valid for most applications: quiescent stages cannot be detected, and neither can eggs; great difficulties arise in the case of commodities such as flour; and background noise becomes a limiting factor in the case of large masses of grain because of settling. However, with smaller quantities of grain such as those used in routine inspection, settling should not be a problem, and the feeding stages could undoubtedly be detected. Instrumentation for this specific application is available as a commercial unit from SASAD Mg. Tsz., Budapest, Hungary, the so-called Insectofon(R). We have not seen this device as yet but eagerly await opportunity to test its effectiveness.

Acoustic microscopy is another new approach that bears close watching for possible application to insect detection. This technique involves the use of very high frequency ultrasound (ca. 100 mHz) in a scanning laser acoustic microscope. Such sound has different velocities in tissues of different densities, so insect tissue might be differentiated from plant tissue.

IR CO_2 analyisis - The differential infrared (IR) CO_2 analyzer with intermittent airflow under slight negative pressure (4, 5) is a promising method of detecting hidden infestations of insects. Prior to the development of this system, our attempts to use insect-produced CO_2 as an indicator of insect presence have been complicated by 1) the CO_2 in the air, which comprises about 300 ppm, and 2) by the fact that an insect produces so little CO_2 per unit time. Currently two commercial prototypes based on our original concept are being tested. Technicon Instruments, Inc., of the United States and Horiba Instruments, Inc., of Japan have both produced instruments (both systems use Horiba IRCO_2 analyzers) for use in routine grain inspections. The Technicon system simultaneously processes 3 samples, which makes the system larger and more stationary. The Horiba system is much smaller and processes only one sample at a time, but it is very portable.

Currently, several new approaches to the use of CO_2 for detection are being developed for both specific and general applications. A "closed loop" concept being studied would eliminate the problem of system air contamination and make more efficient use of the CO_2 analyzer which is designed to use continuous airflow. As a result of the continuous recirculation of air, the insect-produced CO_2 steadily increases the concentration of CO_2 within the sealed system. Insect presence is noted by a positive change in slope on a strip chart recorder, or by a rising meter reading.

It is proposed that the CO_2 detection be used in continuous surveillance of large grain bin storage facilities. Also a microcomputer-controlled sampling routine is being studied in which probes are dispersed at intervals throughout the grain mass. Computer comparisons will be made of the current CO_2

concentration at each probe site with respect to the previous concentration and the total CO_2 profile of the storage facility.

Finally, the Lawrence Livermore Laboratories of the U.S. propose to continue development of their miniaturized atmospheric carbon dioxide detector system (MACDS). Their system is a CO_2 detector with extreme sensitivity, yet the entire package including optics and electronics can be held virtually in the palm of your hand.

Future

At this juncture it seems appropriate to provide some background into infrared radiation detection of hidden insects because many new and exciting possibilities now exist and the field is generally unfamiliar to stored-product entomologists.

All physical bodies that have a temperature greater than absolute zero have an infrared radiation spectrum referred to as a black body curve. The particular wavelength location of this curve is a function of the body's absolute temperature. Since living metabolizing tissue (e.g., an insect) generally has a higher temperature than its surrounding environment (a grain kernel), the possibility exists of detecting the different radiation characteristics of an infested commodity. A variety of detectors is available for the detection of infrared radiation.

In general, IR detectors are either quantum or thermal devices. Quantum devices (photon detectors) are used to detect the IR radiation that results when incident radiation quanta interact with the electrons in a solid and thus excite these electrons to a higher energy state. Although such detectors are extremely sensitive, random thermal excitation of the electrons in the solid produces the problem of electrical noise. Systems utilizing these detectors must usually be cooled to reach adequate sensitivity and do not seem appropriate for examining foods for live insects. Thermal detectors, on the other hand, function by absorption of IR radiation that changes the temperature of the detector material. This change in temperature may be manifested as a thermal electromotive force (thermocouples and thin-film thermopile detectors), a change in resistance (bolometers), expansion of a gas that causes a diaphragm to move (Golay cell), or a change in electrical polarization of a crystal produced by changes in temperature (pyroelectric detectors). Thermal detectors, therefore, seem more appropriate for the assay of biological material.

Unfortunatuely, most of the thermal detectors mentioned are relatively insensitive and are wavelength independent. In addition, these devices (with the notable exception of the pyroelectrics and some thin-film thermopiles) respond slowly. However, these two apparent disadvantages are offset by the fact that these instruments can be used at room temperature so there are no critical cooling requirements.

The fast-response pyroelectric detector appears to be a most advantageous alternative for IR detection. This detector is a thermal sensor of electromagnetic radiation that contains a permanently polarized dielectric crystal. Incoming radiation causes the temperature of the crystal to rise. The increased temperature alters the lattice structure through expansion, thereby changing the magnitude of polarization. These changes in electrical polarization are sensed as an electrical current directly proportional to the rate of change in the temperature of the material (6). Optical scanning of an area of interest results in a varying electrical signal from the detector. This signal is then used to create a television-like display that is actually a visible image of the infrared profile of the scanned area. Either shades of gray or different colors may be used to indicate areas of varying IR wavelength and hence of varying thermal temperature.

Far infrared imaging - The use of radiation in the far infrared (FIR) portion of the spectrum for purposes of imaging has only recently been demonstrated (7). If imaging objects within various materials now proves to be feasible, its potential for detecting hidden insects is apparent. Previously the use of this portion of the spectrum was restricted because of the lack of effective radiation sources and detectors and the fact that resolution is poor relative to other techniques. However, developments in laser and IR detector fields have made FIR imaging possible. Because many substances have IR "windows," (i.e., areas in the spectrum where IR radiation can be transmitted), it is possible to penetrate materials that cannot be penetrated by other methods.

Photoacoustic spectroscopy - As early as 1888, inventors such as Bell, Tyndall, and Roentgen were well aware of the scientific potential of photoacoustic spectroscopy (8, 9). This unusual technique enables one to obtain spectra similar to optical absorption spectra for any type of solid or semisolid material whether it is crystalline, powder, amorphous gel, etc. (10).

Briefly, the process is as follows. The sample to be studied is placed in an airtight chamber equipped with a sensitive microphone and exposed to intermittent monochromatic light. Any light absorbed by the sample is converted to heat, and the resulting temperature at the surface of the sample fluctuates at the frequency of the chopped light. These fluctuations create pressure changes in the chamber that can be detected by the microphone and converted to an electrical signal. As the wavelength of the monochromatic light is varied, the amplitude of the electrical signal varies in direct proportion to the surface optical properties of the sample. The presence of an insect-produced contaminant on the surface should be readily detectable. Further, the use of long wavelength infrared light should permit penetration of the interior of the kernel and the detection of an actual hidden insect.

Results in our laboratory and conversations with Dr. Rosencwaig (personal communication) suggest a real potential for this technique in the detection of hidden insects. Currently, two commercial instruments are available, but these have not been tested with our specific needs in mind. The advantages of such a technique to stored-product entomology would seem to lie with the virtually unlimited number of wavelengths of light available and the fact that effectiveness is not limited by the physical state of the sample.

Pyroelectric vidicon - Recent advances in the field of thermal imaging have given rise to a device known as the pyroelectric vidicon. This imaging detector has two unique properties: 1) it is capable of operating at ambient temperature and 2) it detects only changes in temperature, not differences. This latter characteristic is considered by some to be a disadvantage, since it does require that the incoming signal be chopped or that the detector be scanned (1).

Basically the vidicon consists of a glass envelope fitted with a germanium faceplate, a pyroelectric target, an electron gun, and beam-shaping electrodes, as in standard vidicons. When an IR image is focused on the target, the absorbed heat energy creates a temperature change that causes changes in charge distribution of the pyroelectric material. The resulting distribution, which reproduces the thermal image, can be read by an electron beam.

CONCLUSION: We should be ever mindful that technologies may exist outside the realm of stored-product entomology that could be most beneficial in the detection of hidden insects. For example, photoelectron spectrometry is a technique that measures the energies of electrons emitted by a sample that is bombarded with x-rays: commercially available spectrometers that presently permit the identification and quantification of different amino acids in seed samples might be adaptable to insect detection. Nuclear magnetic resonance (NMR) imaging too is a recent development. It makes use of the proton spin characteristics in the atomic nucleus. Although the present instrumentation is probably prohibitively expensive, the field should be watched for technological developments that may permit a cost breakthrough. There is little doubt that techniques such as these and others not yet discovered could be adapted to solve the specific problems of hidden insect detection.

REFERENCES:

(1) Bruce, W. A., Street, M. W. Jr., Kvenberg, J. E., Potential use of infrared devices for detecting hidden insects, FDA By-Lines No. 1 (1978).
(2) Kirkpatrick, R. L., X-ray analysis of stored commodities, USDA series (in manuscript).

(3) Street, M. W. Jr., A method for aural monitoring of in-kernel insect activity, J. Ga. Entomol. Soc. 6 2 (1971) 72.
(4) Bruce, W. A., Street, M. W. Jr., Infrared CO_2 detection of hidden insects, Ibid. 9 4 (1974) 260.
(5) Street, M. W. Jr., Bruce, W. A., Hidden insect detection by infrared carbon dioxide gas analysis, Principles of system design, U.S. Dep. Agric., Agric. Res. Ser.-S-85 (1976) 10 pp.
(6) Tiffany, W. B., Introduction and review of pyroelectric detectors, SPIE Infrared Technol. 62 (1975) 153.
(7) Anonymous, Applications ahead for far IR imaging, Ind. Res. (January 1977).
(8) Callahan, P. S., Tyndall, J. Unifier of 19th Century Science, Appl. Opt. (in press).
(9) Vengerov, M., An optical-acoustic method of gas analysis, Nature 158 4001 (1946) 28.
(10) Rosencwaig, A., Photoacoustic spectroscopy, A new tool for investigation of solids, Ann. Chem. 47 6 (1975) 592.
(11) Foreman, J. R., Pyroelectric technology in modern thermal imaging systems, Electron. Eng. (January 1977) 38.

A REVIEW OF THE USE OF PHYSICAL STORAGE PROCEDURES IN EAST AFRICA: ASPECTS FOR IMPROVEMENT AND EXTENSION

C. P. F. DE LIMA
National Agricultural Laboratories
Ministry of Agriculture
P.O. Box 14733
Nairobi, KENYA

INTRODUCTION: In East Africa more than 80 percent of the harvested produce is stored on the farm in traditional granaries. At the subsistence level the staple crops are maize, millets and sorghums. Teff is important in Ethiopia. Rice and legumes often form an important part of the diet. In urban areas wheat is also consumed.

IMPROVEMENTS ON PHYSICAL PROCEDURES IN SUBSISTENCE STORAGE:
Various ashes and inert dusts - Mixing wood ash with grains was previously practiced in East Africa but is not common now. Generally, fairly large quantities of wood ash are required (a ratio higher than 1:5 of ash to grain) for adequate control. Wood ash, cow-dung ash, and inert dusts, although claimed to provide some control (1, 2) are generally not very effective in practical terms when compared with insecticidal dusts. Thus even at the rate of 20 gm ash to 100 gm beans, Schoonhoven (3) recorded fairly high levels of damage in the ash treated grain, even though significant reductions of the pests was obtained. The use of wood ash and inert dusts alone are therefore unlikely to be of much practical benefit but further improvements could be made when these methods are combined with other physical storage procedures like airtight containers or natural physical barriers discussed below.

Natural physical barriers - Several grain types have some form of natural cover when they are harvested. Maize is covered by a husk or sheath, beans are covered by pods, rice paddy has a husk. Usually, only a proportion of the harvest has an intact cover that will act as an effective barrier to pests. The major part of the harvest will not have the natural protective cover because of weathering and varietal effects and will have to be protected in another way. However, by proper selection a significant proportion of the harvest can be protected simply by retaining its natural cover intact. De Lima (4) has shown that approximately one-quarter of a maize harvest of hybrid grain has a sufficiently intact husk cover, to provide the stored crop with adequate protection. A trial to compare the effectiveness of the intact husk with an insecticidal treatment showed that (Figure 1) there was not much difference between the protection given to maize cobs for which the intact husk had been retained (but no further treatment given) and the de-husked cobs which were treated with a 2% malathion dust. These two treatments were far superior

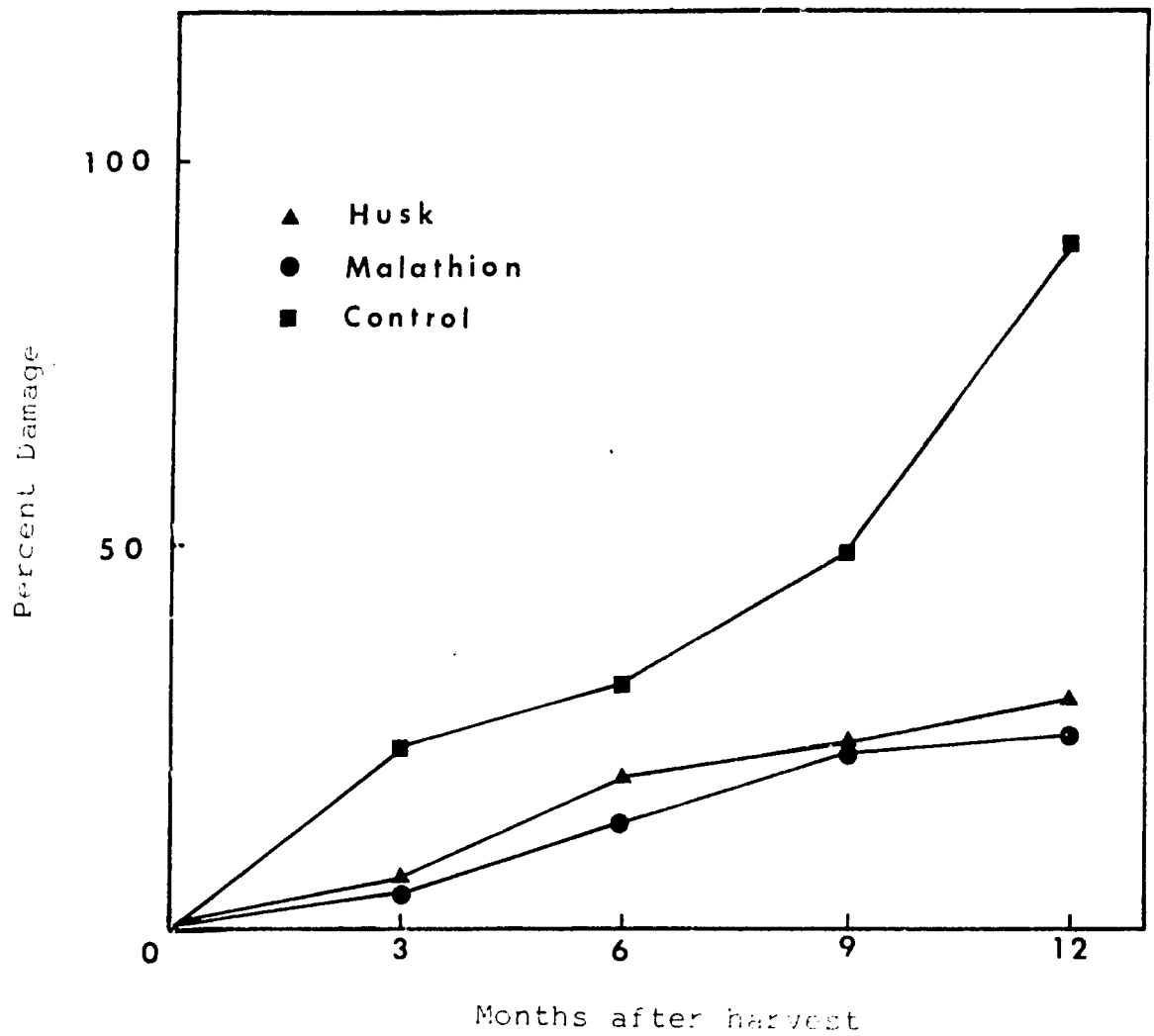


FIGURE 1. Comparative effectiveness of physical control provided by an intact husk cover on maize and an insecticidal dust on de-husked cobs (1975-76 trial in Bukura).

to the control (which was not dusted and had been de-husked). Caswell (5) has shown that the intact pod provides greater protection to the food beans it encloses and Breese (6) found that paddy with sound husk was less damaged by *Rhyzopertha dominica* and *Sitophilus oryzae*.

Semi-hermetic storage - Semi-hermetic conditions are obtained in traditional underground pits in Ethiopia. Boxall (7) was able to suggest improvements in the storage methods. He compared various linings for the under-ground pits: matting and straw; polyethylene sheets or sacks and concrete lining or a combination of these barriers. These linings reduced damage due to moulds by restricting and preventing the ingress of water over

a period of 4 months and also resulted in less damage due to insects and rodents.

Gourds are often used as receptacles for storage of beans, sorghums and millets. Insects breed well in these containers and damage to the grain stored within is often severe. Loss in this situation is especially important from the nutritional view-point because the grains stored in these containers are a scarce commodity often preserved for the use of nursing mothers. McFarlane (8) examined some gourds used in Kenya (empty dry fruit cases of *Lagenaria cineraria* and related curcurbits) and showed that by treating the external surface of the gourd with linseed oil or varnish, the oxygen permeability was greatly reduced and the container could be used as a semi-airtight receptacle if well-sealed at the neck.

IMPROVED PHYSICAL PROCEDURES IN LARGE-SCALE STORAGE: Of the physical storage procedures available for practical use on a large scale under tropical storage conditions, the use of controlled atmospheres provides the most promising approach for improved storage at low cost. Naturally induced inert atmospheres are among the easiest to achieve in large air-tight structures.

Hermetic storage - In Kenya, seventy hermetic ("Cyprus") bins were constructed to hold approximately 100,000 tons of grain as a famine reserve (Figure 2). Over the past 10 years during

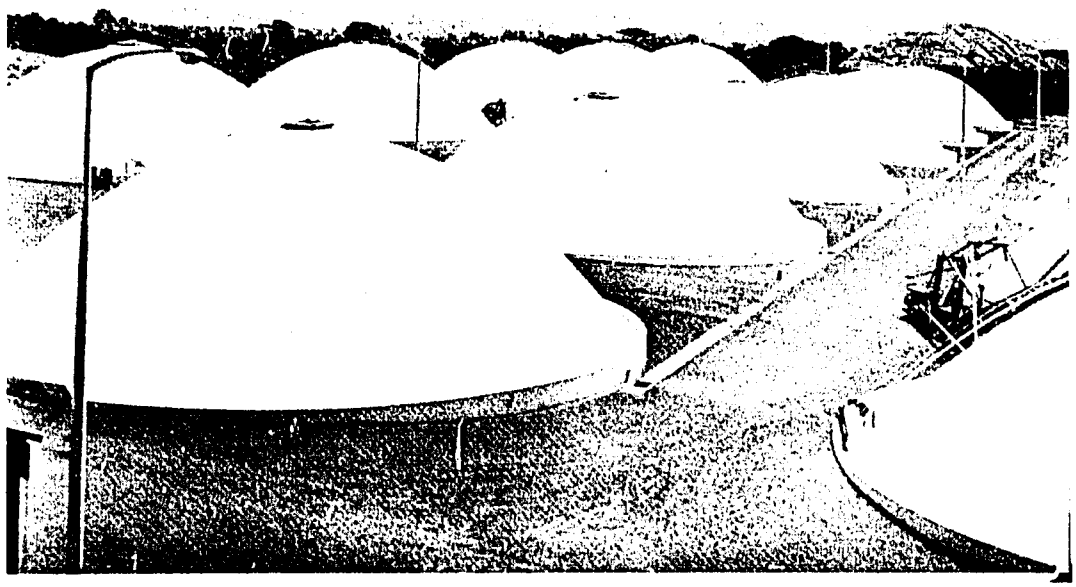


Figure 2. The "Cyprus Bins" - semi-underground hermetic structures. Each bin can hold approximately 1,500 tonnes of grain.

which these structures have been in use, several long-term trials have been conducted to test their effectiveness. The rate of depletion in the oxygen level depends largely on the presence of a pest population. Thus in the absence of a pest population (or its presence at very low levels) the amount of oxygen in a bin would tend to remain the same for a long period of time (Table I).

TABLE I. Storage of maize in the "Cyprus Bins" under hermetic conditions.

Bin no.	Length of airtight storage months	Infestation level insect/kg live/dead		% oxygen
Kitale				
1	33	0.1	5.6	9.25
5	32	-	2.2	8.75
13	32	-	-	8.25
31	21	-	-	10.00
32	21	-	-	17.00
35	21	-	-	12.50
37	21	-	-	10.25
Nakuru				
3	34	0.2	0.3	4.75
4	37	-	-	2.45
9	33	-	0.48	4.05
12	39	-	-	3.20
24	38	-	-	3.00
27	32	-	-	3.20
28	39	-	-	3.60

In the early management of the bins, filling and emptying was done with the help of pneumatic conveyors which caused a fair amount of breakage as as a result the high concentrations of dust and broken grain at certain points in the bins caused heating. Subsequently chain conveyors were installed and their use resulted in negligible breakage and no heating over a two year trial period and in a further two years of routine use.

Of the 70 bins built for use in Kenya, 40 are in Kitale and 30 are in Nakuru. At each site, one-third of the bins are emptied and filled every year so that grain remains in each bin for a maximum period of 3 years. In cases where the grain has remained longer no deterioration has been observed. Several bins were emptied in 1974-75 after a 3 year period of storage and overall weight losses were established as 2.48%. This works out

to approximately 0.8% per year. This overall loss figure includes losses due to grain destroyed by heating or mould, losses due to dust extraction in the clean-up process, losses due to classification of grain as undergrade and losses due to non-estimatable causes like respiration. Losses due to pest damage were negligible. In comparison it should be noted that losses in conventional large scale storage are generally in the region of 2% per annum. Operational costs (including labour, fabric repairs, pest control etc.) were also extremely low and over the 1972-76 period worked out to approximately K£ 0.3 per ton (0.6 U.S. $) for the 4 years period.

Aeration and cooling - In the high altitude areas of Kenya the temperature conditions are sufficiently low to permit cooling of produce for better storage. Stirling (9) was able to show that under general storage conditions of coffee, which are moderately warm, it would be advantageous to ventilate the coffee at appropriate humidities. He developed an automatic control circuit for a ventilation system and showed that under cool dry ventilated conditions parchment coffee could be stored for at least 12 months with negligible woodiness appearing in the cup liquor.

DISCUSSION: One of the most important physical storage procedures that needs special emphasis in the tropics is cleanliness in storage. Good hygiene and proper store construction to minimise harbourage for pests and to enable easy cleaning will go a long way towards preserving the stored grain from unnecessary damage.

Under present storage conditions in developing countries some of the storage receptacles which are already in use as hermetic or semi-hermetic containers could be further improved. In large-scale storage more care and consideration could be given to appropriate store design of conventional stores to promote cooling by aeration.

In many countries consideration needs to be given at the national planning level to the storage of grain as a famine reserve, and for such a purpose the low cost hermetic structures - the "Cyprus Bins" have proved their worth.

REFERENCES:

(1) Khare, B. P., Insect pests of stored grain and control in Uttar Pradesh. Res. Bull. 5 (1972) 152.

(2) Maceljski, M., M. Danon, and Z. Korunic, Comparative research on sensitivity of different stored-product beetles to inert dusts under various conditions. 7th Int. Congr. Pl. Prot. Paris, (1970), 439-440.

(3) Schoonhoven, A. V., Pests of stored beans and their economic importance in Latin America. Proc. XV, Int. Congr. Ent., Washington, 1976, (1977) 691-698.

(4) De Lima, C. P. F., A study of the bionomics and control of *Sitophilus zeamais* (Motschulsky) and *Sitotroga cerealella* (Olivier) and associated fauna in stored maize under laboratory and field conditions in Kenya. Unpubl. Ph.D. Thesis (1978) University of London.

(5) Caswell, G. H., The development and extension of non-chemical control techniques for stored cowpeas in Nigeria. Proc. 1st Int. Wkg. Conf. Stored Product Ent., Savannah, Ga., U.S.A. 1974 (1975) 63-67.

(6) Breese, M. H., The influence of husk defects on the infestibility of stored paddy by *Rhyzopertha dominica* (Fab.) (Col. Bostrichidae) and *Sitophilus oryzae* (L.) (Col. Curculionidae). Proc. XII Int. Cong. Entomol. 1964, (1965) 632-632.

(7) Boxall, R. A., Improvement of traditional grain storage pits in Harar Province, Ethiopia; a preliminary investigation. Int. Pest Control 16 (1974) 4-7.

(8) McFarlane, J. A., Insect control by airtight storage in small containers. Trop. Stored Prod. Inf. 19 (1970) 10-14.

(9) Stirling, H. G., Further experiments on the factors affecting quality loss in stored arabica coffee. Kenya Coffee, January 1975 (1975).

PANEL SESSION ON RADIATION AND OTHER NON-CHEMICAL MEANS OF INSECT CONTROL

Convener - DR. MOSHE CALDERON
Institute for Technology and Storage of Agricultural Products
P.O. Box 6
Beth, Dagan, ISRAEL

POTENTIAL AND LIMITATIONS OF THE USE OF LOW TEMPERATURES TO PREVENT INSECT DAMAGE IN STORED GRAIN

ROBERT B. MILLS
Department of Entomology
Kansas State University
Manhattan, Kansas 66506, U.S.A.

INTRODUCTION: The full potential of the use of low temperatures to control stored-grain insects has not been realized, even in geographical locations where low temperatures are available and are relatively inexpensive to use in cooling grain sufficiently to inactivate or kill stored-grain insects and mites. We who live in temperate climates reap benefits of low ambient temperatures, even without putting forth any effort or expense, but we could economically increase the benefits by moving this cool air through our grain more than we do.

Discussion of the use of refrigeration to cool grain is discussed elsewhere in these Proceedings; refrigeration is being used to remove heat from grain in climates which do not provide naturally cool air, or in climates which have cool air only part of the year, as in temperate areas.

Both high and low temperatures have been used for a long time to kill insects, or at least reduce their damage, in grain and grain products. In the northern parts of the United States and in Canada, "freeze-outs" have been used to disinfest flour mills. The mills were opened for 24-48 hr when temperatures were very low, below -20°C (0°F). The effectiveness of this technique was demonstrated by Cotton and Frankenfeld (1) in Kansas; however, such severe temperatures cannot be depended on to occur in the state.

Dean (2) about 70 years ago demonstrated that flour mills in Kansas could be almost completely disinfested by "superheating" which created temperatures of 43-60 C°(110-140°F) in most of the mill. Although effective, this method was not used much. The sun's energy has been used directly to disinfest as well as to dry small lots of grain. Heating grain in fluidized beds is being studied, as reported by Dermott and Evans (3).

In the First Conference in 1974 in Savannah, Georgia, Nelson (4) and Kirkpatrick (5) presented papers on the use of different types of radiant energy to kill stored-grain insects by the heat produced as radiations were absorbed by the insects and/or the grain. At that same conference Navarro (6), Calderon (7), and Smith (8) dealt with various aspects of controlling stored-food insects using low temperatures.

Use of low temperatures is, and shou'd be, of more interest these days because of insect resistance to insecticides,

especially the protectant chemicals applied to grain as common practice in some places, and because of the increased concern, justified or not, that many people feel about having chemicals put on grain which they are going to eat in one form or another.

Any control method to be acceptable must meet certain requirements: it must be needed, it must be effective, it must be available, it must be economical, it must be amenable to safe application, and it must not harm the product or make it unsafe for humans or animals to consume. Malathion is a chemical that met these reqirements quite well and has been widely used directly on grain as a protectant, but its effectiveness has been decreasing due to resistance of the insects, more in some areas than in others.

Insecticides will continue to have their place in the protection of stored grain. This is evidenced by the continued search for and testing of new insecticides suitable for use on and around stored grain. Other potential control methods for protecting grain from pests should be investigated, and developed when and where appropriate. Thus, we see an active interest in various kinds of radiation, in pheromones, hormones, and pathogens, in varietal resistance, in various kinds of atmospheres, and in the use of temperatures detrimental to stored-grain pests.

Low temperatures are attractive because they do not harm the grain and because they retard the rate of deterioration due to respiration and microorganisms as well as that due to insects and mites. No potentially harmful residues result, and apparently no government agencies have yet required registration of low-temperature usage with all the problems that process involves.

SUSCEPTIBILITY OF INSECTS TO LOW TEMPERATURES: The optimum temperature for most stored-grain insects is between 25 and 39°C. Any lowering of the temperature below the optimum for a species will have some adverse effect. But to cool insects enough to prevent feeding and reproduction, the temperature must be lowered considerably: below 15-17°C for most species. Howe (9) summarized the estimates of optimum and minimum temperatures for population increases which had been reported by numerous investigators. He listed more than 50 species, some of which are given in Table I.

Burges and Burrell (10) listed 9 common grain-infesting species, giving the optimum temperature for development and the temperature at which the developmental cycle requires 100 days (Table II). They stated that, in general, if temperature is reduced to a level at which a species takes 100 days to develop, that species is unlikely to multiply to a dangerous extent.

If moisture content is sufficient for mites, lower temperature is required for protection of the grain. Smith (8) listed the minimum and optimum temperatures for development of some mite species common in stored products (Table III).

TABLE I. Estimated optimal and minimal temperatures (°C) for population increase for selected stored-grain insects. (Adapted from Howe, 1965).

Species	Min.	Opt.
Species Needing High Temp.		
Cold Hardy		
Trogoderma granarium Everts	24	33-37
Cryptolestes ferrugineus (Stephens)	23	32-35
Oryzaephilus surinamensis (L.)	21	31-34
Plodia interpunctella (Hubner)	18	28-32
Moderately Cold Hardy		
Tribolium confusum Jacq. duVal	21	30-33
Ephestia cautella (Walker)	17	28-32
Rhyzopertha dominica (Fab.)	23	32-35
Cold Susceptible		
Tribolium castaneum (Herbst)	22	32-35
Callosobruchus maculatus (Fab.)	22	30-35
Oryzaephilus mercator (Fauvel)	20	31-34
Cryptolestes pusillus (Schönherr)	22	28-33
Species Thriving at Moderate Temperature		
Cold Hardy		
Anagasta kuehniella (Zeller)	10	24-27
Sitotroga cerealella (Olivier)	16	26-30
Sitophilus granarius (L.)	15	26-30
Acarus siro L.	7	21-27
Moderately Cold Hardy		
Sitophilus oryzae (L.)	17	27-31
Cold Susceptible		
Gnatocerus cornutus (Fab.)	16	24-30

TABLE II. Optimum temperature (°C) and temperature at which developmental cycle requires 100 days. (Adapted from Burges & Burrell, 1964).

Species	Opt.	Temp. for 100-day devel. cycle
Oryzaephilus surinamensis (L.)	34	19
Sitophilus granarium (L.)	28-30	17
Cryptolestes ferrugineus (Steph.)	36	20
Tribolium castaneum (Herbst)	36	22
T. confusum Jacq. duVal	33	21
Trogoderma granarium Everts	38	22
Sitophilus oryzae (L.)	29-31	18
Rhyzopertha dominica (Fab.)	34	21
Cryptolestes pusillus (Schonherr)	32	19

TABLE III. Minimum temperatures (°C) for development of some stored-product mites (Smith, 1974).

Species	Min.
Acarus siro L.	0
Glycyphagus domesticus (DeGeer)	0-5
Tyrophagus putrescentiae (Schrank)	8
Cheletus eruditus (Schrank)	10

minimum temperature for development ranges from 0 to 10°C. Sinha (11) listed 10 species of storage mites of importance in Japan and summarized the minimum and optimum temperatures for breeding, as reported by several investigators (Table IV). The

Table IV. Estimates of minimum and optimum temps. (°C) at which 4 mites breed. (Adapted from Sinha, 1968).

Species	Min.	Opt.
Tyrophagus putrescentiae (Schrank)	9-10	23-28
Glycyphagus destructor (Schrank)	10,15	15-25
Acarus siro L.	7	23-30
Cheletus eruditus (Schrank)	12	25-27

minimum temperature ranges from 7 to 15°C. Temperature just low enough to effectively retard insect development (17°C) will be quite suitable for buildup of certain mite populations.

Solomon and Adamson (12) exposed numerous species of stored-product insects to winter conditions in various situations in Britain, and ranked them in categories from "very susceptible" to "hardy."

Knowledge of the species involved and of their relative susceptibilities to low temperatures permits more effective use of low temperatures where they are available. In geographical

areas where ambient temperatures are marginal for cooling by aeration, they may be effective if the only insect pests are relatively susceptible to low temperatures.

ACCLIMATION OF INSECTS TO LOW TEMPERATURES: Is known that some insects (perhaps all of them) acclimate if exposed to gradually decraasing temperatures, and thus are able to survive longer cold exposure and/or lower temperatures than those not acclimated.

Smith (13) found that survival of *Cryptolestes ferrugineus* (Stephens) adults acclimated for 7 or more days at 15°C and then exposed to -6°C was much greater than for those not acclimated. And whereas nonacclimated adults did not survive 3 days at -12°C (10°F), survival was 40.5% of those acclimated for 14 days at 15°C then exposed for 14 days at -12°C. For those acclimated for 28 days at 15°C, survival was 60.8% after 78 days at -12°C (Table V).

TABLE V. Percentage survival of *Cryptolestes ferrugineus* exposed to -12°C after acclimation at 15°C. (From Smith, 1970).

Days of acclimation	Survival
None	0 after 3 days
14	40.5% after 14 days
28	60.8% after 78 days

The supercooling point was -16.7°C for nonacclimated insects, but was -20.4°C after 3 or 4 weeks of acclimation. Smith suggested that this species is able to survive in unheated granaries in the Prairie Provinces of Canada because of its ability to acclimate to low temperatures.

Insects that can move through the grain mass are not exposed to sudden temperature changes and so are able to acclimate according to their capacity to do so.

Evans (14) found that the mean chill-coma temperature (ET_{50}) of *Sitophilus oryzae* (L.) was lowered from 8.43°C for unacclimated adults to 5.29°C for adults acclimated for 8 weeks at 15°C. Mean chill coma of *S. granarius* (L.) treated the same way was lowered from 5.26 to 2.71°C.

Ernst and Mutchmor (15) demonstrated that adults and larvae of *Tenebrio molitor* Fab., *Tribolium confusum* Jacq. duVal, and *Trogoderma variabile* Ballion dispersed more at low temperatures after acclimation at 15 or 23°C than did insects acclimated at higher temperatures.

Sinha (16) reported that 1% of an *Acarus siro* L. culture reared at 6°C for 2 years survived -18°C for 168 hr, while none of a culture reared at 21°C for 1 year survived 72 hr exposure at -18°C.

David et al. (17) acclimated various developmental stages of *Sitophilus oryzae*, *S. granarius*, and *Rhyzopertha dominica* (Fab.) for 3 days at 21°C, for 7 days at 15.5°C, and for 7 days at 10°C, then exposed them to 4.4°C for 2, 4, or 6 weeks. Acclimation increased survival of all species. Although a laboratory strain and a field strain of each species were tested, there was little difference in response, except that field-strain *S. granarius* adults were more cold hardy than the laboratory-strain adults. The hardiest immatures of *S. oryzae* were those of 14-17 days' development, and, when acclimated, more than 25% survived 6 weeks at 4.4°C, while none of the nonacclimated survived (Table VI. Of acclimated *S. granarius* of the same developmental age, 75% or more survived the same exposure while few of the nonacclimated survived. The immatures of *R. dominica* with 21-24 days' development were the most cold hardy but were more susceptible than the other two species. Virtually none, acclimated or not, survived 6 weeks at 4.4°C, and only 9-18% of the acclimated group survived 4 weeks; none of the nonacclimated survived 4 weeks. Only a few acclimated *S. oryzae* adults survived 2 weeks' exposure to 4.4°C, and almost none of the nonacclimated ones survived. Thirty-nine percent of *R. dominica* adults survived 2 weeks' exposure to 4.4°C and only 6-8% survived 4 weeks, while only 1-2% of nonacclimated adults survived 2 weeks. *S. granarius* adults were much more cold hardy, with 90% of the acclimated field-strain adults surviving 6 weeks compared to less than 2% of nonacclimated field-strain adults. Field-strain adults were clearly more cold hardy, whether acclimated or not.

Granovsky and Mills (18) exposed *S. granarius* adults in pint jars (250 insects/250 g wheat) to temperatures gradually decreasing from 26°C to 4.4°C over a period of 109 days. Temperature was decreased in increments of 2.2 C°or less per week. The insects were held at 4.4°C for 9 days, then 100 of them were each placed individually with an undamaged wheat kernel and 100 individually with a kernel with about one-third of the "brush" end cut off. They were held at 4.4°C for 15 days, then at 5.5, 6.5, and 8.0°C for 18, 10, and 7 days, respectively. There was evidence of feeding at all temperatures, but only on cut kernels; the insects apparently were unable to penetrate the pericarp of the kernels at those temperatures. Of 100 weevils in each group, 24 survived on cut kernels to the 161st day of the temperature sequence (after 50 days' isolation with single kernels), while only 10 survived on sound kernels. Although nonacclimated adults were not used as controls to determine degree of acclimation, the tests showed that *S. granarius* can feed on damaged kernels at quite low

TABLE VI. Percent survival (of control) at 4.4°C of acclimated and non-acclimated insects at different developmental stages. (Adapted from David et al., 1977).

Weeks expos. 4.4°C	Acclimated		Non-acclimated	
	Lab.	Field	Lab.	Field
S. oryzae of 14-17 days development				
2	82.8	83.8	1.2	1.6
4	48.4	53.1	0.0	0.0
6	36.6	26.1	0.0	0.0
S. granarius of 14-17 days development				
2	97.1	81.8	36.6	38.1
4	75.8	54.3	2.6	4.1
6	82.8	74.5	0.1	0.9
R. dominica of 21-24 days development				
2	76.9	55.6	16.4	16.0
4	18.3	9.2	0.0	0.0
6	0.3	0.0	0.0	0.0
S. granarius adults				
2	85.8	100.1	33.7	92.7
4	25.9	90.8	3.9	78.3
6	15.7	90.1	0.0	1.8

temperatures and that the proportion surviving is thus increased.

Granovsky (19) found that, during acclimation, *S. granarius* gained dry weight, total lipids, and triglycerides, and decreased in water content, while the opposite occurred for *T. castaneum*. This demonstrates the variability among species in adjusting to low temperatures.

Evans in two papers (20, 21) reported on the capacities for increase of several Australian populations of *S. oryzae* and *S. granarius* at 15°C. The finite rate of increase of *S. granarius* averaged 1.07/female/week, and of *S. oryzae* averaged 1.09/female/week. Evans found that capacity for increase of a given population at 15°C was correlated with fertility at an optimum temperature of 27°C and with body weight, rather than with cold tolerance (chill-coma temperature), or its previous temperature history. He found significant differences in capacity for increase among the populations. Temperature of rearing of immatures influenced capacity for increase at 15°C; weevils of laboratory populations reared at 27°C had a greater capacity for increase at 15°C than those reared at 15°C.

These and other studies not cited emphasize the survival value of acclimation for many of these insects, and also that some may be able to feed and reproduce at lower temperatures than commonly thought; Evans' papers reported that reproductive capacity can be affected by the temperature history of the immatures.

Until more is known about the effects of various kinds of exposures to low temperatures on insects, we will not be capable of recommending precise temperatures for their control. Obviously, we need not wait for all desired information before using low temperatures to control insects; the method is being used successfully in a number of situations.

AVAILABILITY OF LOW TEMPERATURES: Low temperatures may be available naturally, or they may be created by refrigeration equipment (to be discussed in another paper).

In the United States from north to south we have a wide range of ambient temperatures. In Table VII are presented the contrasts in temperature at Fargo, North Dakota (47°N. Lat.); Wichita, Kansas (38°N. Lat.); and Brownsville, Texas (26°N. Lat., the Gulf of Mexico). Locations are shown in Figure 1. Weather records show that Fargo during the two warmest months (July and August) about 50% of the recorded hourly temperatures during 1951-1960 were under 21°C (70°F) and 12-16% below 15.5°C (60°F). In Wichita 10-12% of the observations were of temperatures below 21°C and only 0.5% below 15.5°C. At Brownsville the temperature was almost never below 21°C in July.

The temperatures observed during January, one of the coolest months, were all below 10°C (50°F) at Fargo, and 32% were below -18°C (0°F), as compared to only 14% below 10°C at Brownsville.

TABLE VII. Percentages of observed temperatures[a] below selected levels at different locations in U.S.A.

Location & Lat.		<21°C	<15.5°C	<10°C	<-18°C
July					
Fargo, N. D.	47°N.	45	12		
Wichita, Kans.	38°N.	12	0.5		
Brownsville, Tex.	26°N.	0.0			
August					
Fargo		52	16		
Wichita		10	0.5		
Brownsville		0.08			
January					
Fargo				100	32
Wichita				92	0.4
Brownsville				14	0.0

[a]Total of approx. 7400 hourly observations for each location during 1951-1960.

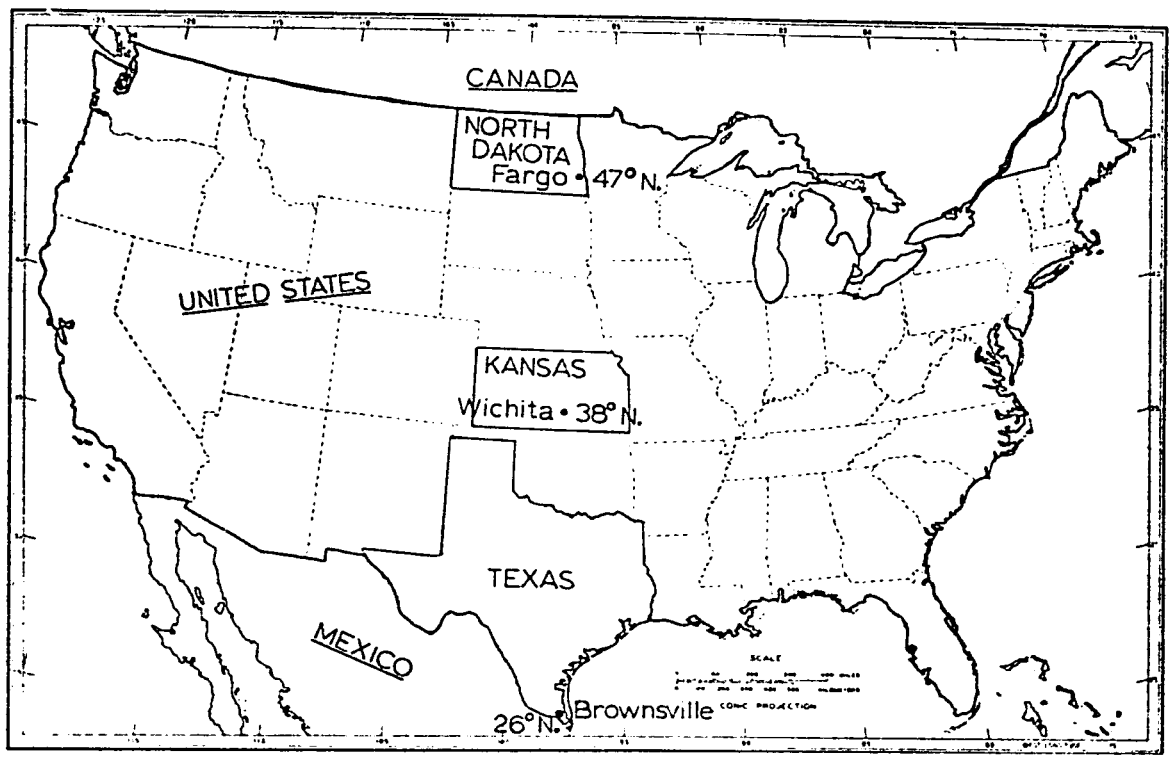


FIGURE 1. Latitude of 3 locations in the United States of America.

Aeration may be advantageous in areas where temperatures are not low enough to halt insect development. It equalizes temperatures throughout the store and by use of selective aeration, temperatures can be reduced below the optimum for insects, thus retarding population development. Aeration is being utilized in the warmer areas of Australia.

In Kansas, harvest of wheat begins just before July 1. The temperature of the grain at harvest varies greatly, but not uncommonly grain is at 30°C or higher when placed in storage. Although we do not have sufficiently low temperatures in July to cool grain below a "safe" temperature, it is recommended to farmers that they aerate grain immediately to remove the "field heat." The mean temperature for July may vary from 21 to 33°C, but over almost 100 years has averaged 27°C. Therefore, on the average, the temperature of grain can be reduced at least to 27°C by using aeration, and with selective aeration more than that. At Wichita, Kansas, in September (2 months after harvest) 43% of the observed temperatures were found to be below 21°C, and 14% below 15.5°C, so grain can be cooled to near the safe level, taking 15-17°C to be the safe level. In October, the temperature can be lowered effectively, since 50% of the hourly observed temperatures were found to be below 15.5°C.

It has been estimated that not more than 30% of the farmers in Kansas use aeration; many do not have the equipment, and those who do, do not use it as much as they should. We could make better use of it earlier in the fall. Benefits can be gained from aeration of grain even when temperatures cannot be lowered as much as desired.

Calderon (7), at the First Conference, discussed the potential for using aeration for controlling insects in warm climates. He pointed out the need for detailed weather data at the storage site so that it can be decided whether effective cooling can be done using ambient air. Also at that conference Navarro (6) discussed the use of aeration of grain as a means of controlling grain storage insects. Navarro et al. (22) reported observations on nearly 2 years' storage of 1142 tons of wheat in Israel, using only ambient aeration to cool the grain, a demonstration of practical use of aeration for cooling grain in a subtropical area.

Aeration is important not only to cool grain but also to equalize the temperatures throughout the grain mass to prevent moisture migration; furthermore, it may be used for ambient-air drying, particularly with high airflows.

Besides the papers already mentioned, there are others with good discussions of aeration of grain, such as Calderon's paper (23) presented at the Grain Storage Seminar in Ibadan in 1971; Burrell's chapter in the book edited by Christensen (24), Storage of Cereal Grains and Their Products (Burrell also has a

chapter in that book on chilling); and a U.S. Department of Agriculture report by Holman (25).

Use of low temperatures, as with any control measure, must be economically feasible. Remarks here will be limited to use of ambient air. Costs range from nothing upward; in areas such as Fargo, North Dakota, small storages of grain may cool sufficiently and quickly enough without aeration, while larger storages may be cooled quickly with aeration. Each situation must be analyzed with regard to availability of suitable air, availability of aeration equipment, and costs of that equipment and of the increasing cost of energy to operate it.

COSTS OF COOLING BY AERATION--AN EXAMPLE: An example of relative costs of aeration and the use of chemicals in Kansas follows. The costs are only estimates, and labor cost is not taken into consideration. Per bushel or per ton costs for materials and labor vary with the size and type of storage facility.

Cost of protectant chemicals applied directly to grain:

Malathion	0.2¢/bushel
Pyrethrins - piperonyl butoxide	0.86¢

Cost of fumigants:

"80:20" (CCl_4:CS_2)	0.8¢/bushel
Phosphine	0.23¢
Methyl bromide	0.3¢

Estimated cost of aeration of a 3000-bushel bin of wheat:

Installation, including full, perforated floor:

Perforated floor	$1,000.00
Fan (1.5 hp)	500.00
	$1,500.00 = 50¢/ bushel capacity

Installation, including "Y" perforated duct, rather than a perforated floor:

Perforated duct	$ 200.00
Fan	500.00
	$ 700.00

Estimated life of fan is 15 years, so cost of equipment ranges from 1.5 to 3.3¢/ bushel/ year.

Cost of operation of the fan: Using 0.1 ft^3/min/bushel airflow, it takes approximately 120 hr for the cooling front to move through a mass of grain. The 1.5-hp

motor consumes about 1.5 kilowatt-hr of electricity at a cost of about 5¢/kilowatt-hr, thus about 7.5¢/hr. For each aeration of 120 hr, the cost will be about $9.00, which equals 0.3¢/bushel.

For Kansas, one recommendation is for at least five aerations per year for wheat stored on the farm, with the first immediately after harvest to remove "field heat"; another perhaps 6 weeks later while temperatures are still too warm to effectively control insects. A month later, temperatures will usually be low enough that grain can be cooled to below the "safe" level as far as insects are concerned.

If five aerations are done, the total cost/year for wheat will be approximately 2-5¢/bushel. In areas farther north, costs will be considerably less. Also, important benefits other than insect control are gained by aeration. It prevents moisture migration, which is not prevented by use of chemicals, except that caused by insect-induced heating. Although the cost is greater than a single treatment with chemicals, the benefits exceed those of insect control alone, and with careful monitoring and selective aeration, total fan operation can be reduced.

FACTORS INFLUENCING EFFECTIVENESS OF COOLING USING AERATION: Several factors influence effectiveness of forced air cooling in controlling insects.

Condition of the grain mass. Sampling and monitoring of the grain should determine as accurately as possible the temperature, moisture content, extent of biological activity and the organisms causing it, and the variability in density and particle size in the grain mass (broken kernels, dust, chaff, etc.), which influence uniformity of airflow. A hot spot caused by molds or insects may not be cooled adequately.

Air-moving equipment. Design of the duct system in relation to the type of storage structure is important, as well as quality and power of the blower. The objective is an adequate and as uniform airflow as possible, in order to effectively and economically cool all parts of the grain.

Weather conditions. Familiarity with the temperature and humidity characteristics of the area, particularly where adequacy of low temperatures is marginal, will permit the most effective use of the low temperatures that are available.

Interrelationships of temperature, relative humidity, and moisture content. Understanding of the interrelationships of temperature, relative humidity, and moisture content is important, especially to prevent adding excessive moisture to the grain during aeration.

There is no doubt that low temperatures could be used to advantage more than they now are, at least in the United States--

particularly ambient aeration. All situations differ--climatic conditions, equipment and energy availability, expertise, the variable biological and physical factors within each grain store--and, of course, economic feasibility.

Use of low temperatures should be considered wherever feasible, either alone or in conjunction with other control methods; and more information should be accumulated on the effects of low temperatures on the biology, behavior, and ecology of the various grain insects.

REFERENCES:

(1) Cotton, R. T., Frankenfeld, J. C. Killing mill insects by freezing. American Miller, Sept. (1942).

(2) Dean, G. A. Heat as a means of controlling mill insects. J. Kansas Ent. Soc. 4 (1911) 142.

(3) Dermott, T., Evans, D. E. An evaluation of fluidized-bed heating as a means of disinfesting wheat. J. stored Prod. Res. 14 (1978) 1.

(4) Nelson, S. O. Radiofrequency, infrared, and ultraviolet radiation for control of stored-product insects: prospects and limitations. Proc. 1st Internat. Conf. on Stored-Prod. Ent., Savannah, Georgia, U.S.A. Oct. (1974) 325.

(5) Kirkpatrick, R. L. The use of infrared and microwave radiation for control of stored-product insects. Proc. 1st Internat. Conf. on Stored-Prod. Ent., Savannah, Georgia, U.S.A. Oct. (1974) 431.

(6) Navarro, S. Aeration of grain as a non-chemical method for the control of insects in the grain bulk. Proc. 1st Internat. Conf. on Stored-Prod. Ent., Savannah, Georgia, U.S.A. Oct. (1974) 341.

(7) Calderon, M. The possible role of aeration in the control of stored product insects in warm climates. Proc.1st Internat. Conf. on Stored-Prod. Ent., Savannah, Georgia, U.S.A. Oct. (1974) 77.

(8) Smith, L. B. The role of low temperature to control stored food pests. Proc. 1st Internat. Conf. on Stored-Prod. Ent., Savannah, Georgia, U.S.A. Oct. (1974) 418.

(9) Howe, R. W. A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. J. Stored Prod. Res. 1 (1965) 177.

(10) Burges, H. D., Burrell, N. Y. Cooling bulk grain in the British climate to control storage insects and to improve keeping quality. J. Sci. Fd. Agric. 15 (1964) 32.

(11) Sinha, R. N. Climate and potential range of distribution of stored-product mites in Japan. J. Econ. Ent. 61 (1968) 70.

(12) Solomon, M. E., Adamson, B. E. The powers of survival of storage and domestic pests under winter conditions in Britain. Bull. Ent. Res. 46 (1955) 311.

(13) Smith, L. B. Effects of cold-acclimation on supercooling and survival of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) at subzero temperatures. Canadian J. Zool. 48 (1970) 853.
(14) Evans, D. E. Some aspects of acclimation to low temperatures in the grain weevils *Sitophilus oryzae* (L.) and *S. granarius* (L.) Australian J. Ecol. 2 (1977) 309.
(15) Ernst, S. A., Mutchmor, J. A. Dispersal of three species of grain beetles as a function of thermal acclimation, temperature, and larval size. J. Stored Prod. Res. 5 (1969) 407.
(16) Sinha, R. N. Effect of low temperature on the survival of some stored products mites. Acarologia 6 (1964) 336.
(17) David, M. R., Mills, R. B., White, G. D. Effects of low temperature acclimation on developmental stages of stored-product insects. Environ. Ent. 6 (1977) 181.
(18) Granovsky, T. A., Mills, R. B. Feeding and mortality of *Sitophilus granarius* (L.) adults exposed to simulated winter farm bin temperatures. (Unpub. manuscript).
(19) Granovsky, T. A. Low temperature acclimation of *Sitophilus granarius* (L.), *Tribolium castaneum* (Herbst) and *Oryzaephilus surinamensis* (L.) (Coleoptera): Effects on survival, physiology, and population interactions. Ph.D. Dissertation, Kansas State University, Manhattan, Kansas, U.S.A. (1978) 190 p.
(20) Evans, D. E. The capacity for increase at a low temperature of some Australian populations of the granary weevil, *Sitophilus granarius* (L.). Australian J. Ecol. 2 (1977) 69.
(21) Evans, D. E. The capacity for increase at a low temperature of several Australian populations of *Sitophilus oryzae* (L.). Australian J. Ecol. 2 (1977) 55.
(22) Navarro, S., Donahaye, E. Calderon, M. Observations on prolonged grain storage with forced aeration in Israel. J. Stored Prod. Res. 5 (1969) 73.
(23) Calderon, M. Aeration of grain - benefits and limitations. OEPP/EPPO Bull. No. 6 (1972) 83.
(24) Burrell, N. J. "Aeration." Ch. 12, Storage of Cereal Grains and Their Products, 2nd ed. (Christensen, C. M., Ed.), Amer. Assoc. Cereal Chem. Monograph Series, 5 (1974).
(25) Holman, L. E. Aeration of grain in commercial storages. U.S. Dept. Agric. Marketing Res. Rep. No. 178 (1960). 46 p.

Contribution no. 79-70-A, Department of Entomology, Kansas Agricultural Experiment Station, Manhattan 66506.

LARGE-SCALE TRIALS ON THE USE OF CONTROLLED ATMOSPHERES FOR THE CONTROL OF STORED GRAIN INSECTS

S. NAVARRO, M. GONEN, and A. SCHWARTZ
Stored Products Division, Agricultural Research Organization, P.O. Box 6, Bet Dagan, ISRAEL

INTRODUCTION: Research on the technology of the application of controlled atmospheres as a substitute for the use of chemical insecticides, has received special attention in view of the problems arising from the development of insecticide resistance and pesticide residues (1). The controlled atmosphere storage of dry grain (for cereals below 13% moisture content) consists of altering the atmospheric composition within a structure containing the grain to give a combination of the atmospheric gases lethal to insects.

Various combinations of atmospheric gases have been suggested for the control of stored-product insects. Controlled atmospheres which could be utilized for grain storage are those with reduced oxygen (O_2) tension and/or those with an increased carbon dioxide (CO_2) content. Means of producing controlled atmospheres include the purging of airtight silos with nitrogen (N_2) (to reduce the O_2 to less than 2%) or CO_2 from tankers (to produce a mixture of 60% CO_2 in air), or to use low O_2 atmospheres produced by hydrocarbon burners (typically producing atmospheres containing 13% CO_2, less than 1% O_2, with the balance N_2). (2, 3).

Field trials aimed at using N_2 or CO_2 to establish and maintain an atmosphere containing 1.5% O_2 or 60% CO_2 have been carried out (1, 4). In these trials the approach was to seal silos to a standard which minimized the amount of gas required to maintain the atmosphere within acceptable limits. Although the use of N_2 or CO_2 from gas tankers gave satisfactory results, they may require long hauls to the site of use. It was demonstrated that on-site generation using exothermic inert-atmosphere generators was promising also (5).

Generation of an inert atmosphere may be possible employing propane burners using a flame generator or by catalytic combustion. The large-scale trials described in this paper were aimed at ascertaining the feasibility of using a catalytic O_2 converter to generate atmospheres for the control of stored grain insects.

MATERIALS AND METHODS: Inert atmosphere generator. The generator consisted of an O_2 converter type CIE manufactured by Sulzer, Switzerland, used in the fruit conservation industry. During operation, propane gas is combusted catalytically without flame, and the exhaust gases are blown into the storage structure by a

blower at a rate of 144 m^3/hr. Combustion takes place in the reaction chamber and following it the gases are cooled by water in a spray cooler. Water removed from the gases leaves the cooler through a seal leg. The exhaust gases were conveyed to the silo by a P.V.C. pipe of 105 mm i.d. The O_2 converter was operated in recirculation, with the gases blown through the roof of the silo and sucked into the converter through a pipe connected to the aeration duct.

Operation of the O_2 converter. The converter was operated in two phases, the purge and the maintenance. In the purge phase the converter was operated continuously until the desired atmosphere was obtained within the bin. Towards the end of this phase, when the O_2 concentration within the bin dropped to 3% to maintain the converter in operation, a calculated flow of ambient air was permitted to penetrate through the recirculated gas entry duct of the converter. In this way O_2 concentrations lower than 0.5% were created within the bin.

In the maintenance phase, the atmosphere created within the bin was maintained for the required period of time. To achieve this it was necessary to operate the converter intermittently to maintain the desired gas concentration against leakage.

Experimental bins. Experiments were conducted in three welded steel bins containing 1252, 1193, and 1106 tons of wheat (referred to in the text as bins A, B, and C, respectively). Bins A and B were similar in shape and dimensions: 14 m diameter, 11 m high, with a flat floor (Figure 1). Bin C had a 9.8 m diameter and was 23.5 m high, with a conical base.

RESULTS AND DISCUSSION: Operation of the O_2 converter. Data obtained on operating the converter in five trials are shown in Table 1. The estimated operation time required in the purge phase for reducing the O_2 concentration from 21 to 0.5% was 57, 59, and 54 hr for bins A, B, and C, respectively. However, from Table 1 it is seen that in different trials the reduction of O_2 concentration was achieved in 37.3 to 74.4 hr and only in trial no. IV did the operation last 60.3 hr, as expected. The main factors responsible for these differences were the gastightness level of the bin and the existing insect population. In trials no. I and III, a longer operation time was required due to low gastightness and in trial no. II the initial high insect population contributed to consumption of O_2 by respiration, thus shortening the converter operation period.

The catalytic converter consumes electricity for the heat exchanger before it reaches its operation temperature, and for the blower. From Table 1 it is seen that the mean energy consumption was 3.01 kw/hr. However, in trials no. II to IV the energy consumption was higher, apparently due to a failure in the

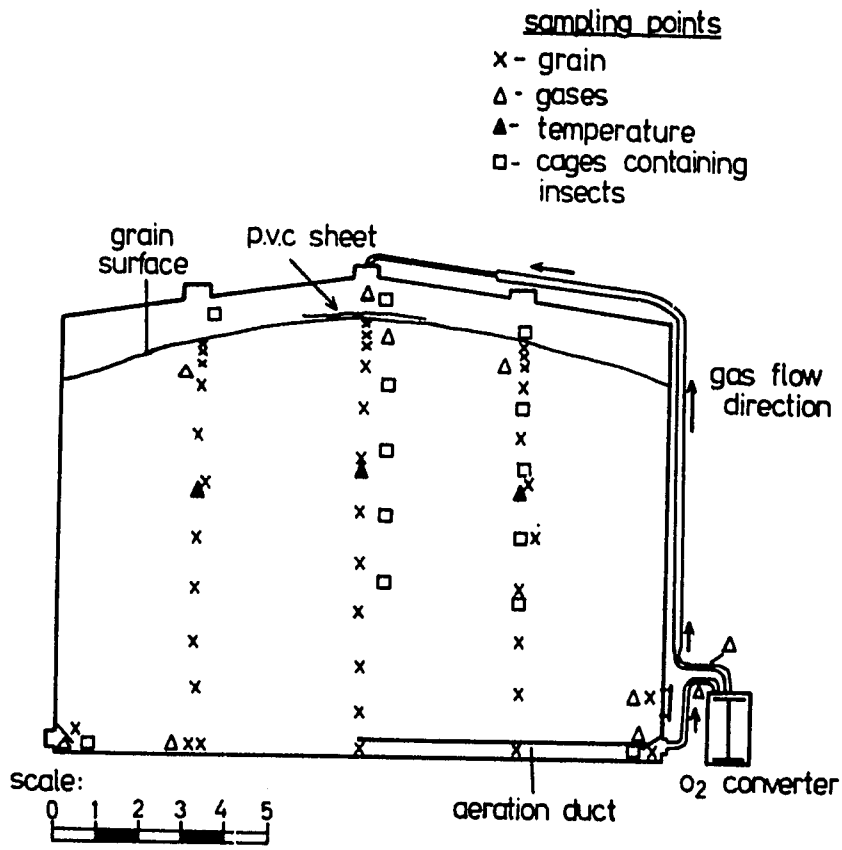


FIGURE 1. Vertical section of the steel bin containing 1193 tons of wheat on which the oxygen converter was tested.

reaction chamber. The results obtained in trials no. I and V were closer to the manufacturers' specifications. The energy consumption during the maintenance phase was higher, due to intermittent operation requiring repeated preheating at each operation stage.

The heated gases were cooled using tap water at a mean rate of 1300 l/hr (Table I). This may present a problem in dry areas, where the water supply is limited. However, an alternative that should be considered for cooling the gases is the use of recirculated water through cooling towers.

Mean propane gas consumption was 1.17 kg/hr (Table I). The longest operation period in trial no. V was 114.5 hr (including the maintenance phase) for which the propane consumption was 136 kg. This figure should be compared with that in the method of application of N_2 which requires approximately 1315 kg of N_2

Table I. Data obtained during the operation of the oxygen converter on three different experimental bins containing wheat

Bin capacity (tons of wheat)	Trial No.	Phase of operation a = purge b = maintenance	Date of trial	Operati time (hr)	Energy consumption rate (kw/hr)	Water required for cooling gases (l/hr)	Propane gas combusti (kg/hr)	Rate of water condensing in the exhaust pipe (l/hr)	Rate of O_2 consumption m^3/h
1252	I	a	March-April 1975	71.7	1.42	1017	1.28	0.90	2.7
1193	II	a	July 1975	37.3	2.80	1371	1.16	1.03	-
	III	a	Sept. 1975	74.4	4.24	1086	1.08	1.26	-
	IV	a	Jan. 1976	60.3	4.21	1852	1.12	1.53	2.6
		b	Jan. 1976	19.5	7.21	1308	1.21	1.07	-
1106	V	a	July 1977	74.2	1.49	-	1.08	0.84	-
		b	July-Augu 1977	40.3	2.72	-	1.38	1.63	-
				Mean	3.01	1300	1.17	1.16	2.65

(calculated for maintaining 1% O_2 for three weeks), based on suggested practical requirements (2). Under conditions in which transport of nitrogen constitutes one of the major costs and necessitates long hauls to the site of use, the method of on-site generation of the controlled atmosphere should be considered.

The exhaust pipe of the converter was connected to the apex of the bin (Figure 1). This was done to permit the water vapor in the gas mixture, which had 90-96% relative humidity, to condense in the pipe. The mean rate of this condensed water collected from the bottom of the pipe was 1.16 l/hr (Table 1). The water was collected to prevent its entry into the bin, thereby increasing the moisture content of the grain.

The calculated mean rate of O_2 consumption by the converter was 2.65 m^3/hr, very close to the figure of 2.6 m^3 by the manufacturers of the converter.

Changes in gas concentration. Typical changes in concentration of O_2 and CO_2 within the bin obtained in trial no. IV are shown in Figure 2. In this trial the purge phase lasted

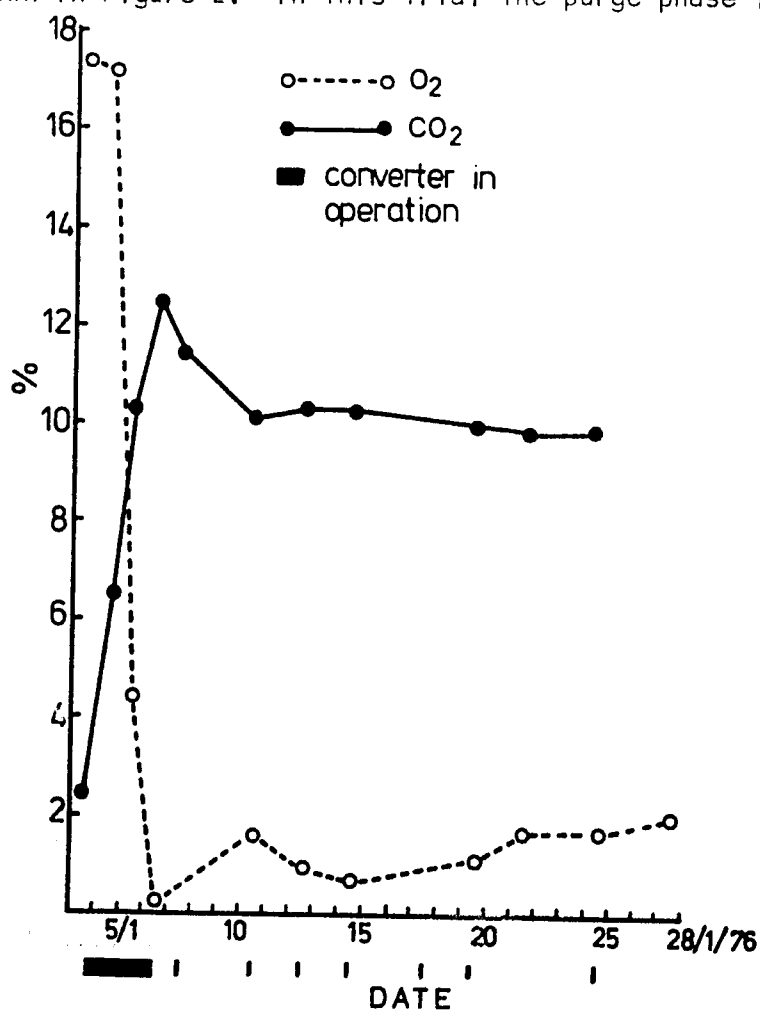


Figure 2. Changes in gas composition by intermittent operation of oxygen converter for a total of 79.8 hr in a horizontal steel bin containing 1193 tons of wheat

60.3 hr, during which the average O_2 concentration was reduced to 0.2%. During the maintenance phase, which lasted 21 days, the O_2 concentration was maintained below 2% by intermittent operation of the converter for a total of 19.5 hr.

Results of other trials showed that at the end of the purge phase O_2 concentration was reduced to the range of 0.2-1.2%. Operation of the converter in all the trials resulted in an increase in CO_2 level to 9.8-13.3%.

In tests carried out using two exothermic inert-atmosphere generators producing 850 m^3/hr of inert atmosphere, concentrations of 0.1-0.9% O_2 were obtained after 24 hr in a bin of 540 tons of wheat (5). Although the volume of the atmosphere and the rate of O_2 reduction by these large units were high, the results of the present study support the feasibility of inert-atmospheric generators for producing low O_2 atmosphere in structures containing grain.

Moisture content and grain temperature. The moisture content of wheat samples taken from different layers of the bin showed that the surface layer was the most markedly affected by purging the grain (Table II). Grain samples taken from 0-10 cm

Table II. Moisture content of grain before and after controlled atmosphere purging, and temperature of the bulk in experimental bins containing wheat

Trial No.	Moisture content of grain (%)				Temperature of grain(°C)
	Surface layer*		Within the bulk		
	Before purging	After purging	Before purging	After purging	
I	12.2	12.8	11.6	11.8	20
II	12.5	13.0	10.7	10.4	36
III	12.2	12.8	10.2	10.1	28
IV	13.0	13.6	10.2	10.5	28
V	9.6	-	11.0	-	33

*Measured on samples taken from the top 0-10 cm of the grain bulk.

below the surface of the bulk showed an almost constant increase of 0.6% in moisture content. To enable the gases containing high humidity to disperse, a P.V.C. sheet (3 x 3 m) was placed above the bulk's surface and below the point of gas entry to the bin. This prevented moistening of grain at the gas inlet location.

Most of the grain in the bulk was not markedly affected by the humidity of the gases.

The temperature factor is an important one in determining the exposure time required to achieve insect mortality (6, 7). Temperature measurements (shown in Table II) indicate that in trial II, the highest temperature (38° C)prevailed for producing mortality at a shorter exposure time.

Insect mortality. Results of tests carried out on mortality of insects naturally found in grain and of test insects introduced into the bulk, are shown in Table III. The 100% mortality achieved in trial no. II can be attributed to the high temperature prevailing in the bulk during the trial. In contrast to this, in trials no. III and IV insects survived, especially in the surface layer and on the bin floor.

Controlled atmosphere storage has no residual effect on grain, which after treatment is subject to further damage by surviving or invading insects. Insect aggregation in an O_2 concentration that permits survival is a limitation of controlled atmosphere storage. The dispersal response of three stored product insects to atmospheric gas gradients has been investigated (8). The results obtained for *Oryzaephilus surinamensis*, *Sitophilus oryzae*, and *Rhyzopertha dominica* in the presence of a stable O_2 gradient indicated that dispersion was significantly restricted by 0.9% O_2. It appears that there is little chance of insects dispersing from low O_2 levels towards regions in the bulk having high O_2 levels as occur in the region of leaks in the structure. Insects already found in such a region may survive the treatment, and form a source for reinfesting the bulk after treatment. The surviving insect populations found in the surface layer and on the bin floor seem, therefore, to have derived from insects already existing in these locations.

The natural insect population recorded in trials no. II, III, and IV comprised, in decreasing intensity, the following species: *O. surinamensis*, *Tribolium castaneum*, *R. dominica*, and *S. oryzae*. It has been demonstrated that in 2.5% O_2, mortality of *T. castaneum* larvae and adults was 100% after 14 days' exposure at 26.7°C (9). In an atmosphere of less than 1% O_2 at 27°C, 95% mortality of *O. surinamensis* and *R. dominica* adults was obtained after exposure for 11.2 and 31.0 hr, respectively. These data suggest that the given gas concentrations for the exposure of 24 days in trial no. IV should cause complete control of insects. Survival of the natural insect population recorded in trial no. IV was found in one out of 56 grain samples taken from the bin. This sample was taken from the region around the aeration duct on the bin floor. In that location, consistently higher O_2 concentrations were recorded than at the remaining sampling points in the bin. This apparently was the cause of insect survival.

Although the mortality of test insects introduced into the bin was high, the causes of survival may be explained as

Table III. Insect mortality obtained in the natural insect population found in grain samples (1 kg), and in test insects introduced into the bin treated with controlled atmospheres

Trial No.	Exposure time (days) after start purging	Sampling location*	For natural insect population: Number of samples examined	For natural insect population: Number of insects per sample	Insect mortality (%): Natural insect population	Test insects introduced into the bin: O. surinamensis larvae	O. surinamensis adults	T. castaneum larvae	T. castaneum adults	S. oryzae larvae	S. oryzae adults	R. dominica adults
II	22	a	5	307	100	–	100	–	100	–	100	–
		b	15	65	100	–	100	–	100	–	100	–
		c	2	8	100	–	100	–	100	–	100	–
III	62	a	5	297	99.9	–	100	–	100	–	100	–
		b	44	29	100	–	–	–	–	–	100	–
		c	6	85	81.1	–	88	–	75	–	100	–
IV	24	a	5	162	100	85	100	96	100	100	100	100
		b	44	46	100	–	–	–	100	–	–	–
		c	7	81	98.1	100	100	92	96	100	100	99

* a = surface layer and head space, b = 0.3 to 9 m depth from surface of bulk, c = bin floor.

follows: (a) Insect cages containing insects were located close to bin opening in the head space and bin floor (Figure 1). Although the O_2 concentration was even during the intermittent operation of the converter, the rate of increase in O_2 levels between each operation was higher in these locations, relative to other sampling points. (b) Trial IV was carried out during the cool season (January) of the year, when ambient temperatures were in the range of 7-17°C. Temperatures at the bin periphery were significantly lower than in the grain bulk, a fact which may have contributed to test insect survival.

Gastightness of the structures. In controlled atmosphere treatment a high standard of gastightness is essential to prevent rapid gas loss. To determine the degree of gastightness, the static pressure test was applied in the present study. This test has the advantage of being independent of bin volume. The test consisted of raising the pressure within the structure by introducing different flow input rates and recording their equivalent differential pressures relative to ambient (10).

Results on static pressure - flow tests and the calculated air ingress rate calculated for different trials are given in Table IV. From the table it is seen that to maintain a static pressure of 10 Pa - the higher the flow rate required, the higher was the calculated air ingress rate that brought about an increase in O_2 level after the controlled atmosphere was generated. However, more field tests are required to collate additional information for interpreting the gastightness measurements in the light of recent developments. The results in Table IV may serve as guidelines for a comparative analysis of the gastightness in large-scale trials.

CONCLUSIONS: The results of this work indicate the feasibility of using an O_2 converter for generating controlled atmospheres in welded steel bins. The experimental structures, with slight modifications, gave a reasonable level of gastightness. However, more research is required to ascertain the feasibility of the controlled atmosphere method in bins different in size, structure, and degree of gastightness.

The application of a controlled atmosphere gave more satisfactory results in grain at high temperatures. Application of the method for insect control when the grain temperature is high, and the use of aeration subsequently to reduce grain temperature, should be considered as complementary conservation methods.

ACKNOWLEDGMENTS: The authors thank Sulzer Brothers Ltd., Switzerland, and their representatives in Israel - Mr. R. Grunstein and Mr. P. Leitner - for the loan of the O_2 converter; silo managers Mr. E. Ben-Ami, Mr. N. Dayagi, and Mr. T. Sherf, for permitting the use of experimental bins; and Mr. Kashanchi, Mr. H. Frandji, and Mr. A. Azrieli, who carried out many of the experimental observations, for their technical help.

Table IV. Results on static pressure-flow tests compared with calculated air ingress rate after controlled atmosphere was generated in welded steel bins

Bin capacity (tons of wheat)	Trial No.	Head space-to-volume ratio	n*	10^3 x b*	10^3 x Flowrate (m^3 sec^{-1}) of 10 Pa	Calculated air ingress rate (%/day)
1252	I	0.049	0.1668	3.491	5.13	2.778
1193	III	0.094	0.6930	0.418	2.06	1.373
	IV+	0.094	0.7277	0.153	0.82	0.876
1106	V	0.079	1.0319	0.130	1.40	1.024

* From equation $Q = b\Delta p^n$

p = pressure difference (Pa)

Q = input flow (m^3 sec^{-1})

\+ Test carried out on same bin after gastightness was improved.

REFERENCES:

(1) Bailey, S. W., Banks, H. J., The use of controlled atmospheres for the storage of grain, Proc. First Int. Work. Conf. Stored Prod. Entomol., Savannah, Georgia, Oct. 1974 (1975) 362.

(2) Banks, H. J., Annis, P. C., Suggested procedures for controlled atmosphere storage of dry grain. CSIRO, Div. Entomol. Tech. Pap. no. 13 (1977).

(3) Jay, E. G., Suggested conditions and procedures for using carbon dioxide to control insects in grain storage facilities. USDA-ARS, 51-46, Sept. 1971 (1971).

(4) Jay, E. G., Pearman, G. C. Jr., Carbon dioxide for control of an insect infestation in stored corn (maize). J. Stored Prod. Res. 9 (1973) 25.

(5) Storey, C. L., Exothermic inert-atmosphere generators for control of insects in stored wheat. J. Econ. Entomol. 66 (1973) 511.

(6) Lindgren, D. L., Vincent, L. E., Effect of atmospheric gases alone or in combination on the mortality of granary and rice weevils. J. Econ. Entomol. 63 (1970) 1926.

(7) Storey, C. L., Mortality of adult stored-product insects in an atmosphere produced by an exothermic inert atmosphere generator. J. Econ. Entomol. 68 (1975) 316.

(8) Navarro, S., Studies on dispersion of grain insects in O_2 and CO_2 gradients in wheat. Rep. Vis. Scient. Plant Res. Inst., Victoria (1977).

(9) Harein, P. K., Press, A. F., Mortality of stored-peanut insects exposed to mixtures of atmospheric gases at various temperatures. J. Stored Prod. Res. 4 (1968) 77.

(10) Sharp, A. K., Irving, A. R., Banks, H. J., Leakage of air into ISO isolated containers. Int. Inst. Refrig., Melbourne, Vict. (1976) 65.

THE EFFECTS OF UV RADIATION ON STORED-PRODUCT INSECTS

W. A. Bruce and P. T. M. Lum
Stored-Product Insects Research and Development Laboratory
ARS, USDA
Savannah, Georgia, 31403
U. S. A.

INTRODUCTION: The current trend toward deemphasizing the use of insecticides to control insect populations has rendered it imperative that appropriate alternative control measures become established. Interest in the use of short wavelength (253 nm) ultraviolet (UV) radiation as a method of insect control has therefore revived in recent years, partly because it is non-chemical and partly because it could be extremely effective in certain situations (e.g. insect rearing facilities). However, despite its documented lethal effects (1, 2, 3), UV radiation has played no part in control programs to date. There are several reasons. Undoubtedly, the primary difficulty is that UV radiation, at least at the shorter wavelengths, can be injurious to human cells although the underlying mechanisms are only partly understood (4). Any attempt, therefore, to employ high intensity sources of UV radiation in areas of human activity would probably be resisted. Lack of penetration of these light rays through some substrates would certainly be a second reason. However, there are alternative ways of using UV: a pest species could be attracted to a shielded trap, a commodity could be irradiated for a very short time, or the phenomenon of photoreactivation (light repair of UV-induced damage) could be used. UV radiation should be viewed not only as a control method with lethal capabilities but also one which can provide new approaches to insect control. For example, pheromone breakdown (5, 6) and the converse, pheromone protection using UV-absorbing compounds, offer exciting possibilities. It is the intention of the authors to provide a brief overview of the use and potential of short wavelength UV radiation as a broad-based tool for insect control.

USES OF UV RADIATION (253 nm): Direct Effects -

1) Indian Meal Moth - The direct harmful effects of UV radiation are well known for several species of insects including the tobacco budworm, *Heliothis virescens* (F.), (7); American cockroach, *Periplaneta americana* (L.), (1, 3); Indian meal moth, *Plodia interpunctella* (Hübner) (8); almond moth, *Ephestia cautella* (Walker) (9); and others (2). However, studies involving these stored-product pest species have been confined primarily to the egg stage.

The effect of UV radiation on the egg stage (8) can be briefly summarized. Eggs collected for a 2 h period were held for 2, 8, 24, 48, or 64 h before exposure to UV radiation from two 15W germicidal lamps (GE 15T8). Eggs 24 h or older showed an

increased sensitivity to UV (λ = 253nm @ 200 $\mu w/cm^2$) with increased age and increased exposure time. Two-h-old eggs showed approximately the same sensitivity to UV as 24-h-old eggs whereas 8-h-old eggs were the least sensitive of all age groups. The reasons for these differences in sensitivity with age are unclear. It is possible that either the differences reflect changes in a suspected target such as nucleic acid composition or other biochemical and physical states during embryonic development (2).

Larvae and pupae received the same treatment as did the eggs. Fourth-instar larvae were exposed to UV radiation for 1-8, 24, and 48 h. Pupae collected every 24 h and ranging in age from 24 to 168 h were exposed for 8, 24, and 48 h. In addition, the local effect of UV radiation was determined by exposing 24-h-old pupae venter up, dorsum up, head only, and terminal segments only. For venter and dorsum exposures pupae were placed on strips of plasticine tape in the appropriate position; head and posterior abdominal exposures were accomplished by embedding the unexposed portions of the pupa in plasticine. Larvae (45 larvae/time period) showed little tendency to pupate after 4 h exposure (Fig. 1). Those that did not pupate continued, in the majority of cases, their wandering search for a pupation site. Irradiation of pupae less than 96 h old produced virtually no normal adult emergence regardless of exposure time. Normal emergence (6-7 days after pupation) is here defined as a condition in which adult moths are structurally complete and non-abberrant and are able to completely disengage from the pupal case. After 96 h of age the percentage of normal adults increased steadily even after 48 h irradiation (Fig. 2). No differences with regard to sex were observed. Normal adult emergence was observed in all exposure positions except that in which the wing area was irradiated. This observation correlates with the fact that the radiation damage was always confined to the wing area in tests in which pupae were not restricted.

2) Stored-Product Mites - Adult females of *Tyrophagus putrescentiae* and *Pyemotes tritici* (Lagreze-Fossat & Montagné) were collected from stock cultures (25° C, 60% RH) and placed on double sticky tape secured to standard microscope slides (25 mites/slide). Three replicates of 100 mites were exposed at each UV dosage. A similar number of controls was used for each test. Radiation intensity measured 900 $\mu W/cm^2$. Periodic exposures were applied hourly for 8 h to achieve a total dosage approximately equal to single dose. After 24 h the mites were counted to determine the percentage of survival.

Continuous exposure of *T. putrescentiae* to extremely high levels of UV radiation (15,000 $\mu W/cm^2$) produced 100% mortality as did equivalent intermittent 8-h exposure. Lower dosages (single exposure) produced more subtle differences. For instance, a 50% survival dose for *T. putrescentiae* was ca. 25 min; for *P. tritici* it was less than 2 min. (Fig. 3).

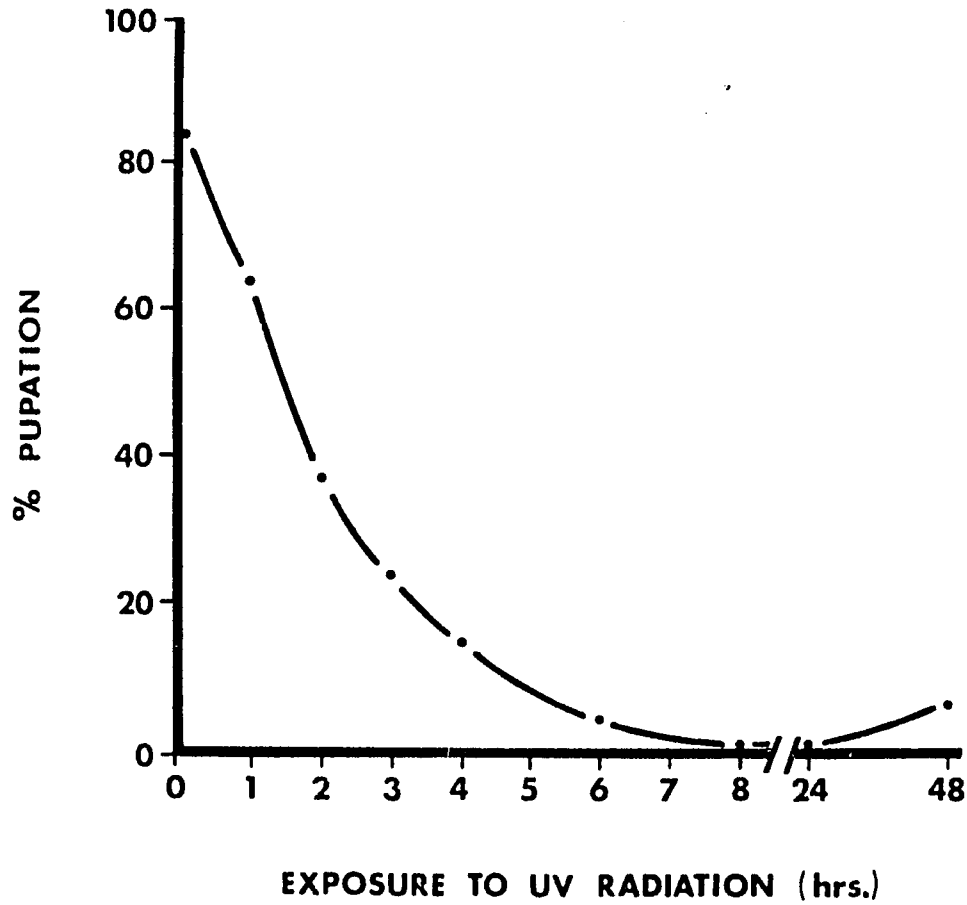


FIGURE 1. Relationship of duration of exposure of UV irradiation on 4th instar *P. interpunctella* larvae and the onset of pupation.

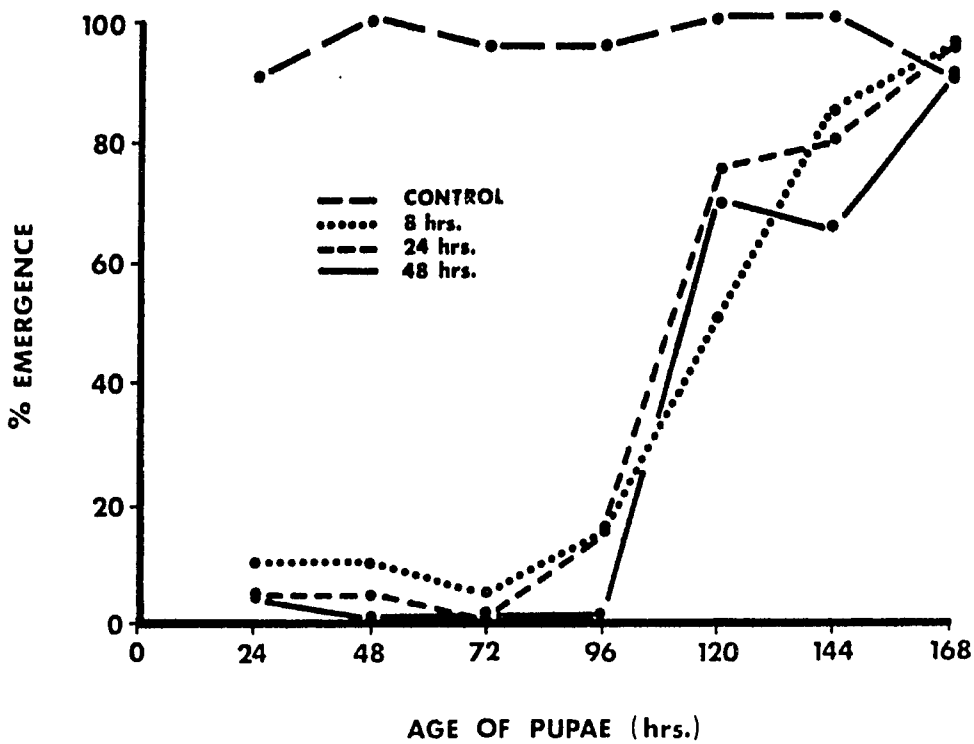


FIGURE 2. Effect of UV irradiation (8, 24, and 48 hr exposure periods) on emergence of *P. interpunctella* pupae.

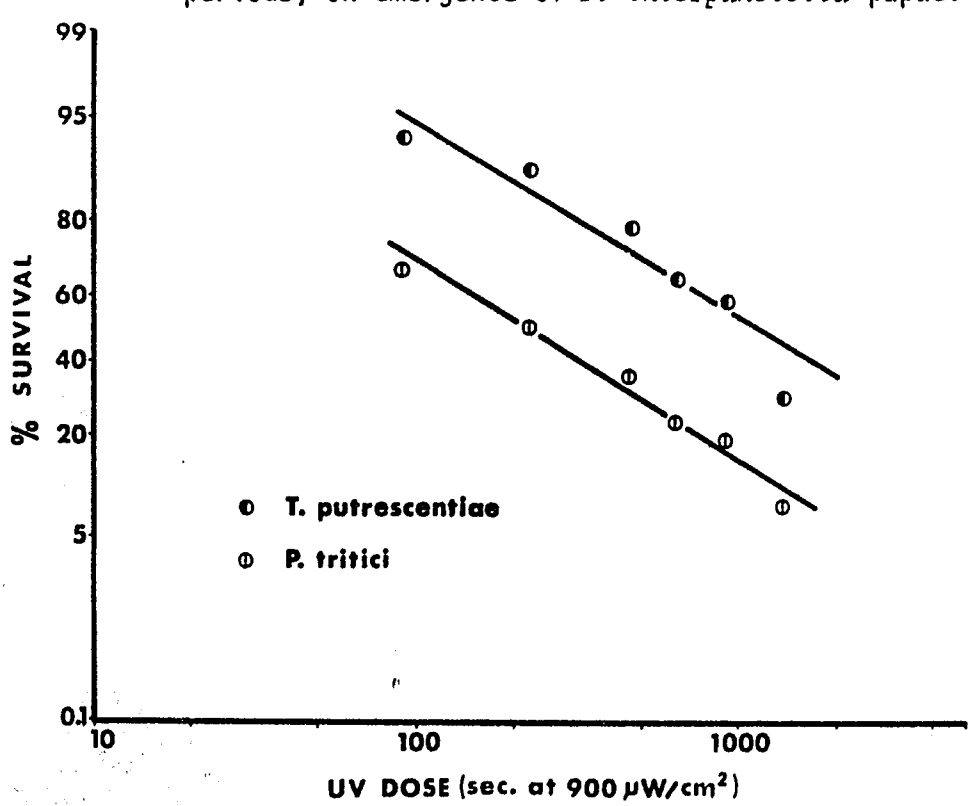


FIGURE 3. Susceptibility of *T. putrescentiae* and *P. tritici* mites to varying durations of UV radiation.

3) Photoreactivation - Photoreactivation is a phenomenon that could have profound impact on any insect control system involving UV radiation. Eggs of the Indian meal moth were collected, prepared, and exposed to UV as described previously. After exposure half the eggs were placed in the dark and half were placed in a lighted (fluorescent) room. Percentage hatch was determined after 72 h. Also, after each of the single exposures of *T. putrescentiae* females to UV as described previously the mites were placed in either lighted or darkened areas.

Exposures to light or dark had no effect on 2-h-old or 64-h-old eggs of P. interpunctella. However, at all other age groupings differences were noted (Table I). The LT_{50} for an

TABLE I. Photoreactivation: Susceptibility of *P. interpunctella* eggs to light or dark regimes after exposure to UV radiation.

Age of eggs at exposure to UV (h)	LT_{50} (Min)		LT_{95} (Min)	
	Light	Dark	Light	Dark
2	2.7	2.5	9.0	7.0
8	3.5	0.6	15.0	3.5
24	4.0	1.0	11.0	3.2
48	2.5	1.0	6.0	2.5
64	0.7	0.4	1.6	1.0

8-h-old egg was ca. 3.5 min in light - 0.6 min in dark; the LT_{95} - 15 min in light - 3.5 min in dark. Results were similar with *T. putrescentiae*. An LT_{50} would require almost a 10-fold increase in time exposure for those mites maintained in continuous light following exposure to UV. In addition, treating mites to periodic exposure to UV gave results similar to those results obtained from mites given single exposures and held in the dark. Mites placed in the dark had higher mortalities than did those mites placed in light after exposure to UV.

Indirect Effects -

1) Pheromone Degradation - One aspect of the use of physical methods to control stored-product insects that has not been adequately studied is that of pheromone degradation. In theory, the concept is simple: disrupt the ability of the insect to communicate with others of its own species and control can be achieved. Pheromone degradation has been demonstrated in the laboratory (5) and also as a potential method of controlling moths in closed systems. This control concept has been described previously (6) so is only summarized here as follows: Biological activity (bioassay: fluttering response of 48-h-old unmated male

moths) of the *P. interpunctella* sex pheromone (Z,E)-9,12-tetradecadien-1-01 acetate impregnated on filter paper disks, was unaffected by 0.5-h exposure to 253-nm UV radiation. Essentially no biological activity occurred after a 2-h exposure which indicated that the male moths were apparently unable to detect the female sex pheromone.

Because a great many trapping and control schemes center around the use of pheromones, knowledge of this breakdown and the resulting implications would be of value. We were also led to speculate on the possibility of protecting these pheromones from UV light.

2) Pheromone Protection - In the matter of protraction, our attention was focused on the common UV absorbing compounds, such as those formulated in cosmetics and sunscreen lotions, as a method for preventing rapid degradation of insect pheromones. These protectants are generally the derivatives of ∿ aminobenzoate, ∿ benzophenone, ∿ phenyl acrylate, or other such compounds considered to be "UV absorbers." When the UV absorber was combined with the sex pheromone of *P. interpunctella,* we found (unpub.) continuing biological activity of the pheromone even after 48 days in the field. The controls essentially lost biological activity within 6 days. Clearly, these compounds offer tremendous potential for shielding light-sensitive chemicals from harmful UV radiation.

Discussion: At this point, it might be instructive to illustrate at least one way in which results of basic research concerned with UV radiation are actually being used in an applied situation in the insect rearing facility.

Stored-product insect rearing facilities throughout the United States and elsewhere are subject to occasionally severe outbreaks of the acarine parasite of stored-product insects, *P. tritici.* The problem of disinfestation of the facility while at the same time continuing the rearing program can be extremely complex. The use of insecticides, fumigants, heat, and cold is almost certainly precluded. The use of inert atmospheres probably could be placed in the same category because it would be necessary to prevent the movement of the inert gas into the rearing chamber which, in turn, might limit O_2 availability to the insects. On the other hand, short-wavelength UV radiation can be used for disinfestation of the facility and the outer surface of the culture jars while still making it possible to maintain the rearing program. The insects in uninfested culture jars are not harmed because the glass or other material will absorb the harmful UV rays. Access to the rearing area is not affected by the use of UV radiation because our studies indicate that short exposure times at periodic intervals resulted in higher mortality than would occur if the UV source was on continuosly. Thus, the hazard to humans need not exist because the UV lamps may be turned off at any time access to the area is required. This

technique has been used successfully at the Savannah Laboratory whenever such outbreaks of pyemotid mites have occurred. When the UV lamps are properly placed and functioning, disinfestation is complete within 1-3 days.

REFERENCES:

(1) Wharton, D. R. A., Ultraviolet repellent and lethal action on the American cockroach, J. econ. Ent. 64 (1971) 252.

(2) Beard, R. L., Lethal action of UV irradiation on insects, J. econ. Ent. 65 3 (1972) 650.

(3) Gingrich, J. B., Pratt, J. J., Jr., Mandels, G. R., Potential of ultraviolet radiation for control of American cockroach populations, Ent. exp. appl. 21 (1977) 112.

(4) Giese, A. C., Photophysiology, Vol. 1, General Principles; Action of Light on Plants, Academic Press, New York (1964).

(5) Goto, G., Masuoka, Y., Hiraga, K., Photooxidation of the sex pheromone (Z,E)-9,12-tetradecadienyl-1-acetate, Chem. Lett. 11 (1974) 1275.

(6) Bruce, W. A., Lum, P. T. M., UV radiation: Effect on synthetic sex pheromone of the Indian meal moth, Fla. Ent. 59 1 (1976) 53.

(7) Guerra, A. A., Ouye, M. T., Bullock, H. R., Effect of ultraviolet irradiation on egg hatch, subsequent larval development, and adult longevity of the tobacco budworm and the bollworm, J. econ. Ent. 61 2 (1968) 541.

(8) Bruce, W. A., Effect of UV radiation on egg hatch of *Plodia interpunctella* (Lepidoptera: Pyralidae), J. stored Prod. Res. 11 (1975) 243.

(9) Calderon, M., Navarro, S., Effects of ultra-violet irradiation on the eggs of *Ephestia cautella* (Wlk.) (Lepidoptera: Phycitidae), J. stored Prod. Res. 7 (1971) 309.

POTENTIAL OF ACCELERATED ELECTRONS FOR INSECT CONTROL IN STORED GRAIN

F. L. WATTERS
Agriculture Canada Research Station
Winnipeg, Canada

INTRODUCTION: It is now apparent that the high expectations of the last 20 years regarding the use of ionizing radiation for the disinfestation of stored grain have not materialized. Although research in various countries (1, 2, 3) indicates that radiation is technically feasible for insect control, high installation and operating costs, reservations concerning the acceptability of irradiated foods, and lack of demonstrated need to substitute radiation in place of chemical pesticides, have precluded its use for the disinfestation of stored grain. Even the comparatively recent development of insect resistance to insecticides has failed to elicit a resurgence of interest in the application of ionizing radiation for the direct control of insects. Perhaps this is because most experimental applications have employed radioactive isotopes such as Cobalt-60 to produce the penetrating radiation required to treat bulk commodities such as stored grain. We are all aware that chemical and physical pest control agents are increasingly being subjected to public scrutiny, especially those products or processes that carry the slightest suspicion of causing carcinogenic effects either during or after treatment of the product. Thus, it appears that progress in the application of radioactive isotopes for the direct treatment of infested grain will continue at a slow pace.

Accelerated electrons is another form of ionizing radiation which has possibilities for the control of pests in stored foods. This form of radiation is characterized by low penetration, high power and high dose rate. Cornwell and Bull (4) added an addendum to their paper to describe the advantages of electron accelerators over Cobalt-60 gamma radiation for the disinfestation of stored grain. Few workers, however, have taken up the challenge of investigating electron machines for insect control. The main emphasis has been on investigations of radiation produced by Cobalt-60. It is only recently that workers at the University of Mexico modified a Van de Graaff electron accelerator and incorporated it into a small-scale pilot plant for the irradiation of infested maize (3). This paper describes further studies of the use of an electron accelerator for the control of insect pests of stored foods.

MATERIALS AND METHODS: The pilot plant was designed for irradiation of infested maize at a rate of 200 kg/hr. The radiation source was a Van de Graaff accelerator which produced electrons with energies up to 1.5 MeV; a beam current of 30 μa was used. The electrons were accelerated inside a vacuum line and emerged

as a beam of electrons which were scanned or defocused by a coil system along the horn extension at frequencies of 1 to 50 Hz.

The flow of grain from the storage tank into the irradiation zone was regulated by valves adjusted to irradiate a single layer of grain. A sloping wire screen caused the maize to tumble during irradiation to facilitate uniform bombardment by electrons. Dose was determined by adjusting voltage and beam current at various flow rates. The maize was moderately infested (45-75 beetles per kilogram) with *Sitophilus oryzae*, *S. zeamais*, and *S. granarius*; *S. granarius* predominated. Samples were sifted at weekly intervals to determine survival of adults.

The pilot plant was modified to determine the susceptibility of three strains of the red flour beetle, *Tribolium castaneum* (Herbst), collected from a silo, a granary, and a laboratory culture. The insects were irradiated in groups of 25 enclosed in 3 mil polythene envelopes, 4 x 5 cm. Four replicates were used for each irradiation dose. They were introduced into the irradiation zone by means of a pulley system operated by remote control.

After irradiation, the insects were placed in vials, each containing 25 grams of whole wheat flour and corn flour (1:1) and stored in a cabinet at 27.5°C, 65% R.H.

Irradiated eggs of a laboratory strain of *T. castaneum* were retained in the envelopes to observe the date of hatching. The newly emerged larvae were then transferred to the flour medium. Larvae, pupae and adults were transferred to flour immediately after irradiation and stored at 27.5°C, 65% R.H. Controls were subjected to the same handling procedures. Insect development and survival were assessed at weekly intervals for 8 weeks.

RESULTS: Survival of adults from infested maize at various times after irradiation was a function of the applied dose (Fig. 1). The 3 krad dose was ineffective because larvae and pupae formed adults after 6 weeks. After 4 weeks, doses of 15 and 25 krad suppressed emergence in most samples but 6 weeks was required for complete control at both these doses.

Experiments on the susceptibility of three strains of *T. castaneum* to irradiation showed variable results at 7 krad and 15 krad (Fig. 2). At 7 krad, the silo strain was less affected by irradiation after 3 and 5 weeks than the granary strain or the laboratory strain. At 15 krad the granary strain was less susceptible than the other two strains at 3 and 5 weeks after irradiation. At 25 krad all 3 strains were equally susceptible.

T. castaneum eggs, 0-2 days old, were highly susceptible to irradiation. Only 34% hatched and formed adults at 1 krad; no eggs hatched at 3 krad or at higher doses. About 74% of eggs in the untreated controls hatched and formed adults.

T. castaneum larvae were less susceptible than eggs. 98% of those irradiated at 3 krad formed adults and survived

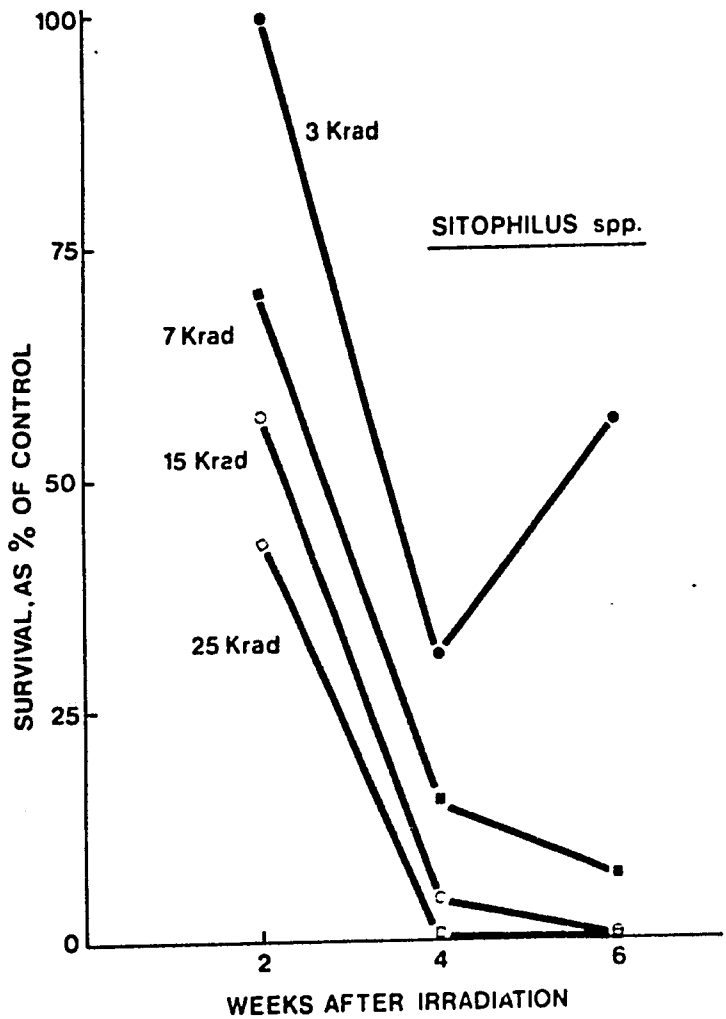


Figure 1.--Response of *Sitophilus* spp. to irradiation with accelerated electrons.

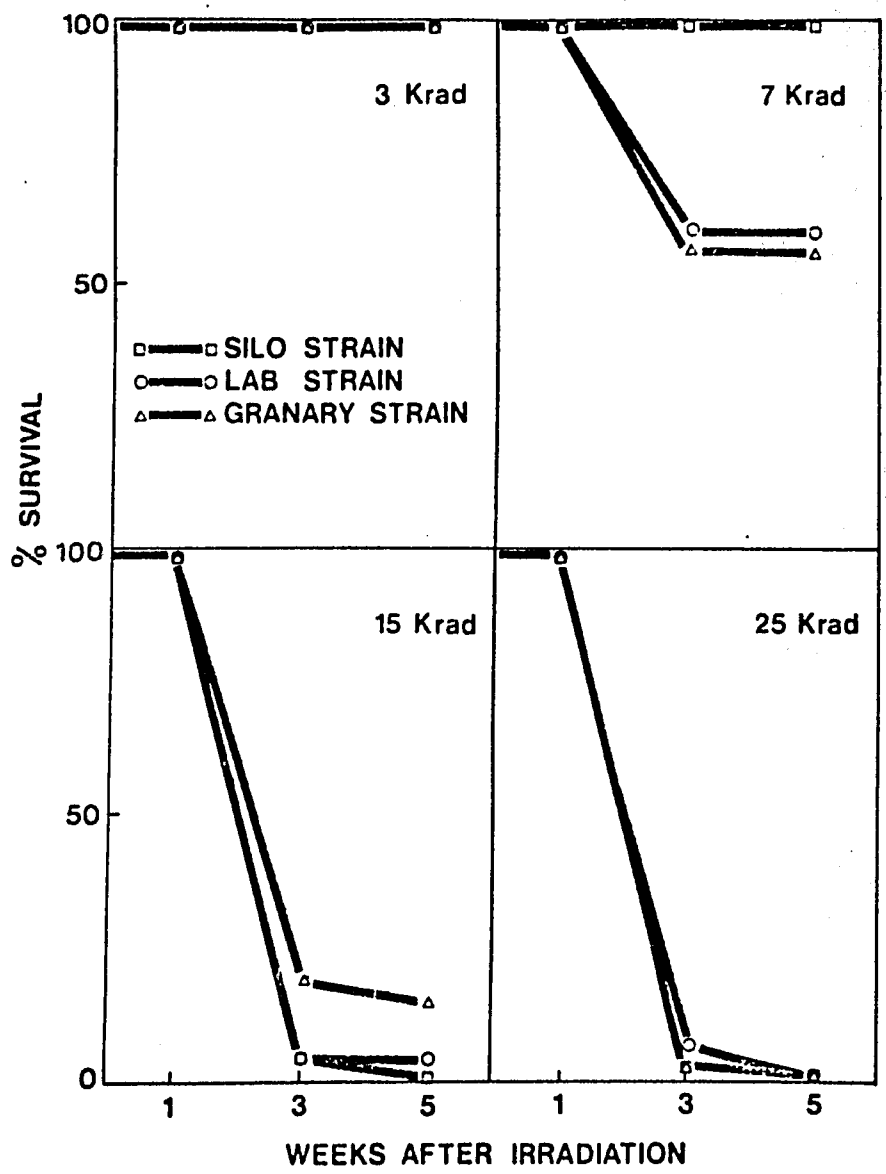


Figure 2.--Susceptibility of three strains of *T. castaneum* to irradiation with accelerated electrons.

(Fig. 3). The numbers that formed adults and survived at higher doses were inversely proportional to the applied dose. At 15 krad, larval development was completely suppressed. Studies with pupae indicate that they are more susceptible than adults to electron irradiation.

At 5 krad, 94% of irradiated *T. castaneum* adults survived for 8 weeks (Fig. 4); at 10 krad, 45% of the adults survived for 8 weeks; and at 15 krad only 2% survived for 8 weeks. Irradiation of adults at 25 krad resulted in complete mortality after 4 weeks. None of the adults irradiated at 5 krad to 100 krad produced viable eggs.

DISCUSSION: The pilot plant studies have shown that accelerated electrons are effective in controlling infestations of *Sitophilus* spp. in maize irradiated at a dose of 15 or 25 krad. However, a dose of 25 krad is required for complete control of *Tribolium castaneum* adults. Since *T. castaneum* adults are the most resistant stage, all other stages would also be controlled at 25 krad.

Differences were observed at 7 krad between a silo strain of *T. castaneum* as compared to a laboratory and a granary strain, both of which were equally susceptible at 3 and 5 weeks after irradiation. At 25 krad all strains responded similarly. Shipp (5) found that wild strains of *T. castaneum* were more susceptible to gamma irradiation than laboratory strains but he did not consider that this would result in any serious control problems at dosages that would be used for control purposes. Brower (6) reported that the response to gamma radiation of a DDT-malathion resistant strain of *T. castaneum* was similar to that of a susceptible strain. Our results showed that although differences among strains may be apparent at low doses, such differences may be of no practical consequence at doses of 25 krad which have been suggested as being suitable for control of stored product insects in wheat and flour (7).

Two factors have limited the use of ionizing radiation for insect control. First is the apparent high cost of installation and operation; secondly, are restrictions that may be imposed due to possible quality changes in the irradiated product. Both of these factors have adversely influenced the widespread acceptance of irradiation for the direct control of stored grain infestations.

Comparisons have been made between Cobalt-60 and electron radiation (4). Although various authors have reported little difference in the biological effects of radiation produced by gamma rays, x-rays and electrons (8), we have, in fact, found that up to 4 weeks after irradiation at doses of 7 and 15 krad, electrons are less effective than gamma rays against *Sitophilus* spp. (3). However, at 25 krad both types of radiation were equally effective 6 weeks after treatment.

It would appear that a commercially viable operation using a Cobalt-60 installation would require the use of an

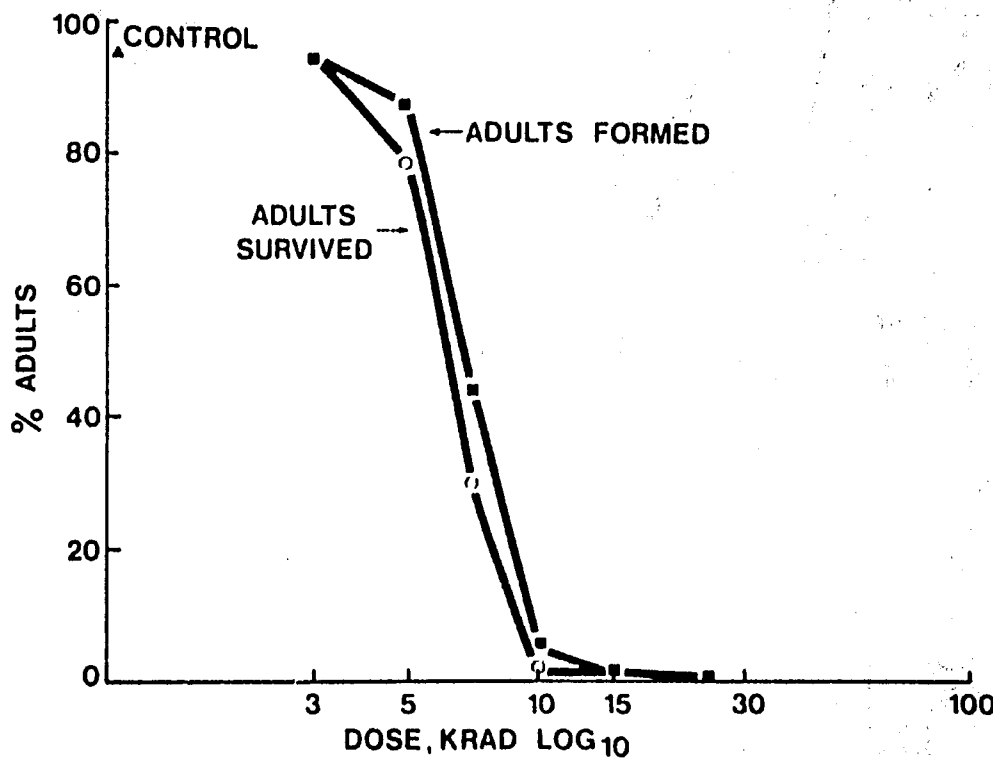


Figure 3.--Formation and survival of *T. castaneum* adults from irradiated larvae.

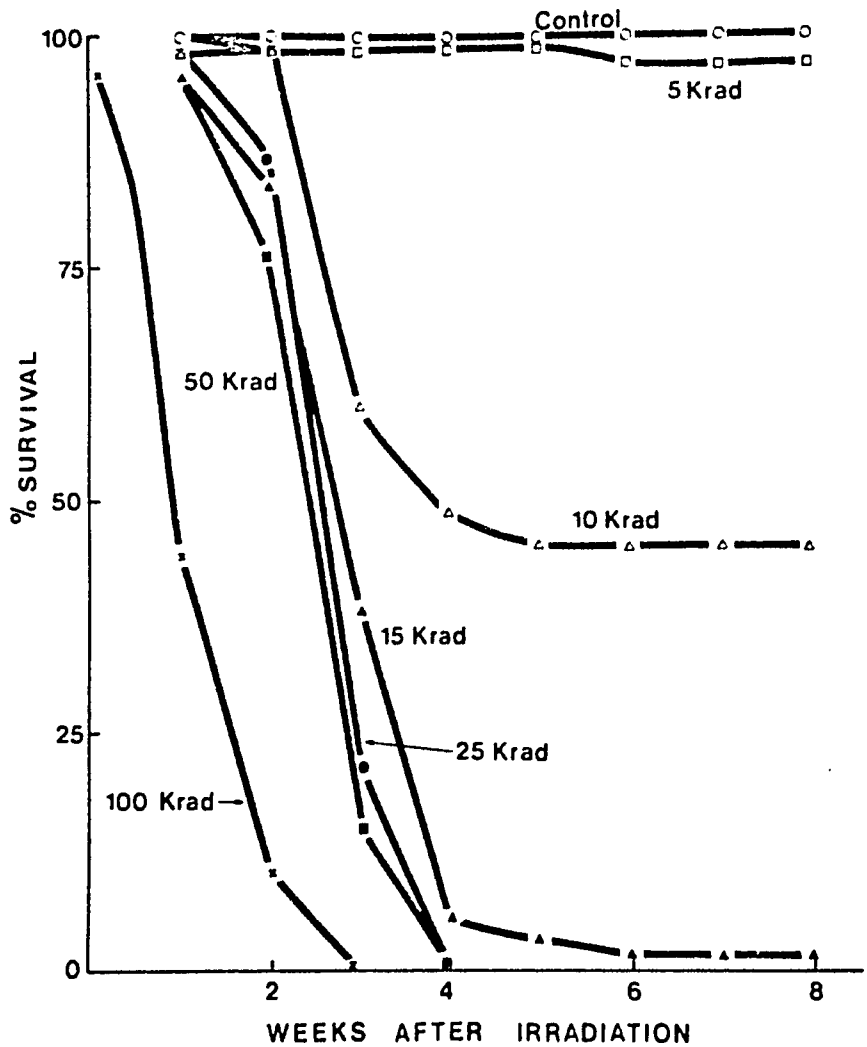


Figure 4.--Survival of *T. castaneum* adults exposed to various irradiation doses.

irradiation facility on a continuous basis (4). Furthermore, since the half-life of Cobalt-60 is 5.3 years, the source would have to be brought up to strength about every 10 months to maintain a satisfactory throughput (4). Since gamma radiation is attenuated in the grain medium according to the inverse square law, a lattice system or a series of baffles is usually employed to provide a uniform dose to the grain as it passes near the source to prevent either underdosing or overdosing. Alternatively, a conveyor system must be used with the object of exposing all parts of the grain to the radiation source.

By contrast, an electron accelerator produces a beam of high energy electrons which are magnetically scanned and diffused in a scan horn before emergence into the air or material to be irradiated. Because electrons have weaker penetrating powers than gamma rays, the material to be irradiated must be passed in front of the scanning horn in a thin layer that is no greater than 0.4 to 1.26 cm thick, for beam current energies of 1 to 3 MeV (9). Taking into consideration the power losses, the utilization efficiency is estimated at 45-55% (9).

Electron machines such as the Radio Dynamics Incorporated Dynamitron have throughputs of the order of 200 to 400 metric tons per hour which compares with the handling rates of commercial elevators. The unit requires less shielding than a Cobalt-60 source and installation is therefore less expensive. An important advantage of an electron accelerator over Cobalt-60 is that the equipment can be switched off when not in use to reduce radiation hazard and permit maintenance.

Operating costs of the Dynamitron for 7,000 hours per year are calculated at 17 cents per ton as opposed to 25 cents per ton for Cobalt-60 for a throughput of 200 tons per hour (10).

If it is assumed that corn is worth $100 per ton, a daily throughput of 3200 tons per day (i.e., 16 hr/day operation at 200 tons/hr) would move $320,000 worth of corn. Assuming losses of 2% without treatment, a fairly conservative overall figure, the daily losses would be $6,400 or $1,664,000 per year (for 260 days operation per year). The total annual cost of operation of the accelerator including depreciation, for 1975 was calculated at $235,000. If this is adjusted to $300,000 for 1978, the cost/benefit advantage would be about 5 to 1.

With regard to possible quality changes in grain caused by irradiation, there is a great deal of evidence already available to suggest that there are no deleterious effects (11). Scientists at the Institute of Physics, National Autonomous University of Mexico are presently collaborating with nutritionists at the University to determine possible changes in vitamins and amino acids of irradiated grain.

We are also mindful that the irradiation of infested grain does not solve all problems. Th grain must be stored in uninfested bins, ships' holds or containers to protect it from further infestation until it reaches its final destination. This

implies that insecticides and good sanitary practices must be employed to supplement radiation disinfestation of the grain. We are confident that in identifying and recognizing the limitations of ionizing radiation, we may be in a better position to determine its proper role for the control of insects in stored grains.

REFERENCES:

(1) Cornwell, P. B., The entomology of radiation disinfestation of grain. Pergamon Press (1966) 236 pp.

(2) Tilton, E. W., Brower, J. H., Status of U.S. Department of Agriculture research on irradiation disinfestation of grain and grain products. In Radiation Preservation of Food. Int. Atomic Energy Ag. Symp. 166/49. Bombay, India (1972).

(3) Adem., E., Watters, F. L., Uribe-Rendon, R., De la Piedad, A., Comparison of ^{60}Co gamma radiation and accelerated electrons for suppressing emergence of *Sitophilus* spp. in stored maize. J. Stored Prod. Res. 14 (1978) 135.

(4) Cornwell, P. B., Bull, J. O., Insect control by gamma-irradition: An appraisal of the potentialities and problems involved. J. Sci. Food Agric. 11 (1960) 754.

(5) Shipp, E., Susceptibility of Australian strains of *Sitophilus* and *Tribolium* species to gamma radiation. In The entomology of radiation disinfestation of grain. (Ed. Cornwell, P. B.) Pergamon Press (1966), 131.

(6) Brower, J. H., Radio-sensitivity of an insecticide-resistant strain of *Tribolium castaneum* (Herbst). J. Stored Prod. Res. 10 (1974) 129.

(7) Brower, J. H., Tilton, E. W., Comparative gamma radiation sensitivity of *Tribolium madens* (Charpentier) and *T. castaneum* (Herbst). J. Stored Prod. Res. 9 (1973) 93.

(8) O'Brien, R. D., Wolfe, L. S., Radiation, radioactivity, and insects. Academic Press, New York (1964) 211 pp.

(9) Brynjolfsson, A., Factors influencing economic evaluation of radiation processing, FAO/IAEA (1971) 13.

(10) Radiation Dynamics Incorporated, Technical Report, T15 75-9 (1975).

(11) Vas, K., Food irradiation technical and legal aspects. Food and Nutrition 3 (1977) 2.

PANEL ON MICRO-ORGANISMS AND RODENTS IN STORAGE

Chairman - DR. F. L. WATTERS
Research Station
Canada Agriculture
25 Dafoe Road
Winnipeg, Manitoba R3T 2M9
CANADA

THE ROLE OF FUNGI IN THE DETERIORATION OF TROPICAL STORED PRODUCTS

J. O. OYENIRAN
Nigerian Stored Products Research Institute
P.M.B. 5044
Ibadan, NIGERIA

INTRODUCTION: Fungi are known to cause various types of deterioration and pose hazards to the life of animals and man whenever they infect stored plant products. Fungal deterioration can be defined as any change resulting from the activities of fungi which renders a product unsuitable for its intended use or reduces the economic value of the material. It is also desirable to include those activities of microorganisms which may result in an increase of processing costs or which may affect amenity value (1). Research on stored food crops in most countries has concentrated more on insect than on fungal deterioration (2). This is partly because most stored product insects are visible to the naked eye and the damage they cause is usually conspicuous and quantitative. However, fungi, especially moulds, do cause various types of deterioration of crops and hazards to the life of animals and man whenever they infect stored food products. These have been extensively discussed in many reviews especially by: Christensen (3); Christensen and Kaufmann (4); Hiscocks (5) Raymond (6); and Eggins and Coursey (7). The various types of deterioration will be mentioned and discussed briefly here.

TYPES OF FUNGAL DETERIORATION OF STORED PRODUCTS:

1. Discolouration. Fungi, especially the microscopic species known as "moulds" cause discolouration of produce. Since they themselves are in different colours - green, yellow, black, brown, etc. - they impart these colours on the produce where they grow and thus change the appearance of such produce.

For instance, *Botryodiplodia theobromae* was responsible for the disease of discolouration of groundnuts widely known as "concealed damage" in Alabama while *Macrophomina phaseoli* caused "black nuts" in Gambian groundnuts (8, 9). Discoloured produce is disliked by manufacturers and consumers for a number of reasons. For instance, in the Hand-Picked-Selected (HPS) groundnuts in Nigeria, the more discoloured kernels present, the greater the task of picking them.

Before the 1950's the cause of discoloured grains was not precisely known. For example wheat in storage sometimes develops dark germs, and in the grain trade these were called "sick" wheat, a poor term, since such seeds are dead, not sick (3). Later, studies by Christensen (10) revealed that fungus mycellum were usually abundant on such discoloured embryos. Tulte was

able to reproduce these symptoms by inoculating wheat grain with moulds, under conditions favourable to their development. Discoloured grains disfigure the prepared flour by appearing as unsightly specks inside it.

Christensen and Linko (11) obtained samples of wheat from commercial bins and stored these in the laboratory with the same moisture contents as the samples had when received. There was progressive increase in percentage brown or damaged germs as moisture content increased. Colonies of *Aspergillus* sp. per gram of grain also increased proportionally.

Although the micropyle is the common place for infection to begin, fungi, bacteria and actinomycetes can develop in any other region of the grain or fruit causing abnormal colouring, either localised or generalised.

2. Destruction of Viability. One reason why agricultural produce is stored is to use as seed for the next crop. Fungi kill the viability of seeds by infecting and destroying their embryo. There is a considerable body of evidence to indicate that invasion of seeds by storage fungi can drastically reduce the germinability of the seed.

Tuite and Christensen (12) stored samples of barley seeds of 19.4% moisture content at room temperature, some of the samples made free of storage fungi and others inoculated with storage fungi. After 15 days the sample inoculated with storage fungi germinated 72% whereas the sample free of storage fungi germinated 98%. They stated, "All of these species of the *A. glaucus* group as well as *A. candidus* and *Penicillium* sp. invade various parts of the seed, including the germ, and directly cause or contribute to reduction in germination."

Qasem and Christensen (13) adjusted corn free of fungi to different moisture contents, inoculated some samples with various storage fungi and left others uninoculated. They stored the samples at several temperatures and periodically tested them for germinability. The samples inoculated with *Aspergillus candidus* and stored at 18% moisture content and 25°C for 4-1/2 months germinated 9%, the controls germinated 94%.

Lopez and Christensen (14) stored corn at 19-20% moisture content and 20°-25°C, some samples free of fungi, others inoculated with different isolates of *A. flavus*. After 74 days, the samples free of fungi averaged 97% germination, and those inoculated with *A. flavus* averaged 13%.

Broadbent (15) found samples of mouldy maize from Government farms in Southern Nigeria having germination of 7-14% while the mould free samples had 100% germination (Table 1).

3. Abnormalities in Growth. Groundnut and maize seed contaminated with *A. flavus* produce deformed plants. The infected young groundnut plants have a greatly decreased growth. Leaves

are of a much clearer green than normal. The follioles develop poorly and are elongated in form. During growth, a large number of sick plants die. Others are continually abnormal in appearance, while some evolve into normal plants.

4. Effect on Flavour and Odour. Mouldiness spoils the flavour of stored produce and also that of the product manufactured from it. Mouldy raw or fried groundnuts have very unpleasant, sour taste when consumed and these are usually spit out from the mouth as soon as chewed.

Effect on flavour is the most objectionable character developed by mouldy cocoa beans and manufacturers claim that amounts as low as 4% mouldy beans can be detected by taste in a sample of chocolate which has passed through all the normal manufacturing processes (16).

Mouldy produce also has a bad odour ranging from the musty odour of mouldy grains to the foul smell of rotting grain or tubers.

5. Biochemical Changes. The development of moulds leads to great modification in the chemical composition of the infected produce. One of the most important effects is an increase in free fatty acid (F.F.A.). This acid is one of the intermediate products of spoilage in materials that contain fats or oils and the characteristic odours and flavours of these fatty acids are what make partially spoiled fats rancid. It has also long been known that deterioration of stored grains is accompanied by an increase in fatty acids. This is because many species of moulds produce lipases which could hydrolyse fats into fatty acids by the process called Lipolysis, thereby increasing the F.F.A. content of the produce. This makes the oil difficult to refine. Sometimes limits are set for amount of F.F.A. permissible in exportable oilseeds and products. In palm kernel trade it is 4.75%, and for every 1% above this amount there is a financial penalty of 0.75% per ton. Moulds also lead to a reduction in the amount of oil extractable from the oilseeds.

Many instances of deterioration of oilseeds were reviewed by Eggins & Coursey (7). These include the work of Barbosa (17) who showed that total losses of oil content and increases on FFA of stored groundnuts in Portugal were associated with the growth of fungi, in particular, *Aspergillus flavus*.

Ward and Diener (18) found that *Aspergillus glaucus* gp., *A. tamarii* and *Penicillium citrinum* cause lipolysis of groundnut oil and reduction in the oil content.

In Nigerian groundnut crop, high acidity of around 5% occurred before 1954 due to high proportion of broken kernels which were easily attacked by moulds. The introduction of shelling machine raised the proportion of whole kernels from 30% to 70% and this reduced the acidity to less than 1%. With a harvest of 700,000 tons, this represents a saving of about £1 million (6).

Coursey and Eggins (19) isolated a number of moulds from palm oil and showed that many of them increased the F.F.A. of palm oil in pure culture studies. Sheridan (20), Coursey and others (21) and Kuku (22) isolated a number of lipolytic fungi from Nigerian palm kernels.

Some work on the effect of moulds on the biochemical property of maize has also shown that the F.F.A. is always increased. Nagel and Semeniuk (23) inoculated corn with pure cultures of nine species of fungi, separately and together. The moulds increased the FFA content of the grains to varying extents from 74.8 units to 384 units.

Goodman and Christensen (24) grew cultures of four species of fungi isolated from mouldy corn - *Penicillium solitum*, *Aspergillus flavus*, *A. candidus*, and *A. amstelodami* - on cornmeal to which the oil originally extracted had again been added. All caused an initial increase in fatty acids in the meal containing oil. In these tests the fatty acids were produced as a result of fungus lipases acting upon the corn oil.

The development of moulds on produce causes other modifications; generally an increase in reducing sugars and a loss in protein, which may lead to flours unsuitable for breadmaking. Moreover, mouldy rice grain breaks easily during polishing. If we preserve damp grain in an anaerobic environment, fermentation, release of carbon dioxide, alcohol, and other volatile substances occurs. The compounds formed give a disagreeable taste, which remains even after drying in the open air.

6. Rotting and Caking. Direct spoilage such as rotting of yams and caking of maize is usually caused by extensive mould infection and damage of these products during storage. Studies by Okafor (25), Ogundana (26) and Adeniji (27) have shown that a number of fungi (*Aspergillus niger*, *Botryodiplodia theobromae*, *Fusarium moniliforme*, *Hendersonula toruloidea*, *Macrophomina phaseoli*, *Penicillium oxalicum* and *P. sclerotigenum*) caused rotting in Nigerian yams.

Studies carried out by several workers, among whom are Okafor (28, 29) Broadbent (15, 30), and Oyeniran (31, 32), showed that over 30 mould species can be associated with the deterioration of maize in Nigeria. Some of these cause the rotting and caking.

7. Absolute Weight Loss. Attack by moulds does cause an absolute weight loss in stored products. A dry matter loss of 12% was found in Fijian copra during a 14 days' storage due to attack by moulds (6). There is also a weight loss when grain is stored, an estimated possible world loss due to this cause was about 1% (32). The loss in the tropics must be much higher.

Nagel and Semeniuk (23) found that four of the nine moulds they tested induced marked organic matter losses in maize. The greatest loss (approximately 40%) was induced by *Aspergillus flavus*, *A. niger*, *Penicillium chrysogenum* in a 4-week period. Losses of 20.1%, 14.5%, 11.9%, 10.4%, and 6.4% in the same period

were induced by *A. candidus*, *Penicillium pallitans*, *P. rugulosum*, *Mucor racemosus*, and *Aspergillus amstelodami*, respectively.

8. Heating. When large quantities of damp grain are preserved, we sometimes notice great increases in temperature within the mass; this phenomenon is known as heating. This phenomenone was reported by Okafor (29) who recorded a temperature of 68°C in a mouldy maize stack in Nigeria. Many other instances of heating of grains during storage were reviewed by Christensen and Kaufmann (4) and heating in bulk storage is an evidence of spoilage in progress or spoilage already completed.

9. Preparation of the material for attack by other agents. Mould damage in stored products prepares such materials for attack by other agents of deterioration, especially insects and mites. It is difficult in many foods to separate the deterioration due to insects from that caused by fungi, but that the two are interrelated is in no doubt. What is in that doubt sometimes is the exact sequence of events and the relative damage cuased by the two agents (6).

Christensen and Hodson (34) showed that both insects and fungi are associated in their deterioration of grains and each enhances the activity of the other. Sikorowski (35) reviewed the whole subject and pointed out that storage insects can live, develop, and reproduce entirely on certain fungi and they undoubtedly play an important part as carriers in the spread of fungi.

10. Production of Mycotoxins. Toxin production is the most serious effect of microbiological deterioration of stored products. A number of fungi are known to produce toxic metabolites into the stored products on which they grow, so that when these products are consumed, they cause diseases known as mycotoxi coses. This is a wide subject on which very much has been written (36, 37, 38, 39, 40, 41). Some notable examples of mycotoxicoses are:

(i) Ergotism, a disease of cattle in Central Europe caused by *Claviceps purpurea*

(ii) Facial ecaema of sheep in New Zealand caused by *Pithomyces chartarum*

(iii) Yellow rice disease of man in Japan caused by *Penicillium citrinum*, *P. islandicum*, and *P. citreoviride*

(iv) Alimentary toxic aleukia (ATA of man and cattle caused by *Fusarium sporotrichiodes*, *F. poae*, and *F. tricinctum*

(v) The complex known as mouldy corn toxicoses caused by *Penicillium rubrum*, *Chaetomium globosum*, *Aspergillus ochraceus*, and other moulds.

(vi) Lastly and most significantly, Aflatoxicosis of poultry and livestock caused by *Aspergillus flavus*.

This last mentioned toxin disease, Aflatoxicosis, has been receiving world-wide attention since 1960 when it was reported to have caused the death of about 100,000 turkeys in Britain (42).

These turkeys were fed with meals containing a particular batch of Brazilian groundnut cake which was infected with *Aspergillus flavus*. The toxic substance was therefore called AFLATOXIN. Our studies in Nigeria have revealed the presence of aflatoxin in Nigerian groundnuts and livestock feed maize, hence the need to take extremely good care of these products during storage (Table I).

Table I. Germination and seedling vigour of the mouldy maize

	Germination %	Seedling height (cm)		
		Minimum	Average	Maximum
Control maize	100	18.0	30.3	38.0
Seed maize				
Sample 1	13.5	5.0	16.6	33.3
Sample 2	7.5	9.0	18.9	32.5

FUNGAL DETERIORATION OF VARIOUS STORED PRODUCTS

1. Cocoa. Early studies on the deterioration of stored cocoa by moulds were carried out on Nigerian cocoa by Laycock (43) and Passmore (44). However, more detailed studies were carried out on Ghanaian cocoa by Bunting (45, 46) and Dade (47) and 12 fungi were isolated from cocoa.

In recent years, studies by Broadbent (48), Oyeniran (49, 50, 51, 52), Oyeniran and Adeniji (53) on Nigerian cocoa have confirmed earlier work and amplified the knowledge on this subject. A total of 32 fungi, the more important of which are indicated in Table II, have been isolated from stored cocoa beans. These were found to enter cocoa beans at different stages from preharvest to storage. For instance:

(i) Before harvest - *B. theobromae*, *Fusarium* spp., *Macrophoma* sp., and *Cylindrocarpon tonkinense*, enter the beans before harvest.

(ii) During fermentation- mostly the thermophilic *Aspergillus fumigatus*, *Mucor pusillus*, *P. varioti*.

(iii) During storage - As a result of insufficient drying, wetting, or moisture absorption, *P. citrinum*, *P. steckii*, *Aspergillus ruber*, *A. chevalieri*, *A. penicilloides*, and *A. candidus*.

The identification of the problems associated with cocoa at these four stages do help immensely to devise control measures which are largely applicable in all cocoa growing areas of the tropical world.

2. Groundnuts. Most of the groundnuts exported from Nigeria are grown in the drier northernly areas of the country, which some others are from areas of higher humidity and rainfall which border

Table II. Some toxic moulds and their toxins

Mould	Toxin
Ammanita phalloides	Phalloidin
Aspergillus chevalieri	Xanthocillin
A. flavus	Aflatoxin
A. fumigatus	Gliotoxin
A. nidulans	Sterigmatacystin
A. ochraceus	Ochratoxin
A. oryzae	Maltoryzine
Fusarium graminearum	Xearalenone
Penicillium citrinum	Citrinin
P. cyclopium	Cyclopiazonic acid
P. frequentans	Citromycetin
P. islandicum	Islanditoxin
P. notatum	Xanthocillin
P. rubrum	Rubratoxin
P. rugulosum	Citreoviridin
P. toxicarium	Citreoviridin
P. urticae	Patulin
Pithomyces chartarum	Sporidesmin

the Niger and Benue Rivers (54). Small quantities are also produced in the Southern parts of the country but these are entirely for local consumption. The problems of fungal contamination of groundnuts in the main growing areas of the North were extensively studied by McDonald and Harkness between 1961 and 1965 following the discovery of aflatoxin in groundnut feeds in U.K. in 1960 (42). Their studies revealed that *Aspergillus flavus* contamination of groundnuts was caused mainly by slow drying after the pods were mature. Further studies revealed the presence of other fungal species such as *Botryodiplodia theobromae*, *Macrophomina phaseoli*, and *Fusarium solani* in shells and kernels in certain conditions (54, 55, 56).

These authors made recommendations as to the time of lifting and windrowing the groundnut plants as well as when to pick the pods during drying. Badly discoloured,broken pods or kernels were to be destroyed.

The mould deterioration of groundnuts during storage and marketing were studied by Broadbent and others. They found that out of 74 market samples of groundnut examined, only 8 were mould free. Most others had less than 2% internally mouldy kernels though some had over 10%. Average internal mouldiness was 2.1%. The degree of internal mouldiness was related to level of moisture content of the samples. Two important factors were thought to

influence these moisture contents; there was moisture absorption during storage and marketing. This was more pronounced during the wet season months. Initial under-drying of many samples mainly of local harvest was also found to be responsible. Seventeen mould species were identified, mostly Aspergillii and Penicillia, the most important of which are *Macrophomina phaseoli*, *Aspergillus ruber*, *Aspergillus chevalieri*, *Aspergillus penicilloides*, *Aspergillus amstelodami*, *B. thobromae*, and *A. flavus*. The preponderance of *A. glaucus* group and *A. penicilloides* confirmed the suggestion that the nuts absorbed moisture during storage (57). Halliday (58) had earlier observed such uptake of moisture by bagged groundnuts in Southern Nigeria. Most of the moulds isolated from groundnuts are known to be toxigenic or lipolytic. Sheridan (20) had previously isolated 10 moulds, all Aspergilli from groundnuts in Nigeria and found 9 of them to be lipolytic.

3. Palm produce. (a) Palm oil. Palm oil is normally traded in world markets on a contract basis of 5% free fatty acid, consignments with higher or lower values being debited or credited respectively at a certain rate per ton per percentage of F.F.A. content. While free fatty acids may arise from purely chemical processes, Coursey and others (19, 21, 59) have shown that lipolytic moulds are the main cause of F.F.A. production in Nigerian palm oil. Mould deterioration of palm oil by lipolysis probably occurs between the time the palm fruits are harvested and the oil is expressed and also during storage of the oil obtained. Deterioration occurs at the former stage because the harvested palm fruits are usually stored for several days or even a week or two before oil expression. The purpose of this storage period is to allow the fruits to become less firmly attached to the bunches, so that they can be more easily removed for oil expression. The bunches are often split into sections and sometimes sprinkled with water-both practices which apparently help to loosen the fruits (60, 61) and are normally left in heaps, often under palm fronds.

Not surprisingly, these conditions also greatly favour the growth of moulds. For instance, Broadbent and Kuku (62) found that six batches of palm fruit examined at this stage all showed some visible mouldiness, in one case only four days after harvest. Wilbaux (63) and Simmons (65) found that palm oil from mouldy fruits had a much higher F.F.A. content than that from mould-free fruits. Coursey and Eggins (19) isolated nine different moulds all with lipolytic ability from palm fruits.

Mould deterioration of palm oil during storage had also been studied by Coursey and others (19, 21, 59). All these studies confirmed that increases in F.F.A. content of palm oil was largely attributable to the lipolytic activity of the infecting moulds.

(b) Palm kernels. Sheridan (20), Coursey and others (21) reported on the moulds infecting palm kernels during storage in

Nigeria, and 13 species were identified, eleven of which had lipolytic effect on the palm kernel oil. Later, Eggins and Coursey (59) also recorded three thermophilic moulds - *Chaetomium thermophile*, *Penicillium emersoni*, and *Thermomyces ibadanensis* from a stack of palm kernels which was heated up to 60°C. These authors also confirmed by analysis that higher F.F.A. content was always obtained from palm kernels which were internally mouldy. Riley and Simmons (65) showed that the F.F.A. content of Nigerian palm kernels awaiting shipment for export was shown to be related to their mould content. Detection of such a correlation despite the masking effects of other factors suggests that moulds may play a dominant role in the production of F.F.A. in Nigerian palm kernels.

More recently Kuku (22) with Adeniji (66) and with Broadbent (62) have studied into detail, the various stages at which mouldiness of palm kernels occurs and the factors encouraging such mouldiness. Such factors include overriping of the palm fruits before harvest, non-heating process of extraction of palm oil from palm fruits, abandoning palm kernels in heaps at very high moisture contents and of course moisture absorption by the shelled kernels during storage. Thirty-seven mould species have been isolated from palm kernels in Nigeria and some of these are indicated in Table III.

4. Maize. Maize is probably the Nigerian cereal which is potentially most liable to post harvest mould deterioration, for not only is it grown mainly in the more humid areas of the country but the first crop, which provides about 80% of total production is harvested during the rainy season. In some areas, harvesting may coincide with a short break in the rains, but even so weather conditions greatly retard both pre- and post-harvest drying of the maize.

Mould deterioration of maize can be considered in relation to the method of storage. Storage of the maize on the cob especially in open-sided cribs allows the maize to dry gradually but effectively enough to keep mould infection at check. However, demand by livestock industry in recent years has forced producers of maize into shelling them soon after harvest at moisture contents of 22-25% (67) and selling them to traders or livestock farms who store them as such. Mould deterioration of such batches of maize had been observed on several occasions. Okafor (28, 29) reported on the microorganisms causing deterioration of a stack of maize which was extensively damaged and heated up by the activities of these organisms. He recorded such mesophilic organisms as *Fusarium moniliforme*, *Aspergillus flavus*, and *Rhizopus arrhizus*, and thermophilic fungi - *Thermomyces lanuginosus*, *Mucor pusillus*, and a *Rhizomucor* sp.

Broadbent (15, 30) and Oyeniran (31, 32) did extensive work on post harvest deterioration of maize in Nigeria. They have found that up to 30 mould species are responsible for this and they

Table III. Some fungal species and the stored products from which they were isolated in Nigeria

Fungal species	Stored products from which they were isolated				
	Cocoa	Ground-nuts	Palm kernels	Maize	Yams
Absidia corymbifera	+			+	
Aspergillus amstelodami		+	+		
Aspergillus candidus	+			+	
Aspergillus chevalieri	+	+	+	+	
Aspergillus flavus	+	+	+	+	
Aspergillus fumigatus	+	+	+	+	
Aspergillus melleus		+		+	
Aspergillus niger	+	+	+	+	+
Aspergillus penicilloides	+	+			
Aspergillus restrictus	+		+		
Aspergillus ruber	+	+	+		
Aspergillus tamarii	+	+	+	+	+
Aspergillus terreus		+	+	+	
Aspergillus versicolor	+	+		+	
Botryodiplodia theobromae	+	+		+	+
Fusarium moniliforme		+		+	+
Fusarium semitectum		+			
Fusarium solani	+				+
Hendersoluna toruloidea					+
Macrophomina phaseoli		+			+
Mucor pusillus	+			+	
Paecilomyces varioti	+		+	+	
Penicillium citrinum	+	+	+	+	
Penicillium decumbens	+			+	
Penicillium frequentans			+		+
Penicillium oxalicum					+
Penicillium steckii	+		+	+	
Penicillium variabile	+	+		+	
Rhizopus arrhizus	+			+	
Syncephala strum racemosum	+		+	+	

infect improperly dried grains as well as grains stored in conditions where they can absorb moisture. The most important species are shown in Table III. Aflatoxin contamination is also a problem in maize because *Aspergillus flavus* is the most prominent species infecting the grains during storage.

5. Yams: Yams are stored in Nigeria in two basically different ways-as the fresh tuber or as processed, dried yam. Considerable losses often occur during tuber storage.

Coursey (68, 69, 70) suggested that losses of 10-20% after 3 months storage and of 50% or more after 6 months may be usual in Nigeria. One of the main causes of these losses is microbiological rotting of these yams during storage. The incidence of rotting in stored tubers has been studied by several workers (25, 27, 68, 71, 72) and seems to vary considerably with locality, storage method and time, yam species and even individual tubers. Coursey (68) for example, found that sometimes less than 5% of tubers showed rotting after storage for 4-5 months, while in others it was up to 50-70%. As already noted, rotting usually leads to considerable weight losses; Adesuyi (72) for instance recorded a weight loss of about 30% after 14 weeks' storage.

While both moulds and bacteria have been implicated in the deterioration of stored yams (25), only the former have been isolated from deteriorating yams. Twenty-four of these were tested for their ability to induce rotting under experimental conditions (25,27) but only eight had this ability. It is interesting, although not unexpected, that all the moulds so far isolated are hydro- or mesophilic. Members of the *Aspergillus glaucus* group, for example, are absent.

Ogundana and others (73) have begun to identify the anatomical and biochemical changes which accompany rotting. They have found that infection by four moulds previously isolated from rotting yams (*B. theobromae, P. sclerotigenum, A. niger, and F. moniliforme*) in each case caused clearing of the starch grains within cells and a disintegration of the cell walls. Their biochemical studies showed that the moulds decreased the carbohydrate content (starch especially) of yam discs and produced extracellular pectic and cellulolytic enzymes in culture.

6. Dried yams: Mould deterioration of dried yam has not been seriously investigated. However, some preliminary investigation was done by Broadbent (74) on his observation of sacks of yam slices heavily infected by moulds. Mouldiness was most evident on the broad cut surfaces of the slices and was enough to give these areas a blue-green appearance instead of the normal whitish colour. Microscopic examination showed that mouldiness was mainly due to members of the *Aspergillus glaucus* group, mainly *A. repens, A. chevalieri,* and *A. ruber*. Other species occasionally isolated included *A. flavus, A. tamarii, A. niger, A. clavatus, A. melleus, Penicillium citrinum,* and *Rhizopus arrhizus*. It is probable that the slices were prepared during the wet season and that drying was sufficiently slow and incomplete to allow the growth of both mesophilic and xerophilic moulds. This conclusion is supported by the results of a moisture content survey of market yam slices in Ibadan (75) where high moisture contents were obtained when new

yam slices arrived in the markets. Increases of 2-3% were also recorded in the moisture content of the old yam slices during the wet months as a result of moisture up-take by the yam slices. Mould deterioration of yam slices especially by xerophilic species may be more serious than has hitherto been thought.

7. Processed cassava (gari): Gari prepared from Cassava roots is a very common staple foodstuff in Nigeria. It is one of the foodstuffs which have microbiological problems only during the storage. The process of preparation involves frying the stuff at high temperatures which would have killed all the previous micro-organisms. After preparation however other fungal spores infect the gari and most of them cause the spoilage in the form of dis-colouration, caking, and off-flavour. Halliday and others (76), Adeniji (77), Opadokun (78), and Oyeniran (79) have shown that gari is susceptible to mould contamination during storage and each author has isolated and identified a number of mould species from samples of gari under various storage and marketing conditions. Some of these are shown in Table III. Adeniji (77) experimentally confirmed that majority of the moulds earlier isolated from gari could individually cause the deterioration of the foodstuff. However, Opadokun (78) did not detect aflatoxin from any of the samples he examined, even though *Aspergillus flavus*, the aflatoxin mould, was one of the fungi isolated.

The most important factor encouraging mould contamination of gari is the high initial moisture content or increase in moisture content during storage. Halliday and others (76) and Oyeniran (79) found that the gari on sale in the markets at certain times of the year had moisture contents much higher than the safe level of 12.7-13.6%. They also found that the mould deterioration of gari of high moisture content is much higher when stored in air-tight condition such as sealed polythene bag than in hessian, while gari of very low moisture contents can keep safe in sealed poly-thene. The setup of free fatty acid in the oil used in the yellow gari was also suspected to occur.

CAUSES OF FUNGAL DETERIORATION OF STORED PRODUCTS:

I. Important Role of Moisture. The primary cause of fungal deterioration of stored products is moisture, which as we all know is an essential pre-requisite for microbiological activi-ty. Moisture in stored produce is divisible into two main types: the chemically bound water which is part of the intrinsic composi-tion of the commodity itself and physically bound water, some of which is loosely held onto the commodity. Moisture content of stored produce therefore refers to the physically bound water (80).

However, it is not the moisture content as such that is the controlling factor in biological deterioration; it is the Relative Humidity (R.H.) of the air within and around the commodity. This is the ratio in percentage of the weight of water contained

in a sample of air at a given temperature to the weight of water which would be contained in that sample if it were saturated at the same temperature.

Biological activity occurs only in the presence of moisture and limits of R.H. can be specified within which biological agencies causing deterioration can develop.

Germination occurs at	95% R.H. or over
Bacteria grow at	90% R.H. or over
Fungi grow at	70% R.H. or over
Mites infest at	60% R.H. or over
Insects infest at	30-95% R.H.

Even though R.H. is the controlling factor, attention is usually focussed on the moisture content because R.H. of produce is difficult to measure while moisture content is not. Both are related and from a measurement of the moisture content of a commodity, the equilibrium R.H. can be deduced.

It is known that microbiological activity is reduced to a minimum at R.H. 70% or less. Seventy percent R.H. has therefore been regarded as a "safe" limit and commodities with moisture contents in equilibrium with R.H. 70% are relatively safe from microbiological deterioration.. Such moisture contents for a few commodities are shown in Table IV.

Table IV. Moisture content equilibrium (at 27°C) values of produce at relative humidity 70%

Commodity	Moisture content percent
Maize	13.5
Wheat	13.5
Sorghum	16.0
Millet	16.0
Paddy	14.0
Cowpeas	13.5
Beans	15.0
Groundnuts (shelled)	7.0
Cottonseed	10.0
Cocoa beans	7.0
Copra	5.8
Palm kernels	5.7
Gari (white)	12.7
Gari (yellow)	13.6

From: Hall (81) and other sources.

Moisture plays its role in causing microbiological deterioration in some specific ways.

(i) Condensation and moisture migration - In bulk grain storage bins, condensation occurs on the inner side of the top during cool weather especially at night following hot weather during the day. Warm air will move from the warm centre of the bulk and when it gets to the cool grain near the surface or at the side, condensation will occur and some water will be formed which will lead to mould attack setting in. The moisture will continue to move 'gradually' into the bulk of grain causing further damage.

(ii) Leakage - Wherever there is a leakage in the storage structure it is possible for water to drip into the commodity stored and thereby cause deterioration.

(iii) Hot spots - This is an interesting phenomenon in bulk grains. It is usually started by a concentration of insect activity which causes heating, sometimes to considerable temperatures. When the hot air from such a pocket moves to cooler grains, condensation occurs and moulds and bacteria develop round the pocket of grains. The microorganisms increase the temperature of the pocket and when the area becomes too hot for the insects, they move out, causing further damage.

(iv) Moisture absorption - Most stored products are hygroscopic, that is, they will exchange moisture with the atmosphere of storage until an equilibrium is reached. This means that when stored in an atmosphere of high relative humidity, literally, 'damp atmosphere,' dry produce will gain moisture. Therefore the relative humidity of storage is essential. An occasional check is necessary on the moisture content of produce stored in atmospheres with fluctuating relative humidities. It is also possible for produce stored in bags to absorb moisture through the floor if placed directly on the floor of the store.

(v) Mechanical or other damage - When produce is mechanically damaged or wounded by other agents such as insects or rodents, they become more liable to mould attack which automatically begins on the wounded or damaged surface or spot. This is because such exposed surfaces are damper and act more or less like a culture medium for moulds to grow. It is a common feature of all stored produce - grains, tubers, cocoa beans, groundnuts, etc. This is the reason why some storage moulds are found on grains at harvest, in addition to a few field fungi which naturally attack them at that stage.

2. Other causes: Other causes that are not directly linked with moisture content can briefly be mentioned.

(i) Preharvest infection - Produce destined for storage is sometimes infected by moulds before harvest. Most of the species of fungus involved at this stage are field fungi while a few storage fungi also come in especially following natural or artificial wounds. Some examples are attack of cocoa beans by *Botryodiplodia theobromae* and other moulds, attack of groundnuts by *Macrophomina*

phaseoli, and attack of maize by *Fusarium moniliforme* and *Penicillium citrinum*.

(ii) Attack during preparation: Moulds attack some produce during the process of preparation of such produce for the market, as a result of some lapses in cultural practices. For example, during cocoa fermentation, moulds infect and penetrate the beans if the fermenting mass of beans is not stirred or mixed thoroughly at intervals during the process. In palm produce, moulds attack the fruits and sometimes the kernels when they are heaped on the ground just before dehusking. In groudnuts the crop has to be lifted at certain times to avoid mould contamination.

CONTROL OF FUNGAL DETERIORATION IN STORED PRODUCTS:

I shall just run through some of the ideas that have been suggested on control of fungal deterioration of stored products beiefly. For this purpose a distinction can be made between produce that is stored dry - such as grains, pulses, cocoa, groundnuts, palm kernels, etc., and those which are stored with high water content, such as yams. However, some of the measures suggested will certainly apply to both types.

(A) Dry produce: For produce that can be stored dry, the important thing is to get the produce dry (that is to safe moisture content), as soon as possible after harvest and keep it dry during storage. This can be achieved by:

1. Either retaining maize, millet, guineacorn, etc., on the cob or head and store in a condition where gradual drying by heat or aeration takes place such as the ventilated crib. Otherwise provide artificial drying if storage as shelled grains is desired. The rachis tends to afford some protection to the grain when unshelled.

2. Cool artificially - or sun-dry produce before bulk storage to avoid moisture formation and migration. For the same reason sufficient shades should be provided for metal silos to prevent fluctuations in temperature inside the grain bulk.

3. If possible, store dried produce in airtight conditions to keep away from fluctuating atmospheric relative humidity which could lead to increase in moisture content, e.g. store in polythene bags, or polythene-lined sacks, airtight warehouses.

4. Prevent pockets of heavy insect activity which could lead to localised moisture increases and mould growth in bulk of grain by proper application of insect-control measures.

5. Avoid mechanical and other types of damage on produce before storage.

6. Keep away produce from wetting and moisture absorption. Store produce away from walls and use dunnage for bagged produce stacked in stores to keep them off the floors.

Other methods of controlling deterioration of dry produce are:

1. Preharvest infection - Sort out and discard produce which bear evidence of pre-harvest mould infection. They serve as rich

sources of fungal inoculum for otherwise healthy produce when stored together in the same structure.

2. Use of fungicides - In the case of stored grains not destined for consumption some fungicides such as captan, benomyl, thiabendazole, borax, etc., have been used to control fungal attack. Their use has been limited because of the toxicity.

3. Addition of chemical preservative agents - The addition of antiseptics to foodstuffs allows for better preservation under certain conditions. The utilisation of these products is subject to regulations in most countries.

Examples of such chemical preservatives are: Proplonic acid, sorbic acid, glycerol, sulfur dioxide, and benzoic acid. Their use in many instances has also been limited to livestock feeds.

4. Other methods of control - Other methods by which fungal development in stored products can be controlled are refrigeration, irradiation, and storage under inert atmosphere. These methods are not widespread because of the cost and high technical expertise required to use them.

(B) Storage of tubers: Storage of tubers poses problems different from those of grain or other dry produce, because it is important to maintain a high water content. Storage of yams must be with good ventilation and high and low temperature extremes must be avoided.

It is important to handle healthy tubers carefully to avoid bruising. Application of wood ash or whitewash to bruises was reported to decrease rot, and Coursey (65) observed the beneficial effect of powdered lime milk and copper oxinate on the incidence of weight losses recorded during storage.

Ogundana and others (73) found benomyl and thiabendazole effective in reducing the activities of fungi in causing yam rot during storage, but these chemicals are rather toxic. Research is currently in progress at the Nigerian Stored Products Research Institute on the use of safer fungistatic chemicals to preserve yams against microbiological rot during storage. Adesuyi (72) successfully stored yams for up to six months by use of curing method, cutting of sprouts from healthy undamaged tubers, use of low temperatures and irradiation techniques.

CONCLUSION: I have in the foregoing paragraphs highlighted the role of fungi in the deterioration of stored products as well as made brief mention of the knowledge of the problem as derived from studies by various workers. It is pertinent to say here that the knowledge is far from complete and experts should still endeavour to find complete solutions to the various aspects of the problem, as the struggle of man against the menace of microorganisms continues.

REFERENCES:

(1) Butler, N.J., and Eggins, H. O. W. (1966) Microbiological deterioration and the tropical environment. In "Microbiological deterioration in the Tropics S.C.I." Monograph 23: 3-13.

(2) Clarke, J. H. (1968) Fungi in stored products. Trop. Stored Prod. Inf. 15: 3-14.

(3) Christensen, C. M. (1957) Deterioration of stored grains by fungi. Bot. Rev. 23: 108-137.

(4) Christensen, C. M., and Kafmann, H. H. (1965) Deterioration of stored grain by fungi. Ann. Rev. Phytopathology 3: 69-84.

(5) Hiscocks, E. S. (1966) The importance of moulds in the deterioration of tropical foods and feedstuffs. In "Mycotoxins in Foodstuffs" edited Wogan, G. N. 15-26.

(6) Raymond, W. D. (1966) The importance of moulds on the deterioration of topical foods and feedingstuffs S.C.I. Monograph No. 23: 21-30.

(7) Eggins, H. O. W., and Coursey, D. G. (1968) The industrial significance of the biodeterioration of oilseeds. Int. Biodeterioration Bull. 1(1): 29-38.

(8) Wilson, G. (1947) Concealed damage of peanuts in Alabama. Phytopathology 37: 657-668.

(9) Pattinson, I., and Thornton, I. (1965) The quality of unshelled groundnuts in the Gambia with special reference to insect and fungal attack. Trop. Sci. 7: 67-74,

(10) Christensen, C. M. (1955) Grain storage studies 21. Viability and mouldiness of commercial wheat in relation to the incidence of germ damage. Cereal Chem. 32: 107-116.

(11) Christensen, C. M., and Linko, P. (1963) Moisture contents of hard red winter wheat as determined by meters and by oven drying and influence of small differences in moisture content upon subsequent deterioration in storage. Cereal Chem. 40: 129-137.

(12) Tuite, J. F., and Christensen, C. M. (1955) Grain storage studies 16. Influence of storage conditions upon the fungus flora of barley seed. Cereal Chem. 32: 1-11.

(13) Qasem, S. A., and Christensen, C. M. (1958) Influence of moisture content, temperature, and time on the deterioration.

(14) Lopez, L. C., and Christensen, C. M. (1967) Effect of moisture content and temperature on invasion of stored corn by *Aspergillus flavus*.

(15) Broadbent, J. A. (1967a) The microflora, germination and seedling vigour of some seed maize. Rep. Nigerian Stored Prod. Res. Inst. (1966) Tech. Rep. No. 15: 113-114.

(16) Wadsworth, R. V. (1955) The quality of raw cocoa as it affects the manufacturer. Trop. Agric. Trin. 32: 1-9.

(17) Barbosa, M. A. deF. (1962) Sobre a influence dos fungas do Amendam armazenado na qualidade de serente e do oleo. Garcia de orta 10: 655-660.

(18) Ward, H. S., and Diener, U.L. (1961) Biochemical changes in shelled peanuts caused by storage fungi. I. Effects of *Aspergillus tamarii*, four species of *A. glaucus group*, and *Penicillium citrinum*. Phytopathology 51: 244-250.
(19) Coursey, D. G., and Eggins, H. O. W. (1961) Origine de la contamination microbiologique de l'huile de palme du Nigeria. Oleagineux 16: 541-547.
(20) Sheridan, A. (1962) Preliminary notes on microorganisms associated with the deterioration of groundnuts and palm kernels during storage in Nigeria. Rep. W. Afr. Stored Prod. Res. Unit. 1961. Tech. Rep. No. 6: 52-55.
(21) Coursey, D. G., Simons, E. A., and Sheridan, A. (1963) Studies on the quality of Nigerian palm kernels. J. W. Afr. Sci. Ass. 8(1): 18-28.
(22) Kuku, F. O. (1971) A preliminary study of mould deterioration of Nigerian palm kernels. Rep. Nigerian Stored Prod. Res. Inst. 1969. Tech. Rep. No. 4: 31-37.
(23) Nagel, C. M., and Sememiuk, G. (1957) Some mould induced changes in shelled corn. Plant Physiol. 22: 20-23.
(24) Goodman, J. J., and Christensen, C. M. (1952) Grain Storage Studies II. Lipolytic activity of fungi isolated from stored corn. Cereal Chem. 29: 299-308.
(25) Okafor, N. (1966a) Microbial rotting of stored yams (*Dioscorea* spp.) in Nigeria. Expl. Agric. 2: 179-182.
(26) Ogundana, S. K. (1969) Physiological studies on the soft rot of yams in storage. M. Sc. Thesis, University of Lagos, Nigeria.
27) Adeniji, M. O. (1970) Fungi associated with storage decay of yam in Nigeria. Phytopathology 60 (4):590-592.
(28) Okafor, N. (1966b) Thermophilic microorganisms from rotting maize. Nature London 210: 220-221.
(29) Okafor, N. (1968) The ecology of microorganisms in a self heating maize stack. Nig. J. Sci. 2(1): 35-40.
(30) Broadbent, J. A. (1967b) Microbiological deterioration of maize used as poultry and livestock feed at farms near Ibadan during the wet season. Rep. Nigerian Stored Prod. Res. Inst. (1966) Tech. Rep. No. 16: 115-118.
(31) Oyeniran, J. O. (1973a) Microbiological studies on maize used as poultry and livestock feed at two research farms in Ibadan, Western State, Nigeria. Rep. Nigerian Stored Prod. Res. Inst. 1970.
(32) Oyeniran, J. O. (1973b) Microbiological examination of maize from various sources soon after harvest. Rep. Nigerian Stored Prod. Res. Inst. 1971, Tech. Rep. No. 3: 27-32.
(33) Anon. (1948) Preservation of grains in storage F.A.O. Agricultural study No. 2., Washington, D.C.
(34) Christensen, C. M., and Hodson, A. C. (1960) Development of granary weevils and storage fungi in columns of wheat, II. J. Econ. Entomol. 53: 357-380.

(35) Sikorowski, P. P. (1964) Interrelation of fungi and insects to deterioration of stored grains. Tech. Bull. 42: Inst. of Agric. Sci.
(36) Forgacs, J., and Carll, W. T. (1962) Mycotoxicoses. Adv. Vet. Sci. 7: 273-382.
(37) Forgacs, J., and Carll, W. T. (1966) Mycotoxicoses. Toxic fungi in tobacco. Science 152: 1634.
(38) Coveney, R. D., Peck, H. M., and Rownsend, R. J. (1966) Recent advances in mycotoxicoses. In "Microbiological deterioration in the Tropics." S.C.I. Mono. (23) 31-43. Soc. Chem. Ind. London.
(39) Wogan, G. N. (1965) Mycotoxins in Foodstuffs. M.I.T., Cambridge, Massachusetts, 1965. 291 pp.
(40) Forgacs, J. (1966) Mycoses and Mycotoxicoses in Poultry. I. Feedstuffs, March 12, 1966: 18-21, 16-71, II. Feedstuffs, March 19, 1966: 25-32, 71-73.
(41) Bamburg, J. R., Strong, F. M., and Smalley, E. B. (1969) Toxins from moldy cereals. J. Agric. Food Chem. 17(3): 443-450.
(42) Sargeant, K., O'Kelly, J., Carnaghan, R. B. A., and Allcroft, Ruth (1961) The assay of a toxic principle in certain groundnut meals. Vet. Rec. 73: 1219-1223.
(43) Laycock, T. (1930) Experiments on the fermentation and moulding of cacao. Bull. Agric. Dep. Nigeria 9: 5-26.
(44) Passmore, F. R. (1932) A survey of damage by insects and moulds to West African cacao before storage in Europe. Season 1930-31. Bull. Imp. Inst., Lond. 30 (3): 296-305.
(45) Bunting, R. H. (1929) Fungi occurring in cacao beans. Yb. Dep. Agric. Gold Cst. 1928: 44-57.
(46) Bunting, R. H. (1931) Deterioration of cacao beans by internal moulds. Bull. Off. Int. Fabr. Choc. Cacao 1(7): 295-303.
(47) Dade, H. A. (1929) Internal moulding of prepared cacao. Yb. Dep. Agric. Gold Cst. 1930: 107-108.
(48) Broadbent, J. A. (1969) The importance of different moulds in causing internal mouldiness of Nigerian cocoa. Rep. Nigerian Stored Prod. Res. Inst. 1967. Tech. Rep. No. 5: 53-57.
(49) Broadbent, J. A., and Oyeniran, J. O. (1969) The penetration of cocoa beans by filamentous moulds during fermentation and drying. Rep. Nigerian Stored Prod. Res. Inst. 1967, Tech. Rep. No. 6: 59-65.
(50) Broadbent, J. A., and Oyeniran, J. O. (1968) A new look at mouldy cocoa. In: "Biodeterioration of materials: Microbiological and Alhed Aspects." Proc. 1st Internat. Biodeter. Symp. Southampton 9-14 Sept. 1968, 695-702. Elsevier Publ. Co. Ltd. England.
(51) Oyeniran, J. O. (1973b) Internal mouldiness of commercial cocoa in Ibadan, Western State, Nigeria. Rep. Nig. Stored Prod. Res. Inst. 1970. Tech. Rep. No. 2, 1927.

(52) Oyeniran, J. O. (1975) Some observations on the quality of Nigerian cocoa from the port of shipment in Lagos. Rep. Nig. Stored Prod. Res. Inst. 1972. Tech. Rep. No. 2: 25-30.
(53) Oyeniran, J. O., and Adeniji, M. O. (1975) Mould deterioration of cocoa during processing and storage in Nigeria. Nigerian J. Plant Protection 1(1): 48-51.
(54) McDonald, D., and Harkness, C. (1963) Growth of *Aspergillus flavus* and production of aflatoxin in groundnuts. II. Trop. Sci. 5: 143.
(55) McDonald, D., and Harkness, C. (1964) Growth of *Aspergillus flavus* and production of aflatoxin in groundnuts. IV. Trop. Sci. 6: 12.
(56) Harkness, C., McDonald, D., Stonebridge, W. C., A'Brook, J., and Darling, H. S. (1966) The problems of mycotoxins in groundnuts (peanuts) and other food crops of tropical Africa. Food Technol. 20(9): 72-78.
(57) Raper, B. K., and Fennel, D. L. (1965) The genus *Aspergillus*. Williams & Williams Co., Baltimore, U.S.A. 686 p.
(58) Halliday, D. (1966) Moisture uptake of bags of groundnuts at Port Harcourt. In: "Further studies of the aflatoxin content of Nigerian groundnuts and groundnut products." Nigerian Ministry of Information, Lagos 1966. 41 pp.
(59) Eggins, H. O. W., and Coursey, D. G. (1964) Thermophilic fungi associated with Nigerian oil palm produce. Nature 203(4949): 1083-1084.
(60) Gray, J. E. (1922) Native methods of preparing palm oil. Ist A. Bull. Dep. Agric. Nigeria 29-50.
(61) Barnes, A. C. (1924) Chemical investigations into the products of the oil palm. Ist special Bull. Dept. Agric. Nigeria.
(62) Kuku, F. O., and Broadbent, J. A. (1977) Studies on mould deterioration of Mid-western Nigerian Palm Fruits and pre-storage palm-kernels at various stages of processing. Rep. Nigerian Stored Prod. Res. Inst. 1973(b): 49-53.
(63) Wicbanx, T. (1963) Les causes de l'acidification de l'huile de palme. Bull. Agric. Congo belge 27: 236-254.
(64) Simmons, R. A. (1965) The bleachability of Nigerian palm oil. Part 2. The effect of delay in processing. Rep. Nigerian Stored Prod. Res. Inst. 1964: 57-58.
(65) Riley, J., and Simmons, E. A. (1967) A survey of palm kernels exported from Apapa and Port Harcourt with special Reference to Discolouration and Infestation. Rep. Nigerian Stored Prod. Res. Inst. 1966 9: 81-85.
(66) Kuku, F. O., and Adeniji, M. O. (1976) The effect of moulds on the quality of Nigerian palm-kernels. Int. Biodetn. Bull. 12(2): 37-41.
(67) Adesuyi, S. A. (1970) A survey of the moisture content of early maize during harvest in the Western State. Rep. Nigerian Stored Prod. Res. Inst. 1968, Tech. Rep. No. 7: 59-61.
(68) Coursey, D. G. (1962) Storage losses in yams. Nigerian Grower and Producer 2(3):

(69) Coursey, D. G. (1967a) Yam Storage I. A review of yam storage practices and of information on storage losses. J. Stored Prod. Res. 2: 229-244.
(70) Coursey, D. G. (1967b) Yams. Longmans, Green and Co., Ltd., London. 230 p.
(71) Coursey, D. G., and Walker, H. M. (1961) A study of the origins of weight losses in stored yams. Rep. W. Afr. Stored Prod. Res. Unit, 1960: 61-64.
(72) Adesuyi, S. A. (1975) Investigations in the storage physiology of yam tubers (*Dioscorea rotundata* Poir) with special reference to the control of sprouting. Ph.D. Thesis (1975) University of Ibadan. 317 pp.
(73) Ogundana, S. K., Naovi, S. H. Z., and Ekundayo, J. A. (1971) Studies on soft rot of yams in storage. Trans. Br. Mycol. Soc. 56(1): 73-80.
(74) Broadbent, J. A. (1971) Mould deterioration in dried yam. (Unpublished report).
(75) Adesuyi, S. A. (1973) Survey of the moisture content and insect infestation pattern on dried yams for twenty-one months in the market in Ibadan (Western State). Rep. Nigerian Stored Prod. Res. Inst. 1971: 65-71.
(76) Halliday, D., Quareshi, A. H., and Broadbent, J. A. (1968) Investigations on the storage of gari. Rep. Nigerian Stored Prod. Res. Inst. 1967. Tech. Rep. No. 16: 131-141.
(77) Adenijii, M. O. (1976) Fungi associated with the deterioration of gari. Nigerian J. Pl. Prot. 2: 74-77.
(78) Opadokun, J. S. (1977) The aflatoxin contents of locally consumed foodstuffs. Part I. Gari. Rep. Nigerian Stored Prod. Res. Inst. 1975. Tech. Rep. No. 7 (Cyclostyled copy).
(79) Oyeniran, J. O. (1978) Microbiological deterioration of gari during storage in polythene and hessian bags (Unpublished).
(80) Mackay, P. J. (1967) Theory of moisture in stored produce. Trop. Stored Prod. Inf. (13): 9-14.
(81) Hall, D. W. (1963) Some essential considerations on the storage of food grains (particularly cereals), legumes and oilseeds in Tropical Africa. F. A. O. Informal Working Bulletin No. 24.

THE DETERIORATION OF COMMERCIAL MAIZE (*ZEA MAYS*) BY INSECTS AND FUNGI

MATT. F. IVBIJARO
Department of Agricultural Extension
University of Ibadan
Ibadan, NIGERIA

INTRODUCTION: Maize, *Zea-mays* L., is a staple food among millions of Nigerians. When fresh, maize is eaten boiled or roasted. When dry, it is made into porridge (akamu, ogi) or into a white solid (agidi, eko). Because the moisture content of fresh maize at the time of harvest in southern Nigeria ranges from 22 to 32% between May and July, maize thus stored becomes mouldy. Insect infestation of the grain is further aggravated by rodents during storage and distribution. In addition to biochemical changes which insect infestation causes to stored grains, discolouration and mycotoxicosis often result from fungal attack.

Most earlier data on losses in stored grains have come from laboratory studies. This paper, however, examines the changes caused by insects and moulds to maize during storage and distribution in open markets in the hope that the findings will draw the attention of farmers and distributors to improved drying methods, better handling and distribution systems; while to the consuer an awareness of quality in his choice of foods.

MATERIALS AND METHODS: Maize on the cob was purchased from three major open markets in Ibadan, in May 1978. Ibadan was chosen being a cosmopolitan city and a major distribution centre for foods in southern Nigeria. Apparently uninfested cobs were then separated from the infested.

I. Physical measurements

(i) Insect population. From each market sample 20 subsamples each of 5 cobs were examined and the total number of adult insects recorded.

(ii) Kernel damage. The cobs from (i) above were shelled and mixed thoroughly and the number of damaged kernels/100 of grain was recorded in 20 subsamples.

(iii) Viability of the maize was determined in apparently clean as well as in infested grains from each market by observing the emergence of hypocotyl in 5 subsamples each of 20 grains of clean and 20 of infested maize placed on moistened Whatman No. 1 filter paper in a petri dish at 27±1°C.

(iv) Mould types. Five samples of clean, and 5 of infested maize each of 20 grains were put on moistened Whatman No. 1 filter paper in petri dishes, covered, and

incubated under the near ultraviolet light to hasten sporulation. Mycelial growth was observed and spores identified.

2. Biochemical measurements
   (i) Free fatty acids. Infested and apparently clean maize grains were ground separately. From each separate portion 6 samples of 5 g were analysed for free fatty acids according to the method of the American Association of Cereal Chemists (1962).
   (ii) Reducing sugars. Soluble carbohydrates were determined by the method of the Association of Official Agricultural Chemists (1950) while sucrose was extracted using the modified anthrone method of Firby et al. (1973).
   (iii) Uric acid was determined according to Eichhorn et al. (1961).

RESULTS. In the commercial maize samples examined, *Sitophilus oryzae* (L.) and *Sitophilus zeamais* Motschulsky accounted for 92% of the total insect population while *Tribolium castaneum* (Herbst.) and *Rhizopertha dominica* (F.) accounted for 6 and 2% respectively. In Table I percentage kernel damage increased with insect infestation

TABLE I.

Insect population, kernel damage and viability in commercial samples of maize

Market	Insect Population	Kernel Damage	Viability (% Germination)	
			Apparently clean	Infested
Sango	48.2	41.0	100	26
Dugbe	36.4	35.5	94	36
Oja Oba	15.4	23.5	98	50

of the grain. Free fatty acids in infested maize was 4.5 mg. KOH per 100 g grain compared with 1.3 mg KOH per 100 g in the apparently clean samples. True uric acid content (mg./100 ml) was 2.05 in infested samples. Insect-infested maize grains were also found to contain moulds belonging to the genera *Aspergillus*, *Penicillium*, *Rhizopus*, and *Fusarium* in a descending order of prevalence.

DISCUSSION AND CONCLUSION. Insects and fungi in agricultural commodities have often caused quantitative loss in addition to undesirable changes. Advanced technological means for detecting insect infestations of grains have received wide attention. However, apart from the prohibitive cost of introducing such technology to developing nations, the need for its use at present is questionable since a large proportion of agricultural produce contains readily observable infestations.

This study shows that maize sold on open markets in Ibadan had physical damage and reduced viability. Increase in fat acidity value in the commercial samples showed that the oily material in the maize must have suffered oxidative degeneration leading to rancidity during storage and distribution.

Uric acid, a major component of insect excreta, has been used as an index of insect infestation of grains (Coombs, 1973; Subramanyan et al., 1955) although creatinine, guanine and allantoin may also be present. It has, however, not been reported whether storage fungi produce uric acids in fungal-infected stored produce. It can thus be reasonably assumed that the increase in uric acid in the commercial maize sold in Ibadan is probably due only to insect attack. The presence of small quantities of uric acid in the apparently clean samples could have been due to undetected insect infestation. Purine and adenine also presumably come only from insect infestation. Therefore the low value of 1.3 mg KOH/100 g must be explained by undetected infestation in the "apparently clean" samples. On open markets in southern Nigeria, maize cobs with apparent insect infestation are usually sorted from the bulk before sales hence the overall mean percentage insect population, kernel damage, and biochemical changes will be higher than we have observed.

In addition to the already observed infestation, the lipolytic properties of the infecting moulds may have contributed to the increase in fat acidity value in the infested maize. Increase in fat acidity value is a useful measure of deterioration. For example, Pingale et al. (1954) recorded a rise of 44, 46 and 49 mg KOH per 100 g of wheat infested by three different insects compared to 19-37 mg KOH per 100 g in uninfested wheat.

Although insect activity in stored grains which results in heating and increased grain moisture encourages the growth of fungi, stored products insects can also be responsible for the introduction and dissemination of storage fungi in a produce (Agrawal et al. 1957, 1958). Mycotoxicosis especially by the *Aspergillus* group has been a major cause for concern (Forgass et al. 1959, 1966) hence fungal attack of maize meant for consumption becomes very important if we consider that porridge, a popular weaning diet all over the country which is also a major light meal for adults comes from maize. It is in the light of this that farmers and distributors of maize must consider seriously improved maize drying methods, and better handling and distribution systems to obviate a possible threat to health.

ACKNOWLEDGEMENT. Part of this study was funded with the University of Ibadan Senate Research Grant for which Dr. M. F. Ivbijaro is grateful.

REFERENCES.

(1) Agrawal, N. S., Christensen, C. M., and Hodson, A. C. (1957). Grain storage fungi associated with the granary weevil. J. Econ. Ent. 50: 659-663.

(2) Agrawal, N. S., Hodson, A. C., and Christensen, C. M. (1958): Development of granary weevils and fungi in columns of wheat. J. Econ. Ent. 51: 701-702.

(3) American Association of Cereal Chemists (1962): Cereal Laboratory Methods. 7th Edition. The Association., St. Paul, Minnesota.

(4) Association of Official Agricultural Chemists, Washington, D.C. (1950): Official Methods of Analysis (7th Ed.).

(5) Coombs, C. W. (1963): A method of assessing the physical condition of insect-damaged grain and its application to a faunistic survey. Bull. Ent. Res. 54: 23-35.

(6) Eichhorn, F., Zealmanowski, S., Lew, E., Rutenberg, A., and Fanias, B. (1961): Improvement of the uric acid determined by the carbonate method for the serum and urine. J. Clinical Pathology 450-452.

(7) Firby, J. N., and Fellers, O. A. (1973): Sucrose determination by a modified anthrone method. Cereal Chem. 50: 210-215.

(8) Forgacs, J., Koch, H., and Carll, W. T. (1955): Further mycotoxic studies on poultry haemorrhagic disease. Poultry Sci. 34: 1194.

(9) Forgacs, J. (1962): Mycotoxicoses in animal and human health. Proceedings 66th Ann. Meeting U.S. Livestock Saint. Assoc.: 426-488. Washington, D.C.

(10) Pingale, S. V., Narayama Rao, M., and Swaminathan, M. (1954): Effect of insect infestation of stored grain studies on soft wheat. J. Sci. Fd. Agric. (U.K.)1: 51-54.

(11) Subrahmanyan, V., Swaminathan, M., Pingale, S. V., and Kadkol, S. B. (1955): Uric acid as an index of insect filth in cereals and milled cereal products. Bull. CFTRI 4: 86-87.

(12) Venkata Rao, S., Nuggehalli, R. N., Swaminathan, M. Pingale, and Subrahamanyan, V. (1958): Effect of insect infestation on stored grain III. Studies on kaffir corn *Sorghum vulgare*. J. Sci. Fd. Agric. (U.K.)9: 837-839.

FIRST SESSION OF SUBMITTED PAPERS

Chairman - DR. N. C. PANT, DIRECTOR
Commonwealth Institute of Entomology
London, U.K.

THE PROBLEMS OF INSECT INFESTATION OF STORED DRIED YAM CHIPS IN NIGERIA

S. A. ADESUYI
NIGERIAN STORED PRODUCTS RESEARCH INSTITUTE
P.M.B. NO. 5044
IBADAN, NIGERIA

INTRODUCTION: Storage of fresh yam tubers (*Dioscorea* spp.) has been very difficult over the years. Losses of between 30 and 50% have been recorded after six months' storage (1). In order to minimize this loss during storage of fresh yam tuber, a fair proportion of it is processed and stored in form of dried yams. Approximately 20-25% of the total yams harvested in the Oyo State of Nigeria are used for the production of dried yams. For this purpose, the fresh tubers are peeled, sliced or whole small tubers used. They are steeped in very hot water for a few hours and sundried. It has been reported that the moisture content of the dried yam in the market was between 12 and 19% (2) depending on the time of production, while the safe moisture content for long-term storage is 15.8 percent (3). Dried yams are stored throughout the year. The dried yams are later milled. The flour is reconstituted with boiling water to form a paste or dough locally known as "amala." It is a very popular dish in the western part of Nigeria. Yams that will not normally store well as fresh tubers e.g. tubers of poor quality and badly damaged yams during harvesting or handling are those processed to dried yam chips.

MATERIALS AND METHODS: The investigations on the problems of insect infestation on stored dried yam chips in Nigeria were carried out in three parts.

1. Establishing the magnitude of the problem
2. Identifying the causes and classifying them into their orders of importance
3. Studying the infestation pattern of the major insect pests

Establishing the magnitude of the problems: The materials used were four bags of newly prepared dried yams and another set of four bags of dried yams from the previous year that had been stored in the depot for about six months and can be termed old stock. The frass and dirt in the old stock were removed.

Each bag was weighed at the beginning of storage. The two sets of dried yams were stored together in a clean store. This was to simulate the normal conditions of storage both by farmers and traders. The moisture content of each set of the

dried yams were taken using ground samples in triplicates by heating in a ventilated oven at 104.5°C for 4.5 hours. Five dried yams from each bag were selected at random and the number of holes due to insect damage counted. The number of holes per treatment was recorded. After four and a half months, the final weight of each bag was taken and the moisture contents determined. The loss in weight was recorded in percentage having corrected for moisture content. The number of holes due to insect damage per treatment was also recorded.

RESULTS: The weight loss in the newly dried yam was 29.5% and in the old stock 39.2%. The average number of insect holes per dried yam in a random sample of the twenty dried yams per treatment was 0 initially and 21 finally for newly dried yams, and 3 initially and 26 finally for old dried yams.

Causes of the loss in weight: In the same trial, all insects present were sieved and identified. This gave an idea of the causes of the losses over the period of storage. The number of each live insect found was recorded. A survey of insect pests on products in the same store and adjacent to where the dried yams were bought was carried out. This was to establish any possibility of cross-infestation.

Results: Table ' shows the species of insects identified on each set of dried yams and the number.

TABLE I. Insect species identified on new and old dried yams and number of each species after 4-1/2 months' storage

Insect species	No. on newly dried yams	No. on old dried yams
1. *Dinoderus porcellus* (Lesne)	>50	>50
2. *Sitophilus zeamais* (Mots.)	>50	>50
3. *Tribolium castaneum* (Herbst)	>50	>50
4. *Araecerus fasiculatus* (Deg.)	40	43
5. *Lasioderma serricorne* (F.)	21	24
6. *Cryptolestes pusillus* (Schn.)	7	6
7. *Callosobruchus maculatus* (F.)	3	4
8. *Carpophilus dimidiatus* (F.) var. *contingens* Wlk.	3	2
9. *Thaneroclerus buqueti* Lef.	2	4
10. Parasitic Hymenoptera spp. Indet.	-	-

D. porcellus, *S. zeamais*, *T. castancum*, and *A. fasiculatus* were the most important in terms of the number present. *A. fasiculatus* was more in practice than recorded because the pest is more active than the other major pests and generally escapes by flying away during assessment. It is doubtful if the others occur more frequently in reality than *A. fasioulatus*.

Classification of insect pests into order of importance:

The four insects already identified to be of major importance in terms of number present were investigated for order of importance. Twenty undamaged dried yams of similar sizes were sterilised at 104°C for one hour in an oven and cooled. They were later conditioned to the same moisture content in a desiccator at 75% relative humidity for one week with a saturated solution of NaCl. Two dried yams were weighed into each of ten kilner jars. The kilner jars were covered with screw caps and fine gauze. The gauze was also covered with black Whatman filter paper gummed to the cover of the jar to prevent contamination by other insects, mites, and psocids (4).

Five adults each of *D. porcellus*, *T. castaneum*, *S. zeamais*, and *A. fasiculatus* taken from the insect culture maintained in our laboratory were carefully dropped into different kilner jars. Each treatment was duplicated and the extra two kilner jars with no insects were used as control.

They were kept at room temperature for ten weeks. At the end of storage damage to the dried yams was assessed by counting the number of holes bored by the insects on them. The frass due to insect damage was collected and weighed. The moisture contents of the dried yams were determined in triplicates by heating in a ventilated oven at 104.5°C for 4.5 hours.

RESULTS: The results in Table III show that *D. porcellus* is the most important of all the major insect pests of dried yams during storage, followed by *S. zeamais*, then *T. castaneum* and least, *A. fasiculatus*.

The infestation pattern of the major insect pests:

A survey was conducted in the main market to assess the monthly condition of the dried yams on sale throughout the year.

Five samples of five pieces of dried yams each were randomly chosen every month from different parts of the main market at Ibadan which serves as the main depot for the product. The number of insect holes in each piece of dried yam was counted and the average recorded. The investigation started in October when new dried yams were being brought to the market. The insect species found in the samples were identified and the number recorded.

The major insect pests collected in descending order of frequency in terms of number are as follows:

TABLE II. Record of insects on products in yam stores and adjacent stores

Product	*D. porcellus*	*S. zeamais*	*S. oryzae*	*T. castaneum*	*L. serricorne*	*A. fasiculatus*	*C. maculatus*
Beans	-	+	+	+	+	-	+
Rice	+	-	+	-	-	-	-
Maize	+	+	-	+	+	+	-
Guinea corn	+	+	-	+	+	+	+

TABLE III. Number of holes and weight of frass produced by each insect species

Insect species	Average No. of holes	Average wt. of frass produced (gm)	% moisture content
D. porcellus	251	12.05	15.3
T. castaneum	6	0.22	15.2
S. zeamais	4	0.31	15.2
A. fasiculatus	2	0.10	15.3
Control	0	0.00	15.2

1. *Dinoderus porcellus* Lesne
2. *Araecerus fasiculatus* Deg.
3. *Sitophilus* Mots. spp.
4. *Tribolium castaneum* (Herbst)

From Table IV it would be seen that dried yams are uninfested from October to March. Infestation starts from April and gradually becomes more serious until August. The condition tends to improve in September when new dried yams start coming into the market.

Table IV. Monthly average number of insect holes per dried yam throughout the year

Month	No. of insect holes per dried yam
October	0
November	0
December	0
January	0
February	0
March	0
April	6
May	13
June	15
July	17
August	25
September	18

DISCUSSION: The problem of insect infestation on stored dried yam chips in Nigeria is very serious resulting in a weight loss of between 30 and 39 percent after 4-1/2 months' storage. The insect damage on the dried yams increased from 0 to over 20 holes per dried yam in the same period. This does not show any improvement over storage losses of stored fresh yam tubers for which processed dried yam was supposed to be an alternative. The problem with stored fresh yam tubers is mainly physiological and microbiological with little or no insect problem.

The causes of the substantial weight and quality loss of stored dried yam have been identified to be insect pests. The method by which the product is displayed for sale and packed predisposes it to cross infestation by insect pests of other products on sale in the same shop or adjacent shops.

The fact that dried yams on sale in the market are uninfested from the farms and not until after March in the markets confirms that the infestation is due to cross infestation from other products in the market. There is therefore a need to prevent cross infestation in the market by not overfilling the jute sacks being used for storing the dried yams as is the practice at present. Overfilling the jute bags exposes a great proportion of the dried yams at the open end of the jute bags because it is impossible to sew up the bags properly. Secondly, the use of polythene lined jute bags will prevent any penetration by insects while the jute bag will protect the polythene bag from rough handling and subsequent damage.

Loss in weight can be reduced substantially if the primary pests, *D. porcellus* and *S. zeamais* are prevented because they especially *D. porcellus* initiate the damage before other insects become important. This explains why at the early stages of infestation, *D. porcellus* was most predominant over other insects which presumably keep off because they cannot initiate damage. *D. porcellus* is able to cause damage to the dried yams because it belongs to the family Bostrichidae whose members are characterised by the presence of powerful jaws with which they can cut directly into wood or other vegetable materials. *S. zeamais* also possesses a pair of stout mandibles or jaws and therefore is able to cause damage to the dried yams.

The results of this work show that pest control measures on dried yams, especially the use of insecticides, are not necessary until April. Farmers or traders who exhaust their stock before April need not control insects under the existing method of storage but should adopt preventive measures discussed earlier.

REFERENCES:

(1) Coursey, D. G. (1967) Yams, Tropical Agriculture series, Longmans Green, London, 1967.

(2) Adesuyi, S. A. (1971) A survey of the moisture content and insect infestation pattern on dried yams for twenty-one months in the market at Ibadan (Western State). Rep. Nigerian Stored Products Res. Inst. pp. 65-71.

(3) Adesuyi, S. A. (1970) The relationship between relative humidity and moisture content of some Nigerian foodstuffs. Rep. Nigerian Stored Prod. Res. Inst. pp. 61-65.

(4) Burges, H. D., and Haskins, K. P. F. (1965) Life cycle of the tropical warehouse moth, *Cadra cautella* (Wlk.), at controlled temperatures and humidities. Bull. Ent. Res. 55, 775, 789.

EFFECT OF TRICALCIUM PHOSPHATE ON *TYROPHAGUS PUTRESCENTIAE* (Schr.) (Acari: Acaridae)

JAN BOCZEK and STANISLAW IGNATOWICZ
Agricultural University of Warsaw
02-766 Warszawa-Ursynów
POLAND

Many insect pests of stored food products are known to be sensitive to tricalcium phosphate contained in their diet. *Sitophilus oryzae* L., *Stegobium paniceum* (L.) and *Trogoderma granarium* Ev. reared on food supplemented with 3% $Ca_3(PO_4)_2$ produced adults, but the second generation was less numerous and produced smaller larvae and adults which weighed less than untreated insects. Inhibition of the development of *Tribolium castaneum* Herst., *Sitophilus oryzae* L., *Cadra cautella* W., *Callosobruchus chinensis* (L.), *Laemophloeus minutus* (Ol.), and *Oryzaephilus surinamensis* (L.) was observed when they were fed on foods with 2-3% $Ca_3(PO_4)_2$ (Majumder 1974, Highland 1975, Lawson 1972, Press et al. 1972). In some species an increase in mortality was noted and in others the reproduction potential was reduced with a decrease in numbers of F_1 offspring. Increased numbers of moultings and deformations of external and internal organs of treated insects were often also observed (Majumder 1974).

Shaver (1974) found that tricalcium phosphate caused an irreversible dehydration of the insects' body. He found rapid mortality of all active stages of various insect species that were in contact with the compound.

Until now the effects of this salt have not been studied on stored product mites.

This study was supported by a M. Sklodowska-Curie grant (FG-Po-360-JB-28).

MATERIALS AND METHODS: The fecundity and longevity of mites were determined for 25 pairs. Young, virgin mites were paired and placed separately in rearing cages with ground wheat germ. The reaction coefficient Wr upon fecundity was calculated with the formula:

$Wr = \frac{Np \cdot 100}{Nk}$ where Np = average number of eggs in the test and Nk = the average number of eggs in the check. The longevity of virgin females and males was determined in each case for 100 adults kept in 40 cages (5 virgin females or males in one cage) with ground wheat germ mixed thoroughly in agate mortar with various concentrations of the salt. The time of development of one generation and mortality during development were compared starting with 50 eggs in each cage (5 cages each with 10 eggs).

The contact action of $Ca_3(PO_4)_2$ was tested on 25 mites of consecutive stages kept in cages with a 0.5 -1.0 mm layer of

the salt on wheat germ. LT_{50} and LT_{95} were defined. Cultures were usually kept at 85% r.h. and 25°C.

RESULTS AND DISCUSSION: The effect of $Ca_3(PO_4)_2$ mixed with food upon fecundity, longevity and time of development is presented in Table I. It was found that the addition of the salt affected the fecundity but at a 6% concentration was lower than the check only by 23.2%. The inhibitory effect increased both in P and F_1 generations with the duration of feeding of females with salt-containing diets. Generation time was then extended by 2.2 - 3.9 days with very low mortality during development. Mites of the F_1 generation, usually more sensitive to the addition of salts to their diet, also reacted only slightly to the addition of $Ca_3(PO_4)_2$. The effect of higher concentrations of tricalcium phosphate on fecundity and on egg viability and mortality during development, is shown in Figure I. A 50% reduction in fecundity compared with the check was found at 18.0 - 21.0% concentrations. When salt was applied in higher concentrations, it affected the adult mite longevity. At a 1.5% concentration, egg laying females lived 15.8 days longer while at 6% concentration the longevity was decreased by 22.2 days when compared to check. Males on diets with a concentration greater than 1.5% also lived for shorter periods of time.

This salt also affected the longevity of virgin mites. At all concentrations, the longevity of males was shorter and females longer than the checks. Males of the F_1 generation lived 16.3 - 40.7 days longer than those in the check, while the females' longevity compared favourably with females living on untreated wheat germ.

Only at 30.0 to 31.5% concentrations was lower egg viability observed. At concentrations of 18.0 to 21.5%, the fecundity was 50% lower and at 31.5% concentration, it was 83.9% lower than the check (Figure 1).

Even at very high concentrations 9.0 to 31.5%, this salt did not appreciably affect mite mortality during development (i.e. 14.0%).

The contact action of tricalcium phosphate on various stages of *T. putrescentiae* is presented in Table II and Figure 2. Within 10-15 minutes after the mites were placed into the rearing cages with the salt, they were excited and tried to escape from the cage. They did not feed at all. After 0.5 to 1.0 hours of contact with the compound, the bodies of the mites were covered with particles of the salt and many mites were already dead. Dead mites had stretched bodies and legs. The inert stages--eggs, larvae and nymphs--were resistant to the salt, and progressed to the next developmental stages. As shown in the data, the younger developmental stages--larvae and protonymphs--were more sensitive to the contact action of the salt. Females were the most resistant.

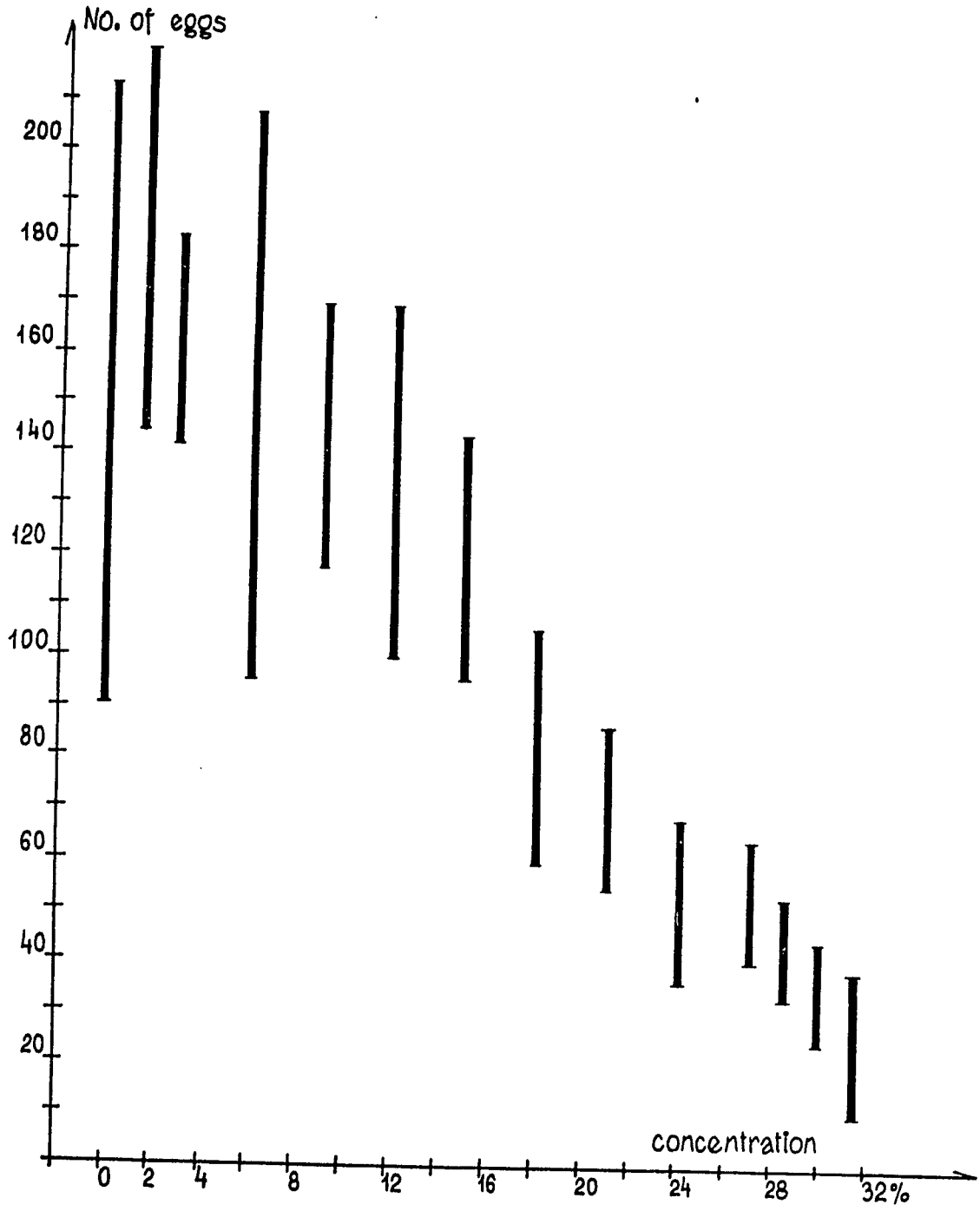


Figure 1. Effect of $Ca_3(PO_4)_2$ at doses 1.5 - 31.5% on fecundity of *T. putrescentiae* (from-to, averages)

TABLE II. Effect of tricalcium phosphate on consecutive stages of *Tyrophagus putrescentiae* and *Acarus siro*/contact action/hours

Species and stage	LT_{50}	LT_{95}
T. putrescentiae		
Larva	0.75	1.00
Protonymph	0.95	2.05
Tritonymph	1.15	3.70
Male	1.15	3.40
Female	1.25	4.00
A. siro		
Larva	0.75	2.10
Protonymph	0.80	1.70
Tritonymph	1.10	2.25
Male	1.20	3.25
Female	1.20	3.75

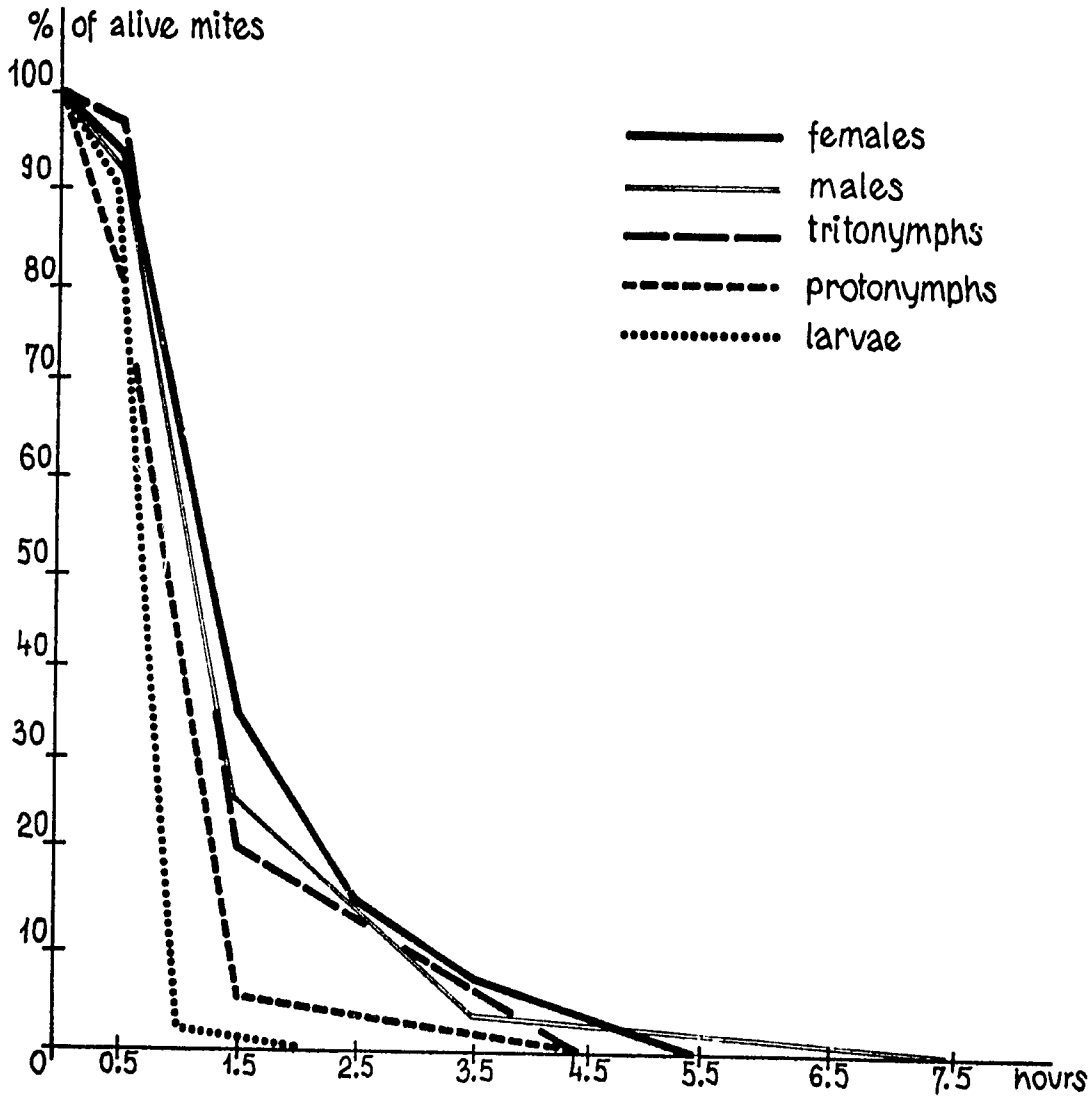


Figure 2. Contact action of $Ca_3(PO_4)_2$:
mortality of various stages of *T. putrescentiae*

TABLE I. Effect of tricalcium phosphate upon the fecundity, longevity, and time of development of *Tyrophagus putrescentiae*/Schr./

Characters studied	Check	Salt concentration (%) in diet		
		1.5	3.0	6.0
Fecundity, no. of eggs	472.4± 68.4	431.6± 54.6	383.4± 88.8	362.9± 85.1
Wr (P generation)		-5.6	-18.8	-23.2
Longevity of reproducing females (days)	56.5± 27.1	72.3± 35.4	52.0± 21.1	34.3± 7.8
Longevity of reproducing males (days)	85.5± 34.6	113.2± 30.3	94.0± 37.3	75.1± 19.6
Longevity of virgin females (days)	152.0± 43.4	160.9± 56.2	136.4± 53.2	166.7± 45.5
Longevity of virgin males (days)	122.0± 31.7	113.6± 20.1	102.4± 22.9	99.3± 39.6
Time of development of generation (days)	14.1	13.5	17.9	16.2
Mortality during development	5.2	4.7	5.1	4.9
Fecundity of F_1 generation	430.5± 29.7	377.2±106.7	365.5± 93.3	405.8±151.7
Wr (F_1 generation)		-20.2	-22.6	-14.1
Longevity of F_1 females		58.8± 19.5	52.0± 15.0	53.8± 19.6
Longevity of F_1 males		101.8± 35.0	125.0± 18.7	126.2± 32.0

However, the differences between consecutive developmental stages were not very great. The LT_{50} ranged from 0.75 to 1.25 hours and the LT_{95} from 1.0 hour for larvae to 4.0 hours for females. Screening tests made for 7 other species of related acarid mites (Table III) showed that *T. putrescentiae* was the most resistant. The LT_{50} and LT_{95} were usually lower for females and males of other species of mites. No significant differences were found in the sensitivity of adult mites as related to age and temperature (10-28°C).

CONCLUSIONS: In contrast to insects, the effect of tricalcium phosphate added to the diet of copra mites in concentrations of 1.0-6.0% was only slight in both P and F_1 generations. The fecundity, longevity, and mortality of the mites were only slightly, if at all, affected. Reduction of the fecundity by one-half was reached at a salt concentration as high as 18.0% in the diet. Mortality during development and egg viability were practically not affected until the concentration of the salt reached 31.5%.

Tricalcium phosphate showed very strong contact action on *T. putrescentiae* causing 100% mortality of all active stages of the mites after 3-5 hours. Inert stages were resistant. Its action was of a physical nature, causing scratching and wax absorbtion of cuticle.

Related species of acarid mites living in stored food products were still more sensitive to the contact action of the salt than *T. putrescentiae*.

REFERENCES:

(1) Highland, H. A. (1975) Tricalcium phosphate as an insect suppressant in flour and CSM. J. Econ. Entomol. 68: 217-219.

(2) Lawson, D. E. (1972) Unpublished data.

(3) Majumder, S. K. (1974) The importance of taxonomy and of laboratory studies on the biology, nutrition and physiology of insects infesting stored products. Proc. 1st Int. Work. Conf. Stored Prod. Entomol., Savannah, Ga., USA: 18-29.

(4) Press, J. W., Phillips, R. H., Lum, P. T. M., Miller, A. M. (1972) Tricalcium phosphate as an additive to CSM and all purpose wheat flour for control of insect infestation. J. Econ. Entomol. 85: 254-257.

(5) Shaver, K. J. (1974) The dual functionality of tricalcium phosphate as a mineral supplement and insect inhibitor. Proc. IV Int. Congr. Food Sci. Techn., Madrid.

TABLE III. Contact action of tricalcium phosphate on females and males of acarid mites/hours/

Species	Females		Males	
	LT_{50}	LT_{95}	LT_{50}	LT_{95}
T. putrescentiae	1.25	4.00	1.15	3.40
T. casei	0.80	1.40	0.75	1.10
T. similis	1.10	1.80	0.75	1.30
T. palmarum	0.75	2.60	0.75	2.10
T. longior	0.55	3.75	0.65	5.10
T. neiswanderi	0.95	1.45	0.75	1.45
A. siro	0.80	1.70	0.75	2.10
T. entomophagus	0.75	1.60	0.70	1.20

AN UNUSUAL MORTALITY OF *SITOPHILUS ZEAMAIS* MOTS. CAUSED BY *SITOTROGA CEREALELLA* (OLIV.) IN MIXED LABORATORY CULTURES

J. N. AYERTEY
Department of Zoology
University of Cape Coast
GHANA

INTRODUCTION: Laboratory observations made on a series of mixed species cultures of the maize weevil, *Sitophilus zeamais* Motschulsky and the Angoumois grain moth *Sitotroga cerealella* (Olivier) cultured on maize showed that *S. zeamais* eliminated *S. cerealella* from all the mixed cultures. However *S. zeamais* suffered a high initial mortality which affected its initial growth in all the mixed cultures (Figure 1). In the 30 experimental jars in which the two species were cultured together, the mean mortality of *S. zeamais* recorded 30 days after the beginning of the experiment amounted to 48%. The mortality of *S. zeamais* cultured alone in similar jars amounted to only 7% during the same period. This difference was surprisingly high ($P < .01$) and a series of investigations were carried out to determine the cause.

EXPERIMENTAL: Source of experimental insects: *S. zeamais* and *S. cerealella* used in these experiments were from stocks originally maintained on wheat for about 10 yr at the Pest Infestation Control Laboratory in Slough, U.K. These were subsequently subcultured on maize for about 2 yr in the same laboratory where this work was carried out. The maize was imported from Ghana and as far as could be ascertained had not been treated chemically. All the cultures and experiments were maintained in a Constant Temperature and Humidity room at 30°C and 70% r.h.

Stage of *S. cerealella* causing mortality of *S. zeamais*: In the culture jars in which the unusual mortality of *S. zeamais* was observed, the culture jars were not examined until 30 days after they had been set up, by which time both species had completed a generation and adults had begun to emerge. In order to determine the developmental stage of *S. cerealella* that killed the *S. zeamais*, another mixed culture was started and observed weekly for 4 weeks. Results obtained in this experiment showed that the significant weevil mortality occurred during the first week (Figure 2) suggesting that adult moths killed the weevils. Further investigations showed that neither physical contact between *S. zeamais* and *S. cerealella* nor a continuous presence of *S. cerealella* in the experimental jars for 2-4 weeks was necessary for weevil death. The latter implies that weevil adults that survived the 'moth effect' during the first week survived

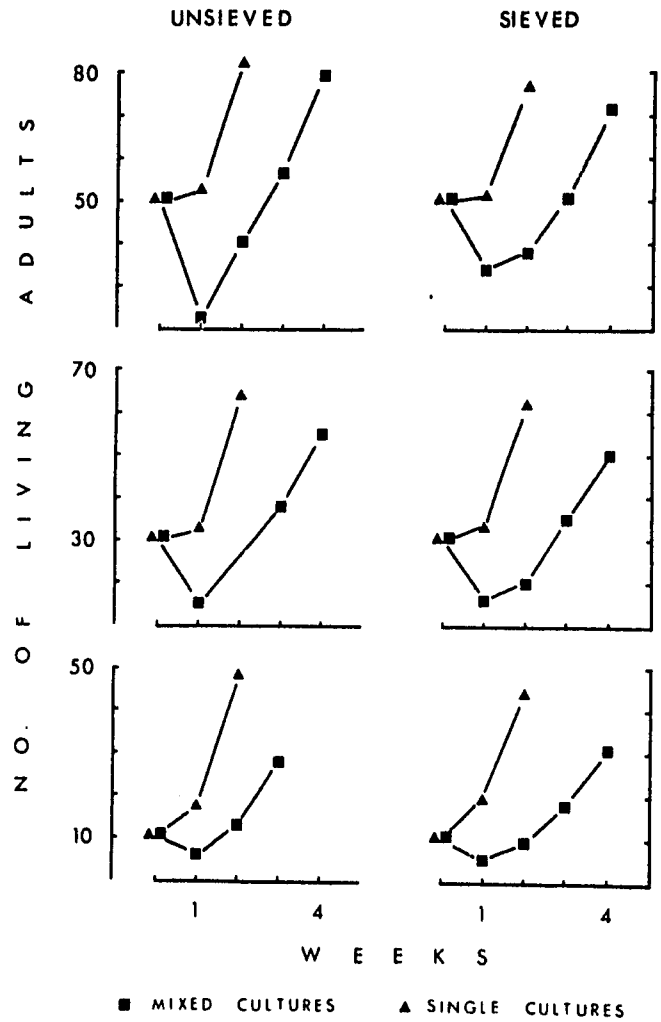


Figure 1. A comparison of the initial population growth of *S. zeamais* cultured alone (single) or with *S. cerealella* (mixed) using 10, 30, or 50 adult weevils. (The high initial mortality of *S. zeamais* is illustrated by the drop in growth recorded during the first week of census).

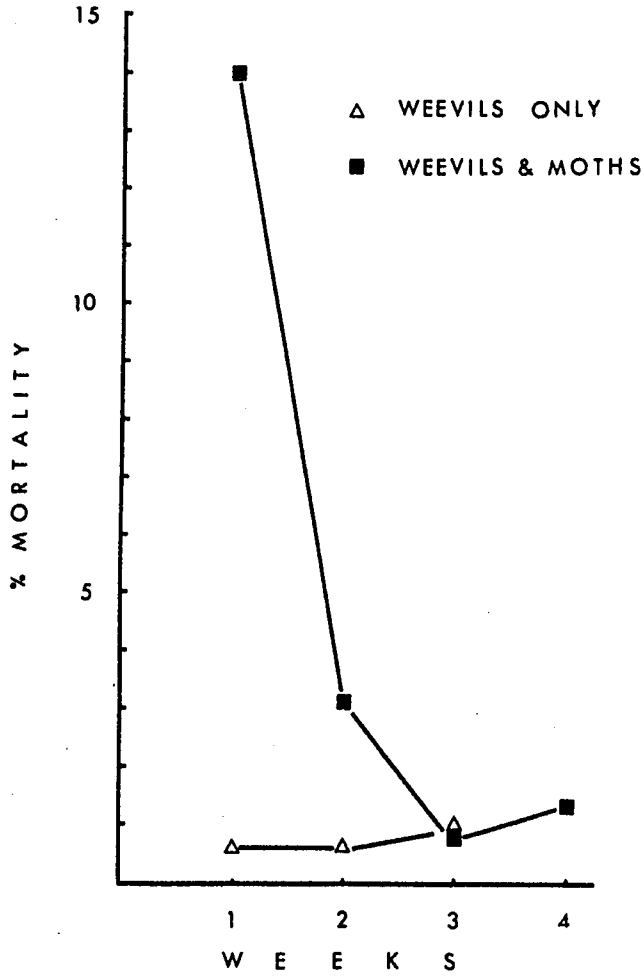


Figure 2. A comparison of the mortality of *S. zeamais* in single and mixed cultures with *S. cerealella* maintained over a four week period. (Scales exaggerated to emphasise differences in mortality)

subsequently, although they did not pass on this ability to their offspring. In all the above investigations, weevil mortality varied considerably between different replicates. It was also observed that older weevils succumbed more readily to the moth effect than younger weevils (Figure 3).

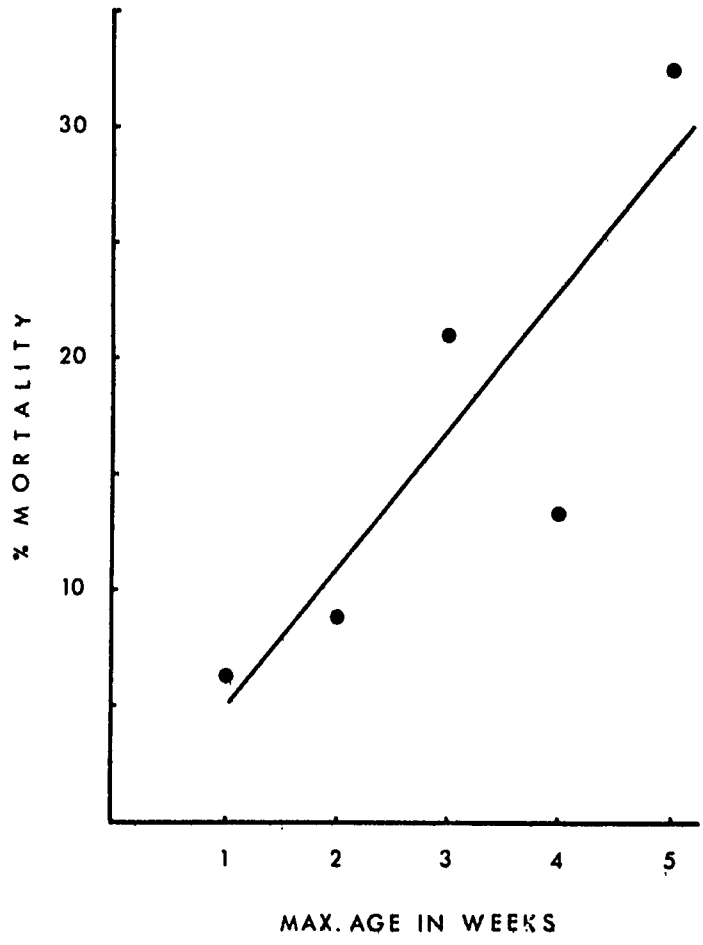


FIGURE 3. Effect of *S. cerealella* on different age groups of *S. zeamais*

Investigations into the effects of moth scales or a possible moth secretion on weevil adults: In the experiments in which *S. zeamais* and *S. cerealella* were placed together on maize grains, the weevils were in direct contact not only with the bodies of moths which died during the period but also with their body scales which they shed into the culture medium. If such dead moths and moth scales killed the weevils by hampering their movement, it would explain why mortality fell after one week of exposure as most of these were removed by sieving at the first count. On the other hand when *S. zeamais* and *S. cerealella* were physically separated by placing the former in tubes before being placed in a moth culture jar, weevil mortality was again high although scales and dead moths were excluded. In all cases the high weevil mortality was confined only to the first week of exposure. It was necessary therefore to determine more precisely whether *S. zeamais* was killed by moth scales or by a secretion released by *S. cerealella*.

About 25 g of maize was placed in each of 16 half litre glass jars grouped into 4 lots of 4 jars each. Eight batches of 200 freshly emerged *S. cerealella* adults were counted and each batch placed in a jar of maize for 3 days and removed by suction after shedding their scales in the food medium. At the same time about 1000 freshly emerged *S. cerealella* adults were confined in a litre jar for about 2 h during which they also shed their scales because of the intense crowding. Four batches of 200 moths each from this latter group were also placed in jars of maize for 3 days and then removed by suction. Moths in this group were referred to as 'rubbed' as they were placed on grain with most of their body scales already shed. The remaining 4 jars of maize were not seeded with moths and served as controls.

Twelve lots of 100 *S. zeamais* adults aged about one week were counted and placed on the above maize grains as follows: Four lots were placed in the 4 control jars (D), another 4 lots went to 4 of the 8 jars seeded with freshly emerged adult moths (A) and the final 4 lots to the jars seeded with 'rubbed' moths (C). One week later, a further 4 lots of weevils of similar age were counted and added to the remaining group of jars (B). The one week delay in group B was to find out if the number of weevils dying on moth-conditioned maize was affected by this delay.

All 16 jars were emptied 7 days after the introduction of *S. zeamais* and the number of dead and living weevils in each jar counted and the weevils discarded. At this count maize grains, moth scales and dead moths were returned to their appropriate jars and these were again seeded with a fresh supply of weevils. This procedure was repeated weekly for a further 2 weeks. In this way moth scales and dead moths were retained throughout the experiment in those jars in which these were present.

	Moth plus scale deposits (A)	Moth plus scales, delayed (B)	Moth plus few scales (C)	No moths or scales (D)
	36	29	21	5
WEEK	5	12	43	10
1	32	15	17	6
	7	4	29	7
Total	80	60	110	28
	5	17	4	2
WEEK	4	16	12	3
2	8	14	5	5
	3	18	3	3
Total	20	65	24	13
	7	9	4	6
WEEK	8	13	5	4
3	5	12	3	2
	8	13	6	5
Total	28	47	18	17

TABLE I. No. of weevils killed when 100 adults of *Sitophilus zeamais* were placed on maize grains conditioned by *Sitotroga cerealella* (see text).

The results of this experiment again showed that the high weevil mortality was still confined to the first week of exposure only (Table I). The cause of death of *S. zeamais* could therefore not be attributed to moth scales or dead moths. In fact during the first week of census, the largest number of dead weevils was from the group with fewer scales (C). The one week delay before introducing *S. zeamais* into the *S. cerealella*-conditioned maize did not reduce weevil mortality either. Indeed it raised it slightly but, unlike the other two groups, the mortality was spread fairly uniformly over the 3 weeks. It appeared therefore that the factor that killed *S. zeamais* in mixed culture with *S. cerealella* was probably a chemical which did not break down in one week in an undisturbed medium.

A scanning electron microscope study of *S. cerealella.* In most of the experiments described above it was found that adult weevils suffered their highest mortality during the first week of exposure to the moth and subsequent exposures did not appear to affect the weevil populations. It was also found that the lethal effects of moth-conditioned maize affected only those weevils exposed during the first week, few of those exposed in subsequent weeks dying. However if the moth-conditioned maize was left undisturbed for a week before *S. zeamais* was added, it remained lethal to the weevils. A microscopic examination of dead moths was therefore made using a Scanning Electron Microscope (SEM) to find out if any changes took place on the moth body after death, and which could be detected by this equipment, to explain the cause of weevil death.

Freshly emerged *S. cerealella* adults were anaesthetised with CO_2 and killed with ether and two pairs of each sex were immediately prepared for mounting. Another lot made up of two pairs of each sex were mounted one week later. Mounting was done onto aluminum stubs with silver dag and the specimens were coated with 400A gold using Polaran Sputter Coating Unit. Several shots were taken of different parts of the body of both sexes of the two lots of moths. Examination of the micrographs showed that different scale types were present on different parts of the body but no differences could be detected between those mounted soon after death and those mounted one week later in either sex. However, at the higher magnifications (x14,000 and above) it was not possible to obtain sharp focussing at certain areas of the body (Figure 4). These areas of obscured vision appeared at several spots but were interrupted by clear areas which showed details of the microstructure of the scales. After the SEM operator made certain that the blurred areas were not due to a technical fault, we concluded that these areas were covered by a secretion. I suggest that this secretion killed *S. zeamais*. The results of these experiments will therefore be discussed on this hypothesis.

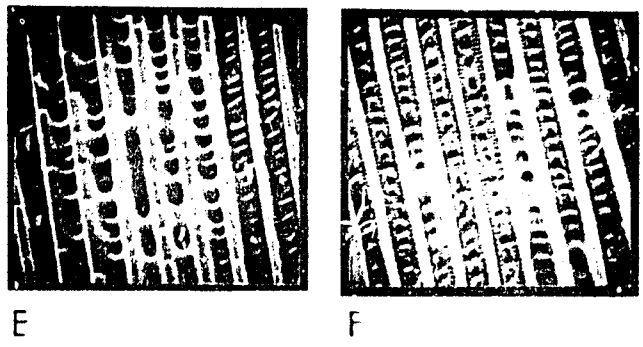


Figure 4. Scanning electron micrographs of wing scale of *S. cerealella* (Mag. x 14,5000) showing clear and blurred areas on scale.

DISCUSSION: In the 30 replicate jars in which *S. zeamais* and *S. cerealella* were cultured together, the mortality of weevils recorded 30 days after the beginning of the culture ranged from 20 - 100%. In 14 of these jars, weevil mortality was 50% and above. In 40 comparable jars in which *S. zeamais* was cultured alone weevil mortality over the same period ranged from 0 -20%. In 30 of these jars mortality was below 10%. The difference in weevil mortality in the two series of cultures was more than could occur by chance. Further experiments have confirmed this unusual weevil mortality. No similar observation has been reported before, although weevil populations have been reported to have been suppressed by *S. cerealella*, through crowding, resulting in a reduction in weevil oviposition (1). If *S. zeamais* was killed by a secretion from *S. cerealella* as I suggest in these experiments, then it should be possible to explain all the results obtained in these experiments on this premise. For the secretion principle to be tenable it should be able to explain the following main points arising out of the experimental results:

1. The variability in the results obtained,
2. The ability of the secretion to kill weevils not in physical contact with moths,
3. Why some weevils did not die after 1 week:
   a) among those that survived an initial exposure to the moths but remained on the moth-conditioned grain
   b) among a fresh supply of weevils placed on grain previously occupied by another batch of weevils,
4. The ability of the undisturbed moth-conditioned grain to kill weevils placed in it one week after setting it up.

From the results obtained in these experiments it appears that *S. cerealella* released a secretion which although it could be found on the body was probably present as a gas as well, or evaporated into gas with time. On release this secretion covered the scales of the moth and probably the food as well. An adult weevil which fed on a portion of grain on which this secretion was deposited would be killed. If a weevil fed on grain not covered by secretion, it survived. On the other hand in its gaseous form the secretion could kill weevils separated from moths by muslin and the likelihood of weevil death would increase if the weevils came to rest on the opposite side of the muslin close to where the moths released this secretion. Thus only weevils which fed on moth secretion or came close to the secretion would be killed. Under these premises the number of weevils dying in different replicates would vary as was found in these experiments. After about a week when nearly all the moths had died, weevils which survived the initial exposure to moths were more likely to survive because only a little secretion would remain, much of it having escaped from the medium through weevil activity. Thus when *S. cerealella*-conditioned grain was left undisturbed for one week, there was no loss of secretion and as many weevils placed on these were killed as those placed on freshly conditioned grain. When the medium has been stirred up by weevil activity for at least one week however, much of this secretion escaped and weevils which remained in the medium, or a fresh supply introduced into the stirred medium survived.

Although no further tests were carried out to determine the nature of the secretion reported above, two main gaseous secretions have been associated with stored product insects: quinones and pheromones. Quinones are secreted from specialised odoriferous glands. The principal constituent of this secretion was found to be ethyl quinone (2). This secretion is the cause of conditioning of the food medium in *Tribolium* (3) and probably the cause of conditioning by several other insects. Conditioning of the food medium has various effects on different insects (4, 5, 6). The other secretion common with insects is pheromones. These have been reported to be present in *S. cerealella* (7, 8). Unfortunately in the present investigations it was not possible to investigate the separate effects of males and females of *S. cerealella* on *S. zeamais*. Because of the variability reported in the results of these experiments, large numbers of moths were required at any one time for experiments. To obtain large enough numbers of each sex of *S. cerealella* for these experiments, large numbers of grains containing immature moths would have to be isolated before the moths emerged. It was not practicable to obtain such large numbers emerging within a few days of each other for experiments which could be satisfactorily replicated. The nature of the secretion or its source is therefore unknown but its effect on

adult *S. zeamais* has been consistently found to cause their death.

REFERENCES:

(1) MacLagan, D. S. The effect of population density upon rate of reproduction with special reference to insects. Proc. Roy. Soc. Lond. 111B (1932) 437.

(2) Alexander, P., and Barton, D. H. R. The excretion of ethylquinone by the flour beetles. Biochem. J. 37 (4) (1943) 463.

(3) Roth, L. M., and Howland, R. B. Studies on the gaseous secretion of *Tribolium confusum* Duval. I. Abnormalities produced in *Tribolium confusum* Duval by exposure to a secretion given off by the adults. Ann. Ent. Soc. Amer. 31 (1941) 151.

(4) Park, T., and Woolcott, N. Studies in population physiology. VII. The relation of environmental conditioning to the decline of *Tribolium confusum* populations. Physiol. Zool. 10 (1937) 197.

(5) Ghent, A. W. Studies of Behaviour of the *Tribolium* flour beetles. I. Contrasting responses of *T. castaneum* and *T. confusum* to fresh and conditioned flours. Ecology 44 (1963) 269.

(6) Takahashi, F. The effect of biologically conditioned food upon larval development. On the effect of population density on the power of the reproduction of the almond moth *Ephestia cautella*. Jap. J. Ecol. 7 (1957) 70.

(7) Agah, A. A. The Biology of *Sitotroga cerealella* With Special Reference To Food And the Effect of Extreme Physical Conditions. Ph. D. Thesis Univ. Lond. (1961)

(8) Keys, R. E., and Mills, R. B. Demonstration and extraction of a sex attractant from female Angoumois grain moths. J. Econ. Ent. 61(1) (1968) 46.

THE DEVELOPMENT OF TWO KOLA WEEVILS, *SOPHRORHINUS GBANJAENSIS* D & T AND *BALANOGASTRIS KOLAE* (DESBR.) ON WILD KOLA, *COLA GIGANTEA* CHEV.

AJIBOLA M. DARAMOLA
Cocoa Research Institute of Nigeria
Gambari Experimental Station
P.M.B. 5244, Ibadan,
NIGERIA

INTRODUCTION: *Sophrorhinus gbanjaensis* D & T and *Balanogastris kolae* (Desbr.) are the most destructive and widely distributed curculionid pests of cultivated kola in Nigeria. Other weevil pests which are either of less economic importance and/or of restricted distribution include *S. insperatus* Faust, *S. duvernoyi* Rouzet and *S. quadricorislatus* Faust. The kola weevils which belong to two genera: *Sophrorhinus* Faust and *Balanogastris* (Desbr.) are field-to-store pests of kola nuts and multiple infestation occurs in the field (1, 2, & 3). Weevil infestation of kola nuts ranging from 34-65% and 100% in cases of late harvest have been reported by these workers.

About twenty-five species of *Cola* have been identified in the tropical rain forest of West Africa but only five species produce edible seeds commonly called nuts. In Nigeria, only two species of *Cola: C. nitita* (Vent.) Schott & Endl. and *C. acuminata* Schott & Endl. are cu'tivated as plantation crops and their nuts are of social and economic importance. *C. nitida* in particular, is the main source of cash income of many farmers in some parts of Ogun, Lagos, Oyo, Ondo and Kwara States. It is also the only species of *Cola* that enters the world market. Kola nuts are chewed primarily as a source of stimulant (caffein content, 2.5%) by the natives both in the rain forest, savanna and sahelian zones and are also used for making dyes for cloth and threads in the latter zones of Africa. The increasing demand for kola nuts on the world market for the manufacture of beverages, soft drinks, e.g. Coca-Cola, Pepsi-Cola, etc., drugs and its potentials have been highlighted by many workers (4, 5, & 6).

Daramola (7) recorded both *S. gbanjaensis* and *B. kolae* on *Cola gigantea* Chev. during his studies on the distribution and host range of the kola weevils in the forest and derived savanna areas and the forest galleries in the southern Guinea savanna zone. *C. gigantea* grows wildly throughout the forest zone which is the major kola producing area in Nigeria. It is a fast growing tree and the grafting of *C. nitida* on it in order to take the advantage of its good growth has been initiated at the Cocoa Research Institute of Nigeria (Ibikunle, 1974; personal communication).

This paper reports studies carried out on oviposition, development and survival of *S. gbanjaensis* and *B. kolae* in *C. gigantea*. The role of *C. gigantea* in the survival of the weevils

during the off seasons of *C. nitida* and *C. acuminata* was also discussed.

MATERIALS AND METHODS: Studies on oviposition and development of *S. gbanjaensis* and *B. kolae* were carried out in cages under a laboratory temperature of 28±1° C.

Oviposition - One-day-old males and females of *S. gbanjaensis* and *B. kolae* collected from laboratory cultures of field-infested kola nuts were paired separately inside plastic rearing cages of 13.5 x 8.5 x 6.2 cm dimension. Four holes (3 cm diameter) were made on each cage and three of these were covered with fine wire mesh. Water was supplied through the fourth hole on a pad of cotton wool. Each pair was confined with a fresh uninfested nut of *C. gigantea* for feeding and oviposition in ten replicates. Nuts were teased out and examined under the dissecting microscope daily for weevil eggs and the numbers recorded. Nuts were replaced with new ones after each observation. Records on oviposition were taken over a period of 35 days because preliminary observations showed that *B. kolae* did not survive on *C. gigantea* under laboratory conditions much longer than 35 days.

Development - The development of weevils from eggs to adults were studied on fresh nuts in which oviposition had taken place in five replicates of five nuts each. Such nuts were placed inside transparent polythene bags specially designed to keep the nuts fresh for as long as required for the development of the weevils in place of fresh banana or *Dorax* sp. leaves as in the traditional method of storage (8). Water droplets from condensation inside the bags were wiped off every other day in order to prevent fungal infection. Incubation, larval and pupal periods were obtained by dissecting nuts on which oviposition has taken place at two days interval based on the knowledge of the biology of the weevils on *C. nitida* (8 & 9). To obtain the incubation periods, an average of ten and five nuts were examined daily as from the third day for *S. gbanjaensis* and *B. kolae* respectively. Larval periods were also determined by examining ten larvae of each weevil every other day until pupae were found. Average of the periods between the end of incubation periods and presence of pupae in the nuts were taken as the periods of larval development. Similar procedures were used to determine the pupal periods of the weevils. The survival of the weevils on *C. gigantea* was also recorded over the oviposition period.

RESULTS AND DISCUSSION: Oviposition - Average pre-oviposition periods of 12.3 (10-14) days and 3.2 (3-4) days were recorded for *S. gbanjaensis* and *B. kolae* respectively.

S. gbanjaensis and *B. kolae* laid a total of 226 eggs (mean: 22.6±3.1) and 303 eggs (mean: 30.3±2.8) in 35 days respectively (Table I).

DEVELOPMENT: The incubation, larval and pupal periods of *S. gbanjaensis* and *B. kolae* are given in Table II. *S. gbanjaensis*

TABLE I. Oviposition and survival of *S. gbanjaensis* and *B. kolae* in *C. gigantea* in 35 days.

Replicates	No. eggs laid in 35 days	
	S. gbanjaensis	*B. kolae*
1	21	21
2	22	30
3	25	32
4	19	35
5	25	27
6	22	33
7	23	31
8	29	31
9	19	30
10	21	28
Total	226	298
Mean	22.6 (19-29)*	29.8 (21-35)
Mortality(%)	10	75

* Range.

TABLE II. Development of *S. gbanjaensis* and *B. kolae* in *C. gigantea*.

Weevil species	Mean developmental periods (days) ± S.E.			Total period* of development
	Egg (incubation)	Larval	Pupal	
S. gbanjaensis	6.6±0.9	20.6±1.8	6.9±0.8	34.4±1.5
Range	6 - 8	19 - 23	6 - 7	32 - 36
B. kolae	6.0±0.7	18.8±1.5	6.4±0.9	31.8±1.9
Range	5 - 7	17 - 21	5 - 7	29 - 33

* No significant difference ($t=1.53$; $P>0.05$) between the total developmental periods of the two weevils.

had an average incubation period of 6.6±0.9, larval and pupal periods of 20.6±1.8 and 6.9±0.8 days respectively. *B. kolae* also had an incubation period of 6.0±0.7 days, larval and pupal periods of 18.8±1.5 and 6.4±0.9 days respectively. The total periods of development of *S. gbanjaensis* and *B. kolae* from eggs to adults in *C. gigantea* were 34.4±1.5 (32-36) days and 31.8±1.92 (29-33) days respectively. There was no significant difference between the total periods of development of the two weevils in *C. gigantea* ($t=1.53$; $P>0.05$).

The mortality of *B. kolae* was very high (75%) especially in the last seven days of the oviposition period. *S. gbanjaensis* survived much better and only 10% mortality was recorded. The high percentage mortality recorded for *B. kolae* might not be unconnected with light interference with the feeding activities of the weevils. Earlier larboratory observations showed that *B. kolae* feeds away from light and hides in the space between the nut (*C. nitida*) and bottom of the cage. But *C. gigantea* nuts are small and as such, the weevils are more exposed to effects of light. This is contrary to the prevailing conditions in the field where most of the nuts still remain inside the pods even when dehisced and the weevils can feed and stay away from light.

Although *B. kolae* laid a higher number of eggs than *S. gbanjaensis* in *C. gigantea* during the duration of the experiment, it is, however, not a measure of the fecundity of the weevils on this wild host. Firstly, *S. gbanjaensis* survived much longer on *C. gigantea* under laboratory conditions and secondly, it has a longer pre-oviposition period and would oviposit over a period of eight weeks of its life span (8).

The result obtained on the development of both *S. gbanjaensis* and *B. kolae* in *C. gigantea* show some similarities to the data recorded on the biology of these weevils under similar laboratory conditions in the cultivated host, *C. nitida*, by Daramola (8) and Ivbijaro (9) respectively. An incubation period of 5.9 days and larval and pupal periods of 26.5 and 7.7 days respectively were recorded for *S. gbanjaensis* at 27.5°C. The incubation and pupal periods recorded for *S. gbanjaensis* in both *C. nitida* and *C. gigantea* were very close. It is only the larval period of 26.5 days in *C. nitida* that is longer than 20.6 days recorded in *C. gigantea*. Although the reasons for the difference are not immediately known, *C. nitida* is a much bigger nut than *C. gigantea* and the amounts of food contained in these nuts might be partly responsible for differences in the larval periods. However, comparative biochemical analyses of the two nuts are required for a better understanding of the influence of food on larval development. average total periods of development of *S. gbanjaensis* in *C. nitida* and *C. gigantea* were 41.2 and 34.4 days respectively.

Ivbijaro (9) reported an incubation period of 5.8 days, larval and pupal periods of 18.5 and 5.0 days respectively for *B. kolae* in *C. nitida* at 27.5°C. These figures are very close to

the incubation period of 6.0 days, larval and pupal periods of 18.8 and 6.4 days respectively recorded in *C. gigantea* in spite of the obvious difference in sizes and speculated larger food materials in *C. nitida*. But *B. kolae* is much smaller compared with *S. gbanjaensis* and as such the amount of food required by the two larvae would be different. It appears that the amount of food in *C. gigantea* is sufficient for a normal development of *B. kolae* as observed in *C. nitidae*.

Although this experiment is not a comparison of the biology of the weevils on its cultivated and wild hosts, results show that *C. gigantea* is a suitable alternative host of the weevils. Both weevil species oviposit and develop at rates which compare favorably with that in the cultivated species. This is of ecological significance in view of the survival of the weevils in the field during the off-season periods of the cultivated kola: *C. nitida* and *C. acuminata*. Daramola (8) reported that the fruiting season of *C. gigantea* overlaps with the major part of the light season of *C. nitida* in his studies on host range of the weevils. The occurrence of *C. gigantea* throughout the kola growing areas help to maintain fairly high levels of weevil populations in and around the kola plantations throughout the year. In addition, *C. nitida* was introduced into Nigeria from Ghana about the middle of the 20th Century (10); it then appears that, *C. gigantea* is one of the original hosts of these weevils.

The destruction of *C. gigantea* in and around kola plantations should form part of the integrated control measures aimed at reducing weevil infestation of kola nuts in the field.

REFERENCES:

(1) Daramola, A. M., and T. A. Taylor, A new species of *Sophrorhinus: S. gbanjaensis* (Sp. nov.) from Nigeria. J. Nat. Hist. 9 (1975) 397-402.

(2) Daramola, A. M., and M. F. Ivbijaro, The distribution and ecology of the kola weevils in Southern Nigeria. Niger. J. Pl. Prot. 1 (1975) 5-9.

(3) Pujol, R., Characons nuisibles aux noix de cola. Cafe Cacao The VI (1962) 105-114.

(4) Beattie, G. B., Soft drink flavours. Their history and characteristics. 1. *Cola* or 'Kola' flavour. The Flavour Industry (1970) 390-394.

(5) Eka, O. U., Chemical composition and uses of kola nuts. J. W. Afr. Sci. Ass. 16 (1971) 167-169.

(6) Ogutuga, D. B. A., Chemical composition and potential commercial uses of kola nuts. *Cola nitida* (Vent.) Schott & Endlicher, Ghana Jnl. agric. Sci. 8 (1975) 121-125.

(7) Daramola, A. M., Host range and distribution of the kola weevils in Nigeria. Niger. J. Pl. Prot. 4 (1978). (in press).

(8) Daramola, A. M., The biology and ecology of the kola weevil, *Sophrorhinus gbanjaensis* D & T (Coleoptera: Curculionidae). J. Nat. Hist. 12 (1978) 661-680.
(9) Ivbijaro, M. F., Studies on the bionomics and control of *Balanogastris kolae* (Desbr.) (Coleoptera: Curculionidae). Ph.D. Thesis, Univ. of Ibadan, Nigeria (1975) 381 pp.
(10) Russell, T. A., The kola of Nigeria and the Cameroons. Trop. Agric. Trinidad 32 (1955) 210-240.

NON-UNIFORM APPLICATION OF GRAIN PROTECTANTS IN COMMERCIAL STORAGES

T. G. AMOS, P. WILLIAMS, AND W. MINETT
Plant Research Institute
Department of Agriculture,
Burnley, Victoria,
AUSTRALIA, 3121

INTRODUCTION: Distribution of insecticide amongst grains has an important bearing on the efficacy and persistence of the insecticide applied to stored grain (1-4). Laboratory experiments and field trials have demonstrated that controlled non-uniform treatment of wheat with malathion and conventional spraying aimed at treating all grain uniformly, were initially equally effective against insects but that greater persistence of the non-uniform treatment had the advantage of extending the period of protection during storage (5, 6).

In a successful field trial (6) the method used for applying the malathion non-uniformly to the grain was cumbersome. A trial was therefore undertaken to assess whether a gravity feed technique for applying the insecticide non-uniformly to the grain would be commercially acceptable. The insecticide used consisted of a mixture of fenitrothion and bioresmethrin, which has replaced malathion as a standard grain treatment in Australia.

MATERIAL AND METHODS: The trial was carried out in North East Victoria, Australia, using vertical steel bins with conical roofs and flat concrete floors, each with a capacity of 1,700-1,800 t.

An insecticide mixture of fenitrothion (100% w/v) and bioresmethrin (5% w/v) with piperonyl butoxide (40% w/v) was applied to Australian Standard White wheat at a rate of approximately 12 mg/kg of fenitrothion, 1 mg/kg of bioresmethrin, and 10 mg/kg of piperonyl butoxide (a synergist for bioresmethrin). Two methods of application were used; a conventional spray treatment, using a water emulsion of the insecticides in a pressurized spray system, and an experimental non-uniform treatment using the insecticide mix in concentrated form applied by gravity feed from a 100 l tank fitted with a constant head device (Fig. 1). Insecticide flowed from the tank through a short tube to the application nozzle. The flow rate at the nozzle was adjusted by a clamp, usually set to deliver 64.0 ml/min to match an estimated grain flow rate of 120 t/h. The insecticide flow was switched on and off by a solenoid valve operated by a microswitch linked to a control bar resting on a rubber flap which in turn rested on a conveyor belt. When wheat flowed along the belt, the flap and control bar were raised, thereby activating the microswitch and the insecticide mixture was released as a continuous flow. This

equipment cost (1977) approximately A$580.00, and installation estimated at A$120.00, making a total cost of A$700.00

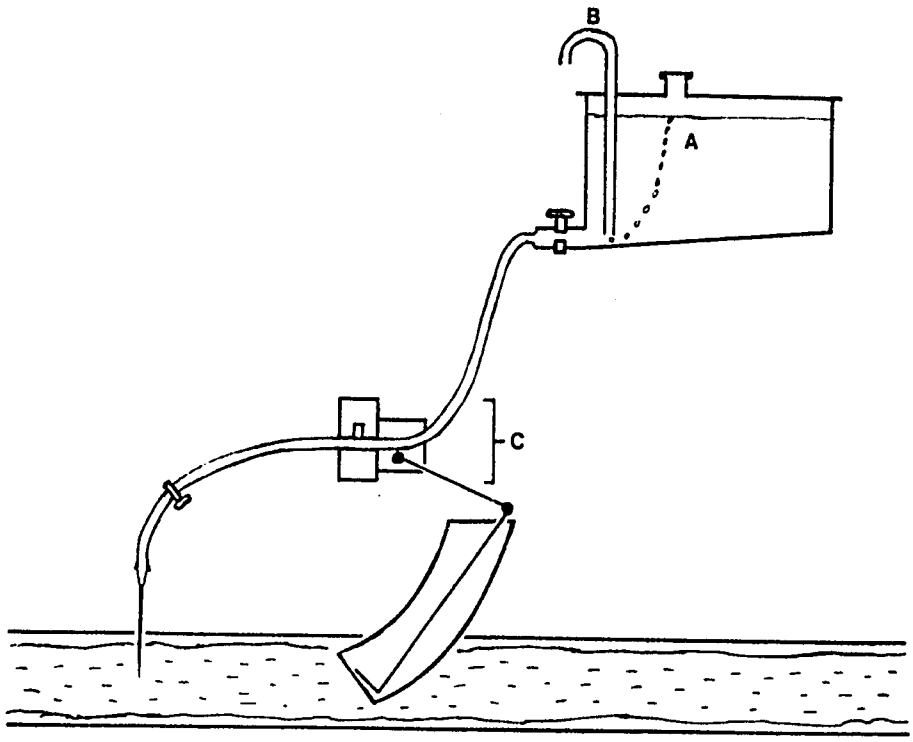


Figure 1. Plan of equipment used to apply a controlled non-uniform treatment of concentrated insecticide to wheat

Treatments were applied to the grain on the conveyor belt at the base of the silos, the treated grain being carried up an elevator to a conveyor belt above the silos and thence through chutes into the silos.

Wheat samples (4 kg each) for biological and chemical assay were taken from the bins immediately after treatment and approximately 6 months later. The samples were collected with a Probe-a-vac suction probe at a depth of 3 m below the surface at the centre, northern and southern sides of the bin.

Chemical analyses for insecticide residues were carried out using a G.L.C. Grain temperatures were measured with a thermocouple probe and moisture content of wheat samples was determined by loss of weight on drying 2 g of ground wheat for 1 hour in an oven at 130°C.

For each treatment bioassays were carried out on three replicate groups of 100 adults of *Rhyzopertha dominica* F., *Sitophilus oryzae* (L.), and *Tribolium castaneum* (Herbst) exposed in grain samples for seven days. Malathion resistant strains of

the three species and malathion susceptible strains of *R. dominica* and *S. oryzae* were used in the bioassays.

RESULTS AND DISCUSSION: During the trial, grain temperatures ranged from 5°-35°C at the surface and from 30°-32°C within the bulk (3 m below surface) in both bins.

Results of the chemical analyses carried out on 100 g wheat samples are shown in Table I. The initial levels of fenitrothion on the wheat were similar in both treatments, but after 6 months' storage there was an indication of greater persistence of fenitrothion resulting from the experimental treatment. To determine insecticide distribution on the wheat more precisely than could be achieved from the 100 g samples, 30 sub-samples, each of 10 g, were taken from each treatment and assayed for fenitrothion. Mean levels of 9.2 and 9.0 mg/kg were obtained for the conventional and experimental treatments, respectively. Variation in residue levels was, as expected, significantly greater in the experimental treatment ($P = 0.002$), and was believed to be responsible for the greater persistence of the fenitrothion in the experimental treatment after 6 months' storage (Table I).

Both the conventional and experimental treatments were very effective against insecticide resistant and susceptible strains of *R. dominica* and *S. oryzae* throughout the 6 month storage period (Table II). Although the levels of bioresmethrin in the samples taken from the conventional treatment were lower than expected, the treatment was still effective against *R. dominica* (bioresmethrin being incorporated into the insecticide mixture specifically to control this species). There was no sign of the effectiveness of the conventional treatment decreasing during the storage period as can occur with malathion when used against susceptible insects (6).

Both conventional and experimental treatments were not effective against *T. castaneum* as revealed by bioassays (Table II). However, it is worth noting that the strain of *T. castaneum* used was known to be resistant to a wide range of different insecticides, including organophosphates and chlorinated hydrocarbons (7). This strain did not originate, and no such strain has yet been found, in Victoria where the vast majority of resistant *T. castaneum* possess the malathion specific type of resistance.

Although both conventional and experimental treatments were equally effective against *R. dominica* and *S. oryzae*, there are considerable advantages inherent in the technique for applying the insecticide concentrates non-uniformly to the grain. The apparatus required is simple, requires no pumps and can be easily installed. Moreover, there is no need of water for mixing the insecticide emulsions as concentrates are used, and therefore water storage tanks, pumps, and other accessories, are not required. Thus, maintenance and running costs can be expected to be considerably lower than those for equipment used for

TABLE I. Chemical analyses of grain samples from 3 m below grain surface in bins of wheat subjected to conventional and experimental non-uniform treatments with an insecticide mixture of fenitrothion and bioresmethrin

		Moisture content (wet basis) %	Bioresmethrin (mg/kg)	Fenitrothion (mg/kg)
Initial assay after treatment	Conventional	10.2	0.23	10.6
	Experimental	9.3	1.4	10.8
Assay after 6 months storage	Conventional	10.2	*	5.6
	Experimental	11.1	*	9.4

*Results of analyses not yet available.

TABLE II. Percentage mortality of malathion resistant (*) and susceptible strains of stored product beetles exposed for 7 days in wheat samples taken from conventional and experimental non-uniform treatments with an insecticide mixture of fenitrothion and bioresmethrin

		R. dominica		*S. oryzae*		*T. castaneum*
		CRD 118*	VRD 15	CSO 231*	VSO 11	CTC 12*
Initial assay after treatment	Conventional	100.0	100.0	100.0	100.0	42.6
	Experimental	100.0	100.0	100.0	100.0	02.0
Assay after 6 months storage	Conventional	100.0	100.0	100.0	100.0	3.6
	Experimental	100.0	99.9	100.0	100.0	6.4

conventional treatment of grain. Another advantage is that greater persistence of the insecticide is likely to result from non-uniform treatment. This will provide protection from insect attack during extended storage periods, and thereby reduce the need for costly retreatment of the grain.

ACKNOWLEDGEMENTS: The authors wish to thank the Grain Elevators Board of Victoria for providing assistance and making facilities available. The work was carried out with the financial support of the Wheat Industry Research Council of Australia.

REFERENCES:

(1) Tyler, P. S., Horler, D. R., Rowlands, D. G., and Robbins, B. (1969) The distribution of insecticides among grains. Pest Infest. Res. 1968, 33-34.

(2) Green, A. A. (1969) The use of insecticides. Chemy. Ind, 1452-1454.

(3) Green, A. A., Tyler, P. S., Kane, J., and Rowlands, D. G. (1970) An assessment of bromophos for the protection of wheat and barley. J. stored Prod. Res. 6, 217-228.

(4) Rowlands, D. G. (1971) The metabolism of contact insecticides in stored grains - II. 1966-1969. Residue Rev. 34, 91-161.

(5) Minett, W., and Williams P. (1971) Influence of malathion distribution on the protection of wheat grain against insect infestation. J. stored Prod. Res. 7, 233-242.

(6) Minett, W., and Williams, P. (1976) Assessment of non-uniform malathion distribution for insect control in a commercial wheat silo. J. stored Prod. Res. 12, 27-33

(7) Champ, B. R., and Campbell-Brown, M. J. (1970) Insecticide resistance in Australian *Tribolium castaneum* (Herbst) - II. Malathion resistance in Eastern Australia. J. stored Prod. Res. 6, 111-131.

THE OVIPOSITIONAL RESPONSE OF THE CIGARETTE BEETLE TO TEMPERATURE AND TO SELECTED ODORS

L. W. FLETCHER, L. C. GARRETT, and D. P. CHILDS
U.S. Dept. of Agriculture Science and Education Administration
Tobacco Storage Insects Research
P.O. Box 10125
Richmond, Virginia 23240
U.S.A.

The cigarette beetle, [illegible], is a cosmopolitan insect species with an [illegible] range (1, 2). It is also the principal [illegible] stored tobacco. In our laboratory most of the research is [illegible] towards finding suitable methods of control for this [illegible]. Part of the ongoing research is the study of behavior as [illegible] physical factors. One phase of this, the ovipositional response of the beetle as affected by temperature was studied earlier by Fletcher and Lane (3). However, their experimental [illegible] permitted only the exposure of test insects to preselected temperatures. Part of this report is concerned with ovipositional response in [illegible] chamber to temperatures, most of which [illegible] in natural situations.

Another area of our research is the ovipositional response of cigarette beetles to attractants with emphasis at this time being placed on food odors. In an earlier study (4) we found that females responded about equally to ethanol extracts of whole wheat flour and of flue-cured tobacco [illegible] in filter paper cups. However, little or no survival occurred when these eggs were placed on finely ground tobacco. After many unsuccessful attempts to transfer the wheat flour rearing cultures to tobacco, the results suggested that our laboratory strain might be physiologically different from wild colonies reared on tobacco. Indeed, it raised questions about the validity of accepting all data acquired from laboratory reared wheat flour strains in laboratory and field tests as being analogous with results that would be obtained if wild tobacco reared colonies had been used.

A successful technique for collecting large numbers of eggs (5) led to the establishment of a large colony of cigarette beetles that is readily reared on finely ground flue-cured tobacco. This has permitted us to search for differences in the behavior of strains of beetles reared on whole wheat flour-brewers yeast medium and on flue-cured tobacco to food odors. With other insects it has been shown that the substrate upon which they are reared has an effect on their ovipositional feeding and response (6, 7, 8, 9, 10). The purpose of this portion of the study was to see if such a difference in response might occur in cigarette beetles that were reared on different medium.

METHODS AND MATERIALS: An experimental arena for observing the effects of temperature on cigarette beetle ovipositional response was formed by placing a plexiglass cover (61 x 61 x 38 cm ID) over a sheet metal plate (76 x 76 x 0.3 cm) Figure 1.

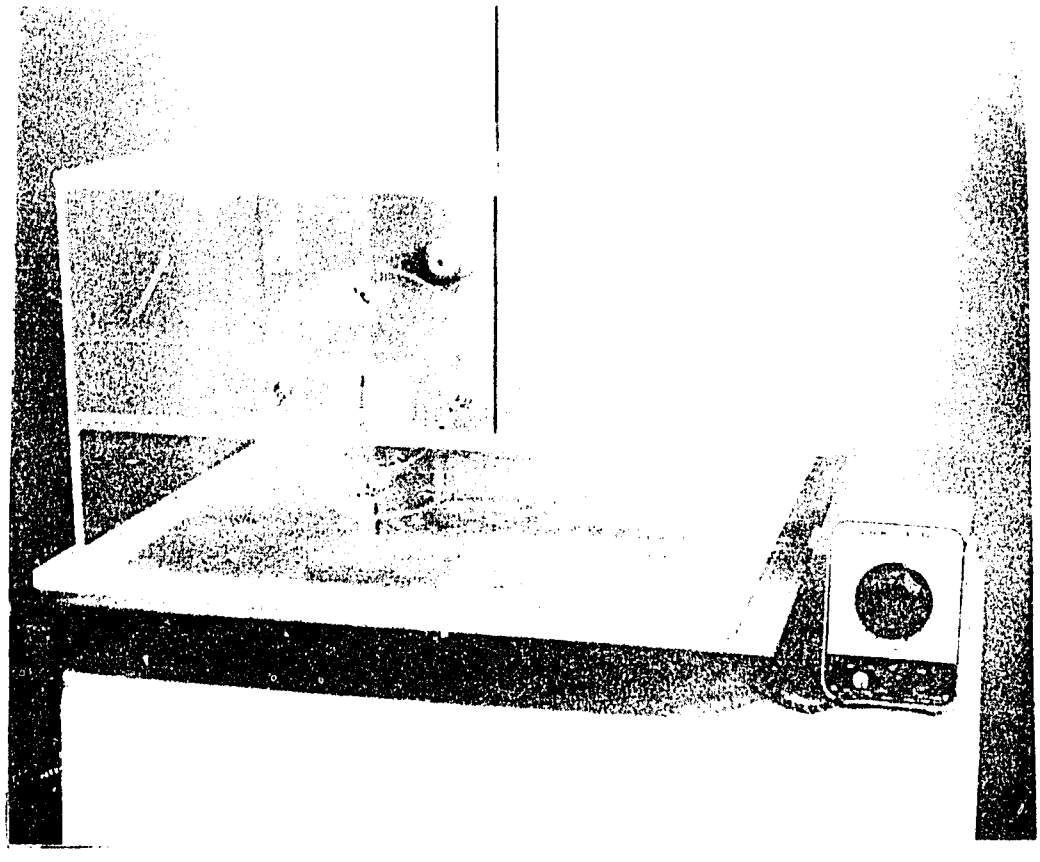


FIGURE 1. Temperature gradient chamber

The plate resting on a center over a 15 cm^2 hot plate was fitted with 20 equally spaced copper-constantan thermocouples arranged in a radial manner and attached to the underside by machine bolts. In addition one thermocouple was placed in air space approximately 20 cm above the arena floor. Temperature within the arena was regulated with a rheostat so that a gradient of 10°- 40.6° C was maintained. Temperature ranges selected for study were 10-15°, 15.6-21.1°, 21.7-26.1°, 26.7-31.7°, and 32.2-40.6°C. Temperatures were recorded at intervals on a multipoint recorder. The test arena was mounted on a work table in a 13 m^3 conditioned room which maintained temperature and relative humidity of 10±2°C and 80±10% respectively. Relative humidity within the test arena was not monitored. Prior to the release of about 600 unsexed insects

(300 males, 300 females assuming a 1:1 sex ratio) within the arena the floor was covered with a thin layer of finely sifted wheat flour. After five days the insects were removed from the test. Isotherms were outlined on the flour covered floor and the medium from each area was removed and placed in separate containers. These were held in our insectory (26.7 ±1°C, 70±5% rh) until emergence was completed. Thus, the ovipositional response or the number of eggs laid was determined by the numbers of adults emerging from each temperature range. In one replicate the true number of eggs laid at the 32.2° - 40.6° C temperature range was calculated by adding the number of emerged adults to the number of unhatched eggs.

The arena used for the ovipositional response to food odors was similar in design and size to the one used for ovipositional response to temperatures (Figure 2). However, the floor

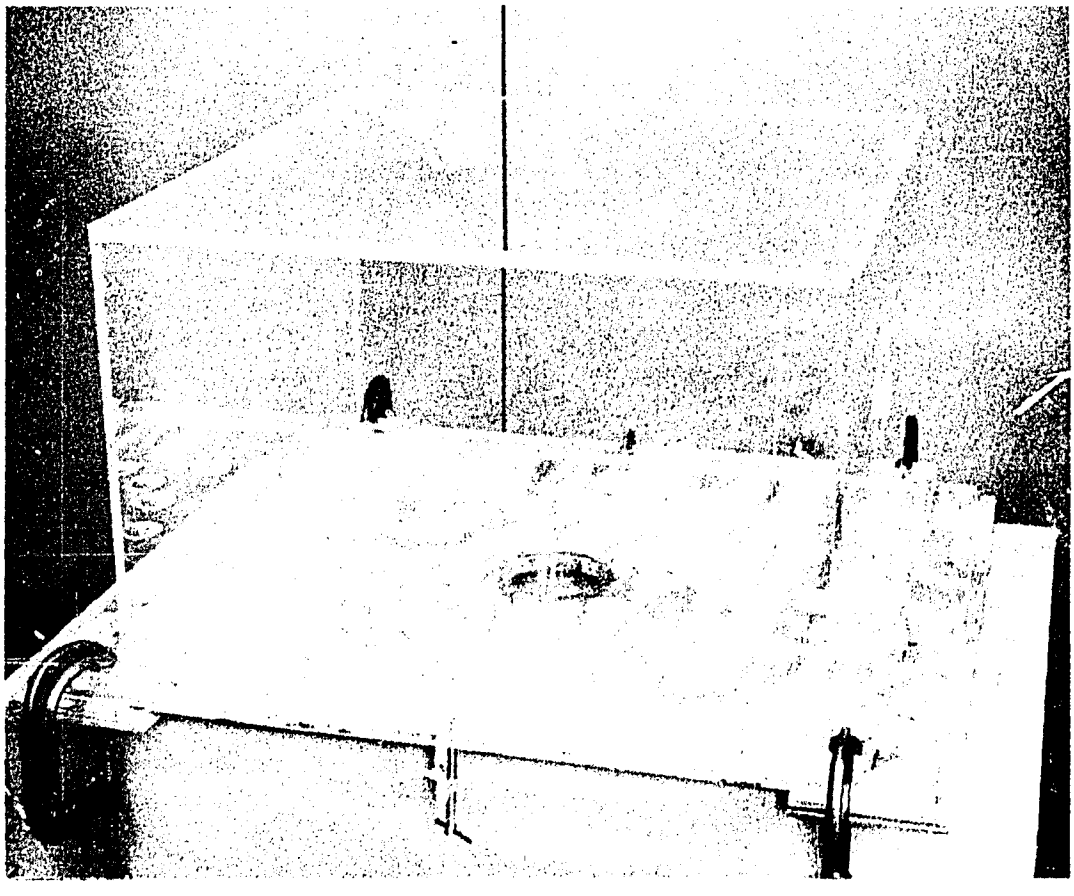


FIGURE 2. Test arena for ovipositional response

was made of 12.7 mm plywood. It contained 40-3.8 cm holes that were arranged radially around a 10 cm center hole. Paper cups 2.5 cm high and 4 cm in diameter were inserted in the smaller holes and the center hole was fitted with the bottom of a 100 mm petri dish. Each cup contained a muslin strip (60 x 1.5 cm), folded into a pad. The pads impregnated with ethanol extracts of food materials served as ovipositional sites and were arranged in a random fashion. Each test (8 odors, 5 replicates) was initiated untreated by releasing 800 unsexed adults (400 males, 400 females assuming a 1:1 sex ratio) into the petri dish. At this time 6-C clamps were used to secure the arena top to the bottom. The tests were made in a room maintained at 26.7±1°C and 70±5% relative humidity. The light regime was 12:12 hours of light and darkness. After 5 days the adults were recovered, the pads were removed, and the numbers of eggs were counted. Two strains of the cigarette beetle were used in this test. One strain reared in our laboratory on whole wheat flour-brewers yeast medium (ca. 14 years) was the source of the second strain that has been reared on tobacco for ca. 4 years.

RESULTS AND DISCUSSION: The effects of temperature on oviposition are shown in Table I. Based upon adult emergence and upon an egg

TABLE I. Numbers of cigarette beetle eggs oviposited on a gradient heat bar covered with a thin layer of finely ground wheat flour as determined by adult emergence. a/

Replicate	Number of adults				
	Temperature range (C°)				
	10-15	15.6-20.6	21.1-26.1	26.7-31.7	32.1-40.6
1	25	210	348	239	1
2	43	332	400	189	0
3	52	135	250	85	0
4	b/	159	146	17	13
5	-	87	105	79	0
6	-	63	150	14	0
7	-	91	173	55	3
8	10	7	87	74	15
Av.	32.5	135.5	207.4	101.5	c/4

a/ Ca. 300 females/replicate.

b/ Temperature rise due to malfunction of 1 conditioning unit.

c/ 211 nonviable eggs sifted from sample.

count fewer eggs were laid at the lower temperatures. The average emergence for temperature ranges of 10-15°, 15.6-20.6°, 21.7-26.7°, 27.2-32.2°, and 32.2-40.6° was 32.5, 135.5, 207.7, 101.5 and 4 respectively. However in last replicate at the highest temperature range 211 unhatched eggs were recorded. So it is quite evident that the data recorded for this range does not reflect what actually happened. In all tests many dead adults were observed in this temperature zone. Their death along with the poor egg hatch observed was probably due to desiccation. The preferred temperature range of 21.7-26.7°C for oviposition partially overlapped the range preferred reported for fourth instar larvae of the cigarette beetle 25.6-27.8°C (11). The finding that oviposition occurred over the entire temperature test range lends some support to the work of Fletcher and Long (3) who reported both oviposition and egg hatch at temperatures below 20°C. However, the numbers of adults emerging from the lower temperature ranges was surprising because in this test females had a freedom of choice in selecting temperatures for oviposition.
This information may be useful when planning fumigation of tobacco warehouses located in colder climates.

The ovipositional response of a cigarette beetle strain reared on whole wheat flour-5% brewers yeast to selected odors is shown in Table II. The preference as indicated by the percent of

Table II. Ovipositional response by a cigarette beetle strain, reared on wheat flour-brewers yeast medium, on muslin strips impregnated with ethanol extracts of M (untreated muslin, WF (wheat flour), Y (yeast), CSM (cornmeal-soybean meal-milk), CMB (comb. tobacco-CSM-Y Y-citrus pulp), UM (used medium), CP (citrus pulp) and T (tobacco) a/ b/

Extract	Percent eggs oviposited Replicate					
	1	2	3	4	5	Average
M (control)	3.5	6.5	8.6	2.1	4.0	4.9
WF	11.4	12.4	9.8	7.1	10.1	10.2
Y	18.8	21.3	31.2	34.2	37.7	28.7
CSM	23.4	26.0	23.3	22.8	13.6	27.8
CMB	9.1	8.9	3.7	8.6	6.0	7.3
UM	1.3	1.2	0.9	1.4	1.0	1.2
CP	26.4	20.2	19.2	16.6	22.9	21.1
T	5.0	3.4	3.2	7.2	4.7	4,7

a/ Ca. 400 females/replicate. b/ Total eggs laid 15,696.

eggs oviposited was as follows: Yeast (Y) 28.7, cornmeal-soybean meal-milk (CSM) 27.8, citrus pulp (CP) 21.1, wheat flour (WF), 10.2, combination of tobacco (T)-CSM-CP and WF (CMB) 7.3. These were followed by tobacco (T) 4.7, and untreated muslin (M), the controls 4.4. The least attractive compound was an extract of used medium (UM) 1.2. The total number of eggs laid by the wheat flour strain was 15,696.

The strain of beetles reared on finely ground flue-cured tobacco preferred the tobacco extract (Table 3) for oviposition. Of the total number of eggs laid (22,281) 26.8% were found on toaacco. Others preferred were extracts of CMB (which contained tobacco) 23.4%, CSM 16.4%, CP 15.5%, Y 11.7%, WF 3.5%, UM 1.9%, and M or controls 0.9%. A comparison of the ovipositional response by both strains is shown in Figure 3.

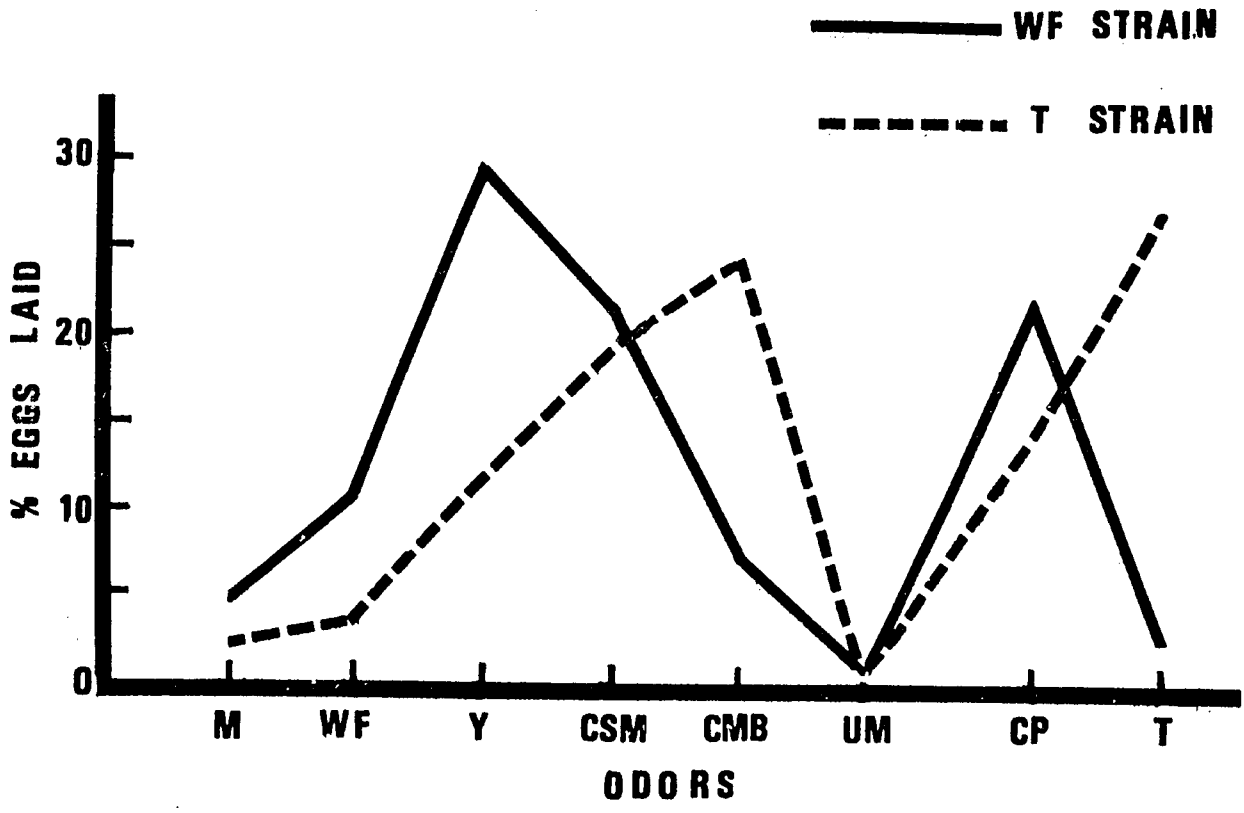


Figure 3. Comparison of ovipositional response of two strains of cigarette beetles to selected food odors

The response of both strains to food odors other than tobacco showed similarities. With the extracts of tobacco and the mixture containing tobacco there is a significant difference in the response. The tobacco strain laid 50% of their eggs on the ovipositional sites containing these 2 extracts while only 12% of the wheat flour strain eggs were laid on sites having the same odors. Other differences in behavior may exist as it has been shown by Yamamoto and Frankel that tobacco reared insects are smaller (12). Any further information in this area of research would be most useful in establishing the quality of laboratory reared insects so that they would compare favorably with wild-standard populations.

ACKNOWLEDGMENT. We thank Mr. John S. Long, formerly with our laboratory and now with Philip Morris, U.S.A., Richmond, Virginia, for his assistance in constructing the gradient heat chamber and for preliminary test evaluations.

Table III. Ovipositional response by a cigarette beetle strain reared on finely ground flue-cured tobacco on muslin strips impregnated with ethanol extracts of : M (untreated muslin) WF (wheat flour), Y (yeast, CSM (corn-meal-soybean meal-milk), CMB (comb. tobacco-CSM-Y-ci citrus pulp), UM (used medium), CP (citrus pulp), and T (tobacco) a/ b/

Extract	Percent eggs oviposited Replicate					
	1	2	2	4	5	Average
M (control)	1.2	1.2	0.47	1.0	0.51	0.9
WF	5.3	4.0	2.7	4.2	1.1	3.5
Y	12.4	12.4	12.6	11.9	9.3	11.7
CSM	18.3	19.7	14.6	15.0	14.6	16.4
CMB	21.9	25.6	25.8	22.5	21.0	23.4
UM	1.4	2.0	1.9	3.0	1.1	1.9
CP	14.2	13.1	14.5	15.0	20.6	15.5
T	25.3	22.0	27.4	27.5	31.8	26.8

a/ Ca. 400 females/replicate.

b/ Total eggs laid 22,281.

REFERENCES:

(1) Howe, R. W., A laboratory study of the cigarette beetle, *Lasioderma serricorne* (F.) (Col. Anobiide) with a critical review of the literature and its biology. Bull. Entomol. Res. 48(1) (1957) 9.

(2) Runner, G. A., The tobacco beetle: an important pest to tobacco products, USDA Bull. 737 (1919).

(3) Fletcher, L. W., Long, J. S., Cigarette beetle oviposition and egg hatch at selected temperatures, Tob. Sci. 178(24) (1976) 172.

(4) Fletcher, L. W., Long, J. S., Influence of food odors on oviposition by the cigarette beetle on nonfood materials. J. Econ. Entomol. 64 (3) (1971) 770.

(5) Fletcher, L. W., A procedure for collecting large numbers of eggs of *Lasioderma serricorne* (F.) J. Stored Prod. Res. 13 (1977) 87.

(6) Hovanitz, W., Chang, V. C. S., Change of food plant preference by larvae of *Pieris rapae* controlled by strain selection and the inheritance of this strain. J. Res. Lepidop. 1 (1963) 163.

(7) Mullen, M. A., Arbogast, R. T., Influence of substrate on oviposition by two species of stored-products moths. Environ. Entomol. 6 (3) (1977) 641.

(8) Yamamoto, R. T., Induction of hostplant specificity in the tobacco hornworm *Manduca sexta*. J. Insect Physiol. 20 (1674) 641.

(9) Schoonhoven, L. M. Loss of hostplant specificity by *Manduca sexta* after rearing on an artificial diet. Ent. Exp. Appl. 10 (1967) 270.

(10) Yamamoto, R. T., Introduction of hostplant specificity in the tobacco hornworm *Manduca sexta*. J. Insect Physiol. 20 (1974) 641.

(11) Fletcher, L. W., et al., Response of cigarette beetle larvae to temperature and humidity, USDA, ARS-S-22 (1973).

(12) Yamamoto, R. T., Fraenkel, G., The suitability of tobacco for the growth of the cigarette beetle *Lasioderma serricorne*. J. Econ. Entomol. 53 (3) (1960) 381.

SECOND SESSION OF SUBMITTED PAPERS

Chairman - DR. P. F. PREVETT
Tropical Stored Products Centre (TPI)
London Road
Slough, Berks, U.K.

REGULATION OF THE BEAN WEEVIL REPRODUCTION (*ACANTHOSCELIDES OBTECTUS* COLEOPTERA BRUCHIDAE) AND RESEARCH ON TECHNIQUES OF PROTECTION OF STORED BEANS

JACQUES HUIGNARD
Institut de Biocenotique Experimentale
des Agrosystemes (ERA 328 C.N.R.S.)
Universite de Tours
Parc Grandmont 37200 Tours
FRANCE

The bean weevil (*Acanthoscelides obtectus*) is an insect probably originating from equatorial regions of Latin America (1 2). This insect has followed the spreading of *Phaseolus vulgaris* crops to the whole of the American continent, to Europe, and then to Africa.

Acanthoscelides obtectus thrives only in regions with a temperate climate where the average day temperature remains under 30°C. Thus in Central Colombia where we studied that insect, it causes important damage only in areas where the crops are located between 1000 and 2000 meters of altitude (areas in which the average day temperature ranges between 20 and 25°C). It has never been found (3) in the hot valleys that separate the Andean cordilleras. In the latter areas, however, bean crops are attacked by another Bruchidae (*Zabrotes subfasciatus*), which causes as much damage. *Acanthoscelides obtectus* shows a double behavior since it can attack *Phaseolus vulgaris* in the fields or during the storage of the seeds (2). Its biology in nature is poorly known, but we have established that the females are attracted by ripe pods, then they bore through the fruit pericarp and lay their eggs in it. The larvae penetrate into the seeds in which the post-embryonary development takes place, In the storage conditions the first part of the oviposition behavior disappears, and the females lay their eggs near the seeds. Unlike *Callosobruchus maculatus* (4) there do not seem to exist two forms of adults adapted either to life in nature or to life in stores. Before thinking of studying protection methods against this insect, we have first examined its biology in storage conditions. So we have analysed the factors regulating the reproduction of that phytophagous insect which can be considered as a specialist according to Orians' definition (5) since it develops only in a very limited number of grains belonging to species of the *Phaseolus* genus.

The reproductive activity of virgin females reared without host plants varies a lot. Some females do not make any mature oocytes while others produce a limited number of them which accumulate in the lateral oviducts but are not released. In the latter case (Figure 1A) the oocytes are formed during the early days of imaginal life, then oogenesis stops. This stopping of oogenesis

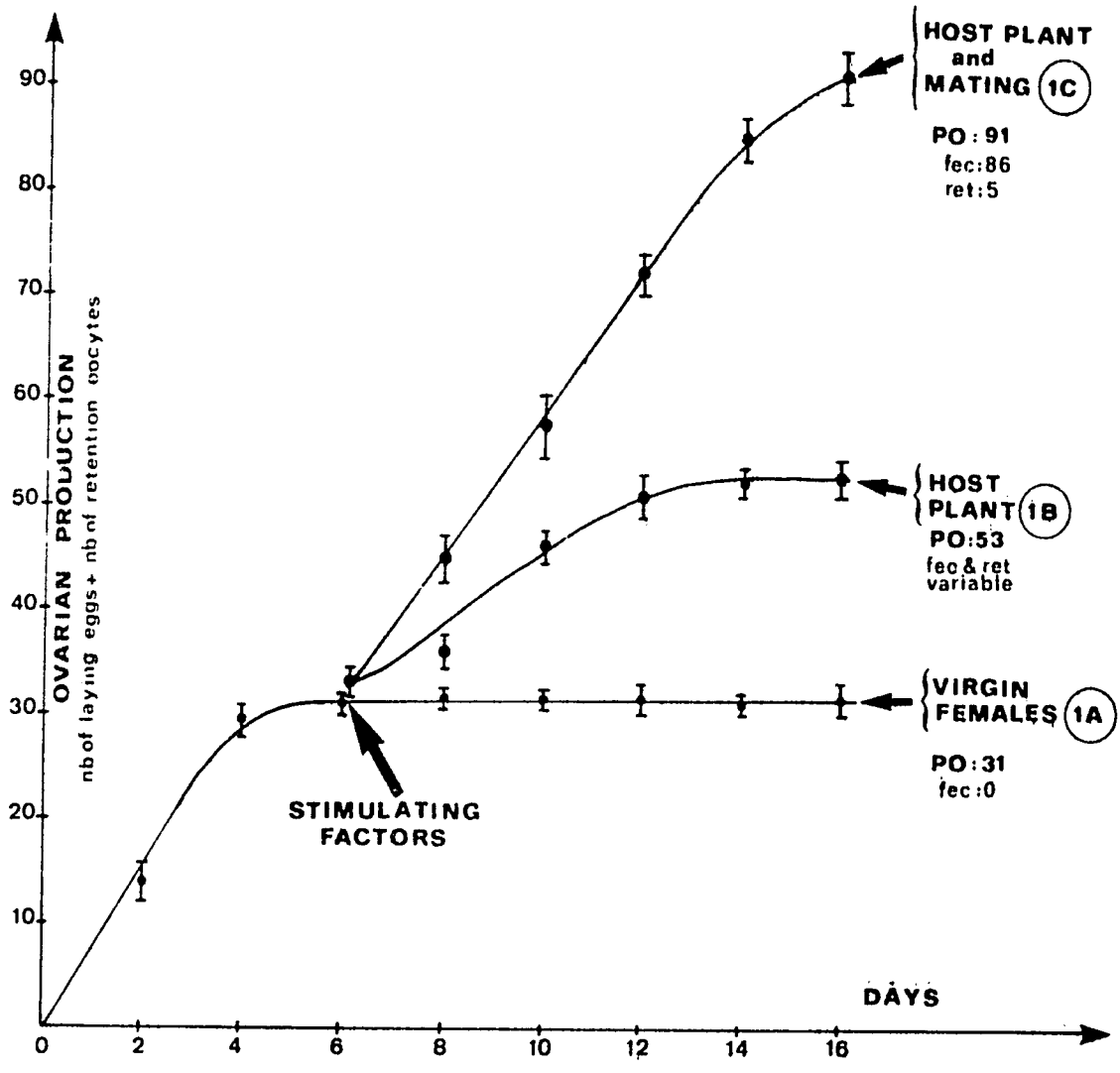


FIGURE 1. Evolution of the ovarian production during the imaginal life in different conditions (cumulative curves).
fec: fecundity ret: number of oocytes in retention into the female's oviducts

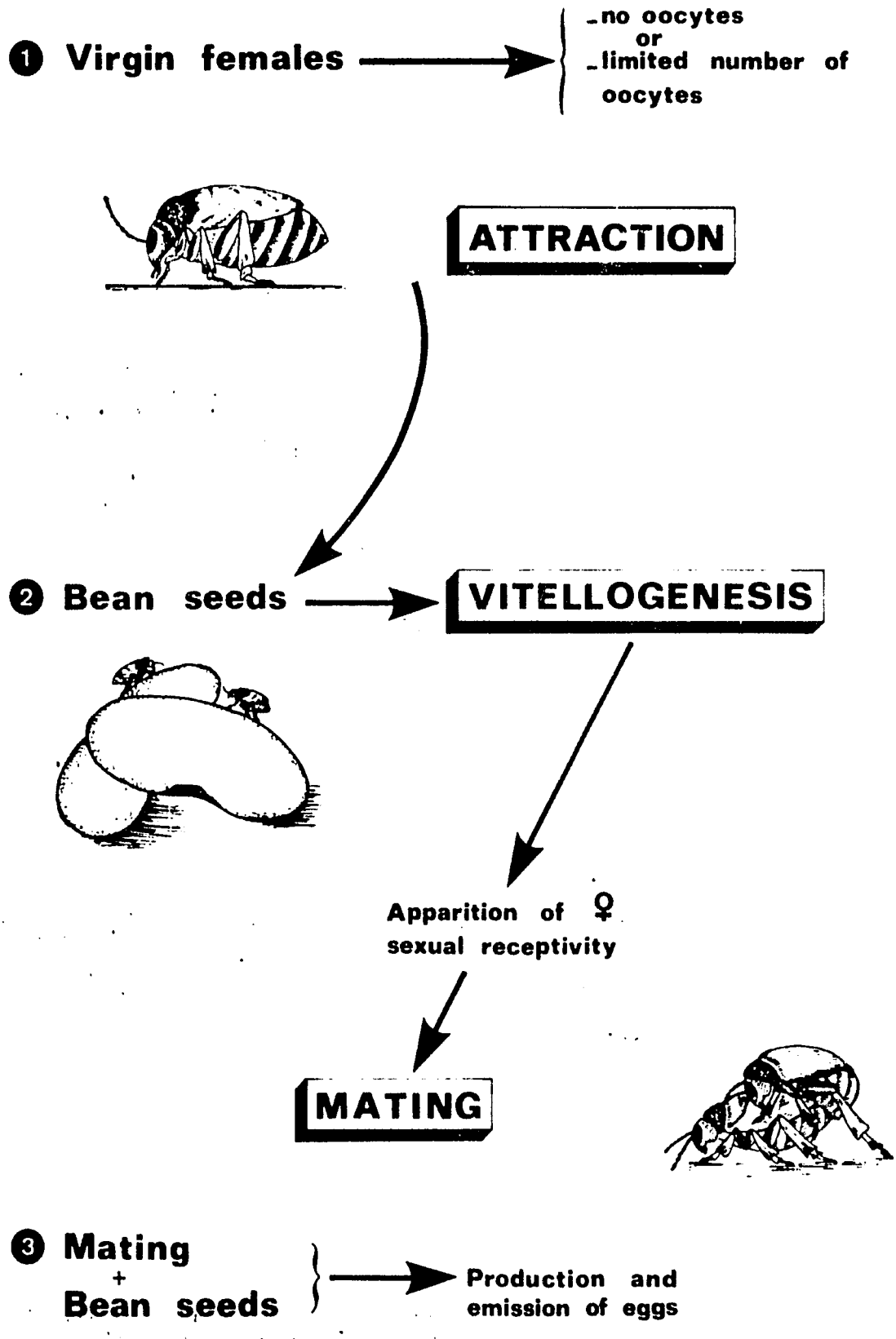


FIGURE 2. Influence of external factors upon sexual behavior and reproduction of the bean weevil.

is probably linked to the absence of external stimulations (6, 7). The introduction of grains of the host plant, which are not used as food by the adults, affects reproduction on three levels:

(1) On the behavioral level, by attracting females (8)

(2) It stimulates oogenesis (Figure 1B) by allowing vitellogenine to be synthetized by the fat body, then to be incorporated into oocytes.

(3) It can induce the emission of oocytes, but an important variability can be observed in that case (some females lay all the oocytes they have formed while others have no fecundity). Pouzat (9, 10) has shown that a certain number of olfactive, gustative or tactile stimulations coming from the bean grain were perceived by the insect and affected the reproductive function, probably by a neuroendocrine way. Mating also influences the reproductive function. Our researches (11, 12) have shown that the spermatophore deposited into the genital tract of females cause the stimulation of oogenesis after mating. Some secretions made by male accessory glands get through the spermatophore wall and the female genital tracts (13), and affect oogenesis by a humoral way. However, the best stimulation of reproductive activity is obtained when there is an interaction between the presence of host plant seeds and mating (Figure 1C).

In these conditions we can imagine the following mechanism (Figure 2):

The presence of bean grains attracts males and females, and the seeds act as a place of meeting. Besides it causes a rapid start of oogenesis, which increases female receptivity in regard to males, and makes mating easier. In effect we have noted (14) that the virgin females without any ovarian activity (absence of vitellogenine, non-functional ovarioles) refuse males.

The mating-host plant interaction allows the production then the release of an important number of eggs which are deposited near the seeds. The regulation of the reproductive function of *Acanthoscelides obtectus* by these two external factors is essential:

(1) Since the first larval instar has a reduced sensorial and locomotory equipment, she cannot find the bean seeds herself. Therefore the adult looks for the trophic environment of the larvae and lays her eggs in it. So the larvae are, when they are born, in an environment favourable to their development.

(2) The females utilize mainly the larval reserves for reproduction. This regulation of oogenesis and oviposition due to the mating limits the oocyte losses by allowing only fertilized eggs to be released, that is those that can give offspring.

This biological study shows that the reproduction of *Acanthoscelides obtectus* is perfectly adapted to the storage conditions and helps to understand how the contamination of seeds can occur. It explains why the attacks can be so important, and go on after the seeds store has been first contaminated, thanks to the development of numerous successive generations. In effect

A. obtectus (an insect of equatorial origin) does not present any diapause in the ordinary conditions of seeds storage. McGuire and Grandall (15) estimate the bean seeds losses caused by that insect in Central America at 35 percent. Schoonhoven (3) estimates them at 20 percent in Colombia, but these are only average estimates and our observations show that in small Colombian farms the losses are undoubtedly much higher.

Therefore it is important to try and discover efficient and cheap control methods, especially to protect the crops of small African and South American farmers. These methods can be worked out at several levels:

(1) In the fields, to limit the attacks before harvesting the grains. The adult insect's feeding and development conditions in nature must be known precisely, as well as its relationships with the host plant. Besides it is indispensable to see, especially in South America where a large number of wild Phaseolinae grow, if there are not any other plants whose grains might shelter and feed *Acanthoscelides obtectus* when *Phaseolus vulgaris* grains are not available. The first results we got show that the insect stays a very short time in *Phaseolus vulgaris* crops (essentially at the time when the pods are ripe). Therefore it is only at that time that a chemical treatment could be undertaken, but its efficiency is doubtful because it will not reach the larvae and the eggs laid inside the pods before the insecticides are used.

(2) When harvesting the grains. Labeyrie (16) has shown that harvesting the pods when they are ripe and shelling them immediately afterwards reduces the attacks considerably. That technique separates the eggs (which are generally stuck on the inner side of the pods) from the grains. So there is no possible development.

(3) When storing the grains. Various techniques have been recommended (fumigations of insecticides, utilization of males sterilized by irradiations....) but there again, they often have a limited efficiency. It is very difficult for small farmers to put them into practice because of their cost. Taking into account the biology of *Acanthoscelides obtectus*, which is very sensitive to temperature variations and develops badly in a temperature above 30°C (17) we have tried to see if storing the grains at a temperature of 36°C could not limit the attacks.

Laboratory experiments show that larvae develop badly (larval mortality of 70 to 80 percent), and that adult reproduction is considerably disturbed.

In males the structure of spermatozoa is often altered, and their grouping into spermatodesms does not occur because the cystic cells are destroyed (Figure 3). When these males mate with sample females reared at 27°C, most of them release a small spermatophore which has no stimulating effect upon oogenesis, and brings no spermatozoa (18). In females, reared at 36°C the formation of oocytes is also altered. The synthesis of vitellogenic proteins actually occurs in the early imaginal life, but it does

Figure 3 :

Influence of a thermal treatment upon the testis structure :

1) Section of a testis of a male reared at 27°C (x 250)

2) Section of a testis of a male reared at 36°C during 10 days (x 250)

A : spermatogonia cysts

B : spermatocytes cysts

C : spermatids cysts

D : spermatodesms

In section 2, the gathering of spermatozoa is disturbed

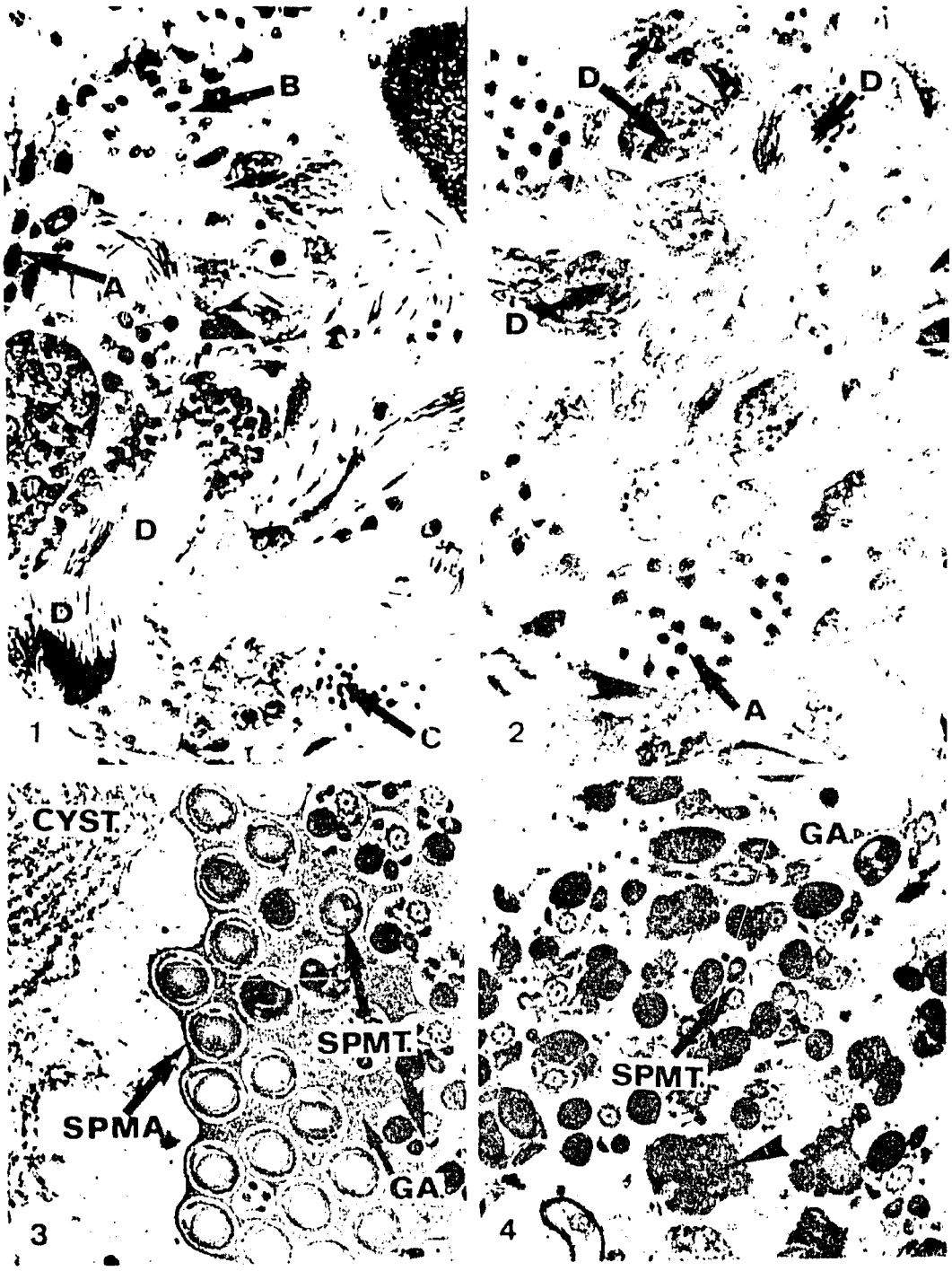
3) Ultrastructure of a spermatodesm of a male reared at 27°C (x 14000)

4) Ultrastructure of a spermatodesm of a male reared at 36°C (x 14000)

Some spermatozoa are abnormal (arrow) : presence of 2 or 3 flagellum, of numerous accessory body, and, alteration of the matrix.

Cyst : cyst cell spma : spermatodesm

Spmt : spermatozoa ga : matrix


B
A
D
D
C
1
D
D
D
A
2
CYST.
SPMT.
SPMA
GA
3
GA
SPMT.
4

not get incorporated. The activity of follicular cells which play an important role in incorporating vitellogenic proteins (19) is disturbed by the heat treatment (Figure 5). This method of protection, which is quite cheap, is interesting because Khelil's researches (20) show that it does not seem to affect the germinative capacity of seeds.

(4) Selection of resistant *Phaseolus* varieties. Legume seeds, and specially those of Phaseolinae contain toxic compounds such as phytohaemagglutinines, inhibitors of proteases, cyanogenic glycosides, non protein aminoacids. Janzen (21) points out that each species of Bruchidae develops only in a limited number of seed species, because it can detoxify only certain compounds. Therefore beans could be selected, with seeds containing certain compounds the insect could not use (and that would not be toxic for man after cooking and would not alter the taste of the food...).

In CONCLUSION, we think it is necessary to use a whole lot of techniques in the fields as well as in the stores (insecticides, Phaseolus varieties with resistant seeds, heat treatment, masking more or less completely the stimulation coming from the host plant). As Labeyrie (22) points out, repetitiveness of the same treatment must be avoided above all. In effect "Resistance to interventions for the protection of crops is not related to the nature of the intervention but to the repetitivensss of the phenomenon." Any repetition of the same method necessarily results in the selection of resistant insects owing to the genetic heterogeneity of populations. Thus, if the heat treatment is repeated regularly over several generations, given the variability of results, we rapidly get heat resisting insects.

Using various methods, which follow each other without any defined frequency, limits the emergence of resistant individuals and enables one to protect the seeds with a maximum efficiency. In effect each method "exerts a selective pressure in a different direction, operates on different types of individuals."

It is in that direction that we must turn to develop effective methods of control, which must take into account the insects' biology in the fields and in stores, as well as the genetic polymorphism of populations.

SUMMARY: The bean weevil *Acanthoscelides obtectus* is an insect originating from equatorial regions of Latin America. This insect has followed the spreading of its preferential host plant (*Phaseolus vulgaris*) in the world. It thrives only in regions with a temperature climate where the average day temperature remains under 30°C. This insect shows a double oviposition behavior since it can attack *Phaseolus vulgaris* in the fields or in stored seeds.

The researches have shown that two external factors (presence of seeds of the host plant, mating) stimulate oogenesis and egg laying. This regulation of reproduction is important and

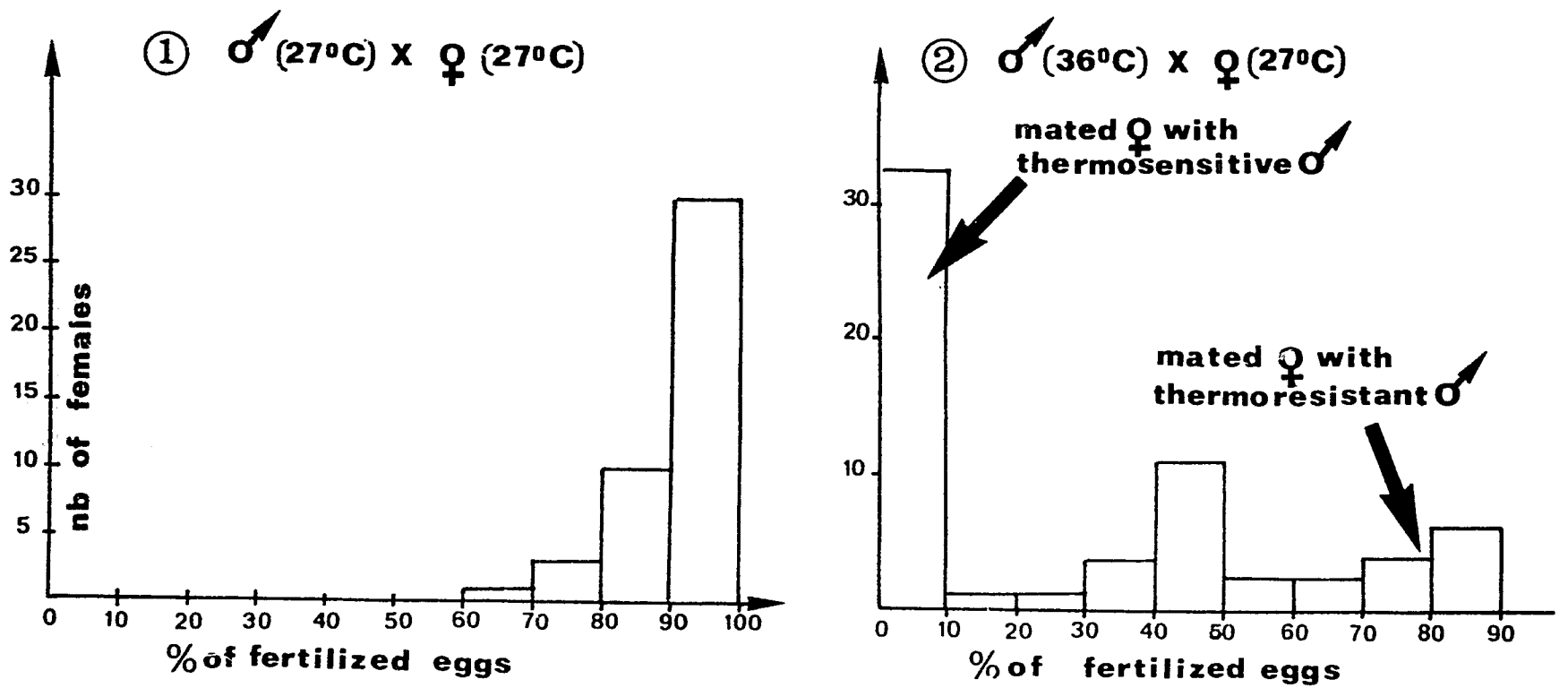


FIGURE 4. Distribution of mated females in relation with the percentage of fertilized eggs.

FIGURE 5. **Influence of a thermal treatment upon the female reproduction.**

Longitudinal sections of ovarioles

1) 6 days old female reared at 27°C with oocytes 3 and 4 in vitellogenesis (x 50)
2) 10 days old female reared at 27°C: the ovariole contains only oocytes in previtellogenesis (x 170)
3) Base of the germarium (female reared at 36°C): the thermal treatment changes the structure and the organization of the follicular cells as indicated by stars (x 250)
4) Follicular cells around the ooctyes of a female reared at 27°C (x 250)
5) Terminal oocyte of an ovariole after a thermal treatment: the follicular cells (stars) are destroyed (x 250)

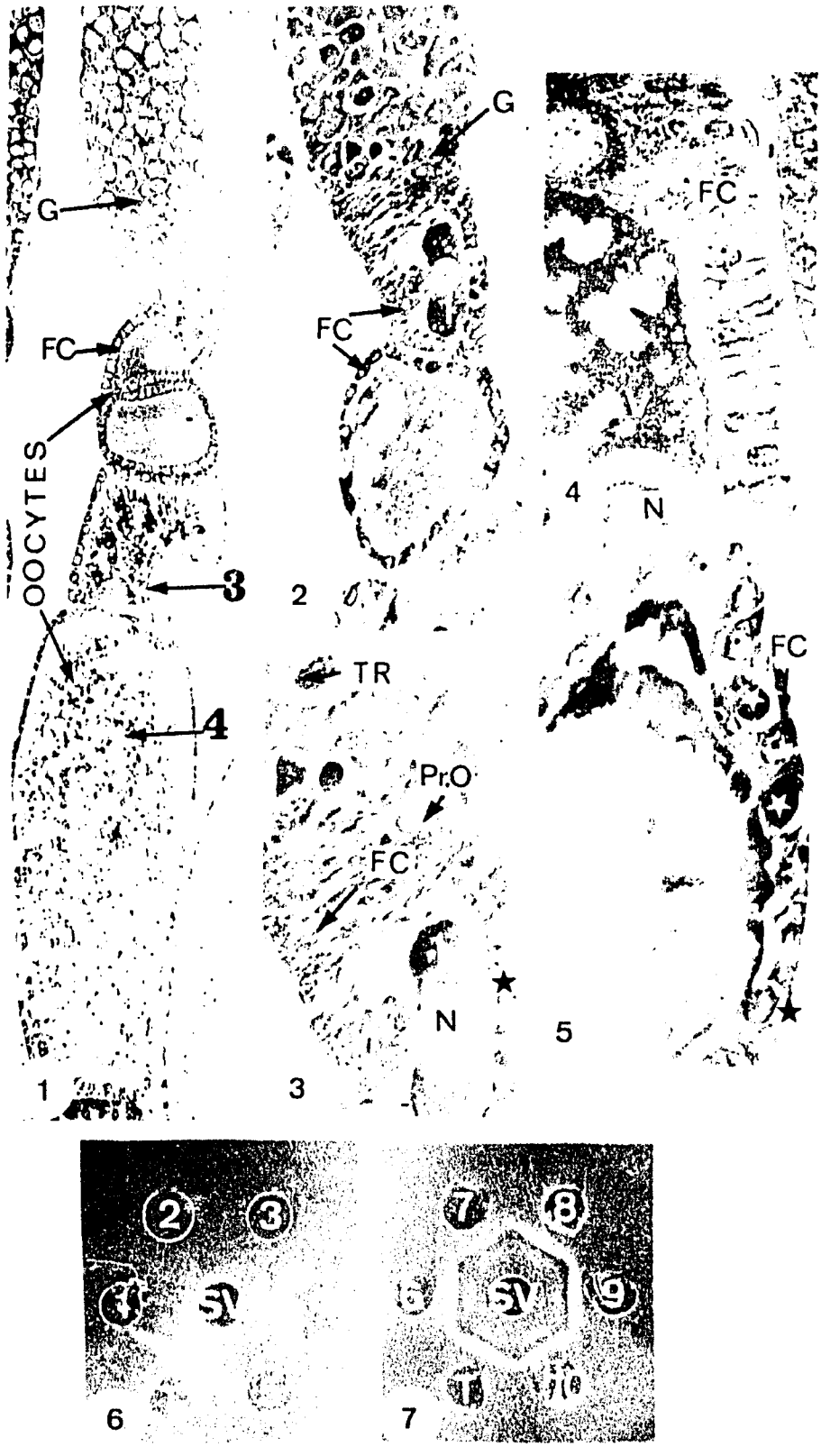
FC: follicular cells G: germarium N: oocyte nuclear

Pr O: previtellogenic oocyte Tr: trophocyte V: vitellus

Immunological detection of vitellogenic protein in the female's haemolymph by OUCHTERLONY technique

6) Before the thermal treatment the young females (1 to 6) do not have synthetized vitellogenine (all reactions are negative)
7) The females produce vitellogenic proteins during the thermal treatment (all reactions are positive)

SV: rabbit antivitellus serum T: extract of oocytes


G
FC
OOCYTES
3
4
1
G
FC
2
TR
PrO
FC
N
3
FC
4
N
FC
5
2
3
5
6
7
8
5
9
10
7

allows production and emission of fertilized eggs in conditions favourable for the development of the larvae which use bean seeds for their alimentation. The reproduction of *Acanthoscelides obtectus* is perfectly adapted to the storage conditions; it explains the importance of the damages.

Elaboration of efficient and cheap control methods is complex. The sensibility of *Acanthoscelides obtectus* to the thermal variations could be a technique for control. A thermal treatment at 36°C sterilizes male and disturbs oogenesis. It causes an important reduction of the seeds loss due to *Acanthoscelides obtectus* during the storage. However a single technique cannot be efficient. It is necessary to use various methods which follow each other without any defined frequency and limit the selective pressures allowing the development of resistant individuals.

REFERENCES:

(1) Zacher, F., Mitt. Deutsch. Gesel. 14 (1955) 3.
(2) Labeyrie, V., in "Entomologie appliquée à l'agriculture" (1962).
(3) Schoonhoven, A., Proc. XV Int. Cong. Ent. (1976) 691.
(4) Utida, S., Pl. Prot. Tokyo 21 (1967) 243.
(5) Orians, G. H., Gates, R. G., Rhoades, D. F., Schultz, J. C., Proc. 1st Int. Cong. Ecol. The Hague (1974) 213.
(6) Huignard, J., Coll. C.N.R.S. Tours (1970) 357.
(7) Biemont, J. C., Cr. Ac. Sc. Paris (sous presse) (1978).
(8) Labeyrie, V., Cr. Ac. Sc. Paris 271 (1970) 1578.
(9) Pouzat, J., Coll. C. N. R. S. Tours 265 (1977) 115.
(10) Pouzat, J., Thèse Univ. Tours (1978).
(11) Huignard, J., Ann. Sc. Nat. Zoologie 16 (1974) 361.
(12) Huignard, J., Ann. Sc. Nat. Zoologie 17 (1975) 1.
(13) Huignard, J., Cr. Ac. Sc. Paris (sous presse) (1978).
(14) Huignard, J., Biemont, J. C., Oecologia (sous presse) 1978.
(15) McGuire, J. V., Grandall, B. S., Int. Agr. Dev. Serv., USDA AID Oct. 1967 (1967) 157.
(16) Labeyrie, V., Cr. Ac. Agr. 43(3) (1967) 138.
(17) Howe, R. W., Currie, J. E., Bull. Ent. Res. 65 (1964) 437.
(18) Huignard, J., Biemont, J. C., Ann. Zool. Ecol. Anim. 6-4 (1974) 561.
(19) Telfer, W. H., Ann. Rev. Entomol. 10 (1965) 161.
(20) Khelil, M. A., Thèse I. N. A. Algérie (1976).
(21) Janzen, D., Coll. C. N. R. S. Tours 265 (1977) 417.
(22) Labeyrie, V., Experientia 33 (3) (1977) 404.

SELECTION OF SUITABLE FOOD TO BE USED AS BAIT FOR RODENT CONTROL IN JAMAICA

D. B. JAYASINGH and K. R. WALKER
Food Storage and Infestation Division
Ministry of Industry and Commerce
20 Hope Road, Kingston 10
JAMAICA, WEST INDIES

INTRODUCTION: Anyone involved in rodent control is sure to wonder what kind of bait to use to attract the rats and mice. In many cases the failure of control is due to the simple fact that they do not eat enough bait. In other words, the success of rodent control to a large extent depends on the palatability of the bait when mixed with poison. When an anticoagulant or a single dose poison is added to the bait, the final mixture must be sufficiently attractive and tasty to entice the rodents to eat it in preference to what they can get in their immediate environment. Rats are omnivorous, eating nearly every type of food, although each species has its own preference. For example, Norwegian rats (*Rattus norvegicus*) avidly consume man's garbage, whereas the roof rat (*R. rattus*) and Polynesian rat (*R. exulans*) generally prefer more plant food. However, they all feed to variable degrees on cereals, nuts, fruits, vegetables and invertebrates, depending on habitat conditions.

There seems to be no universally acceptable bait, and regional or population differences are common. For example, *R. norvegicus* in the eastern United States seems to prefer cornmeal to oats, whereas the reverse is true in some parts of western United States and Canada (1). The only sure way of determining the most acceptable bait in a local population is to conduct careful food-preference tests with non-toxic food. Once the preferred food has been established, its palatability with poison must be tested both in the laboratory and in the field.

Since our Division is also concerned with rodent control, the following experiments were undertaken to determine the most suitable and acceptable bait for their effective control in Jamaica. In sececting the suitability of a bait, the following criteria were kept in mind: (1) the bait had to be attractive to local population of rats, (2) it had to be palatable after mixing with poison, (3) it had to be easily available and at relatively low cost, (4) it should permit even mixing of the poison, (5) it should be easy to mix and easy to handle, (6) it should be effective under a variety of circumstances.

METHODS AND MATERIALS: An experiment was carried out on roof rats which were trapped at the University Hospital kitchen in Mona. These rats were transported to the laboratory and caged individually for about two weeks before being tested. During this period they were fed with standard laboratory rat food (i.e. rat chow). Ten rats (five male and five female) were randomly selected, weighed and transferred into the test cages. They were kept there for a further two days so that they could settle down. During the period of the experiment, the test cages were placed as symmetrically as possible in relation to the windows and other sources of stimulation that might encourage feeding at one side of the cage rather than at the other. The same ten rats were used for all food preference tests. Before and after these, the rats were fed only with laboratory standard diet in the same type of container that was to be used for testing the different food materials. Two types of food were tested at one time to see which one of them was preferred. Into two food containers of similar size and form a sufficient amount of weighed food was placed. After 24 hours, the containers were reweighed (the spillage, if any, was collected and replaced in the respective containers) to determine the amount of food consumed by each rat. For the succeeding three days a similar procedure was followed, but the position of the containers in the cage was alternated to avoid any preference that the rats might attach to any position. The following foods were tested: (1 and 2) dry corn and dry wheat, (3 and 4) soaked corn and soaked wheat, (5 and 6) plain cornmeal and plain wheat flour, (7 and 8) cornmeal with sugar and wheat flour with sugar, (9 and 10) chicken feed (broiler) and cattle feed.

RESULTS AND DISCUSSION: By considering the weight of food consumed by rats (Table I), we can arrange the ten different foods in order of preference (Table 2). Soaked corn is the most preferred followed by chicken feed, and the least preferred one was the plain wheat flour. However, soaked corn cannot be recommended as the most suitable bait under all circumstances, due to the problems associated with soaking and the difficulty in mixing the poison, and further, under our climatic condition the soaked corn either becomes mouldy or dries out quickly. Moreover, such a preparation has to be done for each treatment. The next choice, chicken feed, which is in pellet form, can easily be eaten by rats. Hence it was necessary to find out whether rats preferred this for its pellet form or for something else. Therefore, the chicken feed was crushed like cornmeal and was given to the rats in comparison to plain cornmeal. Table III shows that out of ten rats, six preferred ground chicken feed but there was no significant difference in the amount of food consumed ($P>0.05$). This suggests that the rats preferred the chicken feed for its pellet form. Here again we cannot consider the chicken feed as the ideal

Table 1. Results of feeding tests in which *R. rattus* were given different types of food for three days. The weight of food consumed by individual rats is calculated to per 100 (g) body weight of rats

Sex	Rat body weight (g)	Type of food and amount consumed (g)									
		Dry corn	Dry wheat	Soaked corn	Soaked wheat	Plain corn-meal	Plain wheat flour	Sugar & corn-meal	Sugar & wheat flour	Chicken feed - broiler	Cattle feed
M	154	6.50	10.38	30.51	8.44	11.68	5.20	18.18	0.64	20.07	1.29
M	254	14.96	10.62	24.40	21.65	18.11	6.70	14.96	7.48	9.84	16.14
M	102	6.86	17.64	42.15	18.62	4.90	12.74	28.43	2.94	28.43	1.96
M	129	14.72	11.62	43.41	10.07	17.82	0.77	27.13	2.32	26.35	1.55
M	199	5.0	3.0	39.69	21.60	16.08	1.50	3.51	13.06	10.55	3.51
F	144	11.80	4.16	32.62	9.02	12.50	3.47	14.58	1.38	20.83	6.25
F	149	1.34	10.06	35.57	16.10	13.42	4.69	16.77	0.67	18.79	4.69
F	137	6.56	2.18	29.92	9.48	18.97	2.91	20.43	2.18	22.62	10.94
F	135	7.40	2.96	31.85	9.62	20.00	5.18	20.74	11.11	21.48	4.44
F	124	13.70	8.06	33.06	16.93	11.29	11.29	16.93	8.87	12.90	5.64
	Total	88.84	80.64	343.18	141.53	144.95	54.45	181.66	50.67	191.86	56.41

TABLE II. Order of food preference shown by *R. rattus*

	Types of food									
	Dry corn	Dry wheat	Soaked corn	Soaked wheat	Plain corn-meal	Plain wheat flour	Sugar & corn-meal	Sugar & wheat flour	Chicken feed - broiler	Cattle feed
Total weight of food (g) consumed by ten rats in three days	139	120	512	227	229	79	258	84	277	98
Mean weight (g) with 95% confidence limit	13.9 ±6.7	12.0 ±6.7	51.2 ±21.7	22.7 ±9.1	22.9 ±6.8	7.9 ±3.2	25.8 ±5.1	8.4 ±5.5	27.7 ±3.5	9.8 ±7.22
Mean weight of food (g) consumed per 100 (g) body weight of rat with 95% confidence limit	8.8 ±2.8	8.1 ±3.1	34.3 ±3.7	14.1 ±3.3	14.5 ±2.8	5.4 ±2.4	18.2 ±4.3	5.1 ±2.9	19.2 ±3.9	5.8 ±2.9
Order of food preference shown by rats (based on body weight/food consumed)	6	7	1	5	4	9	3	10	2	8
% of rats that preferred the food	70	30	100	0	89	11	90	10	90	10

Table III. Preference shown by *R. rattus* towards ground chicken feed and plain cornmeal

Rats		Chicken feed consumed (g) per 100 (5) body weight of rat	Plain cornmeal consumed (g) per 100 (g) body weight of rat
Sex	Weight (g)		
F	150	8.00	14.66
F	128	3.90	25.00
F	140	11.42	12.85
M	190	16.84	6.84
M	170	17.05	8.82
M	143	5.06	15.38
M	149	8.05	7.38
F	100	19.00	4.00
M	132	15.90	6.06
F	125	20.80	3.20
Total		126.02	104.19

Table IV. Comparison of food preference shown by rats towards plain cornmeal and plain wheat flour at the University Hospital

Box No.	Cornmeal No. of g. eaten	Box No.	Wheat flour No. of g. eaten
1 A	6.3	1 B	7.6
2 A	31.3	2 B	12.7
3 A	10.2	3 B	1.2
4 A	0.0	4 B	0.0
5 A	2.5	5 B	1.3
6 A	13.8	6 B	6.3
7 A	18.0	7 B	9.8
8 A	17.0	8 B	5.3
9 A	0.0	9 B	0.0
10 A	0.0	10 B	0.0
11 A	0.0	11 B	0.0
12 A	0.0	12 B	0.0
13 A	0.0	13 B	0.0
14 A	0.0	14 B	0.0
15 A	0.0	15 B	0.0
16 A	0.0	16 B	0.0
17 A	0.0	17 B	0.0
18 A	0.0	18 B	0.0
19 A	0.0	19 B	0.0
20 A	0.0	20 B	0.0
Total	91.10		44.20

bait due to the high cost and the problem of mixing it with poison. Our next choice would be between cornmeal with sugar or plain cornmeal (Table II). The difference in weight between these two or between the percentages of preference is not significant ($P>0.05$) enough to choose cornmeal with sugar. Moreover, when sugar is added to cornmeal, insects, particularly ants, are attracted and we have to consider also the additional cost involved in adding sugar. Hence, the most suitable bait according to the present experiment is plain cornmeal which was ranked fourth in the order of preference. Having established it as the most suitable bait, its palatability and preference after mixing with poison should be tested both in the laboratory and in the field.

Field trial. Since at present we are using plain wheat flour as bait, it was necessary to conduct a test in the field to find out whether the rats preferred plain cornmeal or plain wheat flour. This test was done at the University Hospital kitchen. Two cardboard boxes of similar sizes (11 x 8 x 2.5 cm) were separately filled with a known weight of plain cornmeal and plain wheat flour. At each 20 points, these cardboard boxes were placed side by side on a piece of paper (the paper was used to collect any spillage) and were left for three days, then later collected and the contents reweighed. Of these 20 points, rats ate the food at only seven places (Table IV) and consumed more cornmeal (91.10 g) than plain wheat flour (44.20 g) ($P<0.02$).

Laboratory test. Having established that rats preferred plain cornmeal both in the laboratory and in the field, it was necessary to conduct a palatability test to determine whether the acceptance of the plain cornmeal was affected in any way by the addition of poison (warfarin at 0.025%). Although rats preferred the plain cornmeal to the poison cornmeal ($P<0.02$, Table V), its acceptance was reduced to only 37%, which is not unexpected

Laboratory test and field trial. Since at present we are using wheat flour and warfarin (0.025%) as the bait, it was necessary to compare the palatability of this with that of cornmeal with 0.025% warfarin both in the laboratory and in the field by using the methods described before. It will be observed (Tables VI and VII) that in both situations, rats preferred the cornmeal with poison than wheat flour with the same amount of poison ($P<0.02$).

CONCLUSIONS: Based upon the number of grams of food consumed and number of rats that preferred the food, we can superficially conclude that the soaked corn was the best bait to be used; however, owing to the difficulties mentioned earlier, plain cornmeal seemed to be the most ideal bait for *Rattus rattus* in Jamaica. One important discovery in this experiment was that the wheat flour was certainly not the most preferred bait as it was formerly believed

TABLE V. Results of palatability test using cornmeal + 0.025% Warfarin and plain cornmeal

Rats		Intake of bait (g) per 100 (g) body weight	Intake of plain cornmeal per 100 (g) body weight
Sex	Weight (g)		
M	150	4.66	27.33
M	165	8.48	9.09
M	105	15.23	20.95
F	90	10.00	16.66
M	145	13.10	20.68
M	140	14.28	10.71
M	180	16.66	17.22
M	210	3.33	9.04
M	120	3.33	10.83
F	100	9.00	13.00
Total		98.07	155.51

TABLE VI. Laboratory palatability test using cornmeal + 0.025% Warfarin and wheat flour + 0.025% Warfarin

Rats		Intake of cornmeal bait (g) per 100 (g) body wt.	Intake of wheat flour bait (g) per 100 (g) body weight
Sex	Weight (g)		
M	154	18.83	3.24
F	114	23.68	0.00
M	254	8.66	6.66
F	149	16.10	0.00
M	102	21.56	1.96
F	137	20.43	0.72
F	135	20.74	2.22
M	129	23.25	0.77
F	124	20.16	9.67
M	199	19.54	1.50
Total		182.95	26.74

Table VII. Field palatability test using cornmeal + 0.025% Warfarin and wheat flour + 0.025% Warfarin

Bait box No.	Intake of cornmeal bait (g)	Bait box No.	Intake of wheat flour bait (g)
1 C	22.0	1 W	0.0
2 C	19.0	2 W	0.0
3 C	0.0	3 W	0.0
4 C	13.8	4 W	2.6
5 C	3.5	5 W	1.2
6 C	4.5	6 W	1.6
7 C	0.0	7 W	1.7
8 C	4.6	8 W	1.0
9 C	3.0	9 W	0.0
10 C	7.0	10 W	0.0
11 C	3.0	11 W	0.0
12 C	3.9	12.W	0.0
13 C	3.6	13 W	1.3
14 C	1.6	14 W	14.0
Total	89.60		23.40

to be. This was demonstrated beyond doubt both in the laboratory and in the field. However, it is well known that the food preference of rats varies from place to place depending on the availability of food types to the local population. Within Jamaica, there may be slight regional variation in food preferences, but for all practical purposes, we can conclude that plain cornmeal is the most suitable bait overall among the foods tested in this experiment.

REFERENCE:

(1) Howard, W., and Marsh, R. (1974) Rodent Control Manual. Pest Control 42(8): D-U.

THE IMPORTANCE OF PHYCITINES ON IMPORTS TO BRITAIN IN RELATION TO THEIR BIOLOGY

P. D. COX
Pest Infestation Control Laboratory
Slough, ENGLAND

INTRODUCTION: During the past 35 years, Advisers of the Ministry of Agriculture, Fisheries and Food (MAFF) and the Department of Agriculture and Fisheries for Scotland (DAFS) have been examining cargoes of stored products for insects on arrival in Britain. Information is recorded on the degree of infestation, the species concerned, the country of origin and type of commodity infested. The present paper analyses the records of one particular family of insects on imports to Britain from all over the world for the period 1967-76, during which time nearly 70,000 cargoes were inspected.

The most commonly imported moth is the Tropical Warehouse or Almond moth, *Ephestia cautella* (Walker). It is second only to the Flour beetle, *Tribolium castaneum* (Herbst), both in terms of frequency of import and actual numbers. *E. cautella* belongs to the family Phycitinae which contains the largest number of moth species infesting stored products not only in Britain but throughout the world.

This paper also discusses the pest status of each species in relation to our current knowledge of their biology. In recent years a considerable amount of work has been carried out on the biology of storage Phycitines. All the species described here have been the subject of detailed study at the Pest Infestation Control Laboratory (PICL), England, although currently work is concentrated on *Ephestia cautella*, *Ephestia kuehniella* Zeller, *Ephestia elutella* (Huebner) and *Plodia interpunctella* (Huebner).

Interpretation of records. Records of a particular species on a cargo should be interpreted with some caution but provided the following points are remembered, the records can be a valuable addition to our knowledge of the distribution and pest status of each species

(a) Although an insect found on a cargo arriving in Britain probably came from the country of origin of that cargo, it is possible that it was acquired by cross infestation in the ship during the voyage. Similarly, the finding of a particular species on a foodstuff does not necessarily mean it can complete its life-cycle on that commodity, since it may have strayed onto it from another cargo in the same ship. Cases where this seems likely to account for an unusual occurrence of a species are indicated as such in the tables to follow. Each record should be considered together with what is already known of the insects' biology.

(b) The number of records of a species from a particular zoogeographic region or on a particular commodity may reflect the volume of trade involved and the efficiency of control measures as well as the actual frequency of occurrence of the insect. As far as possible these factors are taken into consideration as each species is described in the present paper. In some of the tables, the number of records are expressed as a percentage of ship inspections carried out. During the period 1972-1975 just over half the tonnage of infestible commodities imported was inspected.

(c) I have used the system of zoogeographic regions adopted by Aitken in her book 'Insect Travellers - Coleoptera' (1). This is based on the natural regions of Jeannel (2) with minor changes to take into account national borders, since MAFF records all relate to individual countries and not usually the particular region in a country.

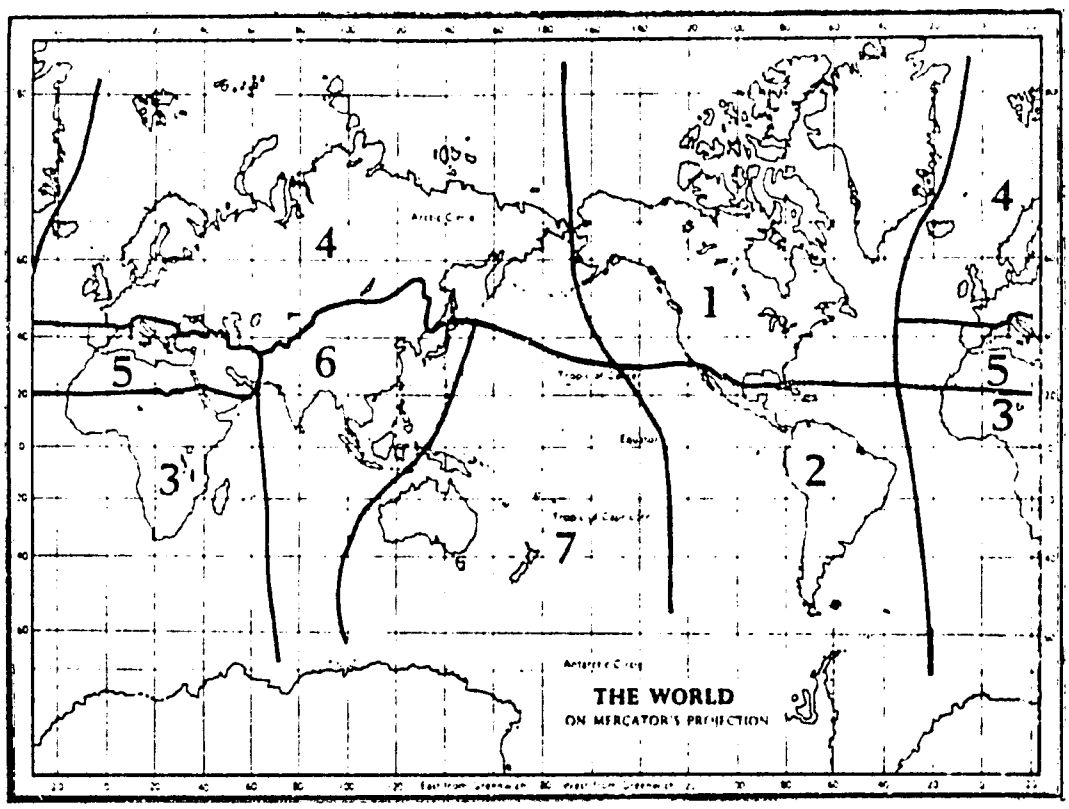


Figure 1. Zoogeographic regions of the world (After Aitken (1)
(1) North America, (2)Central and South America,
(3) Africa, South of the Sahara, (4) Northern Europe,
(5) Mediterranean, (6) Orient, (7) Australasia.

Analysis of infestation by region. The percentage of all cargoes found to be infested by Phycitines over the 10 years was just over 12, and ranged from 24% for Africa, South of the Sahara with over

3800 records, to under 1% for Northern Europe with nearly 30 records (Table I). In most of the 7 regions, *E. cautella* accounted for by far the largest number of records, followed by *P. interpunctella*, the exception being in cargoes from Northern Europe where the order of these 2 species was reversed. The total number of records from all regions was just over 7800 for

Table I. Analysis of infestation by region

Insect	Cargoes infested								
	Amer. North	Amer. C & S	Europe N	Medit-ter.	Africa south	Orient	Austr.	Total	% of insp.
E. cautella.....	141	656	8	539	3712	2327	455	7838	11
P. interpunctella.....	93	50	12	194	94	176	14	633	1
E. calidella....	-	-	-	46	-	-	-	46	<1
E. kuehniella...	13	-	5	4	-	1	15	38	<1
E. elutella.....	1	1?	3	12	5?	2?	6	30	<1
E. figulilella..	-	-	-	6	1?	-	-	7	<1
E. ceratoniae...	-	-	-	3	-	-	-	3	<1
TOTAL ALL SPECIES	248	707	28	804	3812	2506	490	8595	
(as % of inspections)	2	15	<1	10	24	17	8	12	

? Origin of infestations doubtful.

E. cautella and 600 for *P. interpunctella*, while *Ephestia calidella* Guenée, *E. kuehniella* and *E. elutella* had between 50 and 30 records each. *Ephestia figulilella* Gregson and *Ectomyelois ceratoniae* (Zeller) had less than 10 records each.

The Mediterranean was the only region with records of all 7 species, and 2 of the species, *E. calidella* and *Ectomyelois ceratoniae*, were only found on cargoes from this region. *E. figulilella* also belongs to this category because the record of this species from Africa is unconfirmed. *E. cautella*, *E. elutella* and *P. interpunctella* were recorded from all 7 regions, although *E. elutella* is not endemic in most parts of South America, Africa, and the Orient, and so infestations of this species on cargoes from these regions are of doubtful origin. *E. kuehniella* was detected on cargoes from all regions except Africa, South of the Sahara, and Central/South America.

It is generally believed that *Ephestia* spp. and *Ectomyelois ceratoniae* are of Mediterranean origin, with *Plodia* probably from the Americas (3). However, with the exception of *E. calidella*, *E. figulilella* and *Ectomyelois ceratoniae*, the other 4 species are virtually cosmopolitan in distribution through world trade.

Sinha has proposed a climatic plasticity index as a measure of the ability of each species to adapt to various climatic zones, based on the integration of physical limits data and intrinsic rates of increase (3). Using this index for the Phycitines, in order of decreasing adaptability, the species are *E. kuehniella* (600), *E. cautella* (575), *P. interpunctella* (330), *E. calidella* (230), *E. elutella* (165). Indexes for *E. figulilella* and *Ectomyelois ceratoniae* are not given by Sinha but, based on data from Cox (5, 6) and unpublished data, they would probably be at the lower end of the scale near *E. elutella*. It is interesting to note that, apart from *E. kuehniella*, this order is the same as that for the number of records of each species on imports to Britain from all over the world. *E. kuehniella* is not at the top of this list probably because it can thrive only on a much narrower range of foodstuffs than *E. cautella*, the former mainly being confined to cereal and cereal products. Furthermore, these commodities are generally imported from regions, such as North America, with low levels of infestation of all insects on imports.

Analysis of infestation by commodity. Commodity groups chosen for table II are those with the higher levels of infestation. The table also demonstrates the success of *E. cautella* on stored products, in that at least 4% of all cargoes inspected in each commodity group were infested with this species. Commodity groups with the highest number of records of *E. cautella* were oilseeds and products and cocoa beans and products, each with nearly 40% of cargoes inspected being infested.

Plodia was also recorded on all commodity groups but this species only reaches a maximum infestation level of 3%, on nuts. *E. elutella*, whilst infesting all the major groups, never

Table II. Analysis of infestation by commodity

Insect	Cargoes infested							
	Oilseeds and products	Cereals and products	Cocoa beans/ products	Nuts	Dried fruit	Pulses/ products	Carobs/ products	Others
E. cautella	3665	1011	919	546	247	300	116	1034
P. interpunctella	132	141	6	167	104	9	8	66
E. calidella	1?	-	-	7	1	1	35	1
E. kuehniella	-	31	-	1	-	6	-	-
E. elutella	1?	9	4	1	7	1	1	6
E. figulilella	1?	-	-	-	3	-	3	-
E. ceratoniae	-	-	-	2	-	-	1	-
Total all species	3799	1192	929	724	362	317	164	1107
(As % of inspections)	40	6	40	13	6	7	36	5

? Doubtful records.

reached the 1% level of infestation and the record on oilseed was doubtful. Oilseeds and products and cocoa beans and their products were the most frequently infested commodities, with 40% of cargoes examined being infested by one or more species of Phycitine. Carobs and carob products were the next most frequently infested commodities (36%), with *E. cautella* accounting for 26% and *P. edulella* 8%. Thirteen percent of nuts were infested with *E. cautella* and *Plodia*, and 6% of dried fruit cargoes.

Changes in annual rates of infestation. Table III shows how the

Table III. Frequency of infestation by *Ephestia cautella*

	Total No. records per 100 inspections					
	1967-8	1969-70	1971-2	1973-4	1975-6	10-year mean
Africa (S. of Sahara)	34	26	22	19	17	23
Orient	15	17	16	16	14	15
America (C and S)	14	13	12	14	17	14
Australasia	6	8	6	9	11	8
Mediterranean	7	7	4	5	5	5
America (N)	2	<1	<1	1	1	1
Europe (N)	<1	-	<1	<1	<1	<1
Total all regions	2145	1828	1507	1291	1067	
As % of inspections	15	13	10	10	9	

level of infestation of *E. cautella*, the most frequently recorded species1, has altered over the 10 year period. There has been a steady fall in the % of cargoes infested, from 15 in 1967-8 down to 9 by 1975-6. Most of this reduction is due to a fall from 34% to 17% in the cargoes infested from Africa, South of the Sahara. There was no significant change in infestation levels for the other species, except for *P. interpunctella* which fell from 6% to 1% in cargoes from the Mediterranean region.

The importance of each species on imports will now be considered in relation to our knowledge of their biology.

Ephestia cautella. This species is able to develop on a remarkably wide range of stored products, being a pest of cereals, oilseeds, cocoa, nuts, dried fruit, carobs, and their products (Table IV). Whole cereals and soybeans are poor foods for this

Table IV. Records of *Ephestia cautella* on imports

	No. records all regions	Region with largest No. cargoes infested
Oilseeds, Oilseed products	3665	Africa, S. of Sahara
Grain, Grain products	1011	Orient
Cocoa beans, Cocoa bean products	919	Africa, S. of Sahara
Nuts	546	Orient
Pulses, Pulse products	300	Africa, S. of Sahara
Dried fruit	247	Mediterranean
Carobs, Carob products	116	Mediterranean
Others	1034	Orient

species, presumably the hard seed coat preventing penetration by larvae (7). Larvae are unable to develop at all on whole black grams and lentils, although grinding up these foods greatly improves their suitability (8).

E. cautella has spread throughout the world by trade although it is basically a species of warm, tropical countries. It requires a minimum of 15°C for complete development (9) and 17°C for annual doubling of numbers (10). It can, however, breed in warehouses in temperate climates during the summer, although mortality may be heavy in winter (11). Mathlein (12) has shown it to be much less cold tolerant than *E. elutella* and *E. kuehniella* in Sweden. It is also able to establish itself in heated premises, such as the spillage inside machinery and sample rooms of food-processing factories (13). Upper limits for development are about 36°C, development being fastest at 30-32°C, and 70-80% R.H. (9). Limiting humidities are about 20% and above 90% R.H.

Plodia interpunctella. *Plodia*, like the previous species, has a wide host range but is particularly troublesome on dried fruit, grain products and nuts (Table V). It also develops well on whole grains such as wheat (14).

This species is an important pest of stored food products in most parts of the world, although it is basically an insect of warmer climates. It requires a minimum of 18°C for annual doubling of numbers, and has a range of 28-32°C for optimum development, similar to *E. cautella* (10). It occurs sporadically in warehouses in temperate climates (14). *Plodia* is slightly

Table V. Records of *Plodia interpunctella* on imports

	No. records all regions	Region with largest No. cargoes infested
Nuts	167	Mediterranean
Oilseed, Oilseed products	132	Africa, S. of Sahara
Grain, Grain products	141	America, N.
Dried fruit	104	Mediterranean
Pulses, Pulses products	9	Africa, S. of Sahara
Cereals, Cereal products	8	Mediterranean
Cocoa beans, Cocoa bean products	6	Orient
Others	66	Orient

more cold tolerant than *E. cautella*, being able to survive some winters in grain silos in Southern England (15). The minimum R.H. permitting complete development is around 25% R.H. (16).

Ephestia kuehniella. *E. kuehniella* is the major pest of flour mills in countries of temperate climate. This species is also known in many other parts of the world where it has been spread through trade. However, it is rarely recorded from India, the Far East apart from Japan, and some parts of Africa where it appears to be replaced in flour mills by *E. cautella* and *Corcyra cephalonica* Stainton (17). On imports to Britain it is mainly confined to those from Australasia, N. America and N. Europe (Table VI). Laboratory studies have shown that for complete development, lower limits are around 10°C and near 0% R.H., and upper limits near 30°C and above 75% R.H. (18). Infertility of adults at 30°C prevents a second generation being established at this temperature (16). Thus, the temperature requirements of *E. kuehniella* probably account in part for its absence on imports from Central and South America, much of Africa and the Orient. It is also restricted in its spread by a limited ability to develop on different foods, being confined mainly to cereals and cereal products. Although development has been demonstrated in the laboratory on cocoa beans, dried fruit, nuts and pulse products, it is much slower with lower survival than on cereals. Table VII records the ability of each species to develop on the major types of stored foodstuff, based on laboratory data from a number of sources including our own work at PICL.

Table VI. Records of *Ephestia kuehniella* on imports

	No. records all regions	Largest number cargoes infested
Wheat, wheat products	17	America, N.
Maize, maize products	6	Europe, N. America N.
Rice	5	Mediterranean
Other grains	3	Australasia
Peas, pea products	6	Australasia
Gallnuts	1	Orient

Table VII. Ability to develop on various commodities, mainly based on published laboratory data

	Cereal/ prod.	Soya bean/ prod.	Cocoa bean/ prod.	Nuts	Dried fruit	Pulses/ prod.	Carob/ prod.
E. caut.	Y(9)	Y(34)	Y (9)	Y(24)	Y(24)	Y(8)	Y(24)
P. inter.	Y(14)	Y(34)	Y(36)	Y(14)	Y(14)	Y(37)	Y(*)
E. calid.	Y(32)	?	?	Y(24)	Y(24)	?	Y(24)
E. kuehn.	Y(19)	X(34)	X(36)	X(*)	X(20)	X(20)	X(*)
E. elut.	Y(35)	Y(34)	Y(35)	Y(38)	Y(35)	Y(35)	Y(*)
E. fig.	Y(32)	X(*)	X(*)	Y(24)	Y(24)	Y(*)	Y(24)
E. cera.	?	Y(39)	?	Y(27)	Y(32)	?	Y(32)

Y: Able to develop from egg hatch to adult emergence, with good survival.

X: Unable to complete development or only very slowly and with poor survival.

?: No laboratory data available.

(): Numbers refer to references at end of paper.

(*): Unpublished data from recent work at PICL.

Fraenkel and Blewett suggested that part of this species' success on cereal products such as flour was due to its relative insensitivity to lack of riboflavin in low extraction flour (19). Furthermore, *E. kuehniella* can develop equally well on starch and glucose, unlike other Phycitines. It appears to feed indiscriminately on germ and endosperm of whole grain, although first

instar larvae can only feed on whole grain when it is damaged (20). This may be a factor in the lower incidence of this species on whole grain than on cereal products.

The ability of *E. kuehniella* to develop at exceptionally low moisture content/R.H. is probably another reason for its success in flour mills, and hence its abundance on imports of milled cereal products.

Ephestia elutella. *E. elutella* is found on cereal products less frequently than *E. kuehniella* but is able to develop on a wider range of foodstuffs than the latter species (Table VIII). Both

Table VIII. Records of *Ephestia elutella* on imports

	No. records all regions	Region with largest No. cargoes infested
Grain, grain products	9	Australasia
Dried fruit	7	Mediterranean
Cocoa beans	4	Europe, N. (trans-America, N. shipped)
Nuts	1	Mediterranean
Carobs	1	Mediterranean
Peas	1	Europe, N.
Others	7	Mediterranean

facts are reflected in their incidence on imports: 31 and 9 records on cereal and cereal products for *E. kuehniella* and *E. elutella* respectively, but records on 2 and 6 other main commodity groups respectively, although the record of *E. elutella* on oilseed is doubtful. *E. elutella* is also the only storage moth to be found regularly on tobacco.

This species does not develop very well on low extraction or even whole meal flour (19). On whole grain, only the embryo is eaten, leaving the endosperm untouched, unlike *E. kuehniella* which eats both.

Although both species have been spread throughout the world by trade, *E. elutella* is essentially a species of temperate climate where it can be a serious pest on whole grain kept in store for several years(21). Its infrequent appearance on imports probably reflects its comparative lack of success in establishing itself in the more tropical regions. Furthermore, vigorous control measures in N. America and other temperate regions, together with the short storage periods of grain before export, have considerably reduced its occurrence on imports from these areas in recent years.

In the past, *E. elutella* has been frequently confused with *E. cautella*. Thus, early records in the scientific literature of the former species are of doubtful value in establishing its world distribution and ability to attack particular products.

The small number of laboratory studies conducted on this species have shown that it can complete development at 15°C but not at 10°C (16). Individual developmental stages are able to survive much lower temperatures than this, however. At 30°C, although development is completed, only a few of the adults bred at this temperature are able to produce a second generation. Development is completed at humidities as low as 25% R.H. at both 15°C and 30°C.

Ephestia figulilella and *E. calidella*. The greater frequency of *E. calidella* than *E. figulilella* on imports (Table IX) reflects a

Table IX. Records of *Ephestia calidella* and *Ephestia figulilella* on imports; all records from Mediterranean

	E. calidella	*E. figulilella*
Carobs, carob products	35	3
Nuts	8	-
Dried fruit	1	3
Others	2	1?

? Doubtful record on sunflower seed from Malawi.

similar pattern of infestation found in warehouses, such as carob stored in Cyprus (22). Thus, *E. figulilella* is usually less of a storage pest than *E. calidella*, the former being commonly associated with fallen fruit, freshly harvested carobs and other crops, and in some areas attacking ripe dates still on the tree. *E. calidella* on the other hand, while still capable of attacking appropriate crops before harvest, is commonly found in stores on dried fruit and carobs. Both species have a winter larval diapause partly controlled by daylength but in *E. calidella* diapause is weaker than in *E. figulilella* (23). This may further reflect the stronger affinity of *E. figulilella* for the pre-harvest field situation and the greater ability of *E. calidella* to exploit the storage environment.

On a semi-artificial diet, the lower limit for complete development of both species is between 50% and 30% R.H. (5),

whereas on a similar diet *E. cautella* can develop down to about 20% R. H. (9). Presumably the drier conditions and lower moisture content of products in storage, in contrast to their pre-harvest field condition, are less suitable for the development of *E. figulilella* and *E. calidella* than *E. cautella*. The temperature limits for *E. cautella*, *E. calidella* and *E. figulilella* are very similar, being 36°C and 15°C. However, the range of products which can support complete development of *E. cautella* is much greater than for the other two species (Table VII). Development of *E. cautella* on almonds is considerably faster and survival higher than in *E. figulilella* and *E. calidella* (24), *E. cautella* being the commonest insect on almonds imported to Britain (25).

In laboratory tests on almonds in California, *E. cautella* was a stronger competitor in mixed populations than *E. figulilella*, due in part to variation in egg viability and possibly egg predation (26). This may be another factor in the lower numbers of the latter species in stores where other species are also present.

<u>*Ectomyelois ceratoniae*</u>. *E. ceratoniae* differs from the other Phycitines on imports in regularly attacking some products in the field prior to harvest, especially citrus fruit and carobs (27). It can also be a serious pest of almonds and carobs in stores after harvest, mainly in the Mediterranean region (28, 29). It has been shown that attack by this species predisposes carobs to attack by *Ephestia cautella* and other storage pests (30). It is apparently unable to complete more than one generation in stores. Unlike other storage Phycitines, cereal products are a poor food for *E. ceratoniae* and this severely limits its frequency on imports. It is not surprising therefore that it is the least common Phycitine on imports to Britain, being recorded only 3 times in 10 years, twice on almonds and once on carobs from the Mediterranean. Its spread within a store or cargo is further limited by the lack of a larval wandering period prior to pupation, a density regulating mechanism useful in the confined spaces of a store or ship's hold. (6). Other aspects of its behaviour that may hinder the development of *E. ceratoniae* in stores include the requirement for fluctuating light, temperature and humidity field conditions before adults will mate and lay fertile eggs. Furthermore, unlike other Phycitines, this species will not mate in confined spaces (6).

<u>*Mussidia nigrivenella*</u>. *Mussidia nigrivenella* Ragonot was not recorded during the period of the current survey but it is another Phycitine which has been imported on produce from West Africa in the past. It is the main storage pest of maize in Nigeria, Ghana and Togo, attacking mature but undried grains on the cob (4). This species also attacks cocoa beans, calabar and butter beans.

<u>Diapause in storage Phycitines</u>. Some strains of all seven species have been shown to exhibit diapause, expressed as a delay in

development of fully mature larvae enabling them to survive adverse conditions such as low temperature, food shortage or stress imposed by toxicants. Diapause may also synchronise adult emergence to ensure successful reproduction in a favourable environment. The ability to enter diapause and the particular conditions of temperature and daylength controlling it, will help to determine whether a species exported from one region can successfully colonise another region of the world.

The importance of factors such as temperature and photoperiod in controlling diapause in *P. interpunctella* and *E. elutella* (3.), *E. cautella*, *E. figulilella* and *E. ceratoniae* (32, 23) have been studied at PICL, England, in recent years. Diapause is to some extent photoperiodically controlled and is stimulated by temperatures near to the developmental minimum. Termination of diapause and synchronisation of post-diapause emergence is hastened by exposure to low temperatures for long periods. The more recently discovered diapause in some strains of *E. cautella* (33) and *E. kuehniella* (18) are the subject of work currently in progress at PICL.

ACKNOWLEDGEMENTS: I am grateful to K. G. Smith and Dr. R. W. Howe (PICL) for criticism of the manuscript. Thanks are also due to the Advisers of MAFF and DAFS on whose inspection reports the figures in this paper are based, and to the staff of the Information and Training section (PICL) who prepared the yearly Analyses of Ship Inspections.

REFERENCES:

(1) Aitken, A. D. (1975) Insect Travellers. Vol. I. Coleoptera. Tech. Bull. Minist. Agric. Fish. Fd. No. 31 xvi + 191 pp., London, HMSO.

(2) Jeannel, R. (1960) Introduction to Entomology. (Translated by H. Oldroyd). London: Hutchinson, 344 pp.

(3) Heinrich, C. (1956) American moths of the subfamily Phycitinae. Bull. U.S. Natn. Mus., 207, 1-581.

(4) Sinha, R. N. (1975) Climate and the infestation of stored cereals by insects. Proc. 1st. Int. Wkg. Conf. Stored-Prod. Ent., Savannah 1974, 117-141.

(5) Cox, P. D. (1974) The influence of temperature and humidity on the life-cylces of *Ephestia figulilella* Gregson and *Ephestia calidella* (Guenée) (Lepidoptera: Phycitidae). J. Stored Prod. Res. 10 (1), 43-55.

(6) Cox, P. D. (1976) The influence of temperature and humidity on the life-cycle of *Ectomyelois ceratoniae* (Zeller)(Lepidoptera: Phycitidae). J. Stored Prod. Res. 12 (2), 111-117.

(7) LeCato, G. L. (1976) Yield, development and weight of *Cadra cautella* (Walker) and *Plodia interpunctella* (Huebner) on twenty-one diets derived from natural products. J. Stored Prod. Res. 12(1), 43-47.

(8) Chaudhary, R. R. P., and Bhatta Charya, A. K. (1976) Larval developmental behaviour of *Ephestia cautella* (Walker) on several food commodities. Bull. Grain Tech. 14: 3-8.
(9) Burges, H. D., and Haskins, K. P. F. (1965) Life-cycle of the tropical warehouse moth, *Cadra cautella* (Wlk.), at controlled temperatures and humidities. Bull. Ent. Res. 55, 775-789.
(10) Howe, R. W. (1965) A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. J. Stored Prod. Res. 1: 177-184.
(11) Burges, H. D. (1956) Some effects of the British climate and constant temperatures on the life-cycle of *Ephestia cautella* (Walker). Bull. Ent. Res. 46, 813-835.
(12) Mathlein, R. (1961) Studies on some major storage pests of Sweden, with special reference of their cold resistance. Meddn. St. Växtsk. Anst. 12: 83, 1-49.
(13) Freeman, J. A. (1974) Infestation of stored food in temperate countries with special reference to Great Britain. Outlook on Agric. 8, 34-41.
(14) Williams, G. C. (1964) The life-history of the Indian meal moth, *Plodia interpunctella* (Huebner) (Lep. Phycitidae) in a warehouse in Britain and on different foods. Ann. Appl. Biol. 53, 459-475.
(15) Solomon, M. E., and Adamson, B. E. (1955) The powers of survival of storage and domestic pests under winter conditions in Britain. Bull. Ent. Res. 46, 311-355.
(16) Bell, C. H. (1975) Effects of temperature and humidity on development of four pyralid moth pests of stored products. J. Stored Prod. Res. 11, 167-75.
(17) Freeman, J. A. (1962) The influence of climate on insect populations of flour mills. XI. Int. Congr. Ent. (Vienna 1960), II, 301-308.
(18) Jacob, T. A., and Cox, P. D. (1976) The influence of temperature and humidity on the life-cycle of *Ephestia kuehniella* Zeller (Lep., Pyralidae). J. Stored Prod. Res. 13, 107-118.
(19) Fraenkel, G., and Blewett, M. (1946) The dietetics of the caterpillars of three *Ephestia* species, *E. kuehniella*, *E. elutella* and *E. cautella*, and of a closely related species, *Plodia interpunctella*. J. Exp. Biol. 22, 162-171.
(20) Fraenkel, G., and Blewett, M. (1943) The natural food requirements of several species of stored products insects. Trans. R. Ent. Soc. Lond. 93, 457-490.
(21) Richards, O. W., and Waloff, N. (1946) The study of a population of *Ephestia elutella* Huebner (Lep., Phycitidae) living on bulk grain. Trans. R. Ent. Soc. Lond. 97, 253-298.
(22) Ashman, F., Webley, D. J., and Achillides, N. Z. (1974) Space treatment of warehouses using Dichlorvos. EPPO Bull. 4(4): 429-445.

(23) Cox, P. D. (1975) The influence of photoperiod on the life-cycles of *Ephestia calidella* (Guenée) and *Ephestia figulilella* Gregson (Lepidoptera: Phycitidae). J. Stored Prod. Res. 11, 75-85.

(24) Cox, P. D. (1975)a The suitability of dried fruits, almonds and carobs for the development of *Ephestia figulilella* Gregson, *E. calidella* (Guenée) and *E. cautella* (Walker)(Lepidoptera: Phycitidae). J. Stored Prod. Res. 11, 229-233.

(25) Freeman, J. A., Smith, K. G., and Hart, J. J. (1973) Infestation problems of imports. Pest Infestation Control. PICL Report 1968-1970. HMSO, 205 pp.

(26) Soderstrom, E. L., and Lovitt, A. E. (1973) Interspecific competition of *E. cautella*, *Plodia interpunctella* and *E. Figulilella* in Malathion-treated and untreated almonds. J. Econ. Ent. 66, 741-744.

(27) Gothilf, S. (1969) The biology of the carob moth, *Ectomyelois ceratoniae* (Zell.) in Israel. II. Effect of food, temperature and humidity on development. Israel J. Ent. 4, 107-116.

(28) Calderon, M., Navarro, S., and Donahaye, E. (1969) *Ectomyelois ceratoniae* (Zell.), a major pest of stored almonds in Israel. J. Stored Prod. Res. 5, 427-428.

(29) Ashman, F. (1968) The control of infestation of carobs, *Ceratonia siliqua* L., with special reference to Cyprus. Rept. Int. Conf. Prot. of Stored Prod., Lisbon-Oeiras 1967, 117-120.

(30) Dobie, P. (1978) The effects of a previous field infestation upon *Ephestia cautella* and *Lasioderma serricorne* infesting carobs. J. Stored Prod. Res. 14, 35-39.

(31) Bell, C. H. (1976) Factors governing the induction of diapause in *Ephestia elutella* and *Plodia interpunctella*) (Lepidoptera). Physiol. Entomol. 1 (2), 83-91.

(32) Cox, P. D. (1973) The biology of *Ephestia calidella* and *Ephestia figulilella*, and a comparison with the biology of *Ephestia cautella* and *Ectomyelois ceratoniae*. Ph.D. thesis. 309 pp., University of Bath, England.

(33) Hagstrum, D. W., and Sharp, J. E. (1975) Population studies on *Cadra cautella* in a citrus pulp warehouse with particular reference to diapause. J. Econ. Ent. 68, 11-14.

(34) Cox, P. D., and Simms, J. A. (1978) The susceptibility of soya bean meal to infestation by some storage insects. J. Stored Prod. Res. 14(2/3): 103-109.

(35) Waloff, N. (1948) Development of *Ephestia elutella* Hb. (Lep., Phycitidae) on some natural foods. Bull. Ent. Res. 39, 117-130.

(36) Noyes, W. M. (1930) Moth pests in cocoa and confectionery. Bull. Ent. Res. 21, 77-121.

(37) Reyes, W. M. (1930) Biology and host range of *Plodia interpunctella* (Pyralidae: Lep.) Philipp. Entomol. 1, 301-311.

(38) Zacher, F. (1927) Summer dangers in the manufacture of and trade in sweets. Mitt. Ges. Vorratsschutz III (4), 45-56.
(39) Gothilf, S. (1968) The biology of the carob moth, *Ectomyelois ceratoniae* (Zell.) in Israel. I. Mass culture on artificial diet. Israel J. Ent. 3, 109-118.

THE PREVENTION OF INSECT INFESTATION IN STORED DATES

J. McCALLUM-DEIGHTON
ICI Plant Protection Division, Fernhurst, Haslemere,
Surrey, ENGLAND

and

ALA-UD-DIN DAOUD ALI
Director General Plant Protection,
Ministry of Agriculture and Agrarian Reform,
Baghdad, IRAQ

The annual production of all date varieties in Iraq in 1974 was approximately 350,000 tonnes, of which 250 - 300,000 tonnes, valued in 1974 at £13 million, were exported.

The main production area, especially of the high quality dates for export, is in the region around Basrah in the south of the country, where harvesting of the dates commences in September. In the region around Baghdad, harvesting occurs in October.

Dates are collected in the orchards and put into wooden 'field' boxes, although these boxes are being replaced by perforated plastic crates. The 'field' boxes are left in the orchards for at least two weeks to allow further ripening to occur, and insect infestation can then occur. Windfalls, which are usually insect infested, are put into the same 'field' boxes, and add to the insect infestation. These 'field' boxes are used to transport the dates to the packing sheds, and here the dates, still in boxes, can be left for several weeks before further processing.

Ephestia cautella is the most serious insect pest of post-harvested dates in Iraq, infesting dates in the orchards, packing sheds and stores (A.A. Hussain 1974). Infestation can occur when the dates are on the palms if the harvest is delayed, or if the variety is late maturing. Infestation of windfalls is common, as is infestation in the stores. The most serious insect pest of stored dates is *Oryzaephilus surinamensis*, infestation being apparent from December onwards, and reaching a peak in April.

Before packing and export, the dates are fumigated with methyl bromide. The highest quality dates are packed in cardboard cartons having a cellophane window, the cartons being contained in cardboard boxes. High quality dates are also exported in wooden boxes lined with waxed paper. Lower quality dates are exported in palm-leaf bags contained in hessian sacks. Packed dates can become re-infested with insects, either in the packing sheds, or when waiting for export. Sometimes the wooden boxes are sprayed with malathion after leaving the packing sheds.

MATERIALS AND METHOD: Four trials were done in Baghdad using export packages, or materials used to make such packages, and one trial using perforated plastic 'field' crates. Each trial compared three or four rates of pirimiphos-methyl (from 'Actellic' 50)* as deposits on the outer surfaces of the packages, with a water treatment and, in most cases, with a malathion treatment. All deposits were produced by spray application using a knapsack sprayer. The types of surface treated, and the rates and volumes of application are given in Table I. When the spray had dried, the

Table I
SUMMARY OF INSECTICIDE TREATMENTS

Trial No.	Substrate treated	Rates of application	Spray Volume
1	Cardboard boxes (containing untreated window cartons)	0.125, 0.25 and 0.5 g pirimiphos-methyl/m^2 and 1 g malathion/m^2	50 mls/m^2
2	Wooden export boxes (lined with untreated waxed paper)	As in Trial 1	50 mls/m^2
3	Waxed paper (placed in untreated wooden boxes)	0.03125, 0.0625, 0.125 and 0.25 g pirimiphos-methyl/m^2	25 mls/m^2
4	Plastic 'field' boxes	As in Trial 1	25 mls/m^2
5	Hessian sacks (containing untreated palm-leaf bags)	As in Trial 1	50 mls/m^2

relevant packages of dates, or loose dates, were put into the treated containers. Fifteen replicates of each treatment were used, and they were randomised, placed in rooms, and exposed to severe insect infestation by releasing into the rooms, at one month intervals, large numbers of laboratory-reared susceptible strains of *Tribolium castaneum*, *Oryzaephilus surinamensis* and *Ephestia cautella*.

Three replicates of each treatment were removed from the rooms and examined for biological effectiveness of the

* Registered Trade Mark of I.C.I. Plant Protection Division.

Table II
BIOLOGICAL EFFECTIVENESS OF VARIOUS TREATMENTS AFTER 3 MONTHS

Substrate treated	Rate of application	% mortality & total number insects found	
		%	Total
Cardboard boxes	0.5 g pirimiphos-methyl/m^2	100	20
	1 g malathion/m^2	100	25
	untreated	71	24
Wooden boxes	0.5 g pirimiphos-methyl/m^2	93	68
	1 g malathion/m^2	91	55
	untreated	58	26
Waxed paper	0.125 g pirimiphos-methyl/m^2	92	24
	0.25 g pirimiphos-methyl/m^2	97	30
	untreated	42	57
Plastic 'field' boxes	0.5 g pirimiphos-methyl/m^2	100	18
	1 g malathion/m^2	100	11
	untreated	83	6
Hessian sacks	0.5 g pirimiphos-methyl/m^2	100	23
	1 g malathion/m^2	100	18
	untreated	97	30

treatment, and residue analysis, 1 week, and 1, 3 and 6 months after treatment. At the time of sampling, the inner surfaces of the containers were examined for live and dead insects, and separate random samples of dates taken for biological assessment, taint testing where relevant, and residue analysis. For the biological examination, each date was cut in half, all visible live and dead insects removed, and the dates boiled for five minutes and any hidden insects collected by floatation in kerosene (Hussain pers. comm.).

Samples of the treated containers were taken during the 3 and 6 month examinations and bioassayed with laboratory-reared susceptible strains of *T. castaneum*, *O. surinamensis* and *E. cautella*. Samples of dates from the treated containers were also taken at these times and tested for any possible taint.

RESULTS AND DISCUSSION: Irrespective of the surface treated, lower rates of application of pirimiphos-methyl were more effective than 1 g malathion/m^2. Even this relatively high rate of malathion did not prevent insect infestation, and the survival of many insects, as was obvious when malathion was applied to hessian sacks (Table III). In the second trial, where wooden boxes were treated,

Table III
BIOLOGICAL EFFECTIVENESS OF VARIOUS TREATMENTS AFTER 6 MONTHS

Substrate Treated	Rate of application	% mortality & total number insects found	
		%	Total
Cardboard boxes	0.5 g pirimiphos-methyl/m^2	100	55
	1 g malathion/m^2	96	111
	untreated	74	132
Wooden boxes	0.5 g pirimiphos-methyl/m^2	76	54
	1 g malathion/m^2	42	78
	untreated	32	56
Waxed paper	0.125 g pirimiphos-methyl/m^2	95	21
	0.25 g pirimiphos-methyl/m^2	98	51
	untreated	30	73
Plastic 'field' boxes	0.5 g pirimiphos-methyl/m^2	91	116
	1 g malathion/m^2	52	268
	untreated	52	292
Hessian sacks	0.5 g pirimiphos-methyl/m^2	100	11
	1 g malathion/m^2	26	53
	untreated	-	<1000

imperfections in the box construction prevented complete insect control, and would have even prevented a much higher rate of application from giving complete kill of insects. Improvements in the box design would be necessary to achieve better insect control. Further, the insect infestation pressure was much higher than would usually occur.

Deposits of pirimiphos-methyl were very toxic to the three bioassay species when tested 3 and 6 months after treatment (Tables IV and V). A deposit of 0.5 g pirimiphos-methyl/m^2, and

Table IV
BIOASSAY OF SUBSTRATES 3 MONTHS AFTER TREATMENT

Substrate	Treatment	% kill after 24 hours			
		Adults		Larvae'	
		T.c.	O.s.	E.c.	T.c.
Cardboard	0.25 g pirimiphos-methyl/m^2	100	100	100	100
	0.5 g pirimiphos-methyl/m^2	100	100	100	100
	1 g malathion/m^2	100	100	100	55
	untreated	0	2	19	0
Waxed paper	0.0625 g pirimiphos-methyl/m^2	100	100	100	92
	0.125 g pirimiphos-methyl/m^2	100	100	100	96
	0.25 g pirimiphos-methyl/m^2	100	100	100	100
	untreated	0	0	9	19
Wood	0.25 g pirimiphos-methyl/m^2	96	98	100	-
	0.5 g pirimiphos-methyl/m^2	100	100	100	-
	1 g malathion/m^2	100	100	100	-
	untreated	0	1	55	-

' = exposure for 48 hours

T.c. = T. castaneum; O.s. = O. surinamensis; E.c. = E. cautella

Table V
BIOASSAY OF SUBSTRATES 6 MONTHS AFTER TREATMENT

[illegible]	Treatment	[illegible] after 4 [illegible]			
		[illegible]		[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] pirimiphos-methyl/m²	[illegible]	[illegible]	[illegible]	100
	[illegible] pirimiphos-methyl/m²	-	-	[illegible]	100
	[illegible] malathion/m²	[illegible]	[illegible]	[illegible]	100
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] pirimiphos-methyl/m²	[illegible]	[illegible]	[illegible]	-
	[illegible] pirimiphos-methyl/m²	[illegible]	[illegible]	[illegible]	-
	[illegible] pirimiphos-methyl/m²	[illegible]	[illegible]	[illegible]	-
	[illegible]	[illegible]	[illegible]	[illegible]	-
[illegible]	[illegible] pirimiphos-methyl/m²	[illegible]	[illegible]	[illegible]	100
	[illegible] pirimiphos-methyl/m²	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible] malathion/m²	[illegible]	100	[illegible]	100
	untreated	[illegible]	0	[illegible]	0

[illegible] easily affected

L.c. = L. cucullanum; O.s. = O. surinamensis

[illegible] lower amounts, were at least as effective, and frequently more effective, than 1 g malathion/m².

Residues (Anon 1974) of pirimiphos-methyl were always low, or non-detectable, except in trials 3 and 4 (Table VI), and in those trials the residues were lower than the figure of [illegible] recommended as a residue tolerance by the FAO/WHO Joint Expert Panel on Pesticide Residues (Anon 1977). The type of treatment used in Trial 3, where waxed paper was sprayed, would probably never be used commercially as it is too time consuming, and a recommendation for the use of pirimiphos-methyl to treat perforated plastic 'field' crates (Trial 4) could not be made as no treatment prevented large numbers of insects from entering the crates by the end of the trial.

Table VI
RESULTS OF ANALYSES OF DATES FOR RESIDUES OF INSECTICIDES (mgms/kg)

Substrate Treated	Rate of application	Residues in dates after			
		1 week	1 month	3 months	6 months
Cardboard boxes	0.5 g pirimiphos-methyl/m^2 1 g malathion/m^2	<0.01 <0.01	<0.01 <0.01	0.08 <0.01	<0.01 -
Wooden boxes	0.5 g pirimiphos-methyl/m^2 1 g malathion/m^2	0.02 <0.01	<0.01 <0.01	<0.01 <0.01	<0.01 -
Waxed paper	0.125 g pirimiphos-methyl/m^2 0.25 g pirimiphos-methyl/m^2	0.09 0.19	0.20 0.47	0.23 0.28	- -
Plastic 'field' boxes	0.5 g pirimiphos-methyl/m^2 1 g malathion/m^2	0.15 0.21	0.23 0.31	0.21 0.20	0.27 -
Hessian sacks	0.5 g pirimiphos-methyl/m^2 1 g malathion/m^2	0.02 0.06	0.05 0.05	0.24 -	0.10 -

(limit of detection 0.01 mg/kg)

In no case was a taint detected in any of the date samples.

ACKNOWLEDGEMENTS: We are grateful to Mr. Jasim Nassaff, Minister of Agriculture, Iraq, and the Directors of I.C.I. Plant Protection Division for their permission to publish this paper. We are also extremely grateful to Mr. R. Pascoe and staff of I.C.I. Plant Protection Division Jealott's Hill Research Station and the Iraq Date Administration for the very considerable technical assistance given.

REFERENCES:

(1) Anon (1974) I.C.I. Residue Analytical Method No. IIA "Determination of residues of pirimiphos-methyl and its phosphorus containing metabolites in crops, water, milk and animal tissues".

(2) Anon (1977) F.A.O. Pesticide Residues Series No. 8, p 627.

(3) Hussain, A.A. (1974) Date palms and dates with their pests in Iraq. University of Baghdad, Iraq.

MICROENCAPSULATED PESTICIDES - A NOVEL CONTROL RELEASE SYSTEM FOR INSECT CONTROL

JOSEPH SIMKIN
Pennwalt Corporation
Technological Center
900 First Avenue
King of Prussia, Pennsylvania 19406
U.S.A.

ABSTRACT: In 1973 Pennwalt Corporation introduced to United States agriculture a new type of controlled release pesticide formulation called PENNCAP-M® INSECTICIDE (Microencapsulated methyl parathion). The ready acceptance by the agricultural community has encouraged Pennwalt to expand the market to include Europe, the Near East, Mexico, Canada, Central and South America. Pennwalt's process for encapsulating pesticides is based upon a patented interfacial polymerization procedure which produces microspheres containing the active material encased in a plastic shell. Some of its advantages are: controlled release of pesticide, enhanced persistence of organophosphate pesticides; sharply reduced mammalian toxicity, reduced phototoxicity; reduction of amount of pesticide introduced into the environment. A unique feature is the versatility of the process for effecting modifications of the capsule wall so that optimum release rate of the encapsulant can be realized for each type of application. This can be demonstrated by a brief explanation of the encapsulation process. Because of this versatility the above encapsulation technique has produced useful formulations for various applications. These include: foliar and soil insecticides; herbicides; insect repellents; insect attractants; pesticides for insects affecting man and livestock; and household pesticides.

Application of microencapsulated pesticides for control of stored product insects is a logical extension of this concept. One objective is the utilization of an economically low dose of pesticide to provide a required minimal residual protection of stored products in shipment. A prognosis for practical utility is based upon results obtained in two separate preliminary probes on stored products. An increased emphasis on evaluations of this technique for insect control in stored products is recommended.

THIRD SESSION OF SUBMITTED PAPERS

Convener - PROFESSOR T. AJIBOLA TAYLOR
Institute of Agricultural Research and Training
University of IFE
Moor Plantation
Ibadan, NIGERIA

SELECTION OF NEW INSECTICIDES FOR USE IN MAIZE STORAGE AT THE FARMER's LEVEL IN NIGERIA

S. A. ADESUYI
Nigerian Stored Products Research Institute
P.M.B. No. 5044
Ibadan, NIGERIA

INTRODUCTION: Maize is a very important crop in Nigeria. It is utilised mainly for human consumption and forms about 50-70 per cent of the constituents of livestock feed. Nigeria produced 1 million tons of maize in 1975.(1), and an appreciable quantity is imported annually to supplement the local production.

About 90% of the maize produced is stored by farmers in their farms or villages in traditional storage structures. It was reported by Adesuyi and Shode (2) that 24.7% of maize stored by the traditional method was lost to storage pests and viability of grains reduced from 97.7% to 28.3% for NSI variety and from 95.8% to 31.6% for FAS 26 variety after 6 months' storage; it was therefore thought essential that maize storage at the farmer's level should be given priority so as to reduce the substantial losses occurring in the farms. Methods of improving the traditional structures and introducing pest control measures suitable for such structures needed to be evolved as the farmers lost confidence in sophisticated methods of storage some years back due to the failure of the silo scheme introduced in the former western parts of Nigeria.

The previous recommendation of insecticides for use in traditional structures was Gamma BHC at 12.5 ppm of cob weight (3). Maize so treated was not to be consumed until after 3 months because of high toxicity. The fact that insect resistance to Gamma BHC has been reported (4) and farmers can sell their treated maize before the recommended 3 months, have made it necessary to investigate new insecticides of low mammalian toxicity with a view to replacing Gamma BHC.

Three insecticides were investigated over a period of 3 years. They are

(1) Iodofenphos, (O.O. - dimethy (-O(2-5 dichloro 4 iodophenyl) thiophosphate with an LD 50 of 2,100 mg/kg for rats and acute dermal LD 50 of 2000 mg/kg.

(2) Pirimiphos-methyl, (2-Diethylamino - 6 methyl pyrimidine)-4-1 dimethyl phosphorothionate with an LD 50 of 2,050 mg/kg for female rats and acute dermal LD 50 of more than 2,000 mg/kg for rabbits

(3) Tetrachlorvinphos, the Cis isomer (Chloro - and phosphate groups adjacent) of 2-chloro-1-(2-4, 5-trichlorophenyl) vinyl dimethyl phosphate, with an LD 50 within the range 4,000 to 5,000 mg/kg for rats, and 2,000 mg/kg for rabbits and dogs.

MATERIALS AND METHODS: The variety of maize used for these trials was the Western Yellow 1, which had been developed and released to farmers. The trials were carried out at the Nigerian Stored Products Research Institute (N.S.P.R.I.) Ibadan. The storage structure used was the improved crib which is the village-level storage structure N.S.P.R.I. has introduced to the farmers in the past 10 or more years. Four cribs, each 1.5 meters wide, 1.5 meters long, and 1.2 meters filling height were constructed for each treatment. Half a ton of the maize variety was loaded into each crib. Three doses of 5, 10, and 15 parts per million (ppm) of the dust formulations of Iodofenphos, 5 percent active ingredient, Pirimiphos-methyl, 2 percent active ingredient and Tetrachlorvinphos 5 percent active ingredient were tried. Each dose with control was tried in four replicates. The cribs were allocated to each treatment and doses at random. The sheath on the maize cobs was removed and the required quantity of insecticide was applied layer by layer on the cobs as the cribs were being loaded. A cigarette tin with holes on the lid was used to apply the insecticide dust.

The assessment of initial moisture content and percentage insect damage was done with ten cobs taken at random from each crib. A ventilated oven was used to determine the moisture content of the maize sample in three replicates of 15 gm each by heating for 4-1/2 hours at 104°C. The shelled maize was divided into subsamples by the method of coning and quartering. The insect damage count was carried out on 500 grains chosen at random from the subsample. Similar samples, for the determination of moisture content and assessment of insect damage, were taken monthly for the 10 months of storage trial.

RESULTS AND DISCUSSION: The mean monthly moisture content of each treatment is shown in Table 1. There was a general rapid rate of drying from September and the moisture content was below the safe moisture content for storage of maize (13.5%) from November until February. It increased from March and by May it was generally above the safe level for storage in silos but remained under 15% and therefore still safe enough for storage in sacks. The increase in moisture content was due to rainfall and high humidity from March.

Table 2 shows the mean monthly insect damage for all the treatments. The trend with the three insecticides was very

Table I. Mean monthly moisture content

Month	Iodofenphos (ppm)				Pirimiphos-methyl (ppm)				Tetrachlorvinphos (ppm)			
	Control	5	10	15	Control	5	10	15	Control	5	10	15
August	27.5	26.6	26.7	27.0	27.2	26.0	26.6	25.9	26.6	26.8	25.9	26.2
September	19.5	19.2	18.9	19.0	18.9	18.5	18.0	18.1	19.8	18.5	18.2	19.8
October	15.2	15.1	15.2	16.2	16.1	15.6	15.5	16.4	16.2	16.4	15.9	15.4
November	11.5	11.9	12.0	12.2	11.6	12.1	12.4	12.6	12.5	12.4	12.6	12.5
December	10.6	10.5	10.9	11.0	10.9	10.2	11.5	11.2	11.6	11.6	11.5	11.7
January	6.9	7.2	7.4	7.9	6.8	7.5	7.4	8.2	11.2	11.2	11.2	11.2
February	10.5	10.1	10.7	10.6	10.7	9.9	10.5	10.4	10.4	10.6	10.6	10.8
March	14.5	13.2	13.1	13.0	14.2	13.2	13.0	12.7	13.4	13.5	12.6	13.0
April	14.6	13.4	12.5	12.6	14.4	13.4	12.9	12.8	14.2	13.7	13.2	13.2
May	14.8	13.6	14.1	13.9	14.5	13.6	14.2	13.5	14.4	13.9	13.8	13.7
June	14.8	13.0	12.2	13.2	14.5	13.2	13.0	13.2	11.9	14.2	14.0	14.2

Table 2. Mean monthly percentage insect damage (averages of four cribs per treatment)

Month	Iodofenphos (ppm)				Pirimiphos-methyl (ppm)				Tetrachlorvinphos (ppm)			
	Control	5	10	15	Control	5	10	15	Control	5	10	15
August	0.4	0.2	0.8	0.5	1.4	1.1	1.2	1.0	0.6	0.4	0.6	0.5
September	4.2	2.8	3.4	3.4	3.7	3.4	2.9	0.0	4.2	0.0	0.5	1.6
October	11.5	8.4	3.8	3.6	11.4	4.5	4.5	0.0	12.5	8.2	5.4	2.5
November	16.4	14.0	5.0	6.2	14.8	11.8	5.2	0.0	15.2	11.6	8.6	2.4
December	20.0	14.5	5.6	7.4	17.6	23.5	7.2	0.4	20.8	13.4	9.5	2.6
January	25.4	15.9	6.8	9.2	20.5	25.0	7.4	3.2	23.6	14.5	9.6	3.0
February	28.5	22.4	5.4	9.8	22.6	27.5	8.4	7.6	25.4	16.4	9.8	3.8
March	30.0	24.5	6.9	10.0	26.1	28.4	9.5	7.0	27.8	18.2	9.4	4.2
April	36.6	26.2	12.2	9.2	29.3	31.2	11.4	3.5	40.5	20.2	9.8	5.5
May	66.4	30.4	45.6	12.6	53.4	36.4	26.5	19.9	55.7	27.5	27.1	10.0
June	75.9	56.8	50.8	16.5	79.5	51.6	49.8	42.5	78.6	48.4	48.8	19.5

similar for each of the doses applied. If an acceptable level of 10% damage is assumed, it can be seen from the results that at 5 ppm the three insecticides were effective for only 2 months, at 10 ppm Iodofenphos and Pirimiphos-methyl were effective for 7 months, Tetrachlorvinphos for 8 months, and at 15 ppm Iodofenphos and Pirimiphos-methyl were effective for 8 months, while Tetrachlorvinphos was effective for 9 months.

The results of these trials show that any of these insecticides applied at 10 ppm can be used by the Nigerian farmers to treat their maize stored in cribs instead of gamma BHC, as they do not generally store for longer than 8 months in such a structure.

In an ideal situation, the three insecticides should not be recommended for use simultaneously because of the problem of insects being resistant against all of them at the same time. In Nigeria, as with many other developing countries, other considerations override the above principle.

Such considerations are:

(1) Comparative effectiveness of the insecticides. The three insecticides tested have satisfied the requirement of being effective in controlling insects on stored maize for a minimum of 7 months.

(2) Toxicity: The three insecticides are much safer than gamma BHC with acute oral LD 50 of 125 mg/kg for rats and dermal LD 50 of 500 mg/kg when compared with their LD 50 quoted earlier.

(3) Percentage active ingredient: It is required that the insecticides to be introduced to the Nigerian farmer should be of very low active ingredient. This has the advantage that large quantities of the dust will have to be applied and better coverage of the produce treated will be achieved.

(4) Cost: The insecticide should be cheap.

(5) Availability: This is by far the most important factor. The insecticide recommended should be readily available, especially during the storage season. Our experience has been that there is acute shortage of recommended pesticide at the time it is most required. This has a damping effect on the farmers, who have taken to these recommendations and seen the beneficial effects. As a result of this, it has not been possible to restrict our recommendation to one insecticide at a time. It has been observed that recommending more than one insecticide at a time results in the sales agents complementing one another rather than competing.

(6) Packaging: Most of the farmers that use insecticides for storage require small quantities. It is therefore desirable that insecticide manufacturers pack them in such small quantities that it is practicable for the farmer to handle and exhaust in one operation. This will reduce the dangers of careless handling, poisoning, wastage, and underdosing or overdosing.

REFERENCES:

(1) FAO (1975) Production year book. Vol. 29.

(2) Adesuyi, S. A., and Shode, D. A. (1977) Assessment of losses in two varieties of maize (FAS 26 and NSI) stored in cribs in the humid tropics. Niger J. Pl. Prot. 3 (1977) (In Press).

(3) Dornes, W. A., and Riley, J. (1962). Small-scale storage of maize in Western Nigeria. W.A. Stored Prod. Res. Unit. Ann. Rep. 1961 85-96.

(4) De Lima, C. P. F. (1972) Lindane resistance in field strains of *Sitophilus zeamais* (Motsch) in Kenya. J. Stored Prod. Res. 8, 167-175.

SOLAR/WIND ENERGY TO COOL TOBACCO STORAGES FOR INSECT CONTROL

D. P. CHILDS, L. W. FLETCHER, F. A. IACHETTA,
J. T. BEARD, and R. D. FLACK
U.S. Dept. of Agriculture, Science and Education Administration
Tobacco Storage Insects Research
P.O. Box 10125
Richmond, Virginia 23240, U.S.A.

It may be said, with confidence, the cigarette beetle *Lasioderma serricorne* (F.) is not a cold hardy insect. According to Runner (1), it was first described from America by Fabricius in 1792 as attacking "American dried plants" found in warm or tropical parts of the country. In this bulletin, Runner states that there had been a noticeable increase and spread of beetles in tobacco factories as heating of factories was improved with the use of steam. This occurred around 1900 indicating that until manufacturing plants were heated well the cigarette beetle was a pest of stored tobacco only in factories located in the southern portion of the U.S. The cigarette beetle is not a pest in products stored in unheated buildings located north of about the 42nd latitude. Over a period of 200 or more years it has not become cold tolerant although it has been exposed in the northern or colder climates to situations that are favorable for development of genetic strains adapted to survival at low temperature.

A literature review of the cigarette beetle prepared in 1957 by Howe (2) lists work by several investigators giving low temperature and exposures which cause mortality of all insect stages. This work, with some reported by Childs et al. (3) is shown in Figure 1. In these tests the insects were not protected from the cold by more than a thin layer of media. The resistance to temperature of 5°C and lower was similar for all stages. At -10°C it appears an exposure of 2 days will kill all stages except the larval and this stage is killed in about 2-1/2 days. The larval stage appeared to be somewhat more tolerant of the cold than the other stages. At 0°C the insects were killed in 12 to 14 days and at 4.5°C larvae were killed in 20 days. At 10°C nearly 35 days of exposure were needed to kill the eggs and larvae.

Tobacco packed in a hogshead, ca. 450 Kg/1.43 m^3, adjusts slowly to change of temperature in the surrounding atmosphere. Childs et al. (4) reported an infested hogshead with tobacco at an initial temperature of ca. 26°C required an exposure of 56 days in a constant temperature room of 4.4°C before the cold killed all stages of the cigarette beetle (Figure 2). This exposure was more than twice the time period needed to kill unprotected insects subjected to a similar temperature. At ca. 10°C

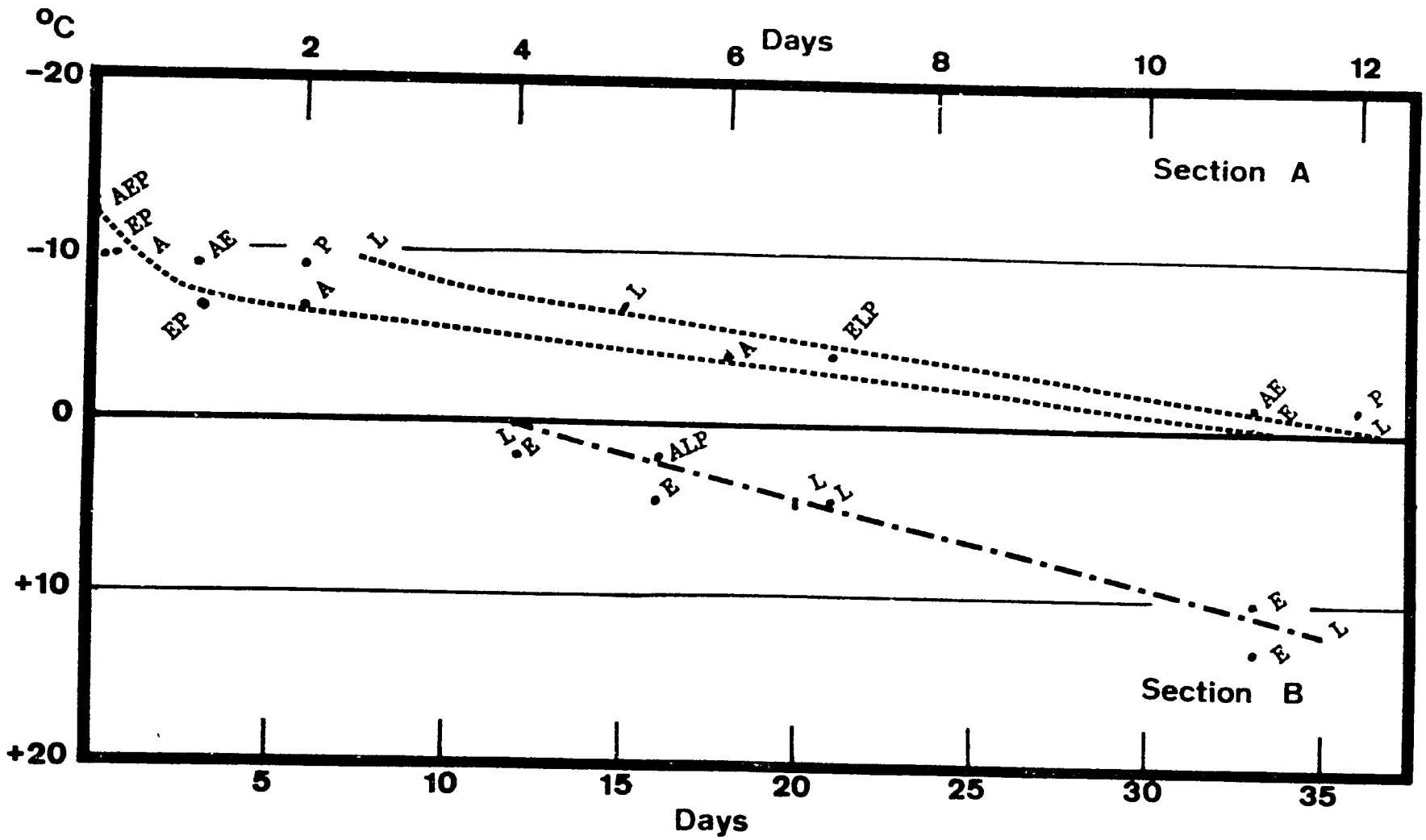


Figure 1.--Number of days required to kill Adults, Eggs, Larvae, and Pupae of the cigarette beetle exposed unprotected to low temperature.

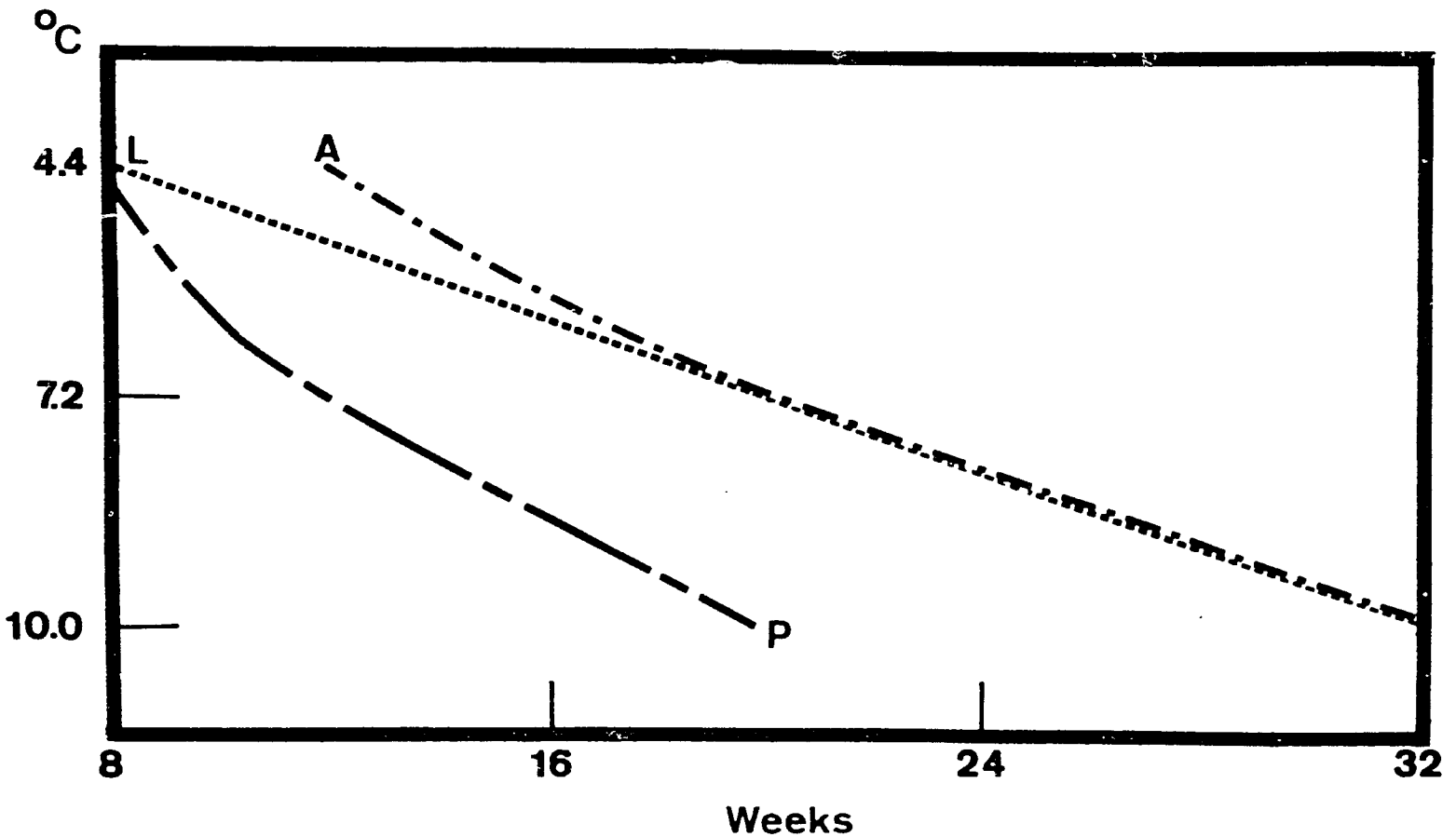


Figure 2.--Weeks of exposure of flue-cured tobacco hogshead to low temperature required for kill of cigarette beetle Adults, Larvae and Pupae.

unprotected insects were killed in 35 days whereas insect infestations in hogsheads lived for more than 200 days. These data indicate to control the cigarette beetle in tobacco hogsheads during the winter season, the tobacco temperature should not exceed 4.4°C over a period of not less than 8 weeks.

Fletcher et al. (5) found that tobacco stored in a fan ventilated warehouse located in Durham, N.C. (36° latitude) from November through April of 1969-70 encountered 91-93 days when its temperature was 4.4°C or lower. Samples of tobacco removed from hogsheads were free of living insects although found in the samples were several hundred dead cigarette beetle adults and larvae and a few dead eggs. Fletcher's work indicated winter kill of the cigarette beetle can be achieved in tobacco hogsheads without expenditure of some electrical energy for cooling the storage during the winter season.

Question is the factor that will determine whether the cigarette beetle can be controlled in commercial storages by mechanically chilling air inside the storages during the winter season. Because of the cost of electrical energy generated at power stations, this cost is to utilize (1) energy required to cool the tobacco in a hogshead to 4.4°C or less over an 8-week period during the winter season in a storage located at Fuquay-Varina, N.C. (latitude 35°33'), (2) the relationship between the design and ventilation of a tobacco storage to use efficiently energy from solar and/or wind sources to cool the storage, and (3) the cost of solar or any mechanical equipment needed to cool the storage.

We are re-examining the time required to cool tobacco packed in hogsheads. When the tobacco was at a steady state temperature of ca. 32.2°C (90°F), hogsheads were moved to a cold room controlled to 4.4°C (40°F). Data given in Figure 3 show quick response to temperature change at the hogshead stave, but change of temperature in tobacco was slower and the quickness of change was related to the depth of tobacco monitored. A hogshead stacked vertically had less openly exposed area than a hogshead stacked on its side. Response to temperature change was slower in the vertically stacked hogsheads but was sufficiently rapid to be considered stable after 20 days.

To determine the thermal conductivity of flue-cured tobacco the engineers designed a guarded hot-plate type apparatus shown in Figure 4. Steady, one-dimensional heat transfer vertically through the 1-foot cube (0.028 m^3) of tobacco was designed by providing a constant voltage to the electrically heated hot-plate under the tobacco and by providing cold controlled ambient temperatures to the top of the tobacco cube. Independently operated heat tapes on the exterior sides and on the bottom of the 1-foot (30.5 cm) thick styrofoam insulation slabs were used as guarded hot-plates to assure one dimensional heat flow through the tobacco. Results of analysis from sets of three test

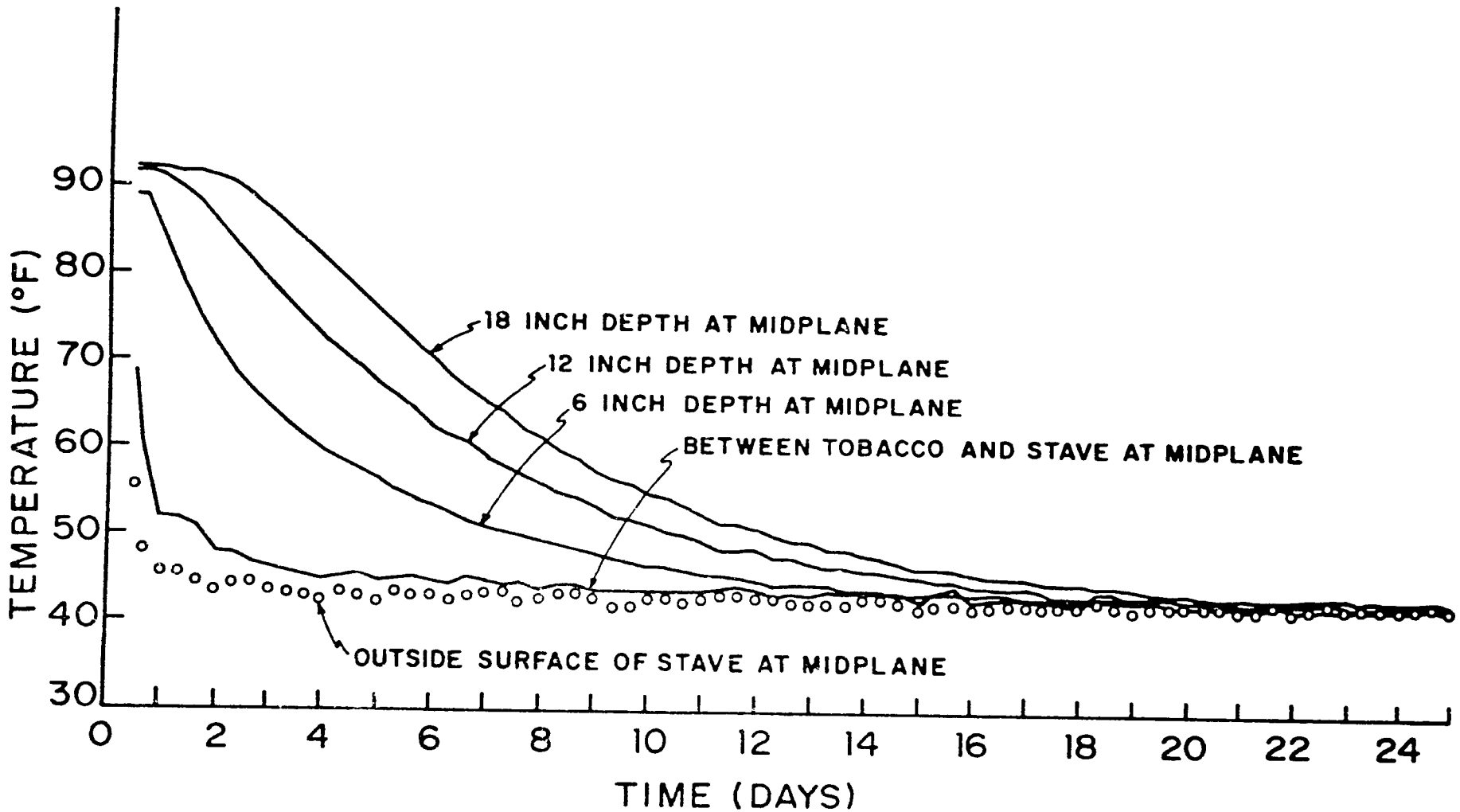


Figure 3, Cool-down temperatures, vertical hogshead

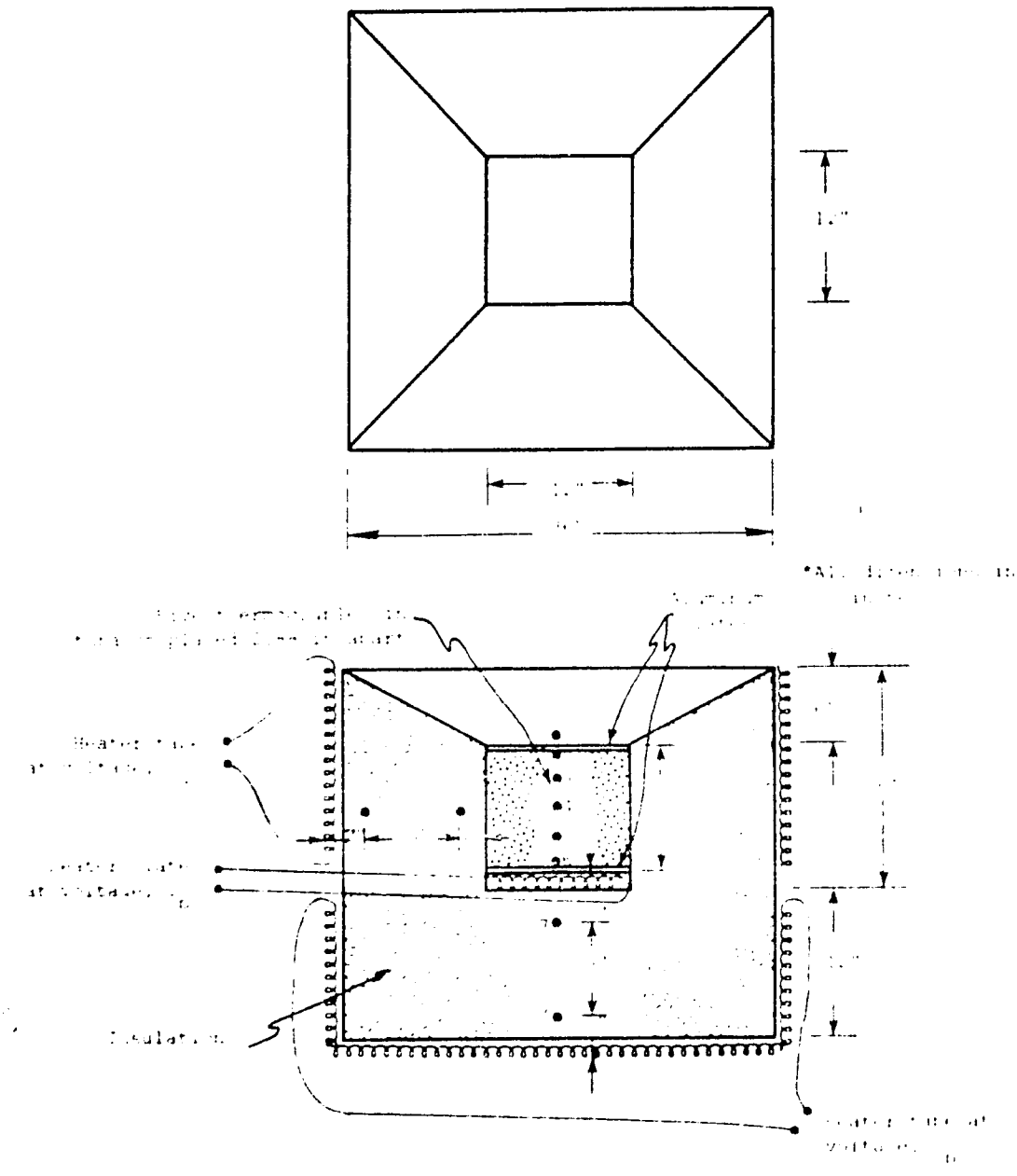
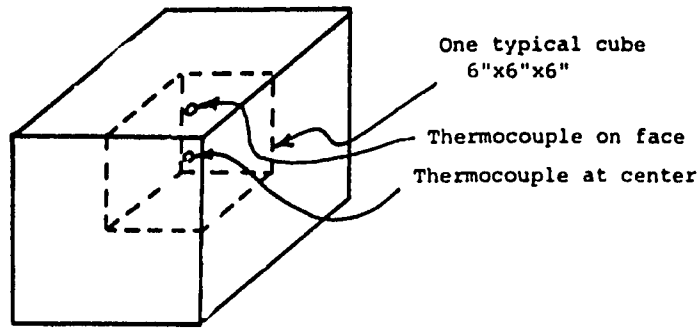


Figure 4. Schematic of Apparatus for Determing Thermal Conductivity



*All dimensions in inches

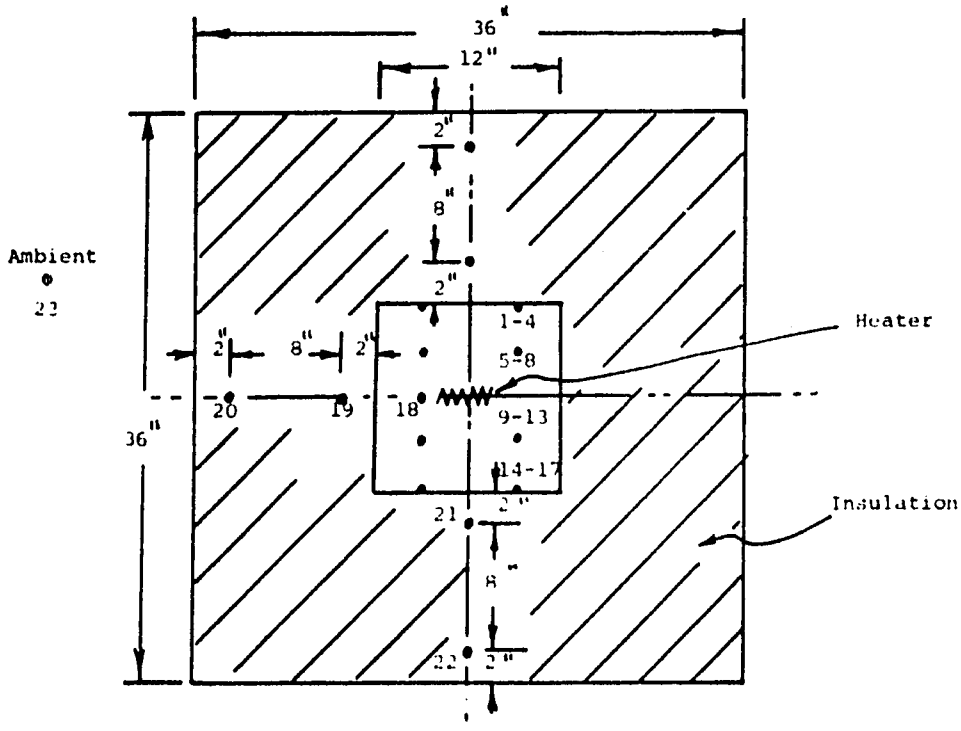


Figure 5. Schematic of Apparatus for Determing Specific Heat Apparatus

METHACRIFOS - A NEW INSECTICIDE FOR GRAIN PROTECTION

A. RENFER, R. WYSIGER, F. KNÜSEL and W. GEELLER
CIBA-GEIGY LTD., Agrochemical Division, CH-4002,
Basle, SWITZERLAND

R.J. HART
CIBA-GEIGY AUSTRALIA LTD., Research Centre,
Kemp's Creek, N.S.W. 2171

INTRODUCTION: [illegible] methacrifos is an organophosphorus insecticide discovered [illegible] methacrifos acts as a contact, [illegible] and fumigant insecticide. It is effective against important arthropod pests of stored products. [illegible] is effective against [illegible] methacrifos [illegible] properties of grain protectants [illegible] in grain [illegible] .

CHEMICAL FORMULA AND FORMULATIONS: [illegible] methacrifos [illegible] :

[illegible]

[illegible]

[illegible]

[illegible]

FORMULATIONS: Formulations used for this study included emulsifiable concentrates EC [illegible] (50 g a.i./kg.); a dust DS (2 g a.i.), [illegible] (100 g a.i./kg.) and a ready-to-use formulation [illegible] (50 g a.i./kg.).

TOXICOLOGICAL PROPERTIES: The acute toxicity of technical and formulated methacrifos to laboratory rats is shown in Table I. The technical grade methacrifos and its EC 950 formulation are slightly toxic to rats by oral and dermal administration.

Technical grade methacrifos and its formulations cause no or moderate skin irritations and no or minimal eye irritations in rabbits.

Technical grade methacrifos is practically non-toxic for birds (Japanese quail). The EC 950 formulation is moderately toxic for birds. The technical grade of methacrifos is highly toxic for rainbow trout, but only moderately to slightly toxic to Crucian carp, bluegill and guppies. The formulations are distinctly less toxic to fish than the technical material.

conditions showed the thermal conductivity of flue-cured tobacco strips to be ca. 0.60 BTU/hr. ft^2 F/in.

Nearly completed is an experiment designed for the measurement of the specific heat of tobacco. The engineers have designed a test unit where electrical energy is delivered to a plate and it is released to the tobacco as thermal energy, Figure 5. By releasing a measured quantity of electrical energy and by measuring the temperature increase of the tobacco, one may compute the specific heat.

This research investigation is now in the engineering phase and results from these basic studies will be used to establish the design requirements for temperature control systems in tobacco storages to control insects during the winter season. Through modeling, competitive designs will be evaluated and the primary criterions for selection will be the system's operational efficiency and its economical structure.

REFERENCES:

(1) Runner, G. A. (1919) The tobacco beetle: An important pest in tobacco products. USDA Bull. 737, 77 pp.

(2) Howe, R. W. (1957) A laboratory study of the cigarette beetle, *Lasioderma serricorne* (F.) (Col., Anobiidae) with a critical review of the literature on its biology. Bull. Ent. Res. 48, pt. 1: 9-56.

(3) Childs, D. P., J. E. Overby, S. J. Watkins, and D. Niffenegger (1970) Low temperature effect upon third- and fourth instar cigarette beetle larvae. J. Econ. Entomol. 63: 1860-4.

(4) Childs, D. P., J. E. Overby, and S. J. Watkins (1968) Low temperature effect on cigarette beetle infestations in tobacco hogsheads. J. Econ. Entomol. 61: 992-6.

(5) Fletcher, L. W., J. S. Long, and C. D. Delamar (1973) Low temperature and infestations of beetles in tobacco hogsheads stored in field warehouses. Tob. Sci. Vol. 175:25 49-50.

The last 3 authors are Mechanical Engineers, University of Virginia, School of Engineering and Applied Science.

Table I
Toxicity of technical and formulated methacrifos to laboratory rats

Preparation	Rat acute oral LD 50 (mg/kg)	Rat acute dermal LD 50 (mg/kg)	Rat acute inhalation LC 50-4h (mg/m^3)
Methacrifos tech.	678	>3'100	>2'200
EC 950	924	>3'100	approx.2'500
F 2	>10'000	>3'100	>1'800
SO 050	>10'000	>4'600	>3'000

The results from the acute feeding studies with rats, dogs and poultry are favourable. Long term feeding studies with rats and mice are in progress.

INSECTICIDAL PROPERTIES: Methacrifos shows extremely high insecticidal activity.

Table II demonstrates the spectrum of activity of methacrifos, especially against stored product insects and also its relevant efficacy against malathion and OP resistant pests. The importance and the occurrence of resistant strains of pests are documented by Chang and Dyte (3).

Direct spraying in a standard Potter spray tower (4) and other experiments have demonstrated the contact activity of methacrifos against beetles, moths, flies, roaches, and mites present in stores (Table III).

A special property of methacrifos is its penetration into grain, by which the internal larval stages are killed (2).

The spectrum of activity of the compound and its various modes of action lead to application of methacrifos as residual protectant for application with bulk stored products and for desinsectization of empty stores and warehouses.

FIELD APPLICATIONS: Application of methacrifos as a surface spray: The following experiment was carried out to measure the efficacy of methacrifos as a surface spray.

In tanneries with a capacity of 75m^3 granary weevils and flour beetles were released in large numbers. The stores were treated one day later with the insecticides (3 formulations of

Table II
LC50 for grain pests after 24h exposure, FAO Method No. 15
(Impregnated filterpaper)

Species (adults)	Strain origin Champ and Dyte (1976)	% a.i. in 0.5ml solvent per 7cm diameter filter paper				
		Methacrifos	Malathion	Gamma-HCH	Pirimiphos-Methyl	Chlorpyriphos-Methyl
Tribolium castaneum:	Australia	0.01	0.78	1.0	0.05	0.03
	Cairo	0.009	0.15	0.27	0.05	0.02
Oryzaephilus surinamensis:	649 N.America	0.05	0.43	0.72	0.58	0.21
	479 W.Asia	0.01	0.21	0.20	0.12	0.03
Sitophilus granarius:	248 S.America	0.003	0.04	0.01	0.04	0.03
	849 W.Asia	0.003	0.06	0.29	0.02	0.03
Sitophilus oryzae:	475 W.Asia	0.006	0.03	0.13	0.13	0.01
	Cairo	0.007	0.01	0.12	0.03	0.12
Rhizopertha dominica:	111 N.America	0.29	10.0	0.02	0.75	0.35
	RD 118 Australia	0.23	5.50	0.05	0.80	0.62
	Basle	0.11	0.44	0.005	0.76	0.36
Acanthoscelides obtectus:	Basle	0.013	0.34	0.21	0.16	0.05
Araecerus fasciculatus:	Nigeria	0.013	0.39	0.19	0.16	0.40

Table III
Spectrum of effectiveness of methacrifos

PEST	
Coleoptera / beetles	**Lepidoptera / moths**
Sitophilus granarius, L.	Sitotroga cerealella, Oliv.
Sitophilus oryzae, L.	Ephestia elutella, Hübn.
Sitophilus zeamais, Motsch.	Ephestia kühniella, Zell.
Rhyzopertha dominica, F.	Cadra cautella, Walk.
Tribolium confusum, Duv.	Plodia interpunctella, Hübn.
Tribolium castaneum, Herbst.	Tineola bisellielle Hum.
Tenebrio molitor, L.	**Orthoptera / cockroaches**
Oryzaephilus spp.	Acheta domesticus, L.
Cryptolestes spp.	Blattella germanica, L.
Trogoderma granarium, Everts	Blatta orientalis, L.
Dermestes spp.	Periplaneta americana, L.
Lasioderma serricorne, F.	**Acarina / mites**
Stegobium paniceum, L.	Acarus siro, L.
Necrobia rufipes, Deg.	Tyrophagus casei, L.
Anthrenus vorax, Waterh.	Tyrophagus putrescentiae, Schr.
Anobium punctatum, Deg.	Glycyphagus destructor, Schr.
Ptinus fur, L.	Glycyphagus domesticus, Deg.
Acathoscelides obtectus, Say	Dermatophagoides pternoyssinus, Tron.
Araecerus fasciculatus, Deg.	
Diptera / flies	
Drosophila spp.	
Piophila casei, L.	

methacrifos, EC 950, SO 050 and P 2) (see Table IV). A mixture of wheat and rolled oats was exposed unpacked on the floor of each room to assess the insecticidal properties of the applied formulation. 1,4,7 and 11 days later, samples of exposed food were taken for checks on infestation rate.

The experiment was successful at dosages of 200-400 mg a.i./m^2. The treatments practically prevented infestation of exposed foodstuffs. This experiment confirmed practical observations.

Application of methacrifos as a space spray: The application of space sprays is a normal method for insect control in various objects such as railway-boxcars, boats, containers and many kinds of empty storerooms. Using this method the spray can be applied

Table IV
Survival and F_1-generation of *Sitophilus granarius* and *Tribolium castaneum* after a clean-out treatment by surface spraying of methacrifos conditions: 22 ± 2° C, 35 ± 5% r.h., 2 replicates

Formulation	Dosage mg a.i./m²	Number of insects released in store	Total (%) F_1-Generation after 12 weeks in exposed samples				Cumulative F_1-Generation after 12 weeks (%)		Reduction in %	
			1 day	4 days	7 days	11 days	S.gran.	T.cast.	S.gran.	T.cast.
EC 950	200	1000	0	0	0	0	0	0	100	100
	400	1000	1	0	0	0	0	1	100	99
SO 050	200	1000	0	0	0	0	0	0	100	100
	400	1000	0	0	0	0	0	0	100	100
P 2	200	1000	0	0	0	0	0	0	100	100
	400	1000	4	0	0	0	3	1	97	99
Untreated	-	1000	142	49	107	102	100	100	0	0

from outside of the rooms. Methacrifos was applied many times as an indoor space spray. An experiment in which encaged pests of stored grains were exposed in the treated rooms is described here.

The cages, containing *Sitophilus granarius*, *Tribolium castaneum* and *Rhizopertha dominica*, were placed at various positions in empty railway-boxcars. Two formulations of methacrifos namely EC 950 and a ready-to-use spray SO 050 were applied with an RL-Atomist (mistblower) in dosages of 75 and 150 mg per m^3. The EC 950 was diluted with water. The capacity of a railway-boxcar is . m^3. After a 4 hour exposure in the treated boxcar the encaged insects were transferred to clean jars. The mortality was determined 20 hours later. The actual dosage of a.i. in the cages was checked colorimetrically (DITEC-method). Air samples were taken 24 hours after application to demonstrate the volatility of methacrifos. Residues of the chemical in the air were present at both formulations and dosages.

The experiment carried out at the harbour of Basle brought successful results concerning the insecticidal activity at dosages of 75-150 mg a.i. per m^3 (see Table V).

<u>Application of methacrifos as a prophylactic grain protectant</u>: Field trials were carried out in several countries in Europe. Wheat, barley and oats were treated with 10 ppm of methacrifos. For the application either an EC 950 diluted in water or SO 050 ready-to-use formulation was sprayed on the conveyor belt with a Rotamatic sprayer or another spray-apparatus. Subsequently the cereals were stored in silos, bins or heaps.

The bioassays, with major grain pests of samples taken in a depth of 2 m, show excellent protection of the grain by methacrifos for several months.

Large scale treatments of stored grain were carried out under commercial conditions in Australia. Thanks to help from C.S.I.R.O., Australia Wheat Board and Queensland Department of Primary Industry, it was possible to treat and store under different conditions thousands of tonnes of various grains.

Table VI summarizes the results of a trial at the experimental station at Kemp's Creek, Australia, where lots of maize, barley, paddy rice and sunflower were treated with 10 ppm methacrifos and stored in 10'000 lt. mini-silos. This trial shows the pattern of degradation of methacrifos in different grains and also the period of protection given by the methacrifos treatment.

<u>Application of methacrifos as a curative grain treatment</u>: The appropriateness of methacrifos for curative treatment of infested grain was shown in several field experiments in Switzerland. The infested goods were imported oats, barley and coffee. Methacrifos was applied as an emulsion or as a powder.

Table V
A comparison of two methacrifos formulations when used for space treatments in empty railway-boxcars; Conditions: 25 ± 1° C, 50-60% r.h.

Cage position	Formulation	Dosage		Test insects					
				S.granarius		T.castaneum		R.dominica	
		Application rate mg a.i./m³	mg a.i./m² measured in cage	Mortality % after 4h	Mortality % after 24h	Mortality % after 4h	Mortality % after 24h	Mortality % after 4h	Mortality % after 24h
Sides	SO 050	75	0.03	100	100	30	70	90	100
		150	0.04	100	100	95	100	100	100
	EC 950	75	0.06	100	100	55	75	85	95
		150	0.06	100	100	90	100	100	100
Floor	SO 050	75	0.14	100	100	25	40	90	90
		150	0.34	100	100	80	95	100	100
	EC 950	75	0.05	90	100	35	80	80	100
		150	0.12	100	100	95	100	100	100
Check	-	-	-	0	10	0	0	0	5

Table VI
Percentage control of F_1-progeny of 4 major pests in a bioassays of various grains stored in mini-silos in Australia with 10 ppm methacrifos; Conditions: 24.5-26.0°C

GRAIN	Test insects Strain origin Champ and Dyte (1976)	Samples taken weeks after treatment		
		0	6	12
WHEAT	*Sitophilus oryzae* CSO-231	100	100	100
	Rhizopertha dominica CRD-37	100	99.7	99.6
	Tribolium castaneum CTC-12	100	99.9	99.7
BARLEY	*Sitophilus oryzae* CSO-231	100	100	99.9
	Rhizopertha dominica RD-118	86.1	97.6	97.4
MAIZE	*Sitophilus zeamais* wild susceptible strain	100	100	100
PADDY RICE	*Sitophilus oryzae* CSO-231	[illegible]	98.9	98.7
SUNFLOWER	*Tribolium castaneum* CTC-12	100	100	100

Six lots of 50 tonnes of barley and two lots of 50 tonnes of oats were treated with 10 ppm a.i. of EC 950. The figures in Table VII demonstrate the efficacy of the product against *Sitophilus granarius* and *Tribolium castaneum* (see Table VII).

In Table VIII the results are given of an experiment in which barley heavily infested with *Sitophilus granarius* and *Oryzaephilus surinamensis* was treated with 15 ppm a.i. as a P 2 formulation. After the treatment the barley was stored in jute sacks at a temperature of 25° C and a relative humidity of 60-65%. The figures show the excellent activity of methacrifos P 2 formulation

Table VII
Curative efficacy of methacrifos against grain pests in infested barley and oats; Storage conditions: wooden bin, 20-25° C, 6 replicates in barley, 2 replicates in oats.

GRAIN	Formulation Dosage (a.i.)	Infestation rate in treated and untreated cereals live insects/lt. cereal after treatment					
		1 week		3 weeks		9 weeks	
		S.gran.	T.cast.	S.gran.	T.cast.	S.gran.	T.cast.
BARLEY	EC 950 (10 ppm)	1	0	0	0	0	0
	Untreated	15	17	21	15	238	25
OATS	EC 950 (10 ppm)	2	0	0	0	0	0
	Untreated	10	9	11	5	72	20

against granary weevils and saw-toothed grain beetles when applied as a curative measure.

In a semi-practical experiment methacrifos EC 950 was applied in a dosage of 20 ppm of a.i. to coffee beans which were infested by coffee bean beetles *Araecerus fasciculatus*. After the treatment a stock of 25 kg coffee beans were packed in metal drums and stored in 28° C for 4 months. To determine the efficacy of methacrifos against the coffee bean beetle, traps were installed on the top of the drums. The adults emerging over three days were counted in samples taken at various intervals. Table IX gives the figures which confirm the excellent and superior efficacy of the chemical against the coffee bean beetle when curatively applied with 20 ppm.

Table VIII
Curative efficacy of various insecticides in barley against *Sitophilus granarius* and against *Oryzaephilus surinamensis*; Storage: jute sacks at 24 ± 2 °C and 60 ± 5 % r.h. 3 replicates (Figures: *Sitophilus granarius*/*Oryzaephilus surinamensis*).

Insecticide Formulation	Dosage (ppm)	Infestation rate in treated and untreated barley Live-insects/kg at weeks after treatment					
		3 weeks		10 weeks		20 weeks	
		adults	reduction[a]	adults	reduction[a]	adults	reduction[a]
Methacrifos P 2	15	0/0	100/100	0/0	100/100	0/0	100/100
Malathion P 2	15	0/0	100/100	1/0	92/100	4/55	93/41
Standard 1 P 2	15	0/0	100/100	0/0	100/100	5/0	[illegible]/100
Standard 2 P 2	15	0/0	100/100	3/15	77/100	2/136	97/0
Untreated -	-	10/254	- / -	13/245	- / -	59/93	- / -

a) Reduction in % = $100 - \frac{t}{c} \cdot 100$ (t = number of live beetles/sample)
(c = number of live beetles/check)

Table IX
Light-trap counts from infested coffee at various intervals after treatment (Figures = Number of adults of *A. fasciculatus*)

Time after treatment	Product/Formulation/Dosage	
	Methacrifos EC 950 20 ppm	Untreated
1 day	1	16
3 weeks	0	6
6 weeks	0	7
9 weeks	0	10
12 weeks	0	11
15 weeks	-	-
18 weeks	0	19

CONCLUSION: Methacrifos is effective against a broad spectrum of insect pests of stores, and their resistant strains. It can be applied as a surface spray, space spray, prophylactic grain protectant or even as a curative grain treatment. This is an interesting product which fills a real need with its exceptional characteristics. A great demand for it can be expected in the coming decade.

REFERENCES:

(1) Wyniger, R. and Hart, R.J. Methacrifos, a new insecticide for the control of insect pests in stored products (XV. Intern. Congress of Entomology, Washington, D.C., 1976, Section 4, Gen. Toxicology) (1976).

(2) Wyniger, R., Renfer, A., Knuesel, F., Gfeller, W. and Hart, R.J. Methacrifos, a new insecticide for the control of insect pests in stored products (Proceedings 1977 British Crop Protection Conference - Pests and Diseases, Brighton) (1977) 1033-1040.

(3) Champ, B.R. and Dyte, C.E. Report of the FAO Global Survey of pesticide susceptibility of stored grain pests, FAO Rome (1976).

(4) Potter, C. An improved laboratory apparatus for applying direct sprays and surface films with data on the electrostatic charge on atomized spray fluids, Ann. App. Biol. 39 (1952) 1-18.

CONTROLLING INSECT PESTS OF STORED TOBACCO BY REDUCING THEIR REPRODUCTIVE POTENTIAL

M. ARTHUR MANZELLI
Philip Morris Research Center
Richmond, Virginia, 23261
U. S. A.

INTRODUCTION: Tobacco, a high priced agricultural commodity, is subjected during storage to devastating infestations of *Lasioderma serricorne* (F.), commonly known as the cigarette beetle or tow bug, and *Ephestia elutella* (Hübner), the tobacco or warehouse moth. The length of the tobacco storage period, which may vary from one and one-half to three years, and the types of storage structures employed, provide these insects with many opportunities to invade the commodity and establish large colonies unless checked by the use of chemical pesticides.

During preparation for storage, the tobacco is exposed to steam-vacuum and re-drying treatments, which, if properly conducted, result in the death of all stages of all infesting insect species. However, after the tobacco has been placed in storage, it is subject to attack by either *L. serricorne* or *E. elutella*, the degree of infestation depending on tobacco type, container makeup, and warehouse construction. In some instances, the infestation potential is reduced by segregating new tobacco stocks from old, or leaf from stems, and with the use of liners or wrappers that either prevent or limit entry by these two insects into the stored tobacco. Generally, however, the containers and their contents permit infestation to take place throughout the entire warehouse complex.

In recent years, chemical control methods for insect infestation in stored tobacco have included the application of pyrethrins, DDVP (Dichlorovos, Vapona) and phosphine (Phostoxin, Detia). Pyrethrum, a botanical contact insecticide of limited capability has not been used as often as DDVP. This latter chemical kills by vapor and contact action, and has been used advantageously in warehouses which are not airtight. However, it has definite limitations, for it can reach and kill only those insects found in the warehouse airspace, and cannot penetrate hogsheads, bales, liners, and cases to kill the insect forms living within the tobacco. Phosphine fumigant is employed to give total kill of infesting insects in and out of the commodity, but airtight warehouses are mandatory for its proper use. The minimum phosphine fumigation period at the exterminating concentration of 200 ppm is forty-eight hours. Following fumigation re-infestation by either the beetle or moth may take place immediately if the temperature of the commodity and surrounding air is above 18°C.

BIOLOGICAL POTENTIAL: Both the beetle and moth have two and one-half to three generations a year in the tobacco storage and

processing areas of the United States. The rate of increase of *L. serricorne* breeding in various food materials has been studied by a number of researchers. Howe (1) has given an excellent review of the literature on this subject, including population figures based on actual warehouse data and on theoretical calculations. Some of the factors that influence the rate of population growth are the temperature and relative humidity (R. H.) ranges within the commodity and warehouse, and the types of tobacco, storage containers, their liners, and warehouse structures employed. The sum total of these factors has an impact on the number of generations per annum of *L. serricorne* that can be produced, and on the rate of increase per generation.

As already noted, both counting and formulae methods have been employed to determine beetle population increases. On a theoretical basis, Howe (1) estimated that at about 25°-27° C. and at a R. H. of 70%, a stable population of *L. serricorne* was capable of increasing by about 60% every week. Warehouse data on rate of increase gave values ranging from 20 to 50% per week. In one instance, Jensen (2) found that one pair of beetles gave 1,500 descendants in four months when protected from natural controlling factors. This number represents a 50% weekly increase.

The number of generations per year for *L. serricorne*, as given in the literature (1, 2) varies from one to seven. In the U.S., it ranges from a low of two and one-half in the tobacco processing areas to a high of five or six in some of the southern growing areas. The temperature and relative humidity ranges within each geographical area dictates the number of generations developed per year. The average number of eggs deposited by the female beetle in the U.S. has been reported as varying from 45 to 115.

The biotic potential of the cigarette beetle can be determined from these data. If we assume that the median number of eggs laid per female is 80, that the mean egg mortality to be about 20% (from laboratory studies), that the environmental stress (ES) (e.g., diseases, predators, parasites, unfavorable microclimate, etc.) produces a 50% mortality in the surviving larvae and that the surviving adults have a 1:1 sex ratio, we obtain the following biotic potential formulae for each generation (Fn):

$$F_1 = \underset{80}{(\text{Median Egg No.})} - \underset{16}{(20\% \text{ Nonhatch})} - \underset{32}{(50\% \text{ Larval Loss to ES})} = 32$$

$$F_2 = \frac{\text{No. } F_1 \text{ Adults}}{2} \times (\text{Median Egg No.}) - (20\% \text{ Nonhatch}) - (50\% \text{ Larval Loss to ES})$$

$$F_3 = \frac{\text{No. } F_2 \text{ Adults}}{2} \times (\text{Median Egg No.}) \text{ etc.}$$

By the end of one season, or three generations, the larval figure can read 16,384 or 8,192 surviving adults.

As can be seen, by the end of the second year of storage or sixth beetle generation (F_6), the descendant adults could number in the millions.

In the case of the tobacco moth, its biotic potential in the field is more difficult to project. The median number of eggs deposited by the female moth is well over 100, and the number of generations per year is three in the tobacco storage and processing areas of the U.S. However, the moth larvae that hatch face a more formidable road to adulthood than do the beetle larvae. The latter remain within the containers to pupate, but the former leave the commodity in which they have been hidden and seek out free spaces to form their pupal cases. They are, therefore, more exposed to external environmental stress factors than the beetle larvae. Nevertheless, the moth has on numerous occasions demonstrated its potential for developing large numbers of very destructive larval infestations, especially in baled tobacco.

RATIONALE AND METHODS: The cigarette beetle control programs in the tobacco storage areas of the U.S. are generally conducted from the middle of April to the middle of October, and an individual warehouse may receive from 120 to 170 separate applications of DDVP during this period, depending on whether they are made with manually operated equipment, or by automatically operated dispensers, respectively. The dosage rate for manual delivery ranges from 0.5 gram to 0.75 gram per 28.32 cubic meters (1000 cubic feet) five days a week, or 0.5 gram per 28.32 cubic meters per day for automatic application.

A medium sized warehouse of approximately 17,668 cubic meter capacity (500,000 cubic feet) exposed to either manual or automatic treatment receives well over 50 kilograms of actual DDVP per season. In addition, if the warehouse is of the sealed type, it may also receive one fumigation per year with phosphine at a treatment level of 22 grams of phosphine per 28.32 cubic meters, or 13.7 kilograms per 17,668 cubic meters.

Without question, the continuous use of these two insecticides contributes greatly to suppressing the cigarette beetle population, but by no means does it prevent initial infestations, or re-infestation of the stored tobacco after aeration has been completed.

The ideal pesticide for the control of insects attacking stored tobacco obviously would be one that when applied to the commodity at the time it is packed for storage would destroy any eggs deposited by visiting female adults, or kill the first instar larvae that emerge from the eggs. The pesticide should be harmless to man, not affect the smoking quality of the tobacco, and be effective for the duration of the storage period. There are proprietary residual insecticides available, such as the chlorinated hydrocarbons and carbamates, that do function as ovicides or larvicides. However, their use is not permitted for

many reasons, including their toxicity to man and their deleterious effect on the smoking quality of the tobacco.

A review of the literature on the use of insect growth regulators (IGRs), a class of chemicals added to the family of pesticides within the past decade, indicates that methoprene (also known as Altosid®), a commercially available product, would warrant study as a control for stored tobacco pests (4). Investigations conducted over a period of three years at laboratory, pilot plant, and commercial levels have shown that this chemical holds promise as a population control agent for *L. serricorne* and *E. elutella* (5, 6). Large scale hoodhead tests have been conducted with the former species under an experimental permit granted to the manufacturers of methoprene by the U.S. Environmental Protection Agency.

Methoprene does not act as an ovicide or even as a true larvicide, but it does prevent the last instar larval form of some insect species from developing into normal pupae or adults. In the prior limits the initial intestinal cycle of a female treated in less than one second. Single application of this IGR at 10 ppm to tobacco prior to the usual 18 hoodhead fumigation prevented the development of *L. serricorne* larvae into first generation adults for a period exceeding two years. Laboratory trials with *E. elutella* have shown it to be more successful in methoprene than *L. serricorne*.

CONCLUSIONS: Although methoprene does not meet all of the criteria for the ideal stored tobacco control agent, it does possess the following positive characteristics:

1) All toxicity studies indicate that it poses no hazard to man or the environment (4).
2) It has no deleterious effect on treated tobacco when employed at the experimental level of 10 ppm. Cigarettes made from treated tobacco were undetectable from control cigarettes in smoking panel tests.
3) At the 10 ppm application level, residues on tobacco have been effective for over a two-year storage period.

Therefore, the possiblity exists that a new agent may be added to our integrated control program for pests of stored tobacco, one that will severely reduce the reproductive potential of both *L. serricorne* and *E. elutella*.

REFERENCES:

(1) Howe, R. W., A laboratory study of the cigarette beetle, *Lasioderma serricorne* (F.) (Coleoptera: Anobiidae) with a critical review of the literature on its biology, Bull. Entomol. Res. 48 1 (1957) 9.
(2) Jepson, W. F., Report of the Department of Agriculture--Entomological Division, Mauritius (1938) 40.

(3) Anonymous, Stored tobacco insects, biology and control, United States Department of Agriculture, Agriculture Handbook No. 233 (1972).

(4) Strong, R. B., Diekman, J., Comparative effectiveness of fifteen insect growth regulators against several pests of stored products, J. Econ. Ent. 66 (1973) 1167.

(5) Manzelli, M. A., Lehman, R. M., ALTOSID(R)--An insect growth regulator for the control of the cigarette beetle in stored tobacco, 27th Tobacco Workers Conf., Atlanta, Georgia, January 11, 1977.

(6) Lehman, R. M., Walker, G. B., Manzelli, M. A., The successful use of an insect growth regulator (IGR) for the control of the cigarette beetle infesting stored tobacco: A two-year laboratory study, Tobacco Chemists Research Conference, Greensboro, N.C., October 5, 1977.

SEX RATIO AGENT IN *Cadra cautella* (WALKER) -- ITS EXPRESSION BY TEMPERATURE, GENETICS, AND MASS PRODUCTION OF THE VIRGIN FEMALE MOTHS FOR SEX PHEROMONE STUDY

FUMIKI TAKAHASHI
Department of Environmental Studies
Faculty of Integrated Arts and Sciences
Hiroshima University
Higashi Sendamachi, Hiroshima 730
JAPAN

PROLOG: Mass production of virgin female moths of *Cadra cautella* (Walker) for sex pheromone study: Females of the almond moth, *Cadra cautella* (Walker), and the flour moth, *Anagasta kühniella* (Zeller), emit a sex pheromone to which the males of both species respond. Our collaborators in Kyoto University started the sex pheromone studies in these species, and finally they isolated and identified the chemical structure of their sex pheromone as cis-9, trans-12 tetradecadienyl acetate (1 and 2). This was the first identification of insect pheromone in Japan.

At the start of the project they requested me to design the mass production of female moths of *C. cautella*, and I presented two kinds of design. One was the system to produce only female moths using a special strain of *C. cautella* named FT-strain which carried the sex ratio agent. In this strain, only female moths emerged when they were reared at 20°C, while both sexes emerged in equal numbers when the rearing temperature was 30°C (3). This character is very useful skipping the steps to separate females from males. However, their speed of development became slow and it took more than 60 days at 30°C from oviposition to adult emergence, and we had to wait for more than two months to obtain the first sample of female moths. Furthermore, for the mass production we needed wide space in temperature controlled room which was not easily accomodated in our laboratories.

Another system was to produce both sexes and separate females from males by hand. When they were reared at 30°C and 70% R.H., the duration from oviposition to adult emergence was about 28 days and we needed relatively shallow space for mass production. Our collaborators hurried to obtain samples for their chemical study and we started the project with this system. The system is diagrammatized in Figure 1.

Each step of life cycle of the moth was already analysed and summarised by Takahashi (4) especially with respect to the effect of population density upon the speed of development, mortality, and reproduction. From the results of this study the most productive system was designed as follows: Eggs were easily obtained by keeping adults in a glass vial without any food.

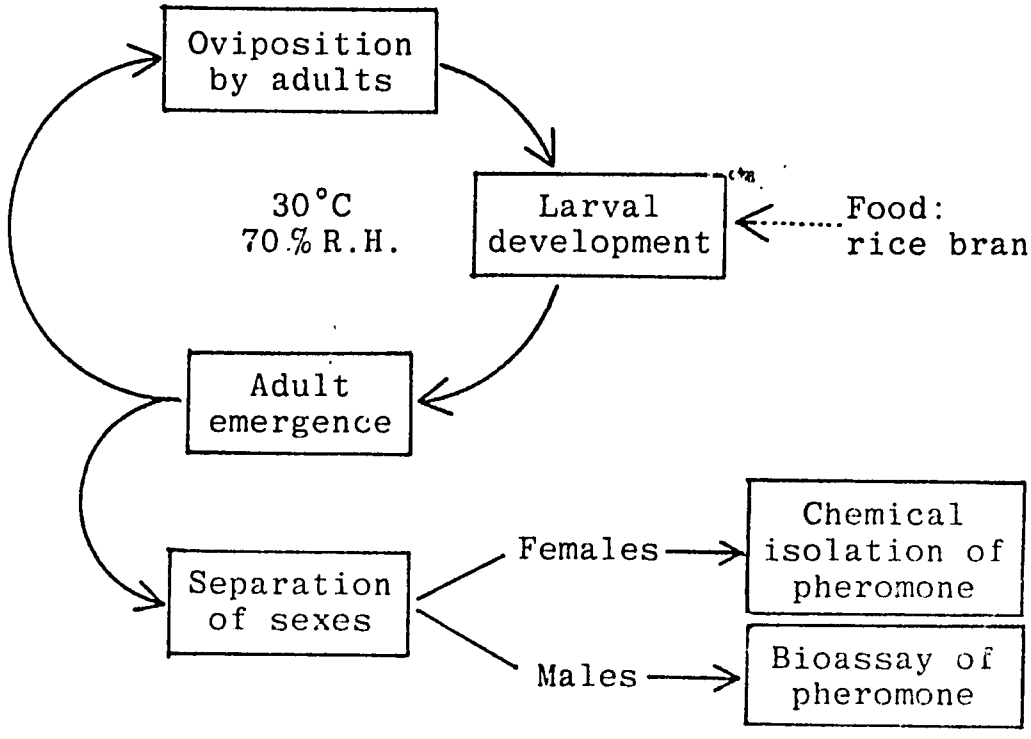


Figure 1. The rearing system of the moths at 30°C

Eggs deposited in a vial were cleaned up from debris, scales, and dead bodies by a soft blow. The rearing with the initial density of 30 eggs per 1 gr of rice bran at a food depth of less than 2 cm was recommended to produce maximum number of moths. But, the wide variation was observed in developmental period at such high density and it wasted labor for collecting moths frequently from vials. Therefore, the density of 20 eggs per 1 gr of rice bran was employed. Practically 8,000 eggs were reared in 400 gr of bran in a vial (27 x 35 x 6 cm).

About 4 weeks later many moths emerged every day. After anesthetization by ether gas they were sexed by hand. Females were stored in a solvent, hexane. However, Dr. Kuwahara, one of our collaborators, found that the solvent did not exhibit any sex pheromone activity to male moths in bioassay. The behavioral study of moths demonstrated the reason why the solvent did not contain the sex pheromone (5).

The sex pheromone was already detectable in female pupae of grayish color which had begun their eclosion. The pheromone content in a female increased up to a maximum after 3 hours from emergence and maintained this level until death if the moths did not mate. The sensitivity of the male moths to the sex

pheromone increased gradually with their age up to the 7th day from their emergence, while their mortality increased greatly after about the 5th day. Most of the moths emerged during a short period of a few hours around the sunset. They copulated within 2 hours after their emergence though their pheromone content in a female and the sensitivity of males to pheromone were not fully developed. When female moths copulated their pheromone activity disappeared rapidly in 4 or 5 hours after the beginning of copulation.

Therefore, the pheromone activity could not be expected in female moths collected in the morning unless their copulation was inhibited. From this fact, some modification was proposed in the mass production system, such as changes of circadian rhythm of moths by changing light and dark period in a day. But, their behavior of emergence was not so strict in responding to light stimuli. The program was, then, changed to the system in which the special character of sex ratio agent was fully utilized. The system is diagrammed in Figure 2.

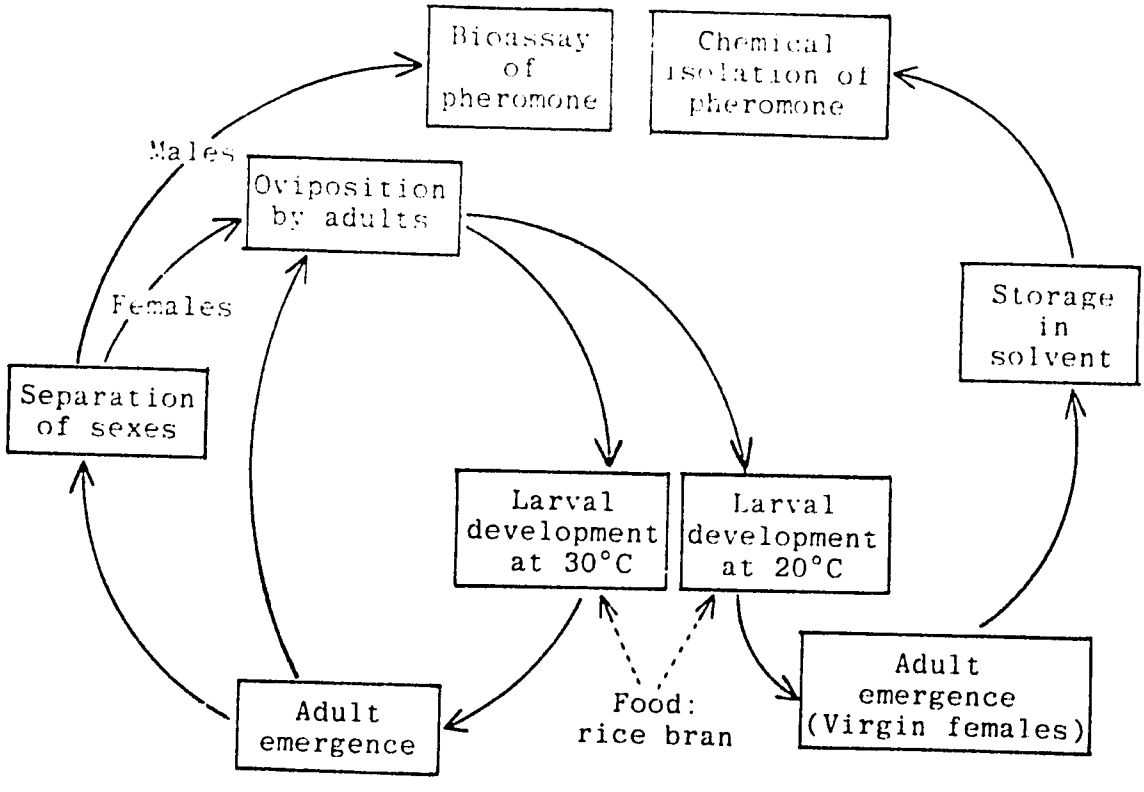


FIGURE 2. The rearing system of the virgin female moths employing their sex ratio agent

An economical rearing method of virgin female moths using FT-strain was established by Takanashi et al. (6). Fundamental methods were similar to those obtained at 30°C and the rearing density did not modify the degree of sex ratio manifestation. About 7,000 eggs were obtained from the moths reared from 200 eggs on 20 gr of bran at 30°C. Using these eggs female moths were raised at about 20°C, 70% R.H. The maximum number of their emergence within a week was obtained at the density of 20-30 eggs per 1 gr of bran at a food depth of less than 2 cm. Practically the rearing was conducted by 10,000 eggs in 400 gr of bran within a vial (27 x 35 x 6 cm) at 20±<5°C. During this project we produced about 1,200,000 unmated female moths and isolated 6 mg of sex pheromone (2).

EXPRESSION OF SEX RATIO AGENT IN *C. cautella* BY TEMPERATURE: The FT-strain of *C. cautella* had been maintained under a constant temperature of 30°C for about 8 years in the laboratory. The sex ratio of adults of this strain was greatly apart from the normal ratio of 1:1 when they were reared at lower temperature. When 150 eggs were reared in 30 gr of rice bran at several combinations of temperature and atmospheric moisture, the number of female and male moths emerged were shown in Table 1. The sex ratio was 1:1 at 30°C even though the percentage of emergence changed with the change of moisture. At 20°C only a few males emerged at every moisture condition while females emerged at almost the same number to those at 30°C. At 25°C, however, some males emerged and Dr. Mutuura found that their copulatory organs were malformed in variable degree. Several abnormal forms of the male copulatory organs were shown in Figure 3. They were abnormal formation of vinculum and of the valva of one side; degeneration of valva and of aedoeagus; pseudohermaphroditic male with a bursa copulatrix; and a super male having a supernumerary valva. The occurrence of these abnormal forms was shown in Table 2 when the insects were reared at 22.5°C and 25°C. Even the apparently normal males had some malformations in their copulatory organs and emerged in retarded days than females. Thus, the effect of low temperature was different on males and females. Male gonad development and the formation and growth of male copulatory organs were especially influenced. The characteristics of the abnormal sex ratio in FT-strain was a consequence of high mortality of males in their larval and pupal stages. The abnormal male adults died faster than normal ones and they could not copulate with females.

SENSITIVE STAGE IN THE DEVELOPMENTAL PERIOD TO LOW TEMPERATURE STIMULATION PROMOTING THE SEX RATIO AGENT: The insects reared at 30°C were exposed to 20°C in various developmental stages for 5 days, but the sensitive stage to produce abnormal males was not detected due to the weak and short duration of stimulation of low

Table 1. Number of female and male moths of FT-strain reared at several combinations of temperature and atmospheric moisture (Takahashi and Mutuura, 1964)

	Atmospheric moisture (% R. H.)											
	29～33			49～57			71～77			82～87		
Sex	♀	(♂)	♂	♀	(♂)	♂	♀	(♂)	♂	♀	(♂)	♂
Temperature												
35 °C	0	0	0	0	0	0	11	0	7	1	0	0
30 °C	0	0	0	38	0	51	57	0	41	6	0	12
25 °C	0	0	0	30	7	19	41	13	31	22	3	18
20 °C	0	0	0	49	0	0	40	2	1	14	0	0
15 °C	0	0	0	0	0	0	0	0	0	0	0	0

♀, ♂ : Apparently normal females and males.

(♂) : Apparently abnormal males.

Atmospheric moisture was controlled by $CaCl_2$ (29～33%), $Ca(NO_3)_2$ (49～57%), NaCl (71～77%), and KCl (82～87%), respectively, and 150 eggs were reared on 30 gr rice bran.

Table 2. Occurrence of abnormal forms of male copulatory organs when they were reared at low temperature. (Takahashi & Mutuura, 1964)

Temperature	Days after oviposition	Number of females	Number of males: Total	Near normal *	Abnormal valva of one side	Malformed vinculum	Degeneration of valva and aedoeagus	Super male	Pseudohermaphroditic male
22.5°C	49～52	110	1	1					
	53～56	124	29	11	2		15	1	
	57～60	36	24	8			14		2
	61～64	16	14	6	1		7		
	65～73	4	7	2			5		
	Total	290	75	28	3	0	41	1	2
25°C	38～40	75	13	6	1	2	4		
	41～44	119	78	34	13	1	29		1
	45～48	14	39	17	2		19		1
	49～52		16	2	3		10		1
	57～58	1							
	Total	209	146	59	19	3	62	0	3

* no males were found with the complete copulatory organs.

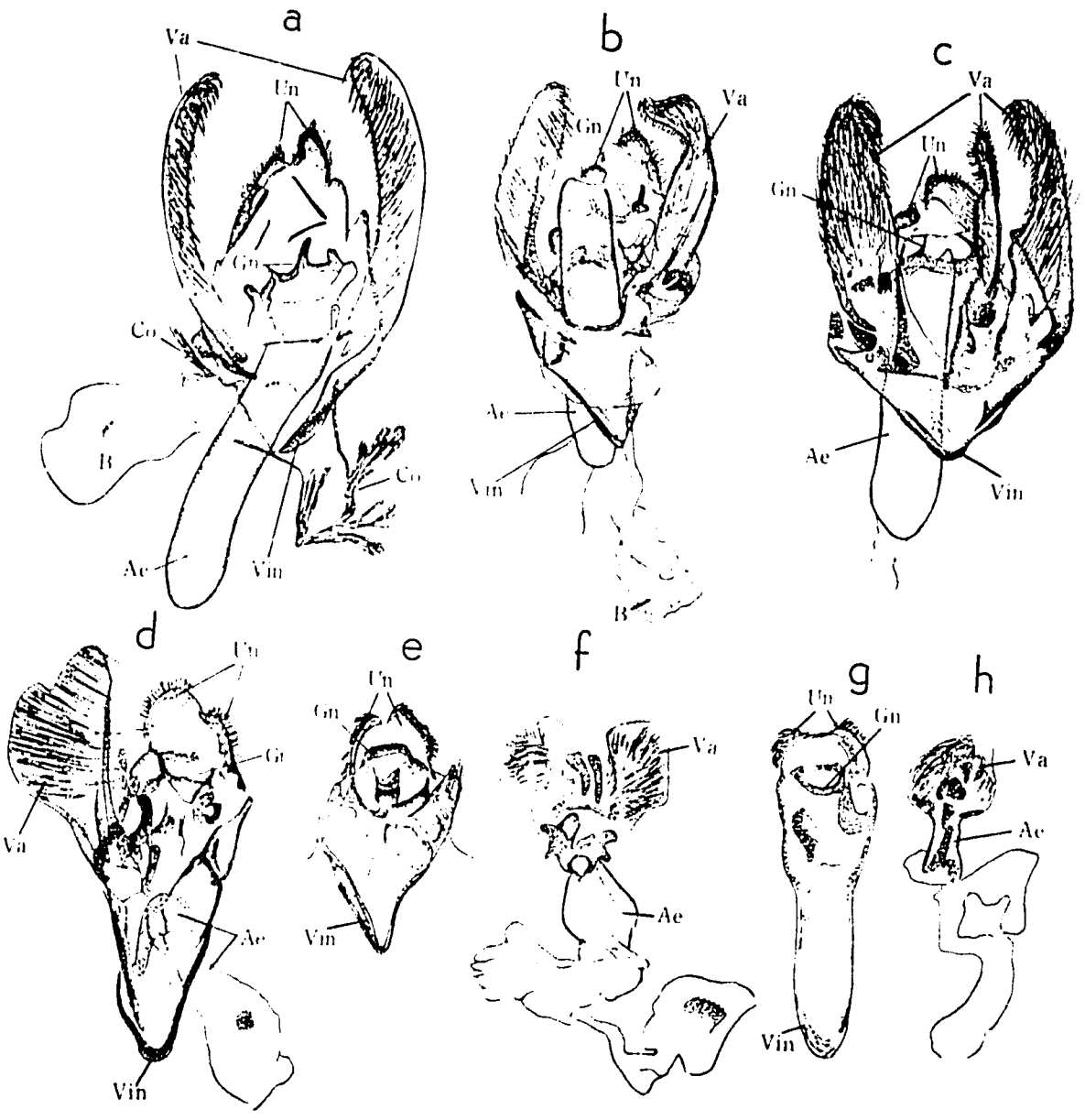


FIGURE 3. Abnormal forms of male copulatory organs in *Cadra cautella* reared at 25°C. Drawn by A. Mutuura (Takahashi and Mutuura, 1964)

a, b: Pseudohermaphroditic males.
c: Degeneration of the valva of one side.
e-h: Degeneration of male copulatory organs. They apparently resemble female, but they have no female characters.
Ae, Aedoeagus; B, Bursa copulatrix; Co, Crest; Gn, Gnathos; Un, Uncus; Va, Valva; Vin, Vinculum.

temperature (3). Takahashi et al. (6) studied again with a little strong stimulation of low temperature (15°C for 10 days). The occurrence of abnormal male copulatory organs was observed in every larval and pupal stage especially from 4th instar to prepupae as shown in Table 3, and the critical stage was not detected. For the practical production of virgin female moths we had to keep insects at low temperature in their whole developmental stages to promote effectively their sex ratio agent.

GENETICS OF THE SEX RATIO AGENT: Takahashi and Kuwahara (7) collected some strains of *C. cautella* and reared at 30°C and 20°C. They were S-strain supplied from Hatano Tobacco Experiment Station in Kanagawa Pref., N-strain collected at a granary in Kyoto City, M-strain collected at a bakery in Osaka City, and W-strain collected at a granary in Kyoto University from where FT-strain was collected 14 years ago. Amongst 5 strains FT- and M-strains express strong abnormality in sex ratio at 20°C. In W-strain males were fewer than females and some abnormal males were found. However, S- and N-strains were normal in their sex ratio. Their sex ratios were rather stable in every season and in every strain. Therefore, it was concluded that the character of sex ratio agent can be frequently observed in some strains and is inherited from generation to generation.

CROSSING EXPERIMENT OF FT-STRAIN WITH N-STRAIN: To examine the mode of inheritance of the sex ratio agent Takahashi and Kuwahara (7) conducted the crossing experiments between FT-strain and strains of normal sex ratio. There were no big differences in the percentages of egg hatching and adult emergence in the crossings between FT- and N-strains (Tables 4 and 5). On the other hand, some abnormal sex ratio and abnormal male copulatory organs were found in some crossings at 20°C (Table 6). However, they could not find clear genetic relation in this crossing experiment.

CROSSING EXPERIMENT OF FT-STRAIN WITH S-STRAIN: The crossing experiment was again conducted between FT- and S-strains. In this case the fecundity was normal in every combination of crossing among strains and hybrids though it was clearly governed by the size of female body following the relation found in FT-strain (Fig. 4). However, a unidirectional incompatibility was found in the rate of egg hatching in the crossing between the two strains (Table 7). The crossing of FT-female x S-male showed very high mortality before egg hatching while normal rate of egg hatching was found in the crossing of S-female x FT-male. The high egg mortality was also found in some hybrid crossings and back crossings. The mortality rate was at the same degree at 30°C and 20°C and this phenomenon was not related to that of sex ratio agent. This will be discussed elsewhere.

Table 3. Effects of low temperature on the sex ratio of moths treated at various developmental stages (Takahashi et al. 1968)

Starting date of treatment in days after oviposition	Approximate stage of development when treated		Replicates	Total number of emerged moths ♀	(♂)	♂
0	Egg		3	15	0	2
2	Larval instar	1st	3	103	28	26
5		2nd	3	81	9	49
8		3rd	3	115	76	28
11		4th	3	119	91	4
14		5th	3	108	74	6
17	Prepupa*		3	98	92	1
20	Pupa		3	119	69	31
Control (no treatment)			4	176	2	146

One hundred eggs were reared on 40 gr rice bran at 30°C. Vials were kept in 15°C for 10 days. *: treated for 11 days.

♀ and ♂ : apparently normal females and males.

(♂) : apparently abnormal males.

Table 4. Percentage of egg hatching in the crossing between FT-strain (F) and N-strain (N) at 20°C and 30°C. (Takahashi & Kuwahara, 1970)

♀ \ ♂	F			N			F_1(F♀ x N♂)			F_1(N♀ x F♂)		
	Number of eggs	Number hatched	%	Number of eggs	Number hatched	%	Number of eggs	Number hatched	%	Number of eggs	Number hatched	%
F												
20°C	649	484	74.6	412	269	65.3	748	545	72.9	600	336	56.0
30°C	778	618	79.4	1013	708	69.9	723	551	76.2	600	276	46.0
N												
20°C	656	516	78.7	489	346	70.8	800	552	69.0	400	274	68.5
30°C	1200	1004	83.7	945	430	45.5	550	394	71.6	432	286	66.2
F_1(F♀ x N♂)												
20°C	400	306	76.5	600	374	62.3	600	480	80.0	558	394	70.6
30°C	400	239	59.8	600	418	69.7	600	483	80.5	604	354	58.6
F_1(N♀ x F♂)												
20°C	819	490	59.8	600	349	58.2	600	370	61.7	800	419	52.4
30°C	600	471	78.5	600	356	59.3	754	477	63.3	800	403	50.4

Table 5. Percentage of adult emergence from eggs hatched in the crossing between FT-strain (F) and N-strain (N) at 20°C and 30°C. (Takahashi & Kuwahara, 1970)

♀ \ ♂	F			N			F_1(F♀ x N♂)			F_1(N♀ x F♂)		
	Number of larvae	Adults emerged	%	Number of larvae	Adults emerged	%	Number of larvae	Adults emerged	%	Number of larvae	Adults emerged	%
F												
20°C	484	262	54.1	269	215	79.9	545	380	69.7	336	209	62.2
30°C	618	559	90.5	708	632	89.3	551	476	86.4	276	242	87.7
N												
20°C	516	396	76.7	346	221	63.9	552	486	88.0	274	226	82.5
30°C	1004	882	87.8	430	384	89.3	394	349	88.6	286	269	94.1
F_1(F♀ x N♂)												
20°C	306	299	74.8	374	276	73.8	480	369	76.9	394	346	87.8
30°C	239	208	87.0	418	357	85.4	483	405	83.9	354	338	95.5
F_1(N♀ x F♂)												
20°C	490	352	71.8	349	278	79.7	370	277	74.9	419	321	76.6
30°C	471	438	93.0	356	328	92.1	477	442	92.7	403	366	90.8

Table 6. Number of emerged moths in the crossing between FT-strain (F) and N-strain (N) at 20°C and 30°C. (Takahashi & Kuwahara, 1970)

♀ \ ♂		F			N			F_1(F♀ x N♂)			F_1(N♀ x F♂)		
		♀	(♂)	♂	♀	(♂)	♂	♀	(♂)	♂	♀	(♂)	♂
F	20°C	220	33	9	117	11	87	263	41	76	143	37	29
	30°C	270		289	310		322	227		249	123		119
		χ^2=94.32*			χ^2=1.85			χ^2=39.99*			χ^2=14.35*		
N	20°C	229	41	126	107	1	113	247	2	237	128	27	71
	30°C	458		424	203		181	181		168	145		124
		χ^2=3.83			χ^2=1.11			χ^2=0.09			χ^2=0.37		
F_1(F♀ x N♂)													
	20°C	147	16	66	157	17	102	176	17	176	178	13	155
	30°C	98		110	172		185	202		203	169	1	168
		χ^2=12.90*			χ^2=4.73*			χ^2=0.37			χ^2=0.14		
F_1(N♀ x F♂)													
	20°C	237	28	87	171	4	103	161	34	82	191	29	101
	30°C	230		208	174		154	229		213	190		176
		χ^2=17.73*			χ^2=4.39*			χ^2=2.73			χ^2=3.99*		

The sex ratio at 20°C was compared with that at 30°C by χ^2-test, in which the males having abnormal copulatory organs(♂) were included in the number of males.

* : significant at 95 % level.

Table 7. Percentage of egg hatching in the crossing between FT-strain (F) and S-strain (S) at 20°C and 30°C. (Takahashi & Kuwahara, 1970)

♀ \ ♂	F			S			F_1(F♀ x S♂)			F_1(S♀ x F♂)		
	Number of eggs	Number hatched	%	Number of eggs	Number hatched	%	Number of eggs	Number hatched	%	Number of eggs	Number hatched	%
F												
20°C	524	413	78.8	532	34	6.4	862	605	70.2	863	2	0.2
30°C	500	409	81.8	1488	85	5.7	483	313	64.8	546	3	0.5
S												
20°C	276	198	71.7	418	376	90.0	840	653	77.7	608	428	70.4
30°C	678	523	77.1	416	390	93.8	768	615	80.1	519	364	70.1
F_1(F♀ x S♂)												
20°C	568	227	40.0	710	171	24.1	798	462	57.9	647	10	1.5
30°C	869	498	57.3	692	151	21.8	549	347	63.2	519	19	3.7
F_1(S♀ x F♂)												
20°C	525	138	26.3	404	186	46.0	440	293	66.6	484	163	33.7
30°C	503	144	28.6	950	672	70.7	429	301	70.2	458	171	37.3

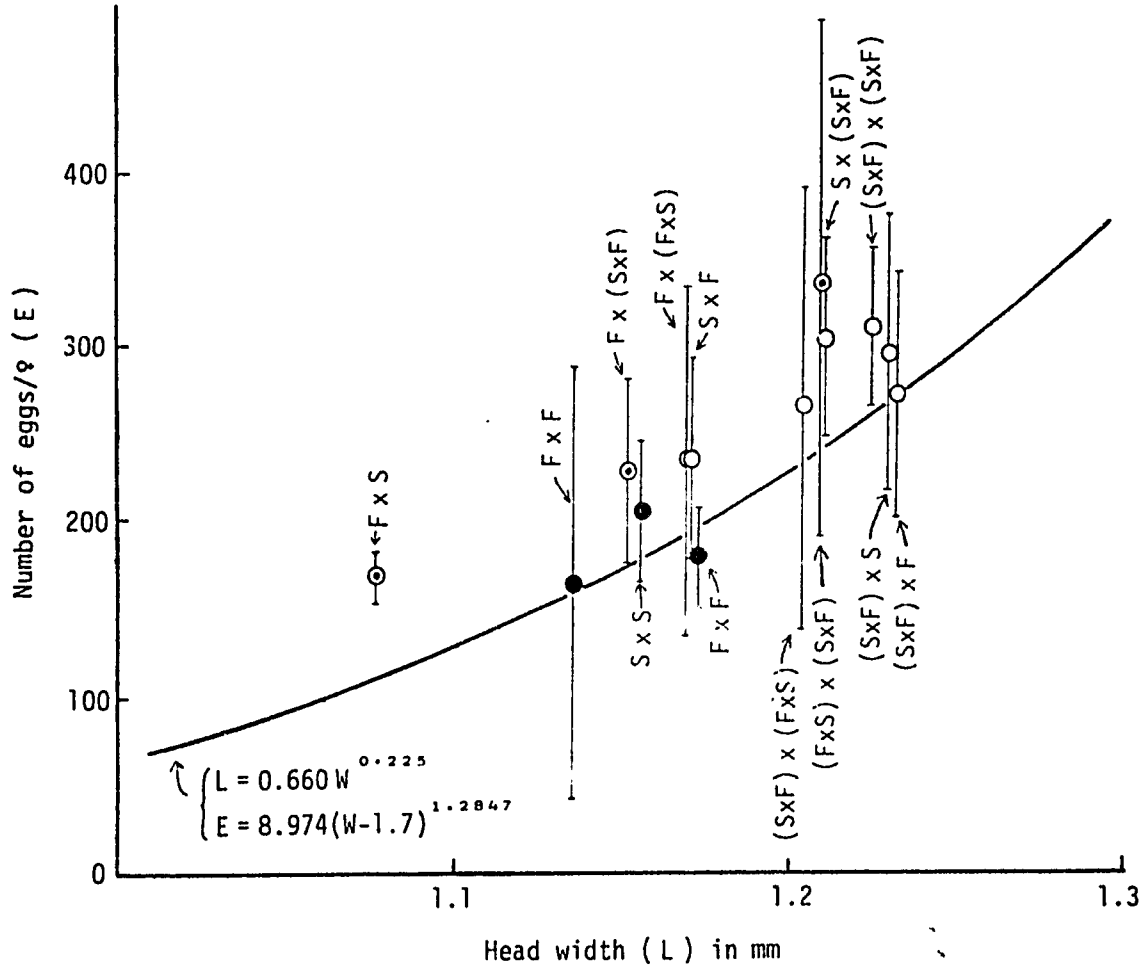


FIGURE 4. Number of eggs deposited by a female moth in relation to her head width in the crossings between FT-strain (F) and S-strain (S). (Takahashi and Kuwahara, 1970)

The larvae of each crossing were reared at 20°C and 30°C and adults emerged at a similar survival rate in every crossing (Table 8). At 30°C the sex ratio was normal but the abnormal sex ratios were found in some crossings at 20°C (Table 9). The results showed much clear relation of maternal inheritance than in the case of crossing between FT- and N-strains.

INJECTION OF THE HAEMOLYMPH OF FT-STRAIN TO THE LARVAE OF NORMAL STRAIN: There are some records that the sex ratio agent in *Drosophila* is spirochete which can be transmitted by injection of haemolymph (8). Trials to transfer the abnormal sex ratio agent were made by injecting larval haemolymph of the FT-strain into larval body of a normal strain (Table 10). However, these attempts were unsuccessful as shown in Table 11.

REFERENCES:

(1) Kuwahara, Y., H. Hara, S. Ishii, and H. Fukami (1971a) Agr. Biol. Chem. 35: 447-448.
(2) Kuwahara, Y., C. Kitamura, S. Takahashi, H. Hara, S. Ishii, and H. Fukami (1971b) Science 171: 801-802.
(3) Takahashi, F., and A. Mutuura (1964) Jap. J. Appl. Ent. Zool. 8: 129-135.
(4) Takahashi, F. (1961) Jap. J. Ecol. 11: 239-245.
(5) Kuwahara, Y., C. Kitamura, F. Takahashi, and H. Fukami (1968) Botyu-Kagaku 33: 159-162.
(6) Takahashi, F., C. Kitamura, Y. Kuwahara, and H. Fukami (1968) Botyu-Kagaku 33:163-168.
(7) Takahashi, F., and Y. Kuwahara (1970) Botyu-Kagaku 35: 11-21.
(8) Sakaguchi, B., and D. F. Poulson (1963) Genetics 48: 841-861.

Table 8. Percentage of adult emergence from eggs hatched in the crossing between FT-strain (F) and S-strain (S) at 20°C and 30°C. (Takahashi & Kuwahara, 1970)

♀ \ ♂	F			S			F_1(F♀ x N♂)			F_1(N♀ x F♂)		
	Number of larvae	Adults emerged	%	Number of larvae	Adults emerged	%	Number of larvae	Adults emerged	%	Number of larvae	Adults emerged	%
F												
20°C	413	266	64.4	34	16	47.1	605	383	63.3	2	1	50.0
30°C	409	388	94.9	85	64	75.3	313	264	84.3	3	2	66.7
S												
20°C	198	187	94.4	376	328	87.2	653	544	83.3	428	348	81.3
30°C	523	386	73.8	390	357	91.5	615	518	84.2	364	314	86.3
F_1(F♀ x S♂)												
20°C	227	136	59.9	171	119	69.6	462	287	62.1	10	2	20.0
30°C	498	419	84.1	151	124	82.1	347	248	71.5	19	3	15.8
F_1(S♀ x F♂)												
20°C	138	118	85.5	186	174	93.5	293	244	83.3	163	154	94.5
30°C	144	138	95.8	188	182	96.8	301	261	86.7	171	151	88.3

Table 9. Number of emerged moths in the crossing between FT-strain (F) and S-strain (S) at 20°C and 30°C. (Takahashi & Kuwahara, 1970)

♀ \ ♂		F ♀	F (♂)	F ♂	S ♀	S (♂)	S ♂	F_1(F♀ x S♂) ♀	F_1(F♀ x S♂) (♂)	F_1(F♀ x S♂) ♂	F_1(S♀ x F♂) ♀	F_1(S♀ x F♂) (♂)	F_1(S♀ x F♂) ♂
F	20°C	290	109	5	52	19	12	357	149	43	16	3	4
	30°C	272		272	73	1	108	191		212	2		4
		χ^2=45.57*			χ^2=11.62*			χ^2=29.58*			χ^2=1.34		
S	20°C	359		395	259	1	258	275		269	348	1	361
	30°C	628		654	285		279	273		245	341		315
		χ^2=0.36			χ^2=0.03			χ^2=0.49			χ^2=1.20		
F_1(F♀ x S♂)													
	20°C	85	48	3	67	20	32	387	67	125	2	1	0
	30°C	208		211	62		62	151		109	3		5
		χ^2=6.81*			χ^2=0.97			χ^2=5.99*			χ^2=0.03		
F_1(S♀ x F♂)													
	20°C	123		163	174		163	121		144	103		124
	30°C	139		131	171		182	135		157	107		138
		χ^2=4.00*			χ^2=0.70			χ^2=0.02			χ^2=0.14		

The sex ratio at 20°C was compared with that at 30°C by χ^2-test, in which the males having abnormal copulatory organs(♂) were included in the number of males.
* : significant at 95 % level.

Table 10. Emergence from the larvae of N-strain which were injected the haemolymph of FT-strain larvae.

(Takahashi & Kuwahara, 1970)

Haemolymph was obtained from	injected into	Number of larvae injected	Number of adults emerged	Mark of moths
FT ♀ ⟶	N ♀	61	26	(A)
FT ♀ ⟶	N ♂	44	12	(B)
FT ♂ ⟶	N ♂	39	10	(C)

Table 11. Number of adults emerged from eggs which were obtained by the crossing of moths emerged in the experiment shown in Table 10 and by their crossing. (Takahashi & Kuwahara, 1970)

Mark of parents in Table 10 and in this table	Reared at 20°C			Reared at 30°C			
	Number of eggs	Number of moths emerged		Number of eggs	Number of moths emerged		Mark of moths
♀ x ♂		♀	♂		♀	♂	
A x B	509	99	100	467	68	61	(D)
A x C	430	79	83	287	65	68	(E)
D x D	700	128	122				
E x E	650	80	65				