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POSTHARVEST HANDLING OF TROPICAL AND SUBTROPICAL FRUIT CROPS

POSTHARVEST HANDLING OF TROPICAL AND SUBTROPICAL FRUIT CROPS

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Food and Fertilizer Technology Center
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PREFACE

This book is the Proceedings of the seminar on "***Postharvest Handling of Tropical and Subtropical Fruit Crops***", held in Taichung, Taiwan ROC in November 1987. The seminar was co-sponsored by the Taiwan Agricultural Research Institute (TARI), and owed much of its success to the organizing ability and devoted work of the organizing staff. To all of them, and to the Director of TARI, I wish to express my deep appreciation. The Center is also indebted to the Council of Agriculture of ROC, which provided a large proportion of the funds for the publication of this volume. The number of requests we have received from potential readers, even before it has been published, give some indication of how badly the information it contains is needed by those working in the field of postharvest handling of tropical and subtropical fruit.

Postharvest losses are a problem in small-scale agriculture everywhere, but are particularly serious in the case of fruit production, particularly the delicate fruits of the tropics and subtropics. Although the market prospects for such fruit are good in both domestic and overseas markets, it has been estimated that 25% or more of fruit produced in Asian countries is lost because of improper handling and storage. If the fruit after harvest were to receive better handling, this enormous amount of produce would then become available on the market, to provide higher income for farmers and quality food for consumers.

The papers published in this proceedings give the results of a great deal of recent research on such topics as chemical treatments, control of thermal stress, packaging techniques and storage methods. Some very useful papers give general information on the extent and causes of postharvest losses of fruit, and ways in which countries can develop practical and efficient postharvest handling systems to suit their particular needs. Several authors emphasize the variation between species, and between different varieties of the same species, in response to particular handling procedures. Some varieties, for example, may respond well to cold storage or heat treatment, while fruit of very similar varieties may be ruined by exactly the same treatment. Of course this does not mean that successful technology cannot be transferred to new species, but it does mean that careful testing is needed.

Fruit production is already making a substantial contribution to the incomes of millions of small-scale farmers in the region, and the future outlook is extremely promising. Given the difficulty of efficient postharvest handling procedures on small-scale farms, especially when these are widely scattered and lie some distance from markets, it is encouraging that the scientists of this region, working with the farmers, have already achieved such success. I hope this volume, containing the research and field experience of many distinguished scientists, will be helpful to all those who are working to improve the quality and storage stability of the fruit harvested in this region.

Cheng-Hwa Huang
Director, FFTC

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Section I.

Postharvest Handling of Fruit: Some General Considerations

DEVELOPING PRACTICAL METHODS AND FACILITIES FOR HANDLING FRUITS IN ORDER TO MAINTAIN QUALITY AND REDUCE LOSSES

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ABSTRACT

This paper presents a general review of factors which must be considered when postharvest handling systems for fruit are being designed. Postharvest technology is often commodity and location specific. Different varieties of the same species may respond differently to the same postharvest treatment; even cultural practices during growth can affect postharvest physiology. To design efficient postharvest handling systems, a sound knowledge of fruit response to mechanical stress, temperature, humidity, atmospheric composition and other factors is needed. The situation of the consumer should also be understood — increased investment in improved postharvest systems is only justified if the consumer can pay for the increased cost. The success of new technology depends on how well it can be integrated into the existing system, as well as the effectiveness of the technology itself.

INTRODUCTION

Most fruit crops are perishable crops which deteriorate in quality rapidly after harvest. It is generally believed that postharvest losses of fruit are high, although estimated figures differ substantially from one report to another[8,13,27]. However, losses in quality and quantity can often be reduced by the development and application of improved handling methods and facilities. The main purpose of this paper is to discuss the proper approach researchers and program designers should adopt, in order to develop practical handling methods and facilities for fruit to meet national or local needs. It is not intended as a comprehensive review of sophisticated postharvest technology, which is available from many publications, some of which are cited in this paper.

Postharvest technology is highly commodity-specific and location-specific. For instance, controlled atmosphere (CA) storage is very useful for apples and pears, but is not appropriate for oranges. Hydrocooling is important when peaches and litchi are to be shipped to distant markets, but is less useful when these fruits are to be marketed locally, and is harmful to some other fruits which cannot tolerate water submersion or showering. Corrugated fiberboard boxes are ideal containers for many fruits, but they are expensive and can be used only if the consumers can afford to cover the cost. Therefore whether a particular technology or facility is practical or not depends on the kinds and varieties of fruit, the type of markets and marketing systems, and the economic and other conditions. A systematic approach is often necessary in the development of practical technologies. This paper will discuss necessary steps to be taken in developing practical methods and facilities.

UNDERSTANDING THE FRUIT

Fundamental knowledge about the postharvest life of a fruit should be obtained before suitable handling methods can be developed. A general knowledge of postharvest physiology, such as is available in many textbook and publications, is insufficient. The species or variety concerned, the growing environment, and the cultural methods make significant differences in the postharvest life of fruit. Agriculture Handbook No. 66 of the U.S. Department of Agriculture[15] provides a useful summary of the handling and storage requirements and storage life spans of 29 kinds of fruit. However, more detailed information is often necessary to develop improved handling methods. Furthermore, there are many species and varieties of fruit which have not yet been well studied, particularly those grown in tropical and subtropical countries. New species and varieties are frequently developed or introduced into new production areas. Cultural methods, such as the use of rootstocks, fertilizers, growth regulators and other agricultural chemicals, change frequently. Therefore, the study of postharvest life of fruit must be a continuous effort. The following items are most important.

Maturity and Quality

Fruit maturity at harvest has a great effect on the eating quality and keeping quality. Unfortunately, a fruit harvested at the time when it has optimum eating quality often does not have the best keeping quality. Fruit harvested earlier often has better keeping quality but poorer eating quality. Therefore, the stage of maturity at which a fruit is harvested is largely determined by the distance to the market, and the handling, storage and transportation methods and facilities available. The basic data of the relationship between harvest maturity, eating quality and keeping quality should be collected in order to develop useful maturity standards. Fruit growers and packers often put too much emphasis on keeping quality and too little on eating quality, or vice versa. United States consumers often complain that many fruits have poor eating quality, despite good appearance. Mangoes, papayas and pineapples shipped from subtropical or tropical areas to the northern United States are often harvested at an immature stage and never develop good eating quality. On the other hand, many apple growers in the northern states harvest their apples too late, because they want to wait for the red color. Late harvest apples have poor keeping quality and are unfit for long-term storage. If the basic data of the relationship between maturity and eating and keeping quality are available, a suitable compromise can be obtained.

Potential Shelf-life

The potential shelf-life of fruit when carefully harvested at different stages of commercially acceptable maturity and kept at room temperature should be examined. Shelf-life varies greatly between different species and varieties, from several hours to several weeks or longer. While shelf life studies are being made, the principal causes of deterioration of the fruit, such as sarivelling, overripeness or senescence, decay, or other disorders, can be examined. This information provides a useful basis for developing practical handling methods and for consumer education.

Response to Various Temperatures, Humidities, and Atmospheres

Refrigeration is one of the most effective ways of extending the postharvest life of fruit. When economic conditions permit, refrigeration is often recommended for shipping and storage of fruit. However, many fruits of tropical and subtropical origin, and some fruits of temperate origin, are sensitive to chilling injury[6,10,15]. In addition, all fruit is sensitive to freezing injury. Therefore, the response of each fruit to different degrees of low temperature needs to be studied

thoroughly. Tolerance to high temperatures also needs to be studied. Many tropical and subtropical fruits develop high temperature injury before being shipped to market. The high temperatures fruit may encounter may be in the field, if the fruit lacks proper protection from the sun, or in packages or stacks with poor ventilation.

Relative humidity also has a great effect on the postharvest life and quality of fruit[14]. Many fruits require high relative humidity (90 – 95%), but others may require slightly lower humidity[1]. Bananas require higher humidity when the fruit is green, but lower humidity when the fruit is ripe[15]. Understanding the requirement and tolerance of each fruit to humidity is important. Those fruits which cannot tolerate high humidity or occasional water condensation on the skin should not be kept in polymeric film bags.

Many other fruits beside apples and pears have a positive response to controlled atmosphere (CA) and modified atmosphere (MA) storage[17]. Some fruits respond favorably to CA or MA even at relatively high temperatures. Banana is one example of such a fruit[20,21]. Each fruit has its beneficial range of O_2 and CO_2 combinations, and its injurious levels of low O_2 and high CO_2. The injurious levels may change with temperature, duration of exposure, and the physiological age of the fruit. This kind of information is useful in developing handling methods, particularly if CA or MA storage or packaging is to be considered. The information will also be useful for identifying disorders caused by low O_2 or high CO_2, or a combination of the two, if the fruit is accidentally exposed to such conditions. In addition to O_2 and CO_2 concentrations, ethylene accumulation in the storage atmosphere can have a significant effect on the postharvest life of fruit[29]. The sensitivity of fruit to ethylene depends on the species and varieties concerned, and the physiological age of the fruit, as well as on the temperature and the O_2 and CO_2 concentrations.

Many fruits, such as avocado, banana, mango, and papaya, are often harvested at the "mature green" or partially ripe stage and ripened after harvest. The ripening treatment, such as ethylene application, and the ripening environment they recieve, including temperature, humidity, and O_2 and CO_2 concentrations, will affect the quality of the fruit after it ripens. The currently recommended best ripening temperatures for various fruits differ slightly according to the species, but are mostly within the range 16°–27°C[15]. However, there is some evidence that the best ripening temperature of any one kind of fruit may vary according to the growing conditions, and therefore reassessment of the temperature may be necessary for different production areas.

Many published research papers give only the best temperature, humidity, or controlled atmosphere for each fruit. This information is often not sufficient for practical application. Too often the best conditions are difficult to obtain or economically unfeasible. There are occasions when the second best or third best condition is most practical. Therefore, researchers should be encouraged to collect and report data covering a wide range of conditions, and include harmful as well as beneficial ones.

Resistance to Mechanical Stress

Mechanical damage, such as bruises, cuts, breaks, deformation, and invisible wounds which lead to fungal attack and physiological disorders, is a major cause of postharvest losses of fruit. Damage may occur during harvesting, hauling, handling, transportation or marketing. It is easy to blame workers for not being careful enough, or simply to tell them to be more careful in harvesting and handling fruit. However, we need more information on how much care is needed for each kind of fruit. We sometimes hear the suggestion that fruit should be handled as carefully as eggs. Is it really necessary, or is it in fact sufficient, to handle fruit as if it were eggs? The answer might be negative. Probably some

small fruits, such as strawberries and raspberries, should be handled more gently than eggs. Other fruits which have relatively tough rinds are more resistant to mechanical stress than eggs. Unnecessarily gentle handling is costly and difficult. If researchers can provide precise information on what level of compression, abrasion and impact forces a fruit can withstand, and on which practices are likely to cause damage and which are not, it will be much easier for engineers and designers to design suitable handling machinery and containers, and much easier for supervisors to instruct fruit harvesting and handling workers so as to provide adequate care without adding wastefully high costs.

Principal Postharvest Diseases and Their Control

Postharvest decay caused by fungi and bacteria is another major cause of losses. The importance of studies on the kinds of disease, route of infection, resistance of hosts, and control measures cannot be overemphasized.

Preharvest Factors Affecting Postharvest Life

The potential postharvest life of a fruit is determined, not only by the genetics of the fruit, but also by many preharvest factors. Weather, plant nutrition, and cultural practices (including chemical sprays) affect postharvest diseases[9], as well as physiological disorders[12]. Therefore, it is necessary to study the effects of preharvest factors on the postharvest life of each kind of fruit.

UNDERSTANDING THE POST-HARVEST FOOD SYSTEMS

Postharvest handling and marketing systems for fruit are so diverse in the different nations or regions that it is neither possible nor necessary for every postharvest horticulturist to become familiar with all systems. However, before trying to develop a new, improved handling method for a fruit, he must have some knowledge of the flow channels of the fruit and how that fruit is marketed in the particular area of interest. The new method he develops has to be compatible with current systems or predicted future systems, otherwise a technically sound method may not be practical. The anticipated impact of the new method on other sections of the marketing channels should be considered.

The application of postharvest technology begins in the orchard. The size of the orchard, the quantity of fruit the grower produces, the educational standard and the economic condition of the grower, the availability of labor, the availability and cost of machinery etc. should all be considered in developing new methods to be used in orchards and packinghouses.

The distance between the orchards and the market is a major factor in deciding what technology should be used. If the distance is short, handling methods can be fairly simple. Farmers' retail markets are popular in both less developed countries and developed ones. Growers harvest their fruit, clean, sort and pack it (or leave it unpacked for bulk transport), bring it to market and sell it directly to consumers. Sometimes the time interval between harvesting and selling the fruit is only a few hours. Very little postharvest treatment is necessary in this case, and the most effective way of reducing losses and maintaining quality is to educate the growers to harvest and handle their fruit carefully. If the time interval is substantially longer, simple cooling facilities (natural or mechanical) will help. If the distance between the orchards and markets is very long and/or the marketing channels are complex, a wider range of technology will be involved, and a greater number of economic and human factors must be considered. A comprehensive survey of the relevant transportation facilities, loading and unloading operations, inspection systems, transaction and pricing structures and information, and handling practices in wholesale and retail markets etc., will be necessary in order to develop new, practical methods. Costs and

profit sharing at each step of the operation and transaction would also be useful information.

If storage is involved in the fruit handling and marketing system, current storage facilities and costs should be surveyed. If the quality or quantity of storage facilities is inadequate improvement or addition of storage facilities should be considered.

The economic conditions and living standards of consumers are also important factors in determining fruit handling methods and facilities. Economic conditions determine the popularity of home refrigerators and consumers' buying power. Consumers in less wealthy nations or regions may not be able to pay high prices for fruit. Overinvestment in handling facilities may result in economic loss, because consumers cannot absorb the added cost. Consumers in wealthy nations have home refrigerators, and can afford to buy high quality fruit at higher prices, so that more sophisticated technology can be applied to maintain fruit quality.

Although this is probably sound in theory, it is oversimplified for the real world. Consumer demand and preference are influenced by many other factors besides the economy. The existing marketing systems may not be sensitive enough to reflect consumer needs or preferences. For example, a newly developed low-ethylene CA storage procedure can keep apples longer and in better condition[22,24]. We thought this procedure would be adopted quickly by U.S. apple growers, to upgrade the quality of apples sold after a long period of storage. However, in reality the growers have been very reluctant to make any investment in this new method, because the wholesale market or chain store buyers are not ready to pay extra for high quality apples. Apple grades are primarily based on appearance, and the internal quality is only classified into pass or fail categories, without going into any further details.

In rapidly developing nations, consumer demands and marketing systems can change rapidly. In Taiwan, for instance, a home refrigerator was considered a luxury item in the early 1960's, but had become popular only ten years later. Supermarkets were rare in Taipei in the early 1980's, and seldom emphasized fresh produce, but grew rapidly in number, size, and the volume of fresh produce they carried only a few years later. Such changes soon demand a higher and more uniform quality of fruit, and therefore better handling methods and facilities. Grading, precooling, refrigeration, and improved packaging, which are considered unnecessary or impractical at one point in time, become essential a few years later. Researchers and planners should not only understand current systems, but also forecast future changes and prepare technology ready for future needs.

Other factors that need to be considered include quarantine requirements, government regulations for markets and prices, availability of labor, and wages at different stages of the food handling system.

REVIEW OF OLD AND NEW HANDLING AND STORAGE TECHNOLOGIES

Handling methods and facilities for fruit change frequently. For instance, small field boxes have been replaced by bulk bins for handling apples, citrus and many other fruits in the United States over the last two or three decades. Bananas grown for export in Central America were formerly shipped in stems, and are now shipped in fiberboard cartons. The methods and facilities used in the United States at present are not necessarily suitable for other countries. Researchers and program developers should make use of the wealth of published literature which covers old and new handling methods. It is generally easier to adapt an existing or old technology than to develop a new one. A brief review of some technologies is presented below. However, this review is by no means complete or comprehensive.

Grading and Packing

Grading and packing can be done either

in the field or in the packinghouse. Strawberries are often graded as they are picked by field workers, and put into containers where they will remain until they reach the retail market, because any additional handling or touching of the berries for regrading or repacking will increase the rate of decay. Small growers of many other kinds of fruit pack their products in simple packingsheds on or near the growing fields. However, when substantial washing, sizing, waxing and other treatments are required, large packinghouses have some advantages. Large packinghouses are commonly used for apples, avocadoes, bananas, citrus fruit, and some other types of fruit. Large modern packinghouses may be more cost effective than small ones, but do not necessarily cause less damage to the product. Equipment and management of a packinghouse are both of equal importance in minimizing losses. It is often necessary to evaluate the damage caused by each step of the operation in a packinghouse, to enable management to identify areas where improvement is needed.

Grade standards may not be important for small growers who sell their fruit directly to consumers in farmers' markets, because the buyers can see all the fruit they buy. However, grade standards are very important if the fruit is to be shipped to distant markets, or sold in more complex marketing systems. Filling up a container with fruit of non-uniform grade not only makes pricing and selling transactions difficult, but also encourages buyers to dig deep down in the container to examine the fruit at the bottom, and therefore causes extra mechanical damage.

Precooling

Cooling fruit quickly after harvest is an effective way to remove field heat, and therefore to slow down the rates of respiration, ripening and deterioration of the fruit. Hydrocooling is very useful for peach, banana, cherry, and litchi, and is probably useful for many other tropical and subtropical fruits. Fruit is either showered with, or submerged in, cold water. The temperature difference between the water and the fruit, the size of the fruit, and the type of packaging, will determine the rate of cooling, and hence the time required for cooling. Some fruits such as strawberry and grape cannot tolerate hydrocooling because the process increases the rate of decay. Hydrocooling also increases the rind turgor of citrus fruit, and therefore increases mechanical damage to the fruit during subsequent handling. Hydrocooling may increase contamination of the fruit with decay organisms, and hypocholorite or fungicides are therefore often added to the water.

Air cooling is useful for all kinds of fruit, including strawberries and grapes. In room cooling, the containers of fruit are kept well-spaced in a refrigerated room. In forced-air cooling, cold air is forced through containers and comes in close contact with the fruit, to speed up the cooling process. Since warm fruit has a very high vapor pressure, the air must be humidified to near saturation with water vapor, in order to reduce the vapor pressure gradient and the rate of transpiration water loss.

Containers

Bulk bins are often used in the field and in packinghouses for fruit which can withstand some pressure caused by the weight of fruit in the bins. The bins are moved with forklift trucks or by some other mechanical means, so that mechanical damage is generally reduced. When bulk bins cannot be used because of a lack of forklift trucks, field boxes or baskets can be used. The materials and shapes of the containers are not very important, but the containers must be small enough to be lifted easily when filled with fruit, and strong enough to protect the fruit during lifting, moving, or stacking. They must have smooth or soft surfaces to avoid mechanical damage, and have adequate ventilation holes. Wooden boxes are commonly used. I have seen bamboo baskets

with cloth liners used for oranges in Turkey, and cleverly designed plastic crates for fruit in Taiwan. These crates have versatile metal handles which can be flipped up when the crates are being carried and flipped down during stacking, to provide support for filled crates stacked on top. Containers which are reused should be disinfected frequently, to avoid inoculation with pathogens. For fruit which cannot tolerate pressure, such as strawberries and grapes, shallow trays or boxes are used.

Corrugated fiberboard boxes (cartons) are probably the ideal containers for fruit during shipping and marketing. The fiberboard can be waxed to prevent it absorbing moisture which would weaken the box. Since cartons are expensive, growers and packers sometimes wish to use them more than once. A grower in New York State told me that he was able to reuse his cartons five times, since he delivered his produce directly to the same retail stores each time. Some growers or packers collect used cartons which have been used once for more valuable industrial goods, and reuse them for fruit. There is nothing wrong in reusing these cartons, provided that they are not contaminated with toxic substances. However, before the cartons are reused for fruit, adequate ventilation holes should be made in them. Inventing a simple tool which will enable such users to make ventilation holes in the used boxes would be very helpful. One common mistake made when packing fruit in a carton or some other container is to overfill the container, causing extra mechanical damage during stacking and shipping.

When cartons are not available for economic or other reasons, materials such as wood, bamboo, or plastic can be used for making containers. If the shipping distance is not very great, the containers should be designed in such a way that they can easily be returned and reused, to reduce costs. Containers often contribute a significant share of the postharvest handling and marketing costs of fruit.

Chemical Applications

The postharvest application of chemicals to control decay or storage disorders is a fairly common practice. Ogawa and Manji[28] have provided a list of 30 chemicals which are currently registered for postharvest use in the United States. The crops on which each chemical may be used, and the decay pathogens that the chemical controls, are also tabulated. The list includes Benomyl, Biphenyl, Sec-butylamine (2-aminobutane), Calcium hypochlorite, Captan, Sodium dehydroacetate, 2,6-Dichloro-4-nitroaniline, Formaldehyde, Imazalil, Methylene chloride, Potassium sorbate, O-phenylphenol, Sodium borate, Sodium dimethyldithiocarbamate, Sodium hypochlorite, Sodium-phenylphenate, Sodium or potassium bisulphate, Sulfur, Sulfur dioxide, Thiabendazole, Thiophanate-methyl, Thiram, Methyl chloroform, Triforine, Zinc ion-maneb complex, Zinc petroleum sulfonate and Ziram. Formaldehyde can only be used for equipment and storage areas and Zinc petroleum sulfonate can only be used for baskets, boxes or crates used in harvesting fruit. Other chemicals on the list can be applied directly to various fruits and other crops.

Very few chemicals are available for postharvest insect control. Ethylene dibromide (EDB) has been used for quarantine treatment against fruit fly, but its registration has been withdrawn for most quarantine use in the United States since 1984. Methyl bromide is another insect quarantine treatment, but is also being considered for a lower residue tolerance or possible withdrawal of registration. Satisfactory alternative chemicals have not yet been found.

Several growth regulators are either applied postharvest to fruit, or are applied before harvest for the purpose of reducing postharvest losses. Davies[11] has reviewed the benefits of applying 2,4-D, various gibberellins, and ethephon to citrus fruit. Ethephon has been used on many fruits to enhance ripening. Daminozide has been used on apples to reduce preharvest drop,

as well as to improve the storage quality of the fruit. It is necessary to understand the indirect, as well as the direct effects of a chemical before it can be applied with safety. For instance, daminozide, which generally has the effect of delaying ripening and senescence in apples, can actually aggravate senescent breakdown of McIntosh apples in CA storage when the ethylene concentration is high[21]. Ethephon reduces the decay rate in tangerines, because it reduces the percentage of plugged fruit and, as an indirect effect, also reduces degreening time[11].

Heat Treatment

Hot water treatment, or a combination of hot water and a fungicide such as benomyl, is often used to control certain decay organisms for peach, papaya and mango[24,32]. The fruit is submerged in hot water (about 49°C) for a period ranging from a few minutes to 20 minutes, depending on the kind and size of fruit. A recent report by Lee[16] indicates that dipping mangoes for five minutes in a 0.1% benomyl solution at 56°C effectively controlled decay without causing any serious injury. Dipping litchi in hot benomyl (0.05% benomyl at 52°C) for two minutes also controlled rotting and browning of the fruit[16]. Hot water treatment is generally a difficult and expensive process, because the fruit temperature will change the water temperature during dipping.

Heat treatment has also been tested for insect control, particularly for quarantine purposes. This is done by keeping fruit such as papaya and mango in moist heat (44°-49°C) for one to several hours. A 1985 report[1] on an experiment carried out in the Philippines indicated that a treatment which maintained the core temperature of mangoes at 46°C for ten minutes resulted in the perfect disinfestation of fruit fly without impairing the market value of the fruit. However, a more recent report[2] has indicated that such treatment can cause severe breakdown of mango flesh. Further studies and development of this "high technology" seem to be needed.

Refrigeration

Refrigeration is a well established method, and is the most effective way of extending the postharvest life of fruit. The most desirable temperature range for each of many important kinds of fruit is given in the USDA Handbook No. 66[15] referred to on p. 1 above. The handbook also provides information on the approximate lowest safe temperature for each chilling sensitive fruit and the highest freezing temperature for each fruit covered in the handbook. The lowest non-injurious temperatures differ, not only between species, but also between varieties of the same species. The growing conditions and harvesting time of a fruit can also affect its sensitivity to low temperature injury.

Refrigeration is generally very costly. Mechanical or vapor compression refrigeration systems require electricity. Where there is a cheap heat source, such as geothermal or solar energy, or methane gas generated from animal wastes, the use of an absorption refrigeration system can be considered.

When using refrigerated storage or transportation, water condensation and water loss problems should be considered. When refrigeration is discontinued and cold fruit is exposed to warm air, water condenses on the surface of the fruit. This may not cause serious problems for some fruits, but may cause rapid deterioration of some other fruits such as strawberry. Poorly designed refrigeration rooms or chambers may have very low humidity, and hence cause rapid water loss and shrivelling of fruit.

Controlled Atmosphere and Modified Atmosphere

Controlled atmosphere (CA) storage is used extensively for apples and pears all over the world. The CA storage conditions for these two fruits, and various aspects of CA technology, have been summarized by several writers[4,5,26,30]. Twenty-two other kinds of fruit have also been reported to have a moderate to excellent potential

of benefitting from CA storage or transportation[17]. These are: apricot, avocado, banana, blackberry, blueberry, sweet cherry, cranberry, fig, grape, grapefruit, kiwifruit, lemon, lime, mango, nectarine, papaya, peach, persimmon, pineapple, plum, raspberry, and strawberry[17]. Probably the list will grow further as more fruits are tested, and as further improvements are made in CA technology. Some of the fruits mentioned above benefit from reduced O_2, some from high CO_2, and some from combinations of the two. Some fruits, such as grapes, which do not benefit from low O_2 and high CO_2 due to decay problems, can benefit from CA to which has been added about 10% carbon monoxide[33]. Application of CO is effective in controlling postharvest decay in some fruits, but unfortunately the gas is very toxic to human beings, and is therefore difficult to handle.

While large CA storage units are costly, small cheap polyethylene chambers can be made for storing smaller quantities of fruit. The chambers can be placed in refrigerated rooms, common storage rooms, or caves. Apple growers in northern China store apples in polyethylene tents, with silicone rubber diffusion windows to control O_2 and CO_2 concentrations, with considerable success. The results are somewhat inferior to modern CA storage, but substantially better than air storage.

Practically all fruits which have a positive response to CA storage are also potentially successful in modified atmosphere (MA) storage in sealed polymeric film. The benefits of MA storage for bananas were demonstrated many years ago[20, 21] and it has now some commercial use for shipping bananas particularly varieties which have a short preclimacteric life in ordinary air. In the long-term storage of bananas in polyethylene bags, decay of the stem tissue, beginning from the cut surface, is a major problem. In order to reduce decay, bananas can be stored in bunches rather than in hands, sealed inside polyethylene bags with ethylene absorbents[18].

While MA storage or shipping seems to have great potential, it has not been very successful for many kinds of fruit, despite numerous experiments conducted by many researchers. The two main difficulties are that it is hard to maintain the stable O_2 and CO_2 levels desirable for fruit inside sealed bags, and that water condensation inside the sealed bags increases the rate of fruit decay. Misuse of this method can cause heavy losses, due to low O_2 and/or high CO_2 damage and decay. Future development of this method depends on the production of improved plastic or other film.

Common Storage and Underground Storage

Common storage, underground storage and cave storage are old methods which have not received enough attention from researchers in developed countries in recent years. Very few new publications on these methods are being published, although they can be very useful in subtropical and temperate zones. Synthetic as well as natural insulation materials can be used to insulate common storage chambers. Storage temperatures can be maintained at a level substantially lower than daytime ambient temperatures by proper control of the storage ventilation. This is particularly true in the winter, spring, or fall seasons in subtropical areas, when there are cool nights. When there is no cool ambient air available for cooling, evaporative cooling can be used to help reduce the storage temperature.

Many citrus fruits are stored in common storage chambers during the winter in Taiwan and Japan. Improved facilities and storage methods can significantly reduce storage losses. Many citrus fruits are stored underground in southern China, and cave storage is an important method of storing apples in northwest China, where large quantities of apples are stored in CA or MA tents in caves. The soil surrounding the underground or cave storage regulates the temperature of the storage systen. However, the quantity of fruit and the surface area of the storage have to be balanced, so that the

soil will not be heated up too much by the heat from the fruit respiration. Ventilation should be controlled in such a way as to make full use of cool night temperatures, and effectively protect the storage system from daytime ambient heat.

Other Treatments

Waxing is used for many fruits, including citrus fruit and apples. Its effects in controlling transpiration water loss and improving the appearance of the fruit can be very significant. Wax can also serve as a carrier for the fungicides and growth regulators which are to be applied postharvest to the fruit. Many researchers have attempted to use waxing to generate modified atmosphere conditions inside the fruit, in order to extend the shelf life, but with very limited success. The difficulty is similar to that encountered when using sealed polymeric film: the coating materials (waxes) and the thickness of the coating determine the gas diffusion rate, and it is simply too difficult to find an ideal material, and to coat the fruit with it at an ideal uniform thickness to generate the desirable MA in the fruit. Nevertheless, research in this field is still active, and new coating materials are frequently being introduced.

The use of ethylene or ethephon to ripen fruit is an established technique. Proper application of ethylene at the right time can reduce postharvest losses. Application of ethylene to avocado induces ripening of the fruit, and makes the fruit less sensitive to chilling injury and more tolerant to longer periods of storage at 2°C[10]. Ethylene treatment for mango before or during shipping increased the acceptability of the fruit to consumers[3]. Ethylene treatment is particularly important for specialty fruits, since neither retailers nor consumers know how to ripen them or when to consume them. I recently heard that some unripe sweetsops were kept on a refrigerated shelf in a Taipei supermarket, and that neither the seller nor the customers knew what to do with the fruit. Customers who bought the fruit out of curiosity had to throw them away, because it was 'inedible.' If the fruit had been ripened with ethylene before being sold, such a loss could have been avoided.

Irradiation has been tried as a means of extending the postharvest life of fruit. Maxie *et al.*[25] concluded in 1971 that it was unfeasible to irradiate fruit and vegetables. However, it may still be possible to use irradiation as a quarantine treatment for fruit to disinfest it of insects[7,31]. The interest in fruit irradiation has grown considerably since EDB was withdrawn from registration in the United States.

DEVELOPING PRACTICAL HANDLING METHODS AND FACILITIES TO MEET REGIONAL NEEDS

A comprehensive understanding of the fruit itself, a thorough knowledge of the food systems in which the fruit is to be handled and marketed, and an extensive review of both old and new handling methods and facilities in use in different parts of the world, provide the basis for developing practical new technology. A strong national or regional program of applied research will be needed to produce such information. This is the foundation for all future extension and education programs for postharvest loss reduction and quality maintenance of fruit crops. The stronger the foundation, the more effective will be the future programs.

The next step should be to identify the major causes of postharvest losses of both quality and quantity, and find out where the losses occur and why. A working group consisting of experts possessing the relevant knowledge described above should be able to identify problems easily. A survey covering major sections in the food system may be necessary.

Probably many problems can be solved without developing new methods, by introducing effective education and extension projects. If new methods or facilities seem to be necessary, a brain-storming approach among experts is recommended, in order to select appropriate methods or facilities. To adopt existing

methods or technology is easier than inventing new ones, and should therefore be given higher priority. Modifying existing technology or facilities to suit regional needs might also be considered. Some old methods may be even more useful than new ones, and therefore should not be neglected. Simple and inexpensive technology and facilities have a better chance of being accepted by those concerned with handling fruit, and should therefore be given higher priority than sophisticated and expensive ones.

Once the candidates of technologies or facilities are identified, 'imagined experiments' should be conducted before real experiments take place. This means that a group of experts should use their imaginations to predict what might happen if the selected technology or facilities were to be used. How well might they fit into the current system? Will their adoption require changes in other sectors in the system? If so, how difficult will is it be to make such changes, and how can they best be made? What will be the cost, and how much benefit can be anticipated? If additional cost is anticipated, will the consumer be able to pay for it? If the answers to these questions favor the adoption of the new technology or facilities, the chances of success are great; if not, the chances are slim. ***The success of a technology depends on the whole system, and not only on the technology itself.*** If the technology or facilities do not pass the imagined experiment, they should probably not be tested in real experiments at all. It would probably be better to look for a new alternative.

If the selected technology or facilities pass the mental experiment, they can then be developed and tested in a selected location. Further modification or improvement may be necessary. If the test is successful, demonstration and extension programs can follow. The development of the new technology or facilities can then be considered complete.

These steps seem to be very obvious, and to contain nothing new. However, too often programs are being implemented in the wrong order. The most common mistake is to introduce a piece of new equipment abruptly into a system which is not yet ready to accept such equipment. For instance, a hydrocooler is of little value if the transportation trucks or rail cars are not refrigerated, or even insulated, so that the precooled fruit warms up quickly during transport. A mistake of this kind can easily be made if the decision maker does not use the brains of experts who understand the fruit, the system and the technology. Aggressive merchants are often very persuasive in selling their equipment and facilities.

The development of postharvest technology and facilities should advance at roughly the same pace as economic growth and a national increase in personal incomes. Postharvest scientists and technologists should have good judgement as to what level of technology should be adopted at present, and what level in the projected future. They should develop technology slightly ahead of the time of need, if resources are available.

THE NEED FOR COORDINATED PROGRAMS

Although the development of new practical methods and facilities seems to be the responsibility of researchers or R&D* workers, its success depends on well coordinated programs. Since the application of new methods or facilities involves direct users as well as other sectors in the food systems, and may indirectly affect growers and consumers, research programs should coordinate with extension and education programs. Researchers also rely heavily on extension workers to collect information about users' needs and users' input, with regard to the performance of new facilities or the usefulness of new methods.

Coordination between R&D workers, policy makers, funding agencies, and management or administrators, is of utmost importance. Management and funding policies have a great

* *R&D: Research and Development.*

impact on the achievement of R&D workers. If the goal is to develop practical methods, the R&D workers should be carrying out mainly applied research, and should be evaluated according to the usefulness of their work, not according to the number of papers they publish. A project often fails because the goals or objectives are not clearly indicated, or because the evaluation standards for workers do not coincide with the goals. Overemphasis on publication is a very common mistake. Many practical methods are neither new nor fancy, and might therefore not be publishable in scientific journals. However, for practical purposes, R&D workers should be encouraged to review and repeat other people's work, and to revise or modify old or existing methods to make them useful to the local situation.

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IDENTIFYING THE MAGNITUDE AND CAUSES OF POSTHARVEST LOSSES OF SUBTROPICAL FRUITS

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ABSTRACT

The determination of the causes and extent of postharvest losses for any type of fruit is an inexact science as standard statistical analysis is often precluded by unknown or uncontrollable variables. Published estimates for postharvest losses of subtropical fruits run as high as 50%. Marketing studies are usually expensive and inexact. It is strongly recommended that prior baseline data be gathered on potential postharvest life and on losses in simulated marketing studies. Reducing postharvest losses starts with the education of all concerned. Simple, homemade field packing equipment is described.

INTRODUCTION

For the purposes of this review, subtropical fruits are considered to be non-temperate zone fruits commonly grown in subtropical latitudes, e.g. in Southern California, the Bahamas, Southern Florida, Kyushu (Japan), subtropical Chile and the Mediterranean coast of North Africa.

As Mukai[36] and Moline[35] have recently pointed out, the determination of the causes and extent of postharvest losses of fruit and vegetables is an inexact science at best: too many variables are usually unknown or uncontrollable. Fruit is a product which is inherently designed to 'self destruct' as, botanically, its role is to release seeds, for which decay or disintegration of the fruit is necessary. This is particularly true for tropical and subtropical fruits, which lack any mechanism for winter dormancy. Such fruits tend to be inherently frail and most are susceptible to chilling, which severely limits the use of refrigeration to prolong postharvest life. Moreover, very few subtropical fruits have been studied in such exhaustive detail as that quintessential temperate zone fruit, the apple, or the banana, the major tropical fruit of international commerce. An exception is citrus, concerning which many examples in this discussion will be drawn.

In general, the extent of typical postharvest losses of subtropical fruit is simply not known. In a 1984 review, Kelman[30] stated that losses of perishable crops in developing countries are commonly as high as 30%. A 1978 report cites far higher figures than this for fruit in some developing countries[38]. A 1980 report from Sri Lanka estimates losses of horticultural crops as between 15 and 50%[37]. Certainly, postharvest losses are commonly far too high. They can be reduced considerably by intelligent study, coupled with constant education of all concerned.

ESTIMATION OF POSTHARVEST LOSSES

Potential Postharvest Life

A neglected field of study is that of determining what the *potential* postharvest life of these fruits may be. Studies of postharvest losses usually fail to start from the ultimate baseline: What would have been the life of the fruit if it had never been handled at all? To attempt to determine this, the senior author has occasionally used 'non-handled controls'. Two results with citrus can illustrate

what is meant. The first was during a season in which postharvest losses of Florida Dancy tangerines were particularly costly. The 'non-handled control' tangerines were clipped on long stems and lowered gently into a carton, while the stems were then clipped closely without the fruit being touched. Thus the fruit was never actually handled. The regular control sample (without a fungicide) was picked from the same trees by the experiment station field workers and run through the packinghouse for the then standard dump-wash-polish-wax-pack treatment. After two weeks at 21°C, only 1% of the 'non-handled control' had been lost from decay, while 20% of the 'regular control' had been lost. Subsequent checking of each stage from tree to packing showed that about a third of the damage was being done by the pickers, and most of the rest of the damage came from an unexpected source, the polisher brushes. This latter finding was then confirmed in a large-scale study in a commercial packinghouse[22]. Another striking example of the value of a 'non-handled control' was in investigating a report of supposed 'gas burn' (ethylene injury) on Texas Marrs Early oranges, a very tender variety. Only the 'non-handled control' was free of the supposed 'gas burn' which was really oleocellosis[9,23] due to picking the fruit too early in the morning, when it was still too turgid.

Simulated Marketing Studies

Our long term experience at Lake Alfred in Florida has been that, having observed postharvest losses in the market place, the best way to initiate studies of the origins of such losses is to carry out simulated marketing experiments. These can be very helpful if repeated systematically, *providing they replicate marketing conditions faithfully.*

Plastic film bags are about as hostile a container as can be used for subtropical fruit. In the 1950's, when plastic bags were first introduced for citrus in the U.S., a simple 'holding study' indicated that as few as four 1/4-inch (6.35 mm) holes in a five pound (2.27 kg) bag provided adequate ventilation. Nevertheless, reports of serious losses in the market place continued. An elaborate and expensive shipping test, involving laboratories in Orlando, Lake Alfred and New York, failed to indicate the basic cause of the trouble[4,6]. A series of simulated shipping tests with packages instrumented for temperature and humidity, and handled exactly as for transit and marketing, revealed the cause of the problem[1,3]. When the fruit was taken from the refrigerated truck or cool store, condensation rapidly disappeared from the fruit stored in net bags, but persisted almost indefinitely inside heavily perforated plastic film bags. Water gathered where the oranges touched the plastic film for long enough to rupture epidermal cells by endosmosis, allowing the entry of fungi.

Basis for Evaluating Losses

Many of the concepts of 'loss' used in various conferences on food losses, (e.g. the National Food Loss Conference held in U.S.A.[5,7]) cannot be applied to subtropical fruit. Decay can be calculated as the percentage of spoiled fruits, but one rotten fruit may soil several others and make them all unsaleable. Most subtropical fruit are 80-90% water, which is nutritionally useless in itself but a water loss of 5-10% can result in a shrivelled, unsaleable fruit that may also have a poor flavor[2,5]. Various peel blemishes (pathological or physiological) can render fruit quite unmarketable. An apparently sound fruit can develop an internal breakdown (which, again, can be pathological or physiological). Only too often industrious research workers gather a mass of data on what is, in effect, a dying sample, so that the result is statistical chaos. One way to avoid this is to reduce observations arbitrarily to some simple, useful, manageable denominator. In many of our studies on packaged citrus, a very useful column on the examination sheets has been headed 'MCI' (= Mad Customer Index!). That is simply the percentage of packages that contained one or more decayed or otherwise inedible fruit. No customer wants to buy such a package, nor does any wise retailer want to sell it. Gathered over a long period, these single figures for each treatment in each experiment can be manageable.

Problems of Statistical Evaluation

As Mukai has recently pointed out[36], standard statistical analysis of postharvest observations over a limited period can be useless. A great many observations over a long period *may* overcome the unseen variables of weather, time of day of harvest, degree of fruit maturity, etc. that can result in extraordinary variability. Table 1 shows a simple comparison of decay in 'Pineapple' oranges picked six times from the same row of trees at approximately weekly intervals. Each picking included fruit from every tree[13]. From each picking, 20 mesh and 20 polyethylene bags were packed. If the experiment had been limited to the December 1, 8 and 29 picking dates, any deleterious effect of poly bags would have seemed minor and mathematically not significant. However, if picking had been limited to December 13, January 5 and 12, the obvious conclusion would have been that the use of poly bags without precooling or fungicides is disastrous. We still do not know the reason for these drastic differences between six successive pickings from the same row of trees. However, one factor that has been established is that the time between picking and waxing can be a serious consideration[34].

Table 1. Decay in simulated 'retail scale' of Pineapple oranges without fungicides or precooling, following six days 'transit' at 15.5°C plus four days 'marketing' at 21°C

Harvest date 1958-59	% decayed fruit		% bags with rot	
	mesh bag	poly bag	mesh bag	poly bag
December 1	0.0	0.9	0	15
8	0.0	1.8	0	30
13	2.5	24.9	45	100
29	2.5	4.3	45	45
January 5	1.9	9.7	25	70
12	2.0	20.0	25	90
Average	1.5	9.9	23.3	58.3

Source: Grierson, W. 1962[13]

One extremely successful statistical study related to the tolerance of Marsh grapefruit to cold storage temperatures. For five years grapefruit were picked randomly along the same row of trees approximately 20 times each season. For each picking, data was reduced to a single figure of 'days in storage at 4.5°C before appearance of incipient chilling injury'[15,17]. Tolerance for that storage temperature ranged from a low of 10 days to a maximum of 73 days. Because the experiment station is also a weather reporting station, a statistically minded graduate student was able to derive correlations between winter temperatures, $r = 0.963$ ($p = 0.01$), pan evaporation, $r = 0.933$ ($p = 0.01$), and tolerance to storage at 4.4°C[29]. Later work indicated that such tolerance to refrigeration was associated with an increased level of reducing sugars in the peel[41], and may be controlled by stress-induced changes in growth regulator levels[23]. Two other statistical studies correlated rough harvesting with subsequent susceptibility to deformation of Marsh grapefruit[43] and development of off-flavors in Orlando tangelos[27]. However, both these studies involved many harvests meticulously replicated throughout a harvesting season.

Role of Variety (Cultivar) and Growing Area

Of all the subtropical fruits, citrus and avocado have been studied in most detail. Nevertheless, even for these two well-studied genera, it can be dangerous to assume that findings (particularly within a single growing season) on an individual variety or within a given district can be applied generally. Thornton[47] has also pointed out that, because large areas of the tropics and subtropics are mountainous, results should also be checked at various altitudes within a given district. In exploratory studies to find suitable fresh lemon cultivars and handling methods for Florida[12], 13 cultivars were cured after harvest in four types of pack, one of which involved the use of a polyethylene carton liner[13]. The response of only two varieties is shown in Table 2. Both varieties were picked from the same grove on the same day. If we had worked

Table 2. Percentage decay in two varieties of Florida-grown lemons stored for 30 days at 15.5°C in cartons with and without polyethylene liners

Cultivar	Without liner	With liner
Sicily	7.9	6.9
Parman	0.0	76.2

Source: Grierson, W. 1962[13]

only with the Sicily variety, we would probably have advocated curing in polyethylene box liners. This could have been disastrous with other cultivars.

Success in extending the shelf life of California avocado varieties Fuerte and Hass grown in New South Wales in Australia, by infiltrating the fruit with 4% $CaCl_2$[52], could not be duplicated with Florida-grown Reed and Monroe avocados, due to a prohibitive increase in decay[8]. There is a fairly extensive literature on the postharvest treatment of citrus and avocado. The situation is more difficult with the more exotic subtropical and tropical fruits that are becoming increasingly popular, certainly on the U.S. market[32,45]. About 20 years ago, we carried out a two-year study of the postharvest characteristics of the carambola or starfruit (*Averrhoa carambola*), working with the Golden Star cultivar[24,49]. We reported, to our surprise, that carambolas were totally resistant to chilling injury. In the intervening years, various new varieties have been introduced into Florida[3], and plantings have increased to the point where a major shipper put many fruit in cold storage to tide over a temporary glut. All except Golden Star were destroyed by chilling injury. A very recent report[31] confirms the poor keeping quality of two recent selections, thus illustrating the importance of selecting any fruit for marketability[2] as well as for palatability and appearance. A further complication is that durability at various storage and transit temperatures may be greatly influenced by maturity and/or ripeness, as in a report of the holding quality of three Israeli avocado cultivars[54]. Fruit placed in cold storage when semi-firm or soft tolerated low temperatures better than firm fruit.

The pitfalls in postharvest studies of such fruits are many. It is best to use small, frequently replicated studies which span as many variables as possible.

Reported Postharvest Losses

Actual postharvest losses are very difficult to ascertain. However, such wastage has been closely monitored by the U.S. Department of Agriculture for several crops, including citrus, marketed within the U.S.A.. Table 3 shows figures extracted from a 1976 review of these studies[40]. Pentzer attributes the sharp decreases in average losses between the two ten-year periods to the development of effective fungicides and improvements in storage and transit refrigeration. Not only are such improved techniques often not available for many other subtropical fruits, particularly in the less developed countries (LDCs), but they take no account of losses after retail sale. A later closely controlled study[4] reported that, within the U.S.A., losses of fruit at the consumer level were approximately double those up to the point of retail sale. For oranges this figure was x 1.82. Various simulated marketing studies confirm this for oranges[18,21], but indicate that post-purchase decay of specialty fruits (tangerines, tangelos, tangors) could be ten times higher than such losses up to the point of retail sale, when fruit is held under 'fruit bowl conditions' at 21°C[19].

Table 3. Losses in marketing of citrus fruits within the U.S.A., comparing the averages for two successive ten-year periods

Product	Average % loss over 10-year period	
	1942-1951	1951-1960
Grapefruit	13.0	2.0
Oranges	15.3	1.4
Tangerines	16.0	7.0

Source: Pentzer, W.T. 1976[40]

Reducing Postharvest Losses

Education

The reduction of postharvest losses starts, not with expensive chemicals and equipment, but with the education of everyone involved in growing, picking, handling and marketing these frail fruits. Everyone involved needs to understand that fruit is *alive*, and that profits for any of the people involved in their production and marketing come only from *repeatedly* placing a healthy, attractive, living product in the hands of the ultimate consumer[16]. This 'human factor' is so important that it has been suggested that sociologists and psychologists be invited to join horticulturists, engineers, economists, etc. in efforts to get more fruit to the consumer in better condition[53].

Picking

More fruit is probably lost due to careless picking than to any other cause. Fruit should be picked carefully, preferably into rigid containers holding not more than 20 kg of fruit. Picking containers should be emptied *carefully* into whatever field containers are being used, and these should be shaded until they are picked up. When postharvest losses are serious, the first thing to check is the quality of the picking. (See comments on comparison of regular and 'non-handled' control samples above).

Rough, careless picking can cause many troubles other than decay. As noted above, strong statistical correlations have been obtained between poor picking practices and later susceptibility to deformation in grapefruit[43], and the development of off-flavors in tangelos[27]. Stylar-end breakdown is a major cause of market losses of seedless Persian (Tahiti) limes. This can almost all be attributed to rough picking[26]. Only too often there is an attitude whereby the grower tolerates poor picking, thinking that consequent troubles can be amended with packinghouse treatments such as fungicides and waxing. Only too often this proves to be a fallacy.

Sanitation

This is again a matter of education, as it is very hard for most workers to imagine that discarded fruit, plant trash, dirty containers, etc. can be putting out untold millions of spores that can rob them of future pay checks. It *is* possible to educate such workers. These authors observed strawberries being picked in Spain, where each picker had a small, marked container into which any damaged or diseased berries were placed. At the ends of the rows were plastic bags into which these containers were emptied, the bags being closed and buried when full. It is no coincidence that the company involved (Pascual Hermanos S.A.) is one of the most successful produce companies in Europe.

For some subtropical fruits, particularly papaya[7,33], there is general agreement that fungicidal spraying of the tree prior to picking is necessary if the fruit are to be shipped any distance. When this is done, attention should be paid to using fungicides from different groups to avoid the selection of resistant strains of fungi in the field that can then make any postharvest fungicidal treatments ineffective.

Field Packing

Many subtropical fruits are being produced by small growers who lack packinghouse facilities. For these, field packing is a practical approach to marketing, but it should *not* be done squatting on the ground pawing over piles of fruit. Fig. 1 shows a simple thatched shelter that is adequate for protecting the fruit, the workers, and the shipping containers from the sun and rain.

Tender fruit should *never* be dumped on a flat table. Fig. 2 shows a simple packing station that any carpenter can make. Note that there are two of these 1.25 m units side by side in the shed shown in Fig. 1. The following excerpt is taken from a recent field packing manual[16]:

> 'Containers for packing are set along the packing ledge. For an export pack you may need to have cartons ready for two or more

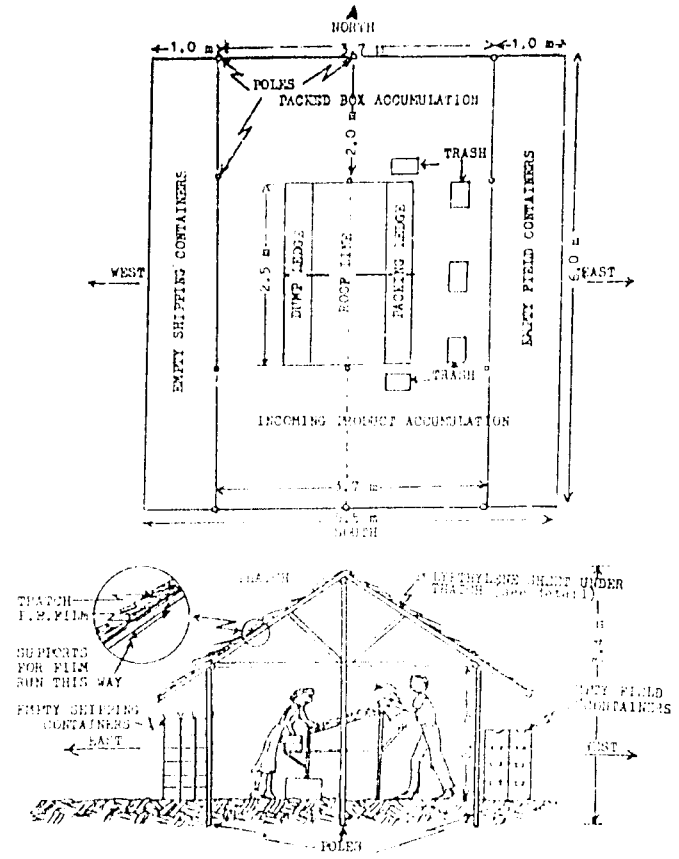


Fig. 1.
Field Packing Station. Constructed entirely of local native materials except for 34 m² of builder's 0.15 mm polyethylene film. From Grierson[16].

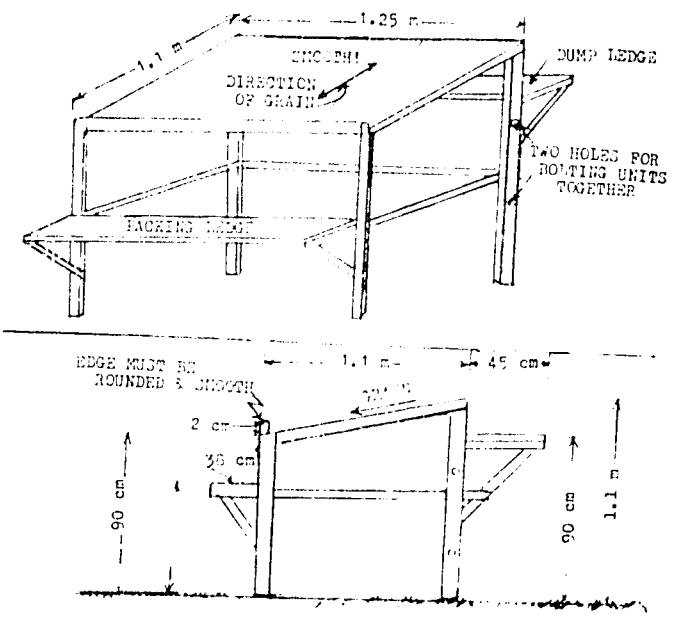
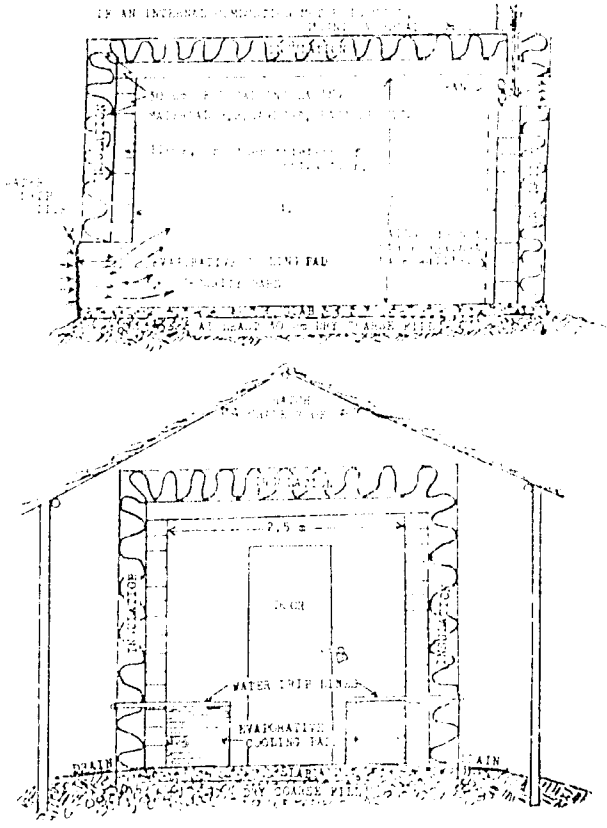


Fig. 2.
Field Packing Stand. Shown here as a single 1.25 m section. Several such sections can be used together, as in the two-unit assembly shown in Fig. 1. Note that the height of the stand may need to be adjusted to suit the stature of the workers. From Grierson[16].

sizes and always a carton or other container off 'off-grades' to be sold locally. Also have containers ready to receive trash. The containers of field-run produce are set on the dump ledge and tipped so that the fruit roll out gently onto the sloping surface towards the packers who then have to make their decisions. Export grade? Large, medium or small size? and so on. DON'T DITHER! Once a fruit is picked up, do something definite with it! (It can be very helpful to have examples of allowable grades and sizes stuck on spikes where the packer can see them constantly). Once picked up, that fruit should go into its proper place with no further handling. Cartons should be packed so that the contents are snugly stowed and cannot rattle around. But do not overfill which causes great damage when the cartons are eventually stacked in highway trucks.'



Cooling and Humidity Control

Mechanical refrigeration is usually beyond the capability of any small grower who is field packing. Attention to humidity control is far more practical, and is often as beneficial for tropical and subtropical fruit as refrigeration (which can be a dangerous tool if overused). Although humidity control is usually thought of as affecting only shrinkage, it can also have profound effects on fruit physiology[15]. A simple evaporative cooler can be made using local materials. One University of California design[4] can give surprisingly effective cooling in arid climates, but needs electrical power. A small internal combustion engine can be used (Fig. 3) if electricity is not available[16]. Even in humid climates, such an evaporative cooler provides some cooling, and the fruit are meanwhile held in nearly 100% relative humidity while awaiting packing. A practical approach is to put fruit picked in the heat of the day in such a cooler overnight. The next morning it is packed without the field heat it held at time of picking.

Fig. 3.

A Simple Basic Evaporative Cooler. If constructed on a concrete slab over at least 30 cm of well drained coarse fill, it can later be converted to mechanical refrigeration, particularly if a vapor barrier of sealed polyethylene film is laid under the concrete slab. From Grierson[16].

Washing

Washing, brushing and polishing should all be avoided if possible. As M.N. Chiang demonstrated in Taiwan 24 years ago[6], washing citrus fruit in pails or tubs drastically increased the rate of decay. Moreover, if fruit is submerged and if the fruit is warmer than the water, contaminated water is drawn into the fruit with obviously unfortunate results[1]. Admittedly, washing reduces certain types of decay in citrus fruit[10], but this is reported by research workers using packinghouse equipment with non-recovery rinses, not washing by hand in tubs or pails. Under field packing conditions, the most that should be attempted is wiping the fruit with cloths frequently dipped in water containing about 30 ml of household bleach per liter.

Fungicides

Fungicidal treatments are, in general, impractical for a field packing operation with one exception. This is a field treatment with 2-aminobutane (*sec*-butylamine) vapor that has proved to be surprisingly effective on citrus fruit[20]. (NOTE: Liquid 2-AB can be explosive and should be handled with the same precautions as for gasoline). We do not know if this treatment is effective on other subtropical fruits. At present, 2-AB has a temporary tolerance under the Codex Alimentarius and is acceptable on citrus fruits in nine countries[5].**

Packinghouse Operations

We have probably exceeded the terms of reference for our assigned topic, but we cannot leave postharvest handling of subtropical fruits in LDCs without expressing agreement with Mittendorf[37] in his view that too much money and effort is commonly expended on buildings and machinery, and too little on relatively inexpensive 'appropriate technology'. That said, we will only note, for the benefit of large-scale packinghouse operations (as for avocados in California and Florida, papayas in Hawaii or citrus in Brazil), the following points: (1) All the above comments on care in harvesting, scrupulous sanitation, prompt humidity control, etc. apply just as much for large commercial orchards as for the small grower-packer. (2) It might be helpful to draw attention to certain recent publications, which merit the attention of any organization with technical staff able and willing to use the advice therein, adapting it to their own local needs. *Postharvest Technology of Horticultural Crops*[28] gives a wealth of detailed information on the postharvest handling of a wide range of horticultural crops, including various subtropicals such as avocado, fig, guava, papaya and citrus. *Fresh Citrus Fruits*[51] deals in depth with the postharvest handling of citrus fruits, including such aspects as the tolerances for pesticide residues found in various countries. Much of the advice is applicable to subtropical fruits other than citrus. *Handling and Storage Practices for Fresh Fruits and Vegetables*[42] deals exhaustively and cheerfully with the handling of Australian horticultural crops, including various subtropical fruits. *Tropical Fruits*[44] differs from other apparently similar texts in that chapters on the growing of most fruits include a section on 'From harvest to consumption'. A recent review article[11] deals specifically with chemical control of postharvest diseases of subtropical and tropical fruits. A more specific, and even more up-to-date review[9] covers, in considerable detail, chemical decay control for citrus fruits.

CONCLUSION

Like all fruit, subtropicals are alive and subject to physiological and pathological diseases just as we are. Those who handle the fruit like newborn babes merit the financial return the fruit can bring to the grower, farm hand, picker, packer, truck driver, merchandiser and all others involved. If anyone along this long marketing chain handles the fruit differently, the money will not flow back from the ultimate retail customers to pay all involved in their production and marketing. 'The strength of a chain is in its weakest link', which is, all too often, the little regarded picker.

** Because 2-AB has not proved to be economically competitive in commercial packinghouse use, its clearance under Codex Alimentarius and its manufacture in the U.S.A. (by Eli Lilly & Co., Greenfield, Indiana) may be discontinued. Its use within LDCs will depend on local regulations, if any, and the availability of 2-AB.

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DISCUSSION

Q. (S K. Sun)
The Tables in your paper indicate the rates of decay and rot for various types of citrus. To what type of decay do you refer?

A. In Florida oranges, *Diplodia* stem end rot was the worst, while *Penicillium* green mold did much less damage. Either kind of rot was increased by rough handling. The spores of *Diplodia* are waterborne, and are kept out of the fruit at the stem end by a membrane which is broken by rough handling.

Q. (W.J. Ho)
Table 2 in your paper shows the difference in the rate of decay in lemons of two varieties, Sicily and Parman. Were they picked at exactly the same time? Did you observe any major differences in the texture or structure of the rind in the two varieties, which might influence the rate of decay?

A. Both varieties were picked from the same grove on the same day by my own assistants. Parman lemons are large with a smooth skin, while Sicily lemons are smaller -- I don't know if this may have been part of the reason for the difference in their rate of decay.

Section II.

Postharvest Handling of Fruit in Asia: Some Country Reports

24a

PRESENT STATUS AND PROSPECTS OF POSTHARVEST HANDLING OF TROPICAL AND SUBTROPICAL FRUITS IN MALAYSIA

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ABSTRACT

Malaysia produces a wide range of seasonal and non-seasonal fruits. Some of the non-seasonal fruits are banana, papaya, pineapple, starfruit, guava, watermelon and sapota, while popular seasonal fruits include rambutan, durian, mango, mangosteen and duku langsat. Efforts to increase production and improve postharvest technology are now under way, and have been given extensive Government support.

INTRODUCTION

Malaysia comprises Peninsular Malaysia (bordered by Thailand in the north and Singapore to the South), and the states of Sabah and Sarawak on the island of Borneo, which lies 700 km to the east across the South China Sea. Peninsular Malaysia covers an area of 132,000 km^2, while Sabah and Sarawak have a combined land area of 198,000 km^2. The capital city, Kuala Lumpur, is located on the west coast of Peninsular Malaysia, and has a population of approximately one million people. Agriculture represents about 26% of the Gross Domestic Product.

Malaysia produces a wide range of seasonal and non-seasonal tropical fruits which are both delicious and nutritious. Some of the non-seasonal fruits are banana, papaya, pineapple, starfruit, guava, watermelon and sapota, while popular seasonal fruits include rambutan, durian, mango, mangosteen and duku langsat. The seasonal fruits are available once or twice a year, and their main fruiting season is from mid-June to mid-August. The time of the minor fruiting season is less clearly defined, but normally occurs from December into February. The fruiting season can fall a month or six weeks earlier or later, depending on the location.

There is tremendous growth potential for the Malaysian fruit industry, in view of the increasing demand in both domestic and export markets. It is planned to expand fruit production from 76,500 ha in 1980 to 263,000 ha by the year 2000. This is in line with the National Agricultural Policy (NAP), a program for national agricultural development in Malaysia up to the year 2000. This policy emphasizes increased food production, for both national self-sufficiency and export.

In recent years, the quantity of fruit exported has expanded considerably, from 71,448 mt (valued at US$6.69 million) in 1978 to 110,448 mt (valued at US$14.33 million) in 1984. The most important overseas market for Malaysian fruit is Singapore, while exports to other countries such as Hong Kong and Japan are gradually increasing. It is realised that, besides the production of higher quality produce, the industry also depends greatly on the availability of appropriate postharvest handling technology.

STATUS OF POSTHARVEST HANDLING

Postharvest handling is considered a major problem in the development of the fruit industry in Malaysia. Rough handling often results in severe damage and losses to the fruit when they reach market. The need for proper handling of produce at a postharvest stage is not given proper attention, as in most cases better handling practices may not necessarily benefit the fruit producers, in terms of monetary return. However, better handling systems have been practised by some growers on highly priced fruit such as starfruit and guava, for selected markets. These systems, however, still need further improvement.

Harvesting

Different kinds of fruit require different methods of harvesting. Some fruit are harvested by hand, using clippers, secateurs or knives. Fruit borne on high branches present a problem. Commonly, a long pole with a bag attached to the end is used in picking. Other means of reaching high fruit are ladders, or climbing the tree. In the case of durian, the fruit is normally allowed to drop onto the ground when it is fully ripe. Determination of fruit maturity is done visually, as most fruit growers have a good deal of expertise in harvesting fruit, gained by long working experience.

Infield Handling

Generally, handling on the farm is not a major problem for most fruit growers, since most orchards are small in size and the fruit is sold locally. Harvested fruit is transported by various means, such as bicycles, motorcycles or Landrovers. Containers such as baskets made of woven bamboo or rattan, or wooden crates, are often used, although both banana and pineapple are handled without the use of any container.

Many banana farms are located a considerable distance from main roads, to which they are connected by narrow, rough jungle tracks which can only be used by small vehicles. The bananas are crowded into these, to be transported to the main roads for collection by larger vehicles. This practice often results in quality deterioration of the fruit, due to severe mechanical injury during transportation[7]. Due to this problem, bananas from such areas can only be marketed locally or in countries where high quality is not a major requirement. With the increase in export demand for good quality fruit from countries such as Hong Kong and Japan, farmers are now becoming more careful in selecting the location of their orchards.

Most pineapple in Malaysia are grown on peat soils. This type of soil poses another problem in on-farm handling, since it does not allow heavy vehicles or machinery to be used. In a country where insufficient farm labor is a major concern, such a factor is a major drawback in the development of fruit production, and is one of the reasons for the decline of the pineapple industry over recent years.

Another problem being faced by fruit growers in highland areas such as the Cameron Highlands, the major producing area for citrus, is severe virus infestation. Although this highland region is more suitable for citrus cultivation than the lowlands, disease problems are so great that production is insufficient even for local consumption. The area of citrus orchards has remained static at around 240 ha. This is largely because of virus disease, but is also because the steep slopes of the highlands make harvesting and postharvest handling difficult, particular in view of the highly perishable nature of the fruit.

Packinghouse Operations

Some fruit is packed on the farm in small packing sheds. The only packinghouse operations commonly practised by fruit growers are to sort fruit according to the grades agreed between seller and buyer, and place the fruit into containers. However, proper packinghouse opera-

tions have been practised by several large fruit producers and exporters. One such organization is the Food Industry Marketing Authority (FIMA), which has been actively involved in promoting large-scale cultivation of mango in the northern states of Peninsular Malaysia. Another active organization is the Federal Agricultural Marketing Authority (FAMA) which has constructed 24 large, modern packinghouse complexes. The Boh Plantation in the Cameron Highlands, which is involved in producing and marketing citrus, is another good example of large-scale packing operations, since it is equipped with the most modern packinghouse line for citrus in Malaysia.

Grading

Fruit grading practices in Malaysia are generally based on prearanged agreements between buyers and sellers. Although uniform standards for some types of fruit have been produced by the Standards and Industrial Research Institute of Malaysia (SIRIM), they have not been widely adopted by growers. Grading is done manually, emphasizing the size, the visual appearance, and any defects caused by mechanical injury or disease. The grading system varies according to the type of fruit and the market it is intended for.

Transportation

Towns and villages in Malaysia are linked by good road and rail networks. Therefore, no problem is encountered in transporting fruit to market, as all markets within Malaysia can be reached within a short period of time. Trucks are commonly used to transport the fruit to both local and Singapore markets. The use of refrigerated trucks is practiced only by FAMA, and by exporters sending fruit from the packinghouse to the port.

Ripening and Degreening

The ripening system practised at present by local fruit growers and dealers is crude, and unpredictable in its effect. Usually fruit is ripened in small rooms, or in wooden boxes or baskets lined with newspaper, close to the market area. The ripening agent used by most fruit operators is calcium carbide, which some customers dislike because it gives the fruit an unpleasant odor.

Ethylene gas and better ripening facilities have recently come into use on the FIMA Plantation to ripen mangoes. Ethylene has also been used on the Boh Plantation in the Cameron Highlands for several years to degreen citrus. Although such methods are being practised by only a few fruit producers, there are good indications that they will be widely adopted in the years to come.

RESEARCH INTO POSTHARVEST HANDLING

Research into postharvest handling of fruit in Malaysia is mainly undertaken by the Malaysian Agricultural Research and Development Institute (MARDI). The main objective is to establish a package of postharvest technology for every fruit crop, which can be utilized for local and export markets. Research activities in MARDI cover harvesting, infield handling, grading, packaging, storage, transportation and ripening. Emphasis is given to priority fruits such as banana, papaya, mango, rambutan, starfruit, durian, pineapple and guava. Other fruit crops such as mangosteen, duku langsat, sapota and jackfruit are also included in the program.

In research and development, the following steps are followed:

- Collection and generation of information through research and literature surveys.
- Development of handling techniques and systems, from small experiments in the laboratory to trials at a semi-commercial and commercial level.
- Dissemination of information to the target groups, especially growers, dealers, exporters and government and private agencies.

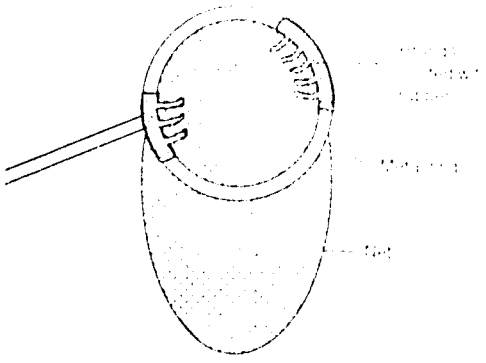
Harvesting

In harvesting, two major aspects are emphasized, maturity indices and harvesting methods. Studies of maturity indices are aimed at establishing the stage of fruit development for optimum harvesting, since this is closely associated with the storage life and eating quality of produce. The methods studied include:

- Visual means (shape, color)
- Physical characteristics (specific gravity, texture, size).
- Chemical attributes (pH, TSS, TTA, and starch, and sugar content).
- Computation (period between flowering or initial fruit setting and optimum growth).
- Physiological attributes (respiratory pattern, ethylene production).

Studies of the maturity indices of local fruits have been conducted for banana, pineapple, mango, sapota, papaya, starfruit, soursop, guava, jackfruit and some other fruits. For banana, the optimum harvesting stages for Mas, Embun and Berangan varieties are reported to be between seven and nine weeks[3], 12-15 weeks[10] and 11-14 weeks[13,14], respectively, from the stage of flower emergence. For mango, studies have been conducted on five varieties, namely Harumanis (MA 128), Golek (MA 162), Tok Boon (MA 123), Apple (MA 194) and MA 200[15].

As well as maturity indices, emphasis has also been placed on the improvement of harvesting techniques. A harvesting tool which is practical, simple and economical has been developed for mango[15].



Harvesting tool for mango

The tool is a pole with a ring and catching net on the end: the ring is 38 cm in diameter, made of metal coated with rubber tubing. The upper part of the ring has five prongs, and the lower part has three. During harvesting, the tool is placed so that fruit is below the prongs and the stem is above them. The tool is pushed when the fruit is attached to the lower ring or pulled when it is at the upper ring, and the harvested fruit is collected in the net.

Storage

Research into fruit storage is mainly concerned with refrigeration and modified atmosphere (M.A.) techniques. The occurrence of chilling injury, and changes in chemical composition and organoleptic properties after storage are studied, in order to ascertain the optimum temperatures for storage over various perods of time. Information on the physiological behaviour of each commodity is now also available. The results of some of the earlier studies have been summarized by Abdullah *et al.*[6].

Refrigeration, however, cannot be used for all types of fruit, as it may cause physiological disorders in addition to chilling injury, such as black heart or internal browning in pineapple. Black heart in pineapple is characterized by the darkening of flesh tissue after the fruit has been stored at temperatures lower than 20°C. The intensity of the disorder is greatly influenced by storage temperature, storage period and the period of exposure to higher temperature after refrigeration[7,8]. Two important local varieties, Mauritius and Sarawak, have been found to develop the disorder during or after storage. The development of black heart can be effectively controlled by thermotheraphy[7], modified atmosphere[19], or by limiting the length of the period the fruit is kept at ambient temperatures after storage[11].

Besides refrigeration, studies have also been conducted on the use of modified atmosphere (M.A.) storage for banana, mango, papaya and rambutan. When it is used for the storage of Mas banana, M.A. storage may result in CO_2 injury, characterized by blackening of the

peduncle and peel, failure to ripen satisfactorily and marked susceptibility to pathological infections. During M.A. storage, the bananas appear to be green and fresh, but they develop symptoms after exposure to normal atmospheric conditions. It was found that the disorder was likely to develop if the storage atmosphere contained more than 10% CO_2, less than 1% O_2, and a C_2H_4 content higher than 0.35 ppm. It should be noted that Mas banana is characterized by a short preclimacteric stage and an early climacteric rise, and is highly sensitive to ethylene[1]. The development of CO_2 injury can be avoided by maintaining the gaseous concentrations within the safe range, controlling certain parameters such as fruit maturity, increasing the efficiency of the gas exchange process between P.E. layers, and by selecting suitable types of ethylene absorbent[5]. If all these factors are controlled, Mas banana can be stored for up to six weeks in refrigerated storage without any deterioration in quality.

Control of physiological weight loss is another important aspect of storage. Some fruits, especially guava and rambutan, may experience a high rate of water loss during prolonged storage, resulting in wilting, shrivelling and excessive weight loss. Attempts have been made to solve this problem through the application of a wax coating and/or the use of appropriate wrapping materials. The storage life of guava (var. Taiwan) is shortened by the development of a bronze-like surface, due to excessive weight loss during storage. By wrapping the fruit in unsealed polyethylene bags and storing it at 5°C, the storage life can be doubled to more than six weeks with minimal weight loss. The use of wax can slightly delay the ripening of pineapple at ambient temperatures, besides providing a better cosmetic appearance by giving the fruit a glossy skin.

Storage research is incomplete unless it includes pathological studies aimed at identifying and overcoming the problems of postharvest diseases. Control methods investigated so far include the application of fungicides and physical treatments. Intensive studies on postharvest diseases in banana[18] papaya, pineapple and mango are now being carried out. Currently, benzimidazole compounds such as benomyl and thiabendazole, as well as prochloraz and hot water treatment, have been found to be effective in controlling postharvest diseases in some fruits.

Grading

The main objective of research in this field is to devise systems for grading selected types of fruit. Some of the aspects being studied are:

- Identification of quality parameters for the grading of selected fruits for identified markets.
- Establishment of grading equipment, in order to assist the selection process.
- Classification of grade standards and specifications according to specific quality parameters and identified markets.

The selected commodities include banana, mango, papaya, starfruit, mangosteen and pineapple.

The work of MARDI on grading systems is being carried out in close cooperation with other relevant agencies and institutions, especially universities, the Federal Agricultural Marketing Authority (FAMA), the Standard Industrial Research Institute of Malaysia (SIRIM) and local exporters. As grading of fruits is a new field of research in Malaysia, the information gathered so far is very limited. Standards for some produce have been published, including those for banana[20], pineapple[19] and mango[21]. There is a need for continual updating, to meet the requirements of different markets. Studies on grading equipment have been limited to pineapple and mango.

Packaging

Research into packaging is mainly concerned with improving and modernizing the existing packaging system. The fastest and most effective approach is to conduct tests on the suitability of different types of containers currently available. Evaluations are made on the strength, ruggedness, resistance to pressure, ventilation, handiness

and economy in relation to the type of produce concerned, and the preferences of dealers and consumers. The most significant achievement has been the introduction of returnable plastic containers, now widely used by the Federal Agricultural Marketing Authority (FAMA) and local fruit producers. Various types of corrugated fibreboard carton have also been introduced for local and export markets.

Ripening and Degreening

Ripening and degreening studies at MARDI are aimed at improving existing ripening and degreening systems on a commercial level for both local and export markets. Studies on this aspect have been intensively conducted for banana[2,3,14,16], papaya, mango, durian, mangosteen, jackfruit and citrus. This research was concerned with understanding the ripening and degreening behaviour of particular fruit varieties, the parameters associated with ripening and degreening, quality evaluation and the development of systems for commercial use. The application of exogenous ethylene to replace calcium carbide has been given special priority.

Transportation

Research on transportation is aimed at evaluating the suitability of handling technology for a specific commodity to bring it from a specific location to a specific market, to develop improvements. A series of studies on the transport of fruit from local orchards to local and Singapore markets has been conducted since 1982. For the Singapore market, trials were carried out on banana and mango[17]. The trials proved to be successful, and encouraged further studies to include other markets with more complex and challenging transportation problems such as Hong Kong and Japan. MARDI has been successful in introducing the commercial application of an M.A. system to overcome the problem of premature ripening of Mas banana during transportation by air. Today, this method has gained wide acceptance among local exporters.

The export of fruit by air is costly, and hence not economically feasible for certain markets. As an alternative, transportation by sea is considered to be economically viable and more suitable for distant markets. Efficient sea transport will therefore promote the expansion of the fruit industry. Appropriate technology for commercial application needed, and in response to this need an intensive research program has been in operation since 1981.

Several problems were encountered in developing handling technology for exporting by sea. Bulk storage at low temperatures can extend the green life of the banana by only 10 days, while storage under M.A. conditions often results in the development of the CO_2 injury described above. The handling technology available for Cavendish banana, is not suitable for the Mas variety. Probably, controlled atmosphere (C.A.) storage is the ideal solution for long-term storage of banana, as the gaseous composition can be precisely monitored. However, this system is still too costly for commercial transportation of banana.

The only alternative is to further modify the M.A. system established for Cavendish, so that it can also be used for Mas banana. The intensive research conducted by MARDI over three years generated at least one practical solution to this problem, involving the use of ethylene absorbents. This method has been successfully tested commercially in eight trial shipments by sea to Hong Kong and Japan since 1985, and proved effective in preserving the greenness of Mas banana for up to six weeks[14].

Experimental shipments of starfruit and papaya have also been successfully sent to Hong Kong. Following these successes, MARDI now proposes to extend its studies on the handling of fruit to other distant markets such as the Middle East and Europe.

COOPERATIVE RESEARCH

It is realized that there is a great need to develop improved technology for the

postharvest handling of fruit in Malaysia. The need is an urgent one, and all available resources should be fully utilized. MARDI, as the leading agricultural research institute in Malaysia, has been involved in cooperative research with many institutions, both national and overseas. The support from local universities, especially the National University of Malaysia and the University of Malaya, has been very encouraging. International collaboration has been obtained from relevant agencies in ASEAN countries and Australia, especially the Australian Centre for International Agricultural Research (ACIAR). Major activities conducted under these programs include:

- Generation of new information on postharvest handling.
- Evaluation of technology.
- Transfer and sharing of expertise.
- Financial aid in research and development.
- Sponsorship and organization of training for staff, both in Malaysia and abroad.

In sending commercial trial shipments countries, MARDI has collaborated with FAMA, local Malaysian exporters, and importers in the countries concerned. It is obvious that through this cooperation a close link has been established between those engaged in research and the private sector.

DEVELOPMENT ACTIVITY

The availability of handling technology for some fruit has created an interest in the private sector to begin trading in fruit. More than 80 companies have been given technical advice by MARDI over the past three years. This is considered a great contribution to the improvement of the fruit industry in Malaysia. Recent statistics show that the number of successful exporters has increased from three companies in 1983 to a total of ten companies in 1986. This figure is expected to increase, since an interest in other market outlets such as the Middle East and Europe has also been expressed by fruit exporters. Efforts have also been made by the government and the private sector to increase fruit production, in order to meet the increasing demand.

The assistance given to fruit growers and exporters is mainly in the form of lectures, demonstrations, advice, trials and field visits. As mentioned earlier, these activities have established a close link between exporters and research workers. As a result of this collaboration, appropriate technology can be channelled directly to the target group. In order to meet the increasing demand for information among growers and exporters, routine courses are organized on a regular basis. This activity has provided considerable impetus to the improvement of the fruit industry in Malaysia.

CONCLUSION

MARDI can be considered the focal point for research and development for fruit in Malaysia. With the increase in both the demand for fruit and the supply, more research should be carried out on postharvest handling, not only by MARDI but also by other research organizations. Cooperation from the international agencies is always welcomed. The development of appropriate and effective handling technology would assist local entrepreneurs to expand their markets. Similarly, the development of new products and the introduction of new technology would benefit suppliers, processors, exporters and consumers.

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DISCUSSION

Comment: (W. Grierson)

I have with me a set of 40 slides which I use to teach small-scale Caribbean farmers that they must handle fruit carefully. I would be very glad to show them to anyone who may be interested.

A Thank you starfruit growers in Malaysia are very receptive to new ideas as long as these are practical, economical, and easily understood. For example, they know it is acceptable to use newspaper lining when packing fruit for the Hongkong maket, but that other packing materials should be used for markets elsewhere. Postharvest handling systems must be specifically adapted to the particular commodity and market.

Q. (Y.L. Chen)

What is the proper storage or transit temperature for starfruit? How long can they be stored in an optimum environment?

A. Starfruit of the variety 'B10' can be stored at temperatures ranging from 5°C to 20°C. At 5°C, the freshness of the fruit can be preserved for up to nine weeks.

Comment: (W. Grierson)

In some work I carried out on starfruit 22 years ago, I found that they could be stored at very low temperatures without showing any signs of chilling injury. However, the new varieties introduced since then are very susceptible to chilling injury.

POSTHARVEST HANDLING OF BANANAS IN TAIWAN

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ABSTRACT

More than half the bananas grown in Taiwan are exported. Improved postharvest handling techniques, such as packing the fruit in cardboard boxes instead of woven bamboo baskets, have greatly reduced postharvest losses over the past twenty years. Growers are being given financial assistance to build small field packing stations where all postharvest operations can take place, and the bananas are transported by overhead cable.

INTRODUCTION

Commercial cultivation of bananas in Taiwan produces fresh fruit for local consumption, and also for export, mainly to Japan. Annual production is about 195,000 mt, of which about 57% is exported, mostly during the period between March and July (Table 1, Fig. 1). Taiwanese growers are small producers, each with about 0.3-0.5 ha of farmland. About 95% of bananas for export are produced in southern Taiwan (c. 5,000 ha). Bananas produced in central Taiwan (c. 3,000 ha) are grown mainly for local consumption (Fig. 2).

Table 1. Average annual total production, exports and local consumption of banana in Taiwan, 1981 – 1985

Item	Amount (mt)	Ratio (%)
Total production	195,282	—
Export	110,198	56.8
Local consumption	85,084	43.2

Data from *Taiwan Fruit Yearbook 1986*[14]

The banana growing area in Taiwan is located at a latitude of about 22-24°N, and includes both subtropical and tropical climates. Bananas are produced throughout the year. The time needed for bunch development varies greatly, ranging from less than three months in the summer to five months in the winter. Bananas are referred to as spring, summer, autumn or winter bananas, according to their harvest season[7]. There are differences in mass, fruit quality and postharvest behavior between these four seasonal types[1,2,6].

In the early 1960's the Japanese market was dominated by Taiwanese bananas. However, their share of the Japanese market has declined sharply since 1970, due to competition from Philippine bananas. In recent years, Taiwanese bananas have taken only about 10% of the Japanese market (Fig. 3).

About 20 years ago in Taiwan, bananas for export were packed in woven bamboo baskets (48 kg). Since 1969, bamboo baskets have been replaced by cardboard cartons (16 kg), and consequently postharvest losses have fallen from 4.45% to 2.87% (Table 2). These losses are mainly due to bruising, latex staining, bad labelling and underweight fruit. (Table 3). Bad crown cutting, fruit deformity and weakness of the pedicel also cause substantial losses.

Table 2. Comparision of average rate of spoilage of export bananas arrived at Japanese ports, in early period (1961-65) and in recent years (1981-85)

Item	1961-65	1981-85
Amount	2,989,765[z]	5,541,887[y]
% of total exports	4.45	[illegible].87

Data from *Taiwan Fruit Yearbook 1976*[13], *1986*[14]
[z] In baskets (48 kg) [y] In boxes (16 kg)

POSTHARVEST HANDLING OF BANANAS FOR EXPORT

All Taiwanese bananas are exported as hands packed in boxes. An increase in the quality of fruit packed in Taiwan has occurred since 1970, the result of improved handling procedures after harvest.

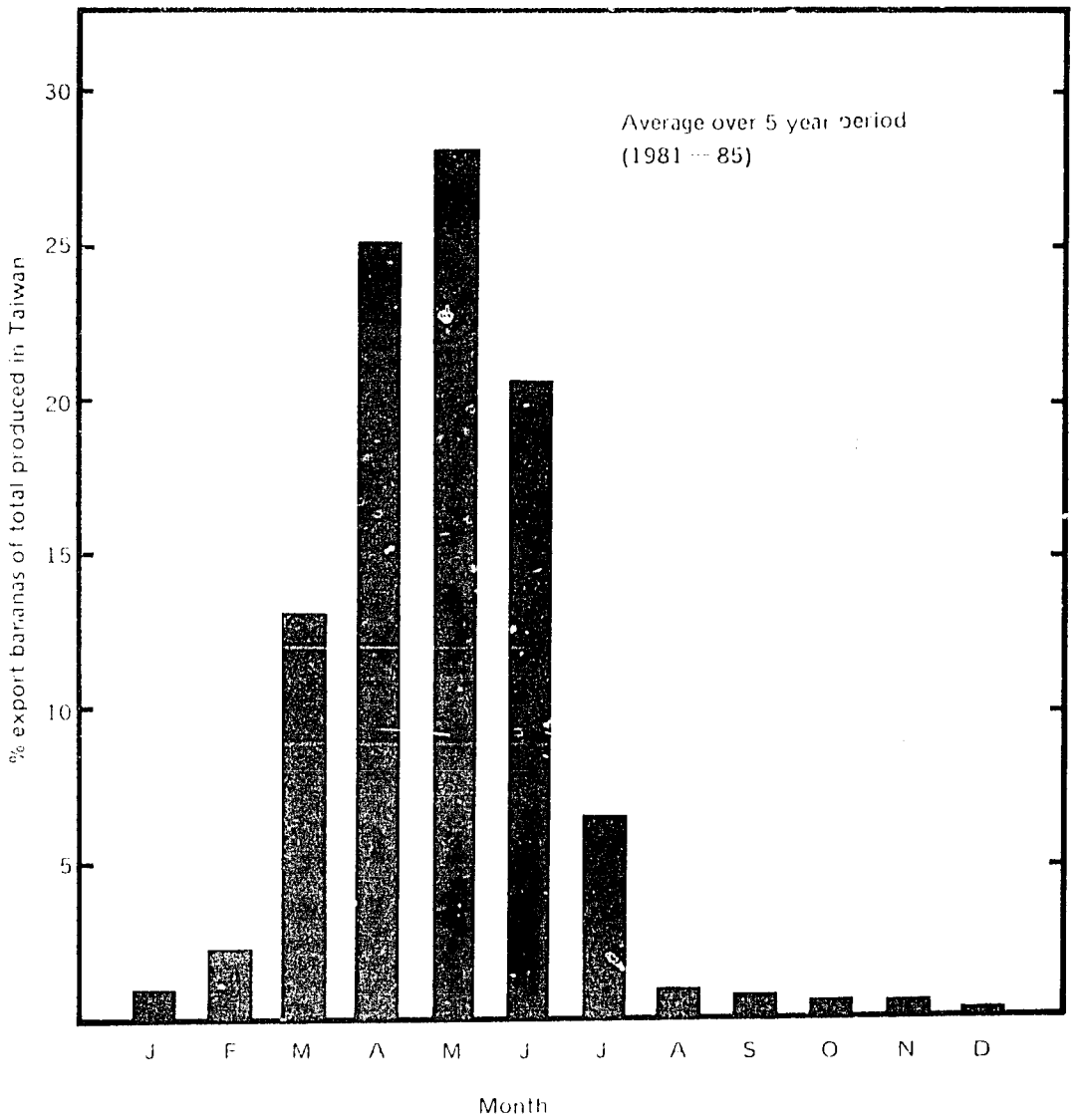

Fig. 1 Percentage of Taiwanese bananas exported each month. Data from the Taiwan Provincial Fruit Marketing Cooperative

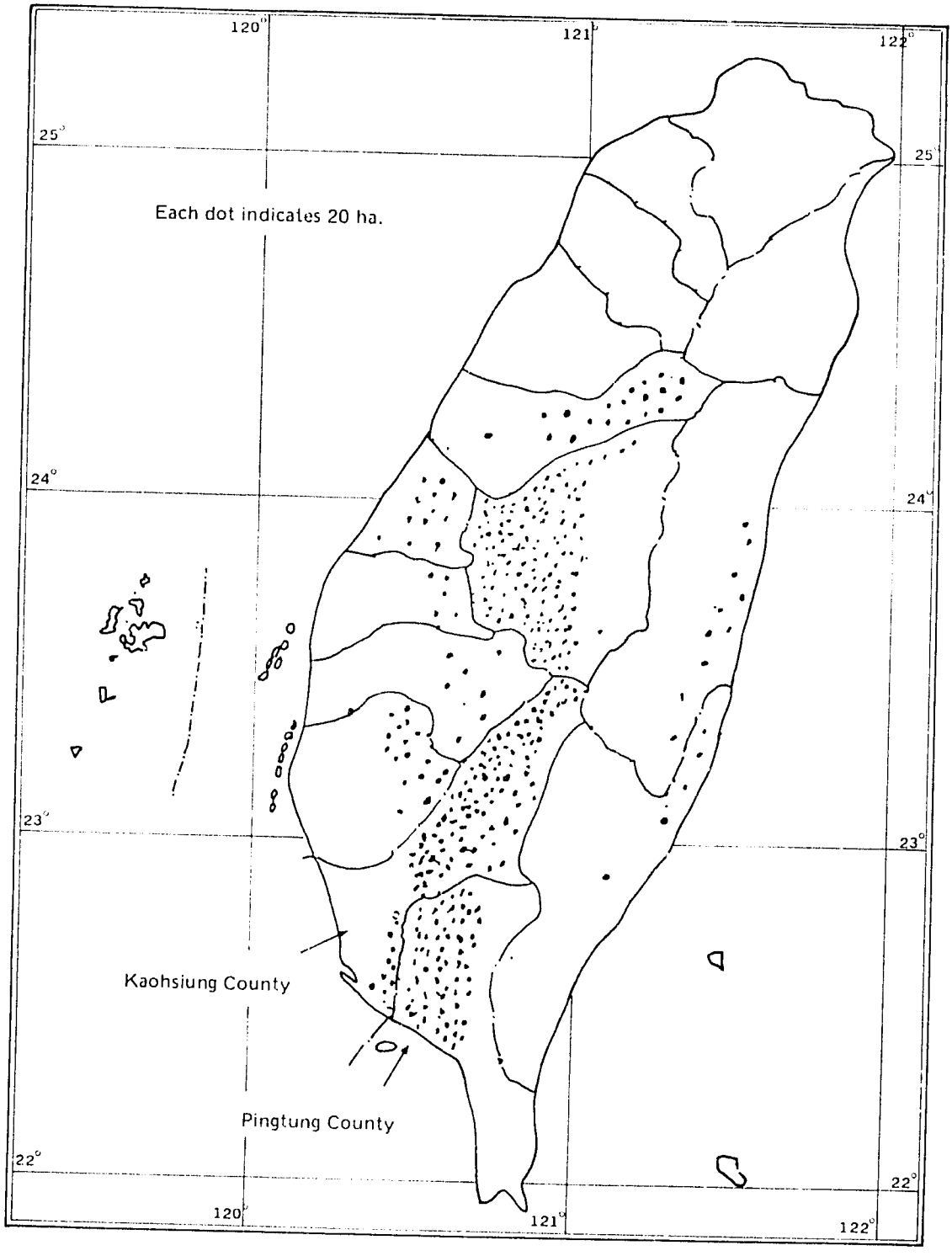

Fig. 2. Distribution of banana producing areas in Taiwan[14]

Table 3. Major defects at Japanese ports of bananas exported from Taiwan*

Year	Defects (%)						
	Bruising	Unclean	Bad labelling	Bad crown cutting	Deformed fruit	Weak finger neck	Underweight
1982	14.45	10.08	12.23	7.66	6.63	8.15	16.32
1983	16.64	14.11	10.73	5.94	6.28	6.98	11.14
1984	24.44	18.88	8.78	9.10	7.32	7.40	11.04
1985	18.20	15.82	10.88	6.84	7.36	5.55	8.44
1986	24.26	19.56	11.56	8.59	7.93	7.54	6.53
Average	19.60	15.69	10.84	7.63	7.10	7.12	10.69

* Data from the Taiwan Provincial Fruit Marketing Cooperative

Harvesting, and Transport from Field to Packing Station

After the banana bunches are cut, they are divided (dehanded) with a sharp sickle on the ground near the banana tree and carried to the pick-up point at the edge of the field. Dehanding may be carried out by some growers at the pick-up point. Detached hands of banana stacked at the pick-up point are transported in a small truck to the packing station. Such a process causes a large number of fruit defects, due to bruising and latex staining. Some growers transport banana bunches protected by cotton pads to the packing station, and dehand the bunches on the ground at the packing station to reduce fruit defects. Fruit defects are further reduced by dehanding hanging bunches from the top downwards, with a special knife (Table 4) and then immediately moving the bananas through a washing tank.

Packing Procedures at the Packing Station

At the packing station, bananas are given the following handling procedure.

(1) *Selection.* Only those fruit of a suitable size (1.8-4.8 kg/hand) and maturity which are free from bruising are selected.

(2) *Weighing.* The total weight of exportable bananas brought to the packing station by each grower is determined.

(3) *Washing.* The fruit is cooled and washed in a washing tank.

(4) *Fungicide treatment.* The fruit is sprayed with, or dipped in, a fungicide solution containing 400 ppm TBZ. The important postharvest diseases of banana in Taiwan

Table 4. Effect of two different dehanding methods on incidence of bruising, scarring and latex staining of bananas[10]

Dehanding method	Severity index[z]		
	Bruising	Scarring	Latex stain
Hanging	1.35a	0.50a	1.75a[y]
On ground	2.09b	1.08b	2.49b

[z] The larger the figure recorded, the more severe is the bruising, scarring and latex stain (0=nil, 5=very severe).
[y] Means followed by the same letter in each column are not significantly different (P=0.05) according to Duncan's multiple range test.

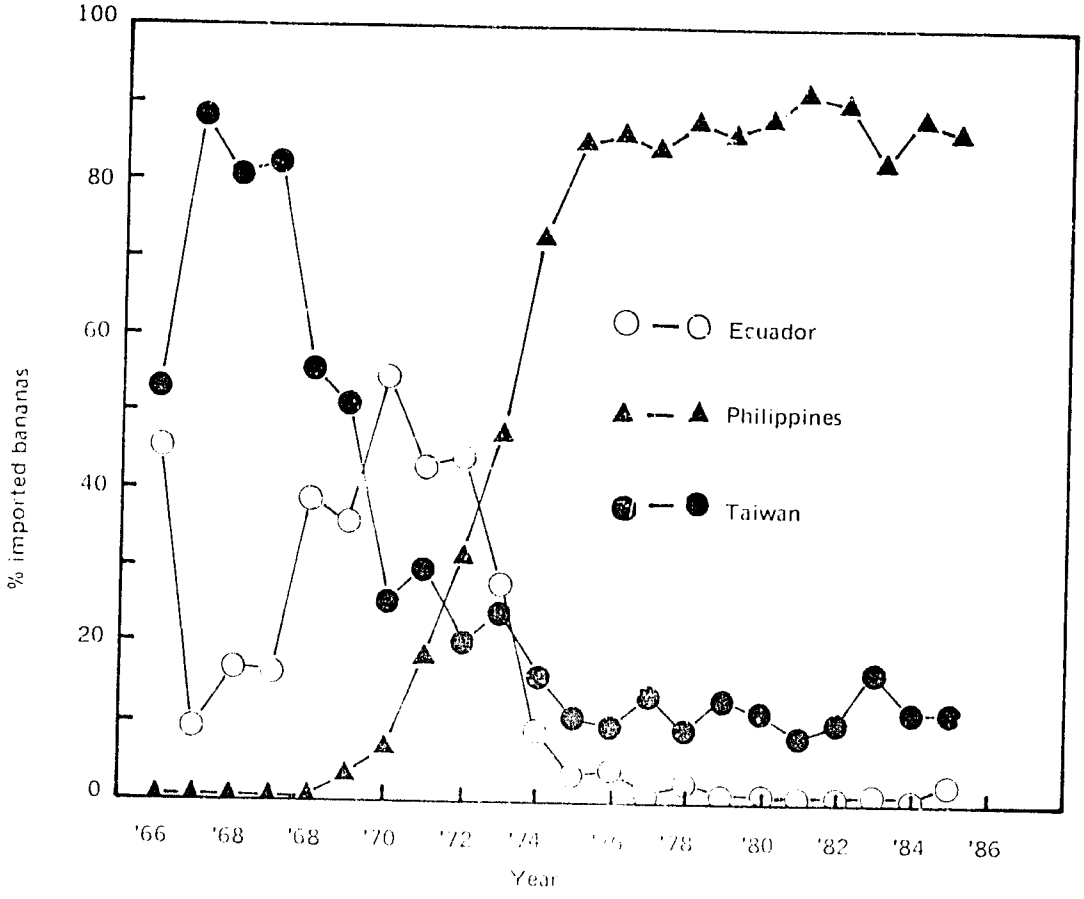

Fig. 3. Percentage of bananas on Japanese market imported from Ecuador, Philippines and Taiwan

are listed in Table 5).

(5) *Quantitative weighing for packing.* Fruit weight per box is about 16.5 kg.

(6) *Labelling.* Each banana hand is individually labelled.

(7) *Packing.* Four to seven hands are packed into each cardboard carton.

Transportation from Packing Station to Wharf

The boxed bananas are then transported by truck from the packing station to the wharf in Kaohsiung*, where they are inspected by the quality controller of the Taiwan Provincial Fruit Marketing Cooperative. One out of every 100 boxes is selected at random and inspected. If the quality score of the bananas in the box is lower than 60 points (Table 6), the whole truckload is rejected and returned to the original packing station for sale at a local market[15].

New Packing System

In order to increase fruit quality and reduce the transport distance from plantation to packing place, a program of building small packing sheds has been carried out in Taiwan since 1975.

*Major port in southern Taiwan near banana producing area. Ed.

Table 5. Postharvest diseases of bananas in Taiwan

Disease	Causal organism	Entry point	Effect
Crown rot	*Thielaviopsis paradoxa* *Botryodiplodia theobromae* *Fusarium roseum*	Cut surface of crown tissue	Softening and blackening of crown tissue, spreading to pedicel and finger; finger drop
Anthracnose	*Colletotrichum musae*	Latent field infection; bruises and abrasions	Brown, spreading, coalescent skin lesions developing during ripening
Finger rot	*Botryodiplodia theobromae*	Wounded tissue	Brownish black discoloration of the skin; softening of the pulp
Freckle	*Phyllostictina musarum*	In the field, from infected leaves	Localized spotting of skin
Deightoniella speckle	*Deightoniella torulosa*	In the field, from dead leaves	Numerous blemishes on the skin

Table 6. Quality attributes of export bananas

	Attribute	Unit	Score reduction (No. points)*
1.	Uneven ripeness	Hand	50
2.	Incorrect number of hands	Box	50
3.	Underweight	Box	45
4.	Incorrect weight	Hand	45
5.	Carton without label	Box	45
6.	Banana detached from fingers	Hand	40-45
7.	Oversized fingers	Hand	35
8.	With freckle disease	Hand	30
9.	Unsuitable stage of maturity	Hand	20
10.	Deformed fruit	Hand	20
11.	Insect contamination	Hand	20
12.	Mechanical injury	Hand	10
13.	Cracked crown	Hand	10
14.	Broken fingers	Hand	10
15.	Weak or injured finger neck	Hand	10
16.	Sunburn or poor color	Hand	10
17.	Scarring	Hand	10
18.	Poor crown cutting	Hand	10
19.	Maturity bronzing	Hand	10
20.	Poor development	Hand	10
21.	Unclean	Hand	10
22.	Inappropriate packing	Hand	10
23.	Inappropriate labelling	Hand	10

* Perfect score without any penalties is 100 points

A grower or a group of growers with a cultivation area of 3-5 ha is given financial assistance from the Taiwan Provincial Fruit Marketing Cooperative to construct a small packing shed near the banana plantation. The grower reduces service charges, since he can perform all handling practices, including treatment, packing and transportation of bananas. However, if bananas are rejected by the quality controller at the wharf, the losses have to be absorbed by the grower. This gives an extra incentive to achieve high standards, and as a result banana quality has improved substantially (Tables 7 and 8). The number of small packing sheds has increased from 14 in 1975, the first year of the program, to 104 this year (1987) (Table 9).

Table 7. Fruit quality on arrival at Japanese ports of export bananas packed in traditional packing stations or small-scale packing sheds*

Type of packing station	Scores of fruit quality[Z]				No. packing stations investigated	
	1983		1984			
	Kaohsiung	Pingtung	Kaohsiung	Pingtung	Kaohsiung	Pingtung
Traditional type	68.8	66.6	56.4	52.1	73	45
Small packing shed	73.5	69.0	69.6	58.5	34	22

* Data from the Taiwan Provincial Fruit Marketing Cooperative
[Z] Perfect score is 100

Table 8. Effect of handling operations from field to small packing shed on the incidence* of mechanical injury and latex staining in bananas[11]

Dehanding method	Transportation method	Occurrence (%)		
		Mechanical injury		Latex staining
		Light	Severe	
Dehanding of hanging bunch	Cableway	37.3	6.2	9.6
Dehanding of bunch lying on ground	Cart, small truck, motorcycle	38.1	15.2	18.3

* Data collected from Kaohsiung wharf, Taiwan ROC, on May 15, 1979

Shipping

After passing inspection at the wharf, boxed bananas are stored temporarily in a large cool room at a temperature of 16°C until they are loaded on board ship. The ship's holds are pre-cooled to 10°C or less before the bananas are loaded. Immediately after loading is completed the hatches are closed, and the temperature is brought down to the operating

Table 9. Volume of export bananas handled by different types of packing station in Taiwan, 1986

Type	Coverage of plantation (ha)	No. Stations	Total export bananas handled (1,000 boxes, each of 16.0 kg)	Ratio (%)
Traditional large type	40-50	180	5,200	80.0
Improved large type	40-50	8	500	7.7
Small packing shed	3-10	104	800	12.3

Data from the Taiwan Provincial Fruit Marketing Cooperative

level as quickly as possible. During the sea voyage to Japan, the hold temperature is maintained at 13.5-14°C.

POSTHARVEST HANDLING OF BANANAS FOR LOCAL MARKETS

For local market distribution, dehanded bananas are packed in plastic crates with polyethylene liners (27 kg) or in woven bamboo baskets lined with used newspaper (50 kg). They are packed in the field, and are not washed or given any other treatment[1]. Bananas for local markets suffer about 9% losses due to mechanical injury and latex staining[2]. Export bananas rejected at the wharf and returned to the packing station are also re-packed for sale at local markets.

STORAGE

Bananas are produced all year round in Taiwan, and the voyage to Japan takes only three to six days. Consequently, there is no storage problem for bananas produced either for local consumption or for export. Nevertheless research into the storage of Taiwanese bananas was undertaken in the 1970's. Results showed that when green bananas were kept at 20°C in an atmosphere containing 2% O_2 and 8% CO_2 their storage life could be extended to two months[3]. The preclimacteric life of bananas could be maintained for at least 30 days if the fruit were kept at 30°C in sealed polyethylene bags with an ethylene absorbent. The bananas themselves caused the O_2 and CO_2 content of the atmosphere in the bag to change to 3.5-8.5% and 3.5-5.0%, respectively, during the storage period[3].

RIPENING

Artificial ripening of banana is widely practiced in Taiwan. At an early stage of the banana industry, ripening rooms were simple and without temperature control. The design of the ripening room has been improved greatly in recent years. The room temperature is controlled by an automatic or semi-automatic refrigerating system. Previously, bananas were ripened by acetylene released from calcium carbide. Since 1982, most commercial banana ripening has been carried out using ethylene converted from ethanol at a high temperature (>350°C) in a ethylene generator. Bananas are kept in a shady, airy place for one or two days before the ripening treatment. Usually bananas are exposed to ethylene or acetylene

for 10-13 hr in summer and 48-72 hr in winter in the closed ripening room, without any temperature adjustment. After treatment, the door is opened to allow fresh air to enter, and the bananas are cooled immediately by spraying them with water. The door is then closed again, and the room temperature set at 13-15°C to allow the bananas to slowly change color. It takes about seven or eight days for bananas to reach color index No.4 or No.5, the standard color for local markets.

POSTHARVEST PROBLEMS

When Philippine bananas began to dominate the Japanese market, Japanese wholesalers experienced difficulty in ripening Taiwanese bananas at 16°C, the ripening temperature recommended by banana companies in the Philippines. Experiments carried out at the Taiwan Banana Research Institute showed that Taiwanese bananas exposed to ethylene at 16°C did not ripe uniformly, even when the ethylene concentration was increased to 5000 ppm[5]. Uniform ripening was achieved by raising the ripening temperature to 20-24°C[7], which had no adverse effect on the shelf life of the bananas[8].

Abnormal ripening of Taiwanese bananas, commonly called "Two-Zone-Color" (Ao-Down in Japanese) has become a major postharvest problem in recent years. Only the basal part of the affected fruit turns yellow after the ripening treatment, while the distal end remains green. The length of the green zone varies depending on the severity of the disorder[9]. In general, the disorder is most prevalent in bananas produced in southern Taiwan and harvested from late April to mid-June. The top three larger hands of the bunch and the out-layer fingers of the hand are more susceptible to the disorder. The stage of maturity of the fruit appears to be of little importance. Severity of the disorder is greatly reduced by covering the bunch with brown paper in the field when the bract of the inflorescene falls[9]. The cause of the disorder is still under investigation.

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DISCUSSION

Q. (W. Grierson)
Do you use treated pads on the wounds where the hands of the bananas have been severed from the stem? We use small treated pads in the Caribbean for this. They are impregnated with thiabendazole, plus alkali to coagulate the latex. The use of such pads is considered essential in the Caribbean for export bananas, unless coagulating water tanks are used.

A. No, we use only a sprayer to apply fungicide. The cost of labor in Taiwan is very high.

Q. (W. Grierson)
Are there any blemishes on the bananas from the latex, where the hand has been cut?

A. There used to be in the old type of operation, in which the hands were stacked. Latex blemishes are not a problem in the modern packing stations, where the bananas are hung from an overhead cable.

Q. (S.C. Tongdee)
What kind of spraying program do you carry out in Taiwan to control banana diseases in the field?

A. There are two main foliar diseases, blackspot and freckle. Diazanon controls most disease, but if the disease potential is particularly great we use Benlate. There are usually about 10 spray cycles a year.

Comment: (F.W. Liu)
One of the slides you showed during your paper presentation gave the rate of defective fruit in 1962 and 1986. The rate of defects in 1986 appeared to be higher than in the earlier year.

A. Yes – this is because banana prices were comparatively high during the earlier period. When prices are high, local producers take much more trouble to protect their fruit.

POSTHARVEST HANDLING SYSTEM FOR SUBTROPICAL FRUITS IN TAIWAN

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ABSTRACT

This paper describes the postharvest handling systems used for citrus and lychee in Taiwan. After the fruit is harvested it is sorted and graded by the farmer before it is sent to the collecting station, where title to the commodity is transferred from farmer to buyer. The fruit is then transported by truck to the packinghouse. In the packinghouse, citrus fruit is washed with brushes, waxed, wrapped, fumigated, packed, pelletized, and shipped. The more delicate lychee are fumigated, precooled and placed in cold storage, before being packed, pelletized and shipped. Fumigation with EDB is required only for fruit exported to Japan.

INTRODUCTION

Taiwan is located between latitudes 21°58′ N and 25°18′ N with the Tropic of Cancer passing through the middle of the island, dividing it into the tropical and subtropical zones. Taiwan is a mountaineous island, with a central mountain range running from north to south. Many subtropical fruit crops, including citrus, lychee, loquat, avocado, longan, and kiwi fruit[2] (Table 1) are grown in the subtropical lowlands, and on the slopelands of the tropical zone[1].

Citrus *(Citrus spp.)* and lychee *(Litchi chinensis)* are the two most important subtropical fruits in Taiwan in terms of both production and planting area (Table 1)[2]. Since both fruit crops are exported to Japan and other countries, postharvest handling systems have been developed by the Taiwan Provincial Fruit Marketing Cooperative, to control fruit quality and meet quarantine requirements. Citrus was first exported to Japan in 1970, while lychee exports began in 1976. 'Ponkan' and 'Tankan' varieties of tangerine *(Citrus reticulia)* and 'Liu-cheng' sweet oranges *(Citrus sinensis)* are the major varieties grown for export (Table 2), while 'Hei-yek' is the leading variety of lychee[3].

Although citrus and lychee are both produced for domestic and overseas sale, the operations used in postharvest handling are quite different, because citrus fruit is far less perishable than lychee[5].

Table 1. Production area and quantity of subtropical fruit in Taiwan, 1987

Crop	Area (ha)	Production (mt)
Citrus	38,442	386,819
Lychee	12,139	13,015
Longan	9,065	68,301
Loquat	2,158	14,241
Persimmon	1,481	10,626
Avocado*	300	3,000

Data from *Taiwan Agricultural Yearbook 1987.*
* Estimated data.

Table 2. Production area and quantity of citrus fruit in Taiwan, 1987

Variety	Area (ha)	Production (mt)
Ponkan	11,087	119,295
Tankan	10,061	94,434
Wentan pomelo	1,446	9,011
Tou pomelo	65	643
Pai pomelo	219	1,825
Satsuma orange	56	454
Valencia	269	1,707
Liu-cheng	12,353	130,129
Lemons	959	10,166
Grapefruit	433	2,775
Other	1 494	16,379

Data from Taiwan Agricultural Yearbook 1987.

POSTHARVEST HANDLING SYSTEMS

Harvesting

Citrus fruit is cut with clippers. A two-cut method, which first cuts the fruit stem from the tree and then cuts the stem down to the calyx without leaving any protrusion, was developed about 20 years ago[5]. Farmers are encouraged to use this method when harvesting fruit, especially fruit grown for export or for storage. However, due to the present shortage of labor at harvest time the snap-picking (twist and pull) method is becoming popular, especially when harvesting 'Liu-cheng' oranges which are fairly resistant to damage and decay. Plastic buckets and small bamboo bins lined with jute cloth are used as picking containers. Harvested fruit is collected in field bins made of plastic or bamboo, and then brought under shelter for sorting, grading and sizing. Fruit is sized into five groups (3L, 2L, square L ($\boxed{L}$), circle L ((L)), M, and S), using a hand-held aluminum sizer with graduated holes.

The inflorescence of lychee has branched panicles, and clusters of fruit are set at the end of the branch. They can only be harvested using the snap method (pulling the fruit branch and snapping it). Fruiting branches are harvested and placed on the ground under trees or some movable shelter for defoliation. They are then sorted to remove substandard and immature fruit, and sized. The fruit is then stacked in bamboo field bins ready to be transported to domestic markets. Fruit intended for export to Singapore is packed in 5 kg plastic bins with a perforated polyethylene (PE) film lining, whereas fruit intended for export to Japan is packed in 5 kg PE mesh bags which are then placed in plastic field bins, with three bags to each bin.

Maturity

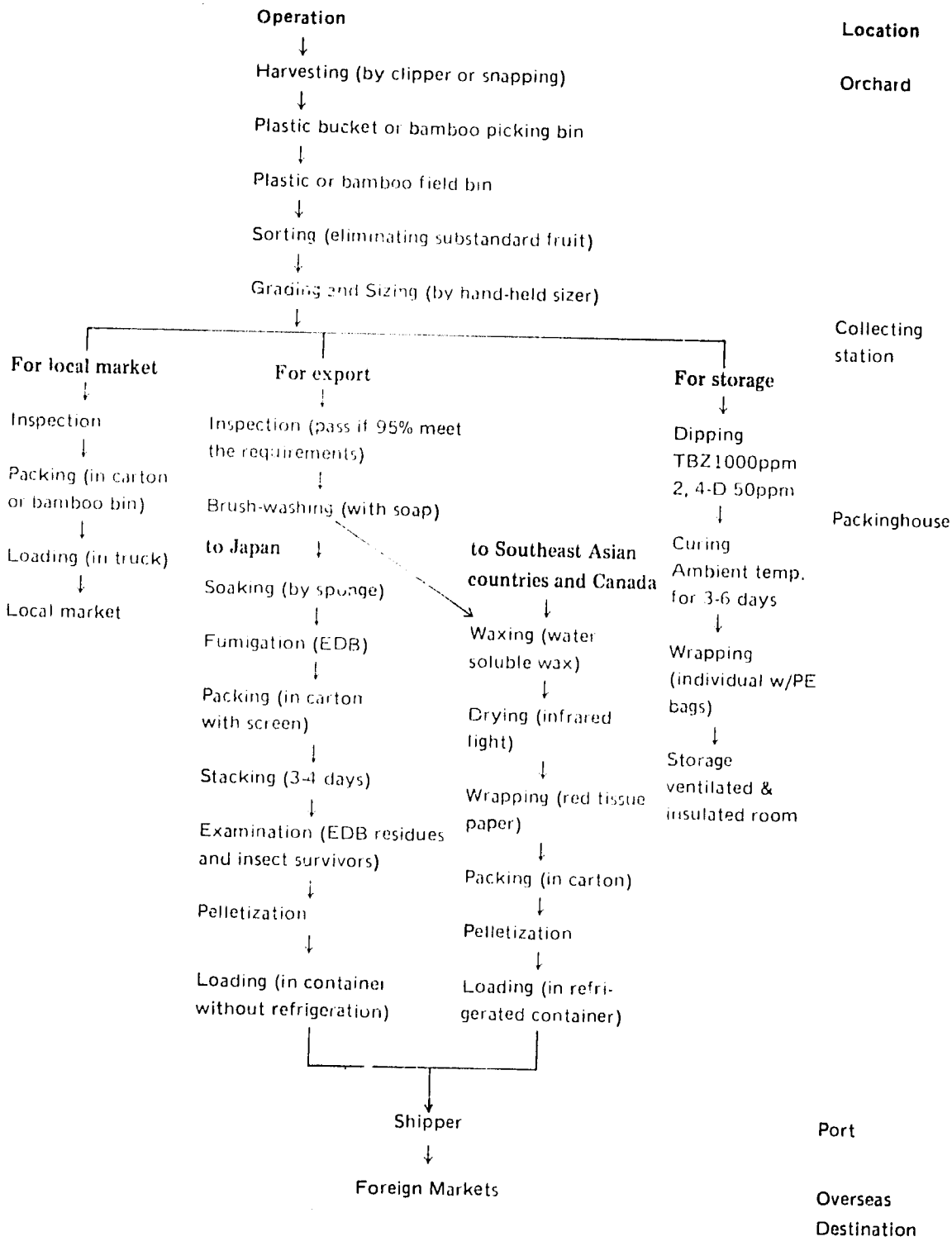
Degreening of citrus fruit caused by the removal of chlophyll from the peel is induced by cold nights and warm days[7]. In Taiwan, citrus fruit is degreened when cold fronts begin to move down from Mainland China in November. However, the early maturing varieties 'Ponkan' and 'Liu-cheng' mature before degreening, and can be harvested at the break stage in October. Fruit harvested at this stage is high in storage ability[6], and can be degreened during storage when exposured to low ambient temperatures.

The maturity of lychee is reflected in the color of the peel. Lychee mature quickly during the high temperature months of June and July. Fully mature fruit is bright red in color. However, lychee are most palatable and have the best keeping quality when the fruit has gained only 80% of its full potential color[8].

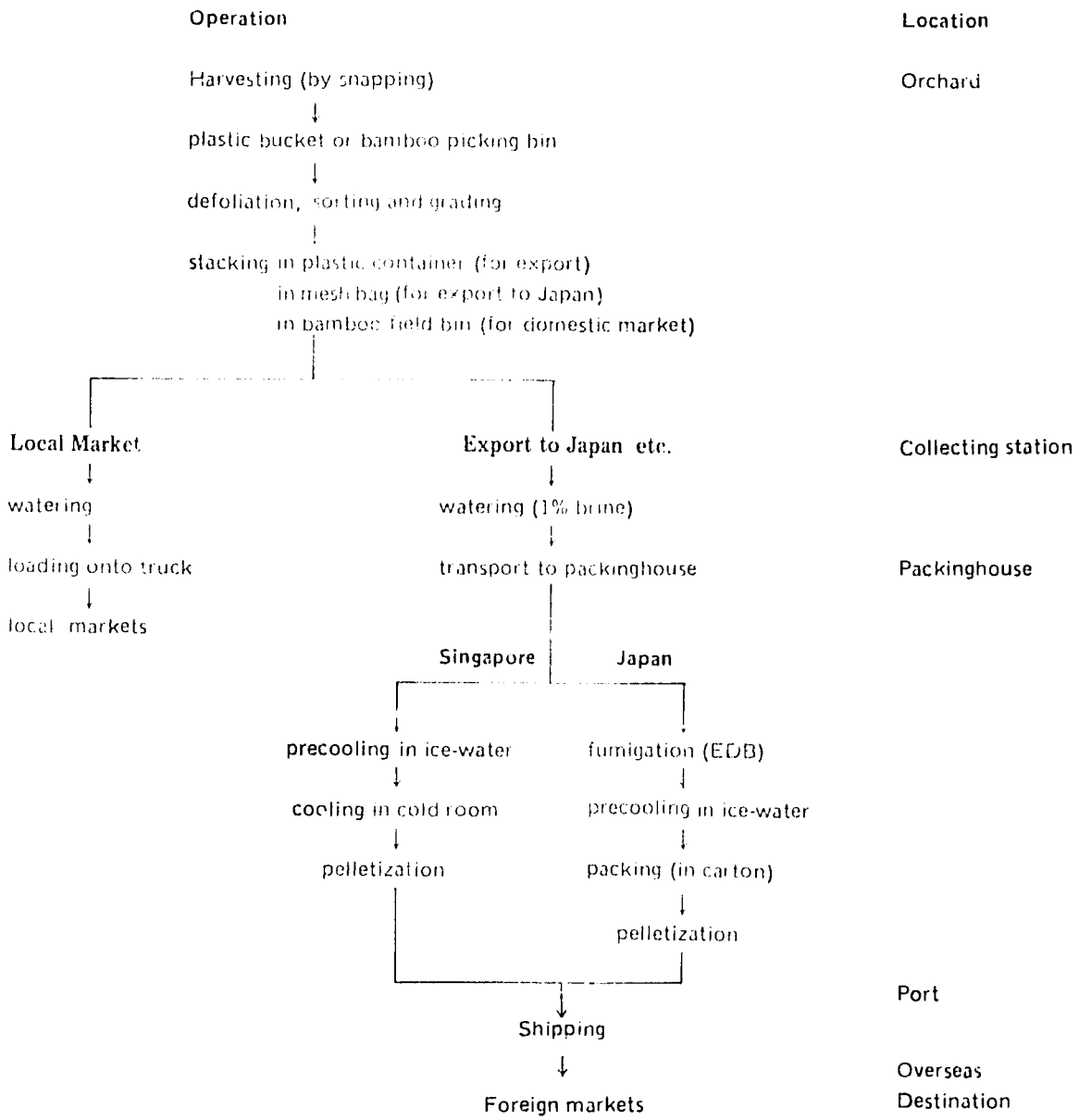
Collecting Stations

Farms and orchards in Taiwan are very small[1] (on average about 1.14 ha) and many diverse kinds of fruit are grown in any one area. This makes it difficult to produce a single type of fruit crop on any large scale, or set up packing-houses close to producing areas. Furthermore, fruit orchards are usually scattered over slopelands, where transport is difficult. It is necessary to establish collecting stations where

Flow Chart of Postharvest Handling System Used for Citrus Fruit in Taiwan



Flow Chart of Postharvest Handling System Used for Lychee in Taiwan



truckloads of fruit can be collected and sent to packinghouses for further treatment.

The collecting station is the place where title to the commodity is transferred from farmer to buyer. Buyers require farmers to sort and grade their fruit according to agreed standards before it is brought to the station. The fruit is inspected, to check whether it meets the standards or not. If it fails to pass inspection, the grading has to be done again. Citrus fruit is only accepted if 95% or more of the fruit meets the requirements. Although there are no strict standards for lychee as far as size is concerned, the peel color is closely checked.

Collecting stations also serve as packing stations for fruit consumed locally, which is packed and transported directly to market. After title to the commodity has been transferred, any lychee which show signs of browning are immediately watered with a 1% brine solution to avoid fruit desiccation.

Packinghouses

When citrus fruit arrives at the packinghouse, fruit intended for export to Southeast Asian countries and Canada is brush-washed using soap, soaked with sponge rollers, waxed with water soluble wax, dried in infrared light and wrapped in red tissue paper. Fruit intended for export to Japan is brush-washed, soaked with sponge rollers and hot-air dried, using fans. All fruit is then sent to the fumigation room for EDB treatment. Fumigation is carried out for two hours at normal atmospheric pressure, while the fruit is kept at a temperature of at least 15°C. When the fumigation chamber is only half full the dosage is 10 grams EDB/m^3 of space (18 oz EDB/1000 ft^3). After fumigation, the fruit is ventilated in the chamber for at least 30 minutes, and is then moved to temporary storage in a screened room where it is kept at ambient temperatures for three or four days, in order to reduce EDB residues in the peel. After storage, the fruit is examined for surviving insects and EDB content in the peel by the Japanese quarantine officers stationed in each packinghouse during the export season. To pass inspection, fruit must have zero insect survivors and an EDB residue lower than 0.013 ppm. 'Liu-cheng' citrus and lychees are packed by weight, while 'Ponkan' and 'Tankan' mandarins are packed by number in corrugated cartons. The number varies according to the size of the fruit, but the net fruit weight in each carton is about 12-13 kg. Cartons of fruit are pelletized, and loaded in refrigerated containers for shipping to Southeast Asian countries. However, fruit exported to Japan and Canada needs no refrigeration during shipping.

When lychee enter the packinghouse, fruit intended for export to Japan is placed in the fumigation room, where it is given an EDB treatment similar to that given citrus fruit except that the dosage is 16 grams EDB/m^3 and the temperature of the fruit is 20°C or more. After fumigation, the fruit is precooled with ice water and packed in mesh bags which are then put in corrugated cartons, with either one mesh bag per carton (5 kg) or two bags per carton (10 kgs). Packed fruit is kept in a cold store until it is shipped. Fruit exported to Singapore needs no fumigation treatment, and is only precooled with ice water and kept in a cold room until shipping. Lychee exported to Japan does not need any temporary storage for the examination of EDB residues. Fruit is shipped to both Japan and Singapore in refrigerated containers at 0°C.

CONCLUSION

Postharvest handling procedures used for subtropical fruit in Taiwan are fairly primitive, because the small size of orchards and their short distance from markets has meant that such fruit have low priority in postharvest research. Only for fruits grown for export have handling procedures been developed to meet statutory requirements. The lack of mechanization and poor management in packinghouses has resulted in low fruit quality control, high

processing costs, and low gross returns. Research is needed to develop better precooling facilities and a cold chain transportation system for lychee, to maintain the freshness and red color of the fruit. EDB fumigation for agricultural products was banned on September 1984 in USA. Although it is still permitted in Japan, provided EDB residues do not exceed 0.013 ppm, it will be prohibited there in the near future. An alternative quarantine treatment must be developed if Taiwan is to continue exporting fruit to Japan. udies on how to control fruit decay, grading and sizing techniques, and improved transport and storage methods should also be considered.

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DISCUSSION

Q. (Y.S. Tsiang)

I understand that Japan will not allow the importation of lychee or other fruit treated with EDB next year. If this is true, what treatment can be used instead?

A. Yes, EDB is still permitted this year but will be banned next year. As to what might be used instead, this is a difficult question. Cold treatment is one possible answer – storing lychee at 0°C will kill most insects. However, oranges and several other types of fruit are very sensitive to low temperatures, and suffer from chilling injury if they are stored at zero temperature. I don't know what method we shall be able to use for such fruit.

Comment: (W. Grierson)

I was deeply involved in the controversy over EDB, and gave evidence in Washington over two years. I deplore the fact that when the USA gets swamped in a wave of hysteria, the rest of the world has to follow suit. At the hearings in Washington, I offered ample evidence that eggs are much more carcinogenic than fruit treated with EDB. Nobody paid any attention.

Q. (Albert T.T. Yu)

I remember that we sent a shipment of frozen lychee to Japan from Taiwan several years ago, and they tasted good. Have there been any further developments in this technique? Is it still practiced in Taiwan?

A. No, the freezing of lychee in Taiwan has now been discontinued.

Comment: (F.W. Liu)

I agree that frozen lychee are very good, but they deteriorate quickly after thawing, and have to be kept frozen right up to the consumer's table. Freezing is a viable alternative, but frozen thawed lychee do taste different from fresh ones. In this meeting we are concerned with how to keep fruit fresh without processing methods such as freezing, cooking or drying.

Comment: (W. Grierson)

I used to freeze lychee from my own tree in Florida, after dipping them quickly for 30 seconds in boiling water. They kept their color well when they were thawed. Frozen products are very popular in U.S.A., and frozen strawberries and raspberries are widely eaten. There should be a case for exploring the export of frozen lychee, to be sold on frozen food counters. There is no need to worry about deterioration or color change after thawing - consumers today are experts in the use of frozen food, and know it should be eaten the same day it is thawed.

Q. (A. Hassan)

Up until a few years ago, the lychees imported into Malaysia were always brown – in fact, I thought brown was their natural color! In recent years the fruit have retained their red color. What improvements have been made in the handling system to bring about this change?

A. Early cooling and proper maintenance of the cold chain will preserve the fresh red color of lychee.

Q. (S.C. Tongdee)

Hydrocooling is usually used for precooling lychee in Thailand. Do you see any possibility of using forced air cooling instead?

A. I doubt whether forced air cooling would be suitable for lychee – the fruit are so small and packed so closely together, it would probably not be efficient. Hydrocooling is the best system if the produce is suited to it.

RESEARCH INTO THE POSTHARVEST HANDLING OF TROPICAL AND SUBTROPICAL FRUIT IN THAILAND

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ABSTRACT

This paper reviews recent research into the postharvest handling of fruit in Thailand. Modified atmosphere storage is being tried for both banana and strawberry, to extend the storage life and improve the market quality. Since most of the export fruit is grown by small-scale producers, there is a major problem in achieving a uniform standard of maturity. Both hydrocooling and forced air cooling systems have been tested for longan, the most important export fruit. Recent research has also been carried out on fungicidal dipping, surface coating and controlled atmosphere storage for other fruits.

INTRODUCTION

There is a growing interest in the export of fresh fruit and vegetables by developing countries. Several factors have contributed to this development. The world is getting smaller, with speedier transportation systems and aircraft with greater capacity for cargo. People travel more, and have a greater appreciation for exotic fruit. It is now possible to supply off-season produce to developed countries in northern latitudes over the winter, since most developing countries which supply off-season produce lie in southern latitudes. From the viewpoint of the developing countries, fruit and vegetables, for which there is a fairly strong domestic demand, are good potential foreign exchange earners. The production and subsequent handling of fruit and vegetables employ a large work force among the rural population, an excellent rural job employment opportunity which provides some kind of social stability. Many countries are thus developing their marketing strategies, in order to capture a share of this expanding market.

Until recently, Thailand's export of fresh fruit and vegetables served only as an outlet for its domestic surplus. Major markets lie in nearby countries. Two newly industrialized countries, Hong Kong and Singapore, import most of their food. Malaysia's agricultural base emphasizes industrial crops such as rubber and oil palm, and Malaysia imports some fruit and vegetable items. Outside the traditional regional market demand has increased rapidly, particularly in Europe which is one of the most rapidly expanding markets. The Middle East's economic development has drawn a large foreign work force into the region, who prefer to consume the traditional fruits grown in their own countries. Japan's rather restrictive import regulations, complex marketing channels, and the demand of its consumers for only high quality produce, has made penetration of this market a rather slow and painful process. At present, there are five types of fresh produce from Thailand allowed into Japan. These are coconut, green banana, pineapple, grapes, and durian. Thai mango cv. Nang Klang Wan was also allowed in last year, but each item seems to require a separate, almost endless negotiation. Korea's high taxation is claimed

to discourage fruit imports, and also favors barter trade. Another market which is the result of increasing barter trade is the European socialist countries: fruit exporters are suddenly finding themselves trading fruit for machinery. Taiwan, a newly industrialized island with high purchasing power, has emerged as an important market for Thai fruits such as pomelo, clementine and mangosteen.

Official export statistics (Table 1) indicate the scale of fresh fruit exports from Thailand.

Table 1 Export of Major Thai Fruit Crops

Unit: million Thai Baht*

Item	Year		
	1986	1985	1984
longan	313	163.4	251
pineapple	198	75	0.6
durian	174	172	68
mango	54	57	31.3
pomelo	45	40	21.2
citrus	36	41	32
papaya	24	37	68.4
avocado, guava, and mangosteen	15.6	10	9
rambutan	14	11.4	4
lychee	12	6	21
banana	11.5	22.8	23
sugar apple (sweetsop)	11.5	13.4	12
coconut	9.6	9.6	8
watermelon	4.5	4	4
grape	4	18.2	12
lime	0.8	4.4	4.4
other fruits	17.2	8	7.2
Total fruits	945	694	578
Value in US$*	36.3	26.7	22.2

* 1US$ = 26 Thai Baht

Thailand faces keen competition in its export of fresh fruit and vegetables from other countries in the region such as the Philippines, Malaysia and the Republic of China, and from countries elsewhere such as India, Mexico, the Caribbean countries, South Africa, the South American countries, Australia, New Zealand and USA. This competition from other exporting countries and the expanded market potential make it necessary for Thailand to improve its handling, transportation, and distribution of produce all the various aspects of postharvest technology.

Most research into postharvest technology takes place within the disciplines of physiology, pathology, engineering or economics. Postharvest research has tended to emphasize the first two, but the latter two are most important when research results are applied commercially.

Available information concerning postharvest handling problems has in fact been gained mainly from research undertaken under temperate conditions on temperate fruit crops. The physiology of tropical and most subtropical fruit has not been intensively studied. The handling of tropical and subtropical fruit under the high temperatures and humidity prevalent in the tropics presents additional problems. Efforts at the Thailand Institute of Scientific and Technological Research to improve the handling and storage of tropical and subtropical fruits follow two general approaches. 1. adaptive research, to review information and technology which has proved applicable to similar crops elsewhere, for possible adaptation to local fruit cultivars. 2. Practical research to develop feasible technology for tropical conditions.

RECENT ADVANCES IN POSTHARVEST HANDLING

Banana

Thailand is probably the only remaining country in the world which grows the banana cultivar Gros Michel on a commercial scale for export. Control by multinationals of the world banana market has made further penetration of

existing markets by Thai bananas impossible. More than 95% of bananas exported from Thailand go to Hong Kong. Recently, the export of a small banana cultivar Khai (Diploid AA) appears promising. One of the major problems encountered by exporters is premature ripening of the fruit before it arrives in Hong Kong, although the sea voyage takes only seven days by sea. There is also some interest in exporting Khai bananas to Europe, a journey of some 25 days.

There are numerous reports that bananas respond very well to controlled atmosphere and modified atmosphere storage. The most effective gas mixture is 2% O2, enriched with up to 10-15% CO_2. Gros Michel bananas became less aromatic when they were stored in more than 10% CO_2. Khai bananas stored in more than 20% CO_2. were less aromatic, but had fewer brown freckles when ripe. The use of polyethylene bags containing an ethylene absorbent to achieve a modified atmosphere has been in commercial use in Thailand for some time. A little more work is needed to adapt this method to the existing handling system. In some cases, Thai growers find it difficult to achieve efficient postharvest handling of good quality fruit, especially in areas with small-scale scattered production where there is no spraying program in the field for disease and insect control. Small-scale producers also find it difficult to harvest their fruit at the proper stage of maturity according to intended storage life.

Strawberry

Strawberry are one of the most perishable fresh fruits. In Thailand, they are successfully grown in the North in increasingly large amounts, to the point of overproduction. Most of the exports, though still limited in quantity, are sent abroad as an off-season supply between December and March.

California leads the U.S.A. in strawberry marketing, selling its fruit right across U.S.A. and into southern Canada. Forced-air cooling together with modified atmosphere transport account for the success of the Californian operation. A similar method has been adopted in Thailand. The effect of elevated CO_2 on the storage life, fruit quality and control of fungal disease (mainly anthracnose) was examined in the laboratory. Subsequently, several trials on modified atmosphere transport, using polyethylene bags injected with carbon dioxide, were carried out last year in cooperation with fruit exporters. The major concern requiring further study is to protect the temperature of the produce while it is on the ground at the airport or at intermediate terminals.

Citrus

Thailand's production of tangerine is rapidly increasing, mainly for domestic consumption but also for export. The export of clementines and pomelos has shown an impressive increase recently. Major markets lie in Hong Kong, Singapore, and Malaysia. The demand in Europe and Taiwan for pink-fleshed pomelos and clementines is also increasing. One special feature of the peak demand for pomelo in Hong Kong is that it corresponds to the Chinese mid-autumn moon festival in September/October.

Citrus fruits are among the least perishable subtropical fruits. At 10°C, the storage lives of tangerine, clementine and pomelo are more than one, two and four months, respectively. One of the most important fields of research is to establish harvest maturity standards. Although elsewhere researchers are interested in methods of degreening citrus, in Thailand we are planning to test various ways of maintaining the green color of clementines, which is claimed to be a selling asset. Waxing and sealed-packaging of individual fruit in plastic film will be tested on a hire contract basis.

Longan

Longan is the top export earner of all Thailand's fresh fruits. Production is concentrated in a belt in the north. Longan is probably one

of the most perishable of tropical fruits, and its shelf life under high temperatures is extremely short. There are two parts of the postharvest handling chain which need special attention: firstly, the precooling of longan to remove field heat in order to provide effective temperature management during transit, and secondly, control of rot during cold storage.

The hydrocooling systems used at present by exporters have been surveyed, and their inadequacies reviewed. Forced air cooling systems are also worthy of further attention.

Results of work on the cold storage of longan using fungicidal dipping, surface coating, and more recently, SO_2 fumigation, showed only the fumigation treatment with SO_2 to be promising. SO_2 fumigation is a postharvest treatment used for grape storage in several countries, but it can cause injury to the rind and discoloration of the aril* of longan, and needs further investigation. Recent revocation of the GRAS status of SO_2 as a sulfurizing agent means that more study is needed of SO_2 residues on treated fruit. It is planned to emphasize research into the handling and storage of lychee in the future, following a similar direction as research into longan.

* Aril: Additional covering that forms on seeds of certain fruit, developing from the stalk of the ovule. Ed.

DISCUSSION

Q. (G. Marlowe)
Are you establishing base lines of respiration rates for the tropical fruits? If so, you are opening up a new understanding about fruit that is relatively unknown to others working in the field, especially those in temperate areas.

A. Yes, that is the kind of basic research we worked on before we started any subsequent work. At the beginning of the survey we studied respiration rates and shelf life of the fruit, and then went on to analyze the present postharvest handling system, possible technological inputs, target groups for the particular technology, and eventual use of the technology. One of our greatest problems is integrating new technology into the existing system, and often development work is held up because we do not know how to do this.

Q. (S.C. Lin)
I am interested in your treatment of lychee with sulfur dioxide. How successful is this?

A. We were able to keep lychees fresh for two to three months when they were stored at 0-5°C. However, there are problems such as SO_2 injury, SO_2 residues, and a possible off-flavor. Right after fumigation there were residues of 50-200 ppm in the rind. There is also a loss of the red color which is such an important marketing asset in lychee, although this is restored if the fruit is kept in a normal atmosphere for a few days. We shall continue looking into the matter.

Q. (Albert T.T. Yu)
I am interested in your comment that the color deterioration found in lychee after SO_2 treatment

is reversible, and that the red color is restored to the fruit a few days after the fumigation treatment. Have you any idea why and how this happens?

A. We haven't looked into the mechanism of this yet. It may be connected to the pH, since if the fruit is treated with slightly acidic water after fumigation, the color will be restored immediately.

Comment: (F.W. Liu)

I am not an expert on lychee, but I think its red color is anthocyanin, which is pH sensitive – if the pH level is high, the color goes; if the pH is low, the color returns. Does SO_2 treatment increase the pH? I doubt it very much. If lychee are harvested green and kept in the dark, will they turn red? If not, then the anthocyanin is not being synthesized.

Comment: (S.C. Tongdee)

The extent of the color change seems to depend on the concentration of SO_2 – the connection between the pH level and the color change has not been investigated yet. Even though the red lychee have bleached to a greenish color, if they are givem continual ventilation for several days after fumigation the color will return. This will not be the original deep red, but a pinkish red. If directly after fumigation the fruit are immersed in water with a pH of 5-6, the color will return immediately. However, we have not studied the reasons for this – in our work we are more concerned to help the merchant sell his fruit quickly than in the theoretical aspects of why things happen.

Q. (W.J. Ho)

In your experiments, you have used SO_2 to control rot. Is it also effective in controlling fruit fly?

A. No, I don't think SO_2 would be accepted as a control measure against fruit fly.

PACKAGING, TRANSPORTATION AND STORAGE FOR SELECTED FRUIT CROPS IN KOREA

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ABSTRACT

To protect apples from bruising during transport and marketing, double thickness cardboard boxes with corrugated padding and vertical separators produced least damage of all the packaging materials tested. Storing fruit in polyethylene (PE) film bags with needle point performations appreciably enhanced the shelf life of apples, pears, grapes, chestnuts, citrus, and particularly persimmons. The packing of persimmons in PE film bags, each bag containing five or more fruit, is now in wide commercial use in Korea. Experiments with hypobaric storage were conducted with apples, and proved to lengthen the storage period. Of the various methods tested of storing persimmons, preservation in a CC_2 salt solution proved to be the best.

INTRODUCTION

Total fruit production in Korea reached 1,475,000 mt in 1986, more than 3.5 times the level of 1971. Ninety-three thousand mt, representing 6.3% of the total crop, was canned in 1986 compared to only 9,661 mt (2.4%) in 1971*. Peaches, grapes and citrus were the most important fruit, with 10.5, 9.1 and 14.3%, respectively, of total fruit production in 1986, while apples accounted for 2.5%. There have been changes in the type of fruit processing. In the early 1970s, canning was the most important, followed by the production of wine and nectar, but ten years later fruit juices had risen to second place, followed by wine, nectar and jam, in that order. In 1987 fruit juice led over all other products, with canning and wine coming second and third, respectively.

However, fruit crops in Korea are predominantly consumed as fresh or table fruit, which limits any consistant increase in consumption. It also causes price fluctuations when markets are flooded with fruit during the peak harvest season, with reduced income for growers as a result. This situation justified the search for improved storage methods, which could provide a year-round or off-season supply of choice fruit. At the moment, more than 90% of fruit in storage is kept in conventional cellars. Less than 9% is kept in low temperature storage, although the capacity is gradually increasing. In addition, about 1,650 m^2** of controlled atmosphere (CA) storage is in operation. On average, more than 35% of apples and pears had come onto the market after only two months' storage, 80% after four months, and 100% after six months. With citrus, more than 25% of crops stored had gone to market within one month, 60% by two months and 100% within three months.

Not only is there a need for improved storage methods, to avoid heavy losses during transport

* Statistics from the Ministry of Agriculture and Fisheries, Republic of Korea, 1987.
** Data from National Agricultural Cooperatives Federation, Korea.

and marketing, but better grading and packaging practices are also needed. The rice hull at present often used as packing for apples should be replaced with other materials, such as foam PE mesh or PE film with entrapped air bubbles. Most of the apples and pears on display in modern supermarkets or department stores are packed in foam polyester mesh in clean labelled boxes made of a double thickness of corrugated cardboard. This report reviews the results of experiments on different packaging materials for apples, and various storage methods for several selected fruit crops in Korea.

PACKAGING MATERIALS AND SEVERITY OF BRUISING IN APPLES

The rice hull used by many apple growers for packing apples provides little protection from pressure bruises, and also punctures the skin. This gives the fruit a damaged, unclean appearance and causes heavy wastage and poor prices. In addition, the net weight of boxes of apples packed in rice hull is likely to be less than the labeled weight. In spite of these problems, only a single trial has been carried out in Korea to seek alternative packing materials and boxes.

The results of this study, in which 'Fuji' apples were packed in rice hull in 15 kg corrugated cardboard boxes, are presented in Table 1[4]. The data shows that excessive bruising and puncture damage occurred, and that injury increased with each step in marketing, beginning with 12.0% when the fruit was picked in the field and rising to 29.9-44.8%, at the wholesale level and 84.7% in retail shops. In addition, the net weight of a box of apples in the retail shop was only 12.8 kg – a surprising 2.2 kg less than the labeled weight. This was because the light, voluminous rice hull used for packing occupied too much space in the apple carton in relation to the fruit itself, resulting in an underweight box.

This failure of rice hull to provide adequate protection for the Fuji apples led to a search for containers and packaging materials which would give better protection and thus provide increased income to growers and greater satisfaction to consumers. Several types of packaging materials were used to pack apples in corrugated cardboard boxes which were then transported by truck on both paved and unsealed roads. The results, shown in Table 2, made it clear

Table 1. Rate of bruising in Fuji apples from orchard to retail shop in 1982. The fruit were packed in rice hull in 15 kg double thickness cardboard boxes

Stage of marketing	Rate of bruising[z]			Weight of box (kg)			
	No. examined	No. bruised fruit	% bruised fruit	Total	Fruit	Rice hull	Box
In orchard	45.0	5.3	12.0	18.9	15.1	2.8	1
At agricultural cooperative	52.3	23.0	44.8	18.9	15.1	2.7	1
At wholesaler A	56.3	23.7	42.1	19.0	15.2	2.9	1
At wholesaler B	46.3	14.3	29.9	16.0	11.7	3.3	1
At retail shop	49.0	42.7	84.7	16.6	12.8	2.8	1
LSD .05	–	14.65	18.99	1.54	1.83	0.47	0

z: Means of 3 replications.

Table 2. Rate of bruising in Fuji apples transported in 15 kg corrugated cardboard boxes, according to packaging material used during transport and type of road surface, 1982

Type of packaging material used	Net weight (kg)	50 km transportation on paved road (60 km/h)[z]		50 km transportation on unsealed road (40km/h)		Packaging material cost/box (US$)[y]
		No. Examined	No. Bruised	No. Examined	No. Bruised	
Molded PVC tray	12.5	48.0	0.7	48.0	30.6	.57
PVC film with entrapped air bubbles	12.5	45.0	0	45.0	3.7	1.15
Corrugated cardboard pads and vertical separators	12.5	45.0	0	45.0	2.2	.24
Foam polyester mesh	12.5	47.3	0	47.3	1.4	.75
Ricehull A (box less than labeled weight)	12.5	47.3	4.2	47.3	45.9	.18
Ricehull B (weight the same as labeled weight)	15.0	58.3	4.0	58.3	54.9	.16
Without any packaging material	12.5	48.3	12.4	48.3	67.6	0
LSD .05	—	—	3.58	—	11.89	

z: Means of 3 replications.
y: 1 US$ = 810 W (1987)

that a net reduction in bruising during transport could be achieved by using molded PVC trays, PVC film with entrapped air bubbles, corrugated cardboard pads and vertical separators, or foam polyester net. The decrease in bruising was particularly marked in apples transported on unsealed roads. If both cost and effectiveness are taken into consideration, corrugated cardboard pads and vertical separators were the best packaging material. For apples transported on a paved road, there was no difference in rate of bruising between apples in the lowest or highest boxes in up to eight layers of boxes. However, when the road was unpaved, there was more bruising in the bottom two layers and the top layer than in the layers in between (see Table 3).

Table 3. Rate of bruising in Mutsu apples transported in 15 kg double thickness cardboard boxes, according to the packaging material used during transport and type of road surface

Road condition	Packing material	Position of layer: Bottom 1	2	3	4	5	6	7	Top 8	Mean
Paved road	Corrugated cardboard pads with vertical separators	3.3	1.1	2.2	2.2	0	0	0	2.4	1.4
	Rice hull	5.5	5.5	6.4	3.2	3.3	4.4	3.3	5.4	4.6
	Mean	4.4	3.2	4.3	2.7	1.7	2.2	1.6	3.8	—
Unsealed road	Corrugated cardboard pads with vertical separators	11.1	3.3	0	1.1	1.1	0	1.1	5.5	2.9
	Rice hull	47.8	47.9	12.9	17.0	16.4	20.9	22.0	48.4	29.0
	Mean	29.5	25.6	6.5	9.1	8.8	10.4	11.6	27.0	—

METHODS OF STORING FRUIT

Effect of Coating with Polyvinyl Chloride Acetate and Sealing with Films of Limited Permeability on Shelf Life of Fruit

In Korea, as in other countries, the principle of modified atmosphere storage has been applied to the storage of apples, pears, grapes, persimmons and citrus, using polyethylene (PE) film.

In numerous trials with various kinds of fruit, persimmons proved to be most suited to this method of storage, especially when they were sealed individually and put in PE film bags, with five fruit per bag[5]. This method has now been adopted almost everywhere in Korea.

PE films 0.02 mm, 0.05 mm or 0.1 mm thick significantly delayed softening of the fruit compared to the control. 0.1 mm PE film was best for astringent persimmon, and 0.05 mm PE film for non-astringent ones (Figs. 1 and 2).

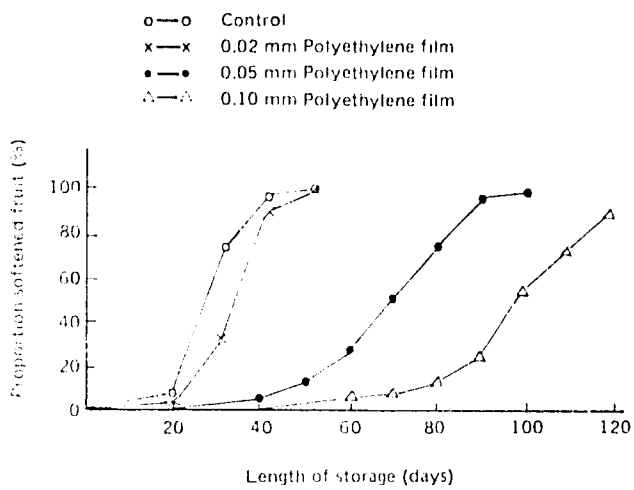

Fig. 1. The effect of sealing Gojongsi persimmons in polyethylene film of varying thickness before placing the fruit in cold storage

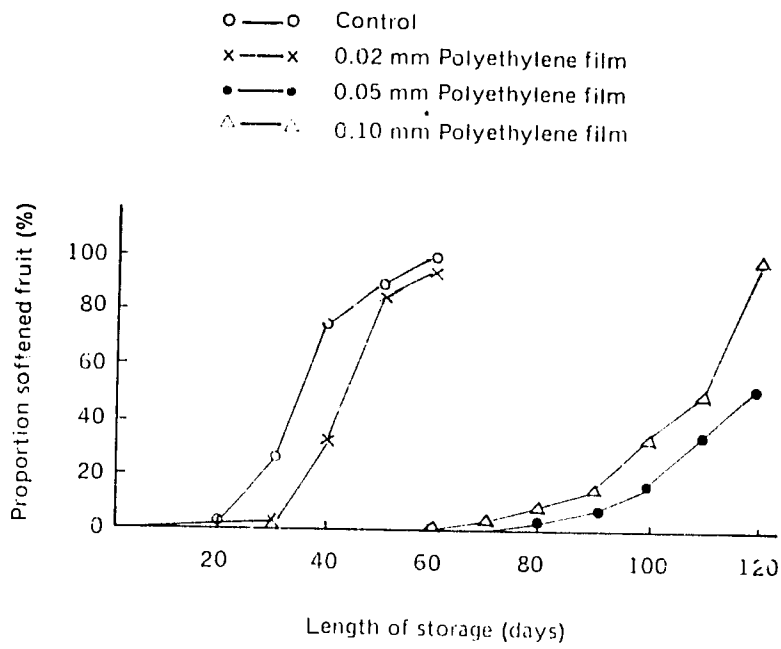

Fig. 2. The effect of sealing Buyusi persimmons in polyethylene film of varying thickness before placing the fruit in cold storage

The time elapsing before the persimmons softened was 16-25 days for fruit stored loose, but 70-87 days for those sealed in 0.1 mm PE bags (20 fruit per bag) and kept in conventional semi-underground cellars ventilated with fresh outside air. When cold storage (0-2°C) was used, loose fruit could be kept for 19-27 days and wrapped ones for 80-92 days (Table 4). Just as the period before the fruit softened could be extended by PE film, so could the period before the fruit rotted (Table 5).

Other investigators have reported that the

Table 4. Storage period of several cultivars of persimmon, defined as the no. days required for 20% of the fruit to soften

Storage Method	Variety									
	Gojongsi		Dobesi		Bansi		Sagoksi		Fuyu	
	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope
Semi-underground storage	17	70	23	77	16	70	21	71	25	87
Cold storage	24	90	25	92	19	80	23	91	27	92

Table 5. Maximum storage period of several cultivars of persimmon, defined as the number of days required for 20% of the fruit to rot

Unit: no. days

Storage Method	Variety									
	Gojongsi		Dobesi		Bansi		Sagoksi		Fuyu	
	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope	No treat-ment	0.1 mm PE envelope
Semi-underground storage	25	80	28	90	23	74	27	83	26	71
Cold storage	3[illegible]	100	35	104	26	99	33	101	31	85

optimum thickness of sealing film depends on the number of fruit contained in each bag[13]. Thus, 0.08 mm PE film is best for bags containing three fruit, 0.06 mm for bags with ten fruit, and 0.04 mm for bags with fifty fruit. The atmosphere in bags of all thicknesses had an O_2 concentration of 5% and 5-10% CO_2.

Coating apples with a layer of polyvinyl chloride or polyvinyl acetate markedly enhanced the freshness of Jonathan apples compared to the control, and appreciably delayed or inhibited softening, shrivelling and physiological disorders such as bitter pit in American Summer Pearmain and Jonathan spot in Jonathan apples. This effect has also been reported for Golden Delicious, Starking, and Fuji apples coated with TAG (fruit coating wax)[5]. Reduced weight loss was particularly noticeable in fruit coated with wax.

A study was made of the use of modified controlled atmosphere (C. A.) storage for oriental pears (*Pyrus pyrifolia*) grown in Korea, where the summer is hot and humid with a long rainy season. The pears were stored in individually sealed PE bags, and a series of experiments tested the effect of film thickness, the addition of chemicals to absorb O_2 and produce CO_2, and the number of needle point perforations in the bags.[9,16] As shown in Table 6, the rate of decay was lowest (17.2%) in Okusankichi pears stored in film bags 0.5 mm thick, and highest (24.5%) in pears stored in 0.1 m film, but decay in both was much less than in the control. Five needle point perforations per bag were better than ten, but various chemical agents tested seemed to have little effect.

Storing the pears in sealed bags resulted in a noticable reduction in weight loss during seven months storage: less than 1% for pears stored in film bags, compared to 8-9% weight loss for pears stored loose. Over time there were changes in the chemical composition of the fruit. Soluble solids increased in fruit stored loose, which brought about a much greater decrease in moisture content, while only a slight decrease was found in sealed ones. On the other hand, total acid (%) and firmness (Kg/ϕ10 mm) decreased much less in sealed pears compared to those stored loose. After storage for two months the concentration of CO_2 gas was 1.9% in the 0.05 mm polythylene film bag perforated with five needle point holes, and 2.4% and 0.7% in the 0.05 mm and 0.03 mm PE film bags, respectively.

As far as grapes are concerned, Sohn and Yoon[14] reported that sealing fruit inside 0.05 mm PE film had a pronounced effect over a prolonged storage period of 70 days. Grapes wrapped in film showed a weight loss of only 4-5% and a moisture loss of 1%, compared to

Table 6. Decay rate in Okusankichi pear harvested on October 9, 1981 and stored at 0–2°C

(Unit: % decayed fruit)

Treatment	Date of inspection				
	Jan. 10 1982	Feb. 10 1982	Mar. 10 1982	Apr. 10 1982	May 10 1982
	Storage period (no. months)				
	3	4	5	6	7
Control	2.5	5.0	37.4	59.6	72.3
0.03 mm polyethylene film[z]	—	3.2	22.1	32.3	58.8
0.05 mm polyethylene film	—	—	17.2	28.4	53.6
0.05 mm polyethylene film + O_2[y] absorber (Ageless 100)	—	—	16.5	27.3	50.2
0.05 mm polyethylene film + CO_2[x] producing reagent	—	—	13.2	23.5	47.6
0.05 mm polyethylene film + 5 needle point perforations	—	—	2.3	12.7	30.5
0.05 mm polyethylene film + 10 needle point perforations	—	—	25.4	42.7	65.7
0.1 mm polyethylene film	—	3.5	25.0	35.4	61.6

z: 3.5 kg film bag containing 8-10 pears
y: 3.5 g ageless 100 sealed with fruit inside the film bag
x: 30 g freshener sealed with fruit inside the film bag

20-22% weight loss and a moisture loss of 10% for those stored loose. CO_2 content around the grapes stored in film increased to 1-2% after two months' storage. With regard to chestnuts, cold storage at 1 ± 1°C with a RH of 85-95% lengthened maximum storage life (based on 10% decay) to 8-9 months, compared to 4-5 months in conventional storage[19]. Sealing chestnuts in polyethylene film, or perforated PE film bags also greatly lengthened the storage period, by approximately two months for conventional cellar storage and two to three months for cold storage. In these trials, the nuts were stored in PE film bags 0.01, 0.03 or 0.05 mm thick. Each bag had a capacity of 1200 cm^3, and 9 or 11 perforations 0.3 mm in diameter. Oranges showed least less of weight and firmness when they were wrapped in 0.05 mm PE film, rather than 0.02 and 0.1 mm film, during three months in both conventional and cold storage[10]. A comparison of the effect of coating Satsuma Mandarins with wax and wrapping them in paper or PE film showed that 0.03 mm PE film and a wax coating both maintained fruit freshness longer than wrapping the fruit in paper, but that PE film produced a higher rate of total loss (decay loss + weight loss) than wax (Table 7).

Hypobaric Storage of Fruit

Experiments on storing apples using hypobaric methods showed that 100 mm and 200 mm Hg retained the freshness of American Summer Pearmain and Jonathan apples more than con-

Table 7. Effects of polyethylene (PE) film, paper wrapping, and wax coating on fruit firmness[z], total loss[y], and flavor[x] of Satsuma Mandarin stored at 10-15°C for 30 days

Treatment	Early Satsuma			Common Satsuma	
	Freshness[z]	Total loss	Off-flavor	Freshness	Total loss
0.03 mm PE film seal	1.1 c[w]	18.9 b	3.1	0.5 c	17.5 a
0.03 mm PE film, 10 1.5 cm holes	2.7 b	29.7 a	2.4	0.9 bc	13.9 b
0.03 mm PE film, 30 1.5 cm holes	2.9 b	29.3 a	2.7	1.2 b	13.7 b
Paper wrapping	3.3 b	26.8 a	1.6	1.3 b	14.9 b
Wax coating	1.2 c	10.2 c	3.4	0.4 c	14.0 b
Control	4.2 a	22.1 ab	1.6	0.3 a	18.4 a

z: Freshness: 0=high; 5=low
y: Weight loss (%) plus decay loss (%)
x: 1 = good flavor; 5 = off-flavor
w: Mean separation by Duncan's multiple range test, 5% level

trolled atmosphere or low temperature storage[2,3]. Sohn has elaborated the physico-chemical changes involved: in apples subjected to hypobaric pressure, the intercellular gas reached equilibrium after only five minutes. This slowed down the climacteric rise and the development of ethylene, compared to fruit under normal atmospheric pressure (Figs. 3 and 4). In addition,

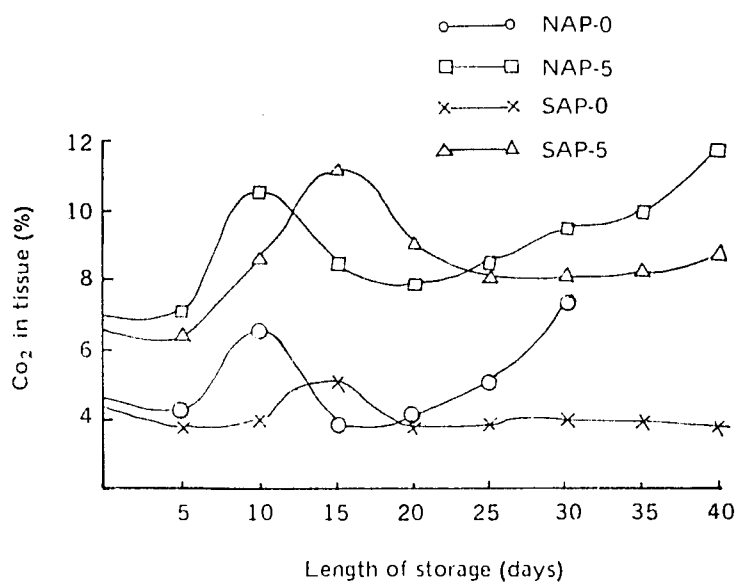

Fig. 3. Effect of subatmospheric pressure on the concentration of intercellular CO_2 in American Summer Pairman apples stored at 21°C

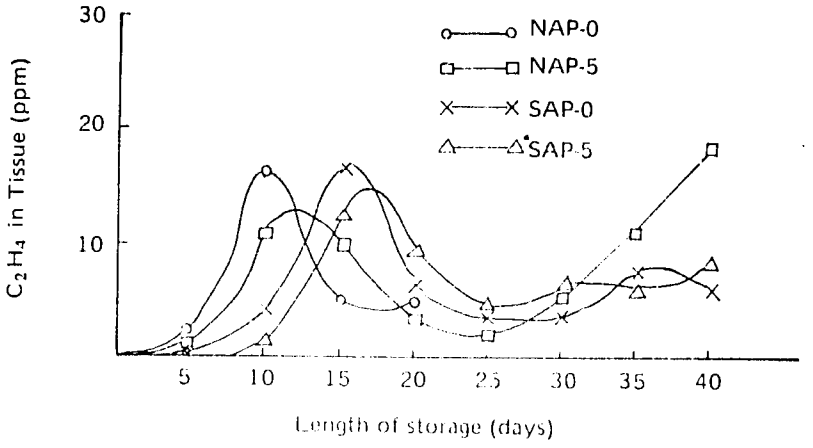

Fig. 4. Effect of subatmospheric pressure on the concentration of intercellular C_2H_4 in American Summer Pairman apples stored at 25°C

subatmospheric pressure maintained skin color, freshness and firmness, and reduced the rate of rotting and weight loss (Table 8).

Storage of Persimmons in Salt Solution

A study of the effect of preserving astringent persimmons (*Diospyros kaki*) in brine showed that it improved the flavor. The taste improved as the salt concentration was increased from 1% to 3% to 5% (Table 9). Soluble tannin decreased rapidly for 60 days, then increased slightly, over the next 30 days, and then again decreased after 90 days. Salt concentrations in the tissue after five months were 0.81-0.83% in persimmons stored in a 1% solution, 2.52-2.62% in those stored in a 3% solution, and 0.15% for those sealed in PE film bags[17].

Table 8. Effect of 40 days' hypobaric storage on the rate of decay, fruit firmness[z], and total sugar[y], reducing sugar[x] and acid content[w] of American Summer Pearmain apples

Treatment	Decay (%)	Firmness (kg/cm^2)	Total sugar (g/100g)	Reducing sugar (g/100g)	Acid content (%)
760 Torr, 0% CO_2	50	1.21	6.85	5.42	0.20
760 Torr, 5% CO_2	48	1.49	7.00	5.42	0.28
660 Torr, 0% CO_2	3	2.45	7.30	5.72	0.42
660 Torr, 5% CO_2	3	2.69	7.25	5.75	0.40

z: Initial hardness; 3.41 kg/cm^2
y: Initial content; 7.41 g/100gr.
x: Initial content; 5.65 g/100gr.
w: Initial content; 0.53%

Table 9. Taste and appearance of persimmons preserved in brine

Treatment	Taste					Appearance				
	No. months' storage					No. months' storage				
	1	2	3	4	5	1	2	3	4	5
Salt 1% (Sept. 28)	±	±	±	—	—	±	±	±	±	—
Salt 1% (Oct. 12)	++	+	+	+	—	++	++	++	++	+
Salt 1% + 5% sugar	++	++	+	±	±	++	++	++	++	+
Salt 3%	+	+	—	—	—	++	++	++	++	+
Salt 3% + 5% sugar	++	+	±	—	—	++	++	++	++	+
Salt 3% after sealed in 0.03 mm PE film	++	S	S	S	S	++	S	S	S	S

S: Fruit softened
++: Excellent

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DISCUSSION

Q. (F.W. Liu)

You show that packing apples with rice hull resulted in a high proportion of damaged fruit. I don't understand why the rate of damage should be so high, since the rice hull should be a good cushion. Could it be because the sharp ends of the rice hull punctured the fruit? Perhaps the fruit should be wrapped in paper. Also, the polyethylene film you used was very thick — 1.0 mm. Does it produce anaerobic conditions, and give the apples a fermented flavor?

A. Yes, the rice hull did have a good cushioning effect, but the very sharp points bruised the skins and punctured them. The paper wrapping normally used for fruit is too thin to protect the apples from puncture damage. Wrapping the apples with newspaper protected the apples from damage, but this cannot be used because consumers will not accept it.

When we started our experiments, we used several types of film for comparative purposes, including 1.0 mm, 0.5 mm and 0.1 mm. Of these, 0.5 mm seems to be the most promising.

Q. (G. Marlowe)

Of all the packaging methods you studied, it appears that the least expensive were the rice hulls and the compartmented cardboard containers. Most of the other methods were rather expensive. Of the two relatively cheap methods, which was favored by the buyers or store managers?

A. When rice hull was used for packaging, managers of supermarkets complained of a problem in disposing of the hull, which they felt also presented hygiene problems and gave their stores an unclean appearance. They much preferred the cardboard containers. Only small-scale retail shops were prepared to accept fruit packaged in rice hull, and now even these are beginning to reject it.

Q. (W.J. Ho)
Do you think of persimmon as a soft fruit or a firm one? Is there any correlation between the level of astringency in different varieties of persimmon and the softening problems encountered in handling them?

A. Temperate fruit are usually not as soft as subtropical ones. Although fruit such as apples can become soft when they are ripe, they tend to lose their taste by this stage and are rejected by the consumer. Similarly, only firm persimmons are chosen for sale.

Softening in astringent persimmon cultivars occurs very rapidly, and the taste deteriorates as the fruit softens. Nonastringent cultivars taste very good when they soften. Both receive the same kind of postharvest handling.

Q. (W.J. Ho)
I am interested in the treatment of persimmon with salt to reduce the level of astringency. This is also done in Taiwan by family growers. Could you please explain the physiological principles behind this treatment?

A. I don't know the physiological explanation. Salt treatment converts the soluble tanning into an insoluble form. This happens because by dipping the fruit into salt, carbon hydroxide is generated which gives rise to the insoluble tannins, in the same way as when the fruit is treated with CO_2.

Q. (W.J. Ho)
Does this treatment soften the fruit?

A. No, it only reduces the astringency.

Q. (S.C Tongdee)
Is there any use of CO_2 treatment to reduce the astringency?

A. Yes, in commercial production persimmon are treated with CO_2 at the packing house.

Comment: (W. Grierson)
In ancient times a Chinese scholar wrote that if persimmon were sealed in saki barrels, the astringency mysteriously disappeared. They were giving persimmons a CO_2 treatment several thousand years ago!

Section III.

New Research on Fruit Storage

68

TEMPERATURE RESPONSE IN CITRUS FRUITS AFTER HARVEST

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ABSTRACT

The effect of temperature after harvest on physiology and fruit quality was investigated in several citrus varieties. Arrhenius plots of the respiratory rate and potassium ion leakage from the rind tissues exhibited break points at the critical temperature, which corresponded closely with the temperature at which chilling injury occurs in each cultivar. The development of the peel color of the fruit rind was also affected by the temperature during curing and storage. The best color was obtained at the optimum temperature, which varied for different citrus varieties and cultivars.

INTRODUCTION

Citrus are one of the most important subtropical fruit in the world. As shown in Table 1, annual production throughout the world in 1985 was 58,438,000 mt, which was much the same production level as banana (including plantain) or grapes (including grapes for wine).

Several citrus varieties, including orange, tangelo, mandarin, clementine, satsuma, lemon, lime, grapefruit and pomelo, are grown in Asian countries (Table 2). Production in Asia is 22-24% of the world's total citrus production[1].

The most important citrus grown in Asia are oranges, followed by tangelo, the mandarin group, lemons and other sour citrus, and grapefruit.

Citrus fruits have a relatively long postharvest life in comparison with other subtropical and tropical fruit. The type of handling before and after harvest, and the citrus variety and cultivar, may both influence fruit quality in marketing.

Citrus fruits are sensitive to chilling. A large amount of research has been carried out on methods to ameliorate chilling injury to citrus fruit, including conditioning[2,3,4], treatment with TBZ (thiabendazole)[5,6,7], high carbon dioxide[8,9], oil[9], and film packaging[9,10,11,12,13,14].

Chalutz *et al.*[15,16] have shown that the extent of chilling injury after storage at temperatures ranging from 2-12°C varied in different citrus cultivars. Hasegawa and Iba[17] have investigated the effect of ambient temperature on the peel color of some citrus cultivars grown in Japan.

It is well known that the temperature affects the relative humidity in the ambient atmosphere. Any change of temperature in the storage room is accompanied by a change in the relative humidity. For this reason, it is necessary when studying the effect of different storage temperatures to consider the simultaneous effect of humidity.

This paper will deal with the effect of the temperature and humidity levels in storage facilities on physiology and storage quality in several citrus varieties.

MATERIALS AND METHODS

The fruit of twelve citrus varieties [hassaku (*Citrus hassaku* hort ex Tanaka), hanayu (*C. hanaju* hort ex Shiral), iyo (*C. iyo* hort ex Tanaka cvs. Miyauchi and Ohtani), kabosu (*C. sphaerocarpa* hort ex Shirai), kinukawa (*C. glaberrima* hort ex Tanaka), kishiu-mikan (*C. kinokuni* hort ex Tanaka), satsudaidai (*C. natsudaidai* Hayata cv.

Table 1. Annual world production of citrus fruit

Unit: 1000 mt

	1980	1981	1982	1983	1984	1985
World production						
orange	38,463	37,751	35,952	39,608	39,432	41,289
tangelo*	7,267	7,106	7,218	8,063	6,580	7,499
lemon and lime	4,878	5,524	5,234	5,801	5,136	5,461
grapefruit and pomelo	4,470	4,356	4,484	4,269	3,971	4,061
others	913	911	960	1,098	1,045	1,128
total	55,986	55,648	53,848	58,839	56,164	59,438
Asia						
orange	6,038	6,234	6,690	6,931	7,002	7,151
tangelo*	3,742	3,690	3,724	4,191	3,234	3,861
lemon and lime	1,212	1,245	1,306	1,317	1,338	1,240
grapefruit and pomelo	850	861	895	1,073	1,025	1,033
others	422	408	449	505	465	536
total	12,264	12,438	13,064	14,017	13,064	13,821

* Including mandarin, clementine and satsuma

Table 2. Annual production of citrus cultivars in Asian countries, 1985

Unit: 1000 mt

Orange	China 1,700*	India 1,350*	Israel 900	Turkey 720	Pakistan 530	Japan 420	Indonesia 380*
Tangelo, mandarin, clementine, Satsuma	Japan 2,494	Korea 371	China 250	Turkey 229	Pakistan 210	Israel 160*	Iraq 46*
Lemon and lime	India 450*	Turkey 300	China 112*	Israel 65*	Cyprus 52*	Philippines 46*	Lebanon 40*
Grapefruit and pomelo	Israel 380	Thailand 240	China 172*	Cyprus 100	Philippines 40*	Turkey 23	Lebanon 20*

* FAO estimate

Kawano), navel orange (*C. sinensis* Osbeck var. brasiliensis Tanaka cvs. Fukuhara, Shirayanagi and Morita), ponkan (*C. reticulate* Blanco), sudachi (*C. sudachi* hort ex Shirai), Satsuma mandarin (*C. unshiu* Marc. cvs. Owari and Miyagawa-wase), and yusu (*C. junos* Sieb. ex Tanaka)] were sorted according to their maturity, size and grade. They were then stored in rooms maintained at a constant temperature (± 1°C).

Respiratory rate was measured by gas chromatography (TCD). Discs of rind tissue were immersed in a measured volume of deionized water at different temperatures. After incubation, the level of potassium which had leaked from the discs of rind was measured, using an atomic absorption spectrophotometer. Peel color was determined by a Hunter type color meter.

Plate 1. Chilling injury in Kinukawa citrus fruit

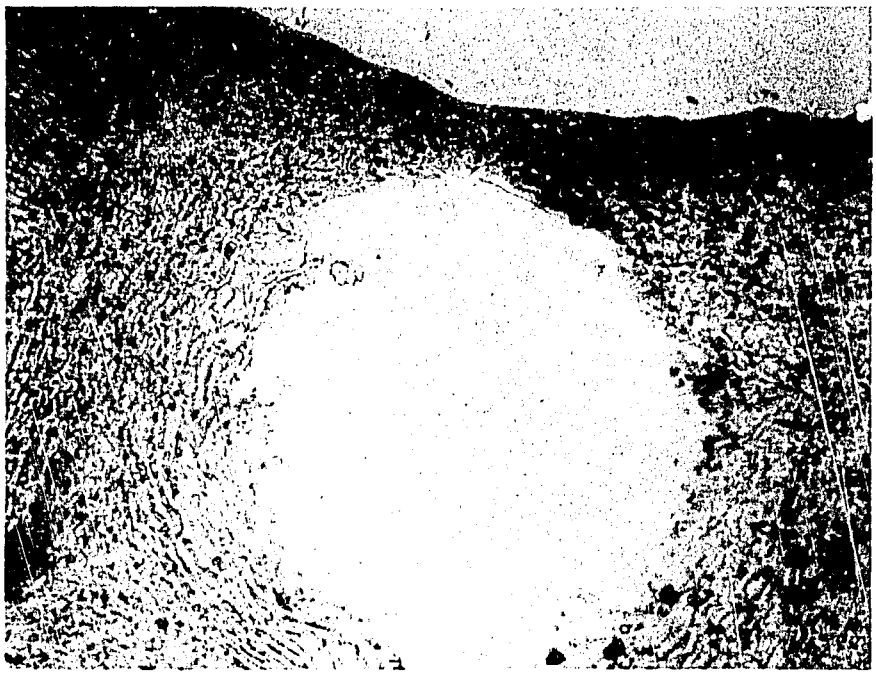

Plate 2. Cell damage caused by chilling injury

RESULTS

Arrhenius Plots of Respiratory Rate of Citrus Cultivars

Fig. 1 shows the relationship between the respiratory rate of two cultivars, Satsuma mandarin cv. Miyagawa-wase and kishiu-mikan, at different temperatures. The Figure shows the logarithm and reciprocal of the absolute temperature, and thus gives the Arrhenius plots of the respiratory rate of these cultivars. Both cultivars exhibited a discontinuity in the Arrhenius plots, indicating the break points. These were 7.6°C for Satsuma mandarin and 8.0°C for kishiu-mikan. Arrhenius plots of the respiratory rate of kinukawa, hassaku, iyo cv. Miyauchi, navel orange cvs. Morita and Fukuhara, natsudaidai and kabosu also exhibited linear lines, with break points at 13°, 11°, 9°, 10°, 5°, 4.5° and 4.0°C, respectively (Fig. 2)[18,19]. These two figures may indicate why the respiration of citrus cultivars responds differently to temperatures that are higher or lower than the cultivar's particular break point[18].

Arrhenius Plots of Potassium Ion Leakage

Fig. 3 shows the Arrhenius plots of the rate of potassium ion leakage from the rind tissues of iyo cv. Miyauchi, kinukawa, hassaku, natsudaidai and ponkan. The lines in this figure show an upward curve in the Arrhenius plots. This shape of the Arrhenius plots may suggest increased permeability when the temperature is lower than the break point.

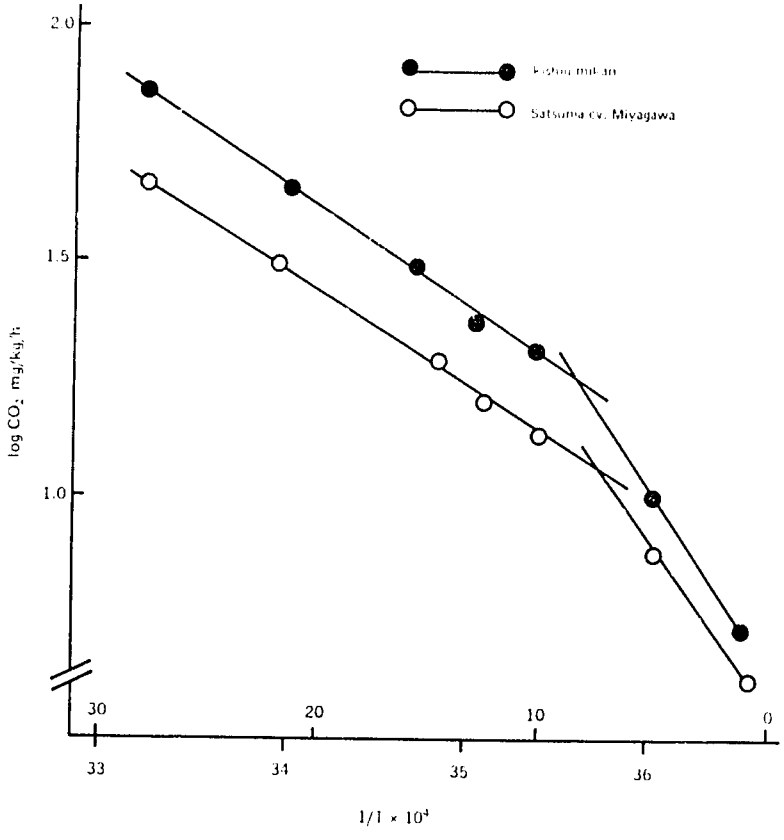

Fig. 1. Arrhenius plots of respiratory rate of two citrus cultivars, Satsuma mandarin cv. Miyagawa-wase and kishiu mikan

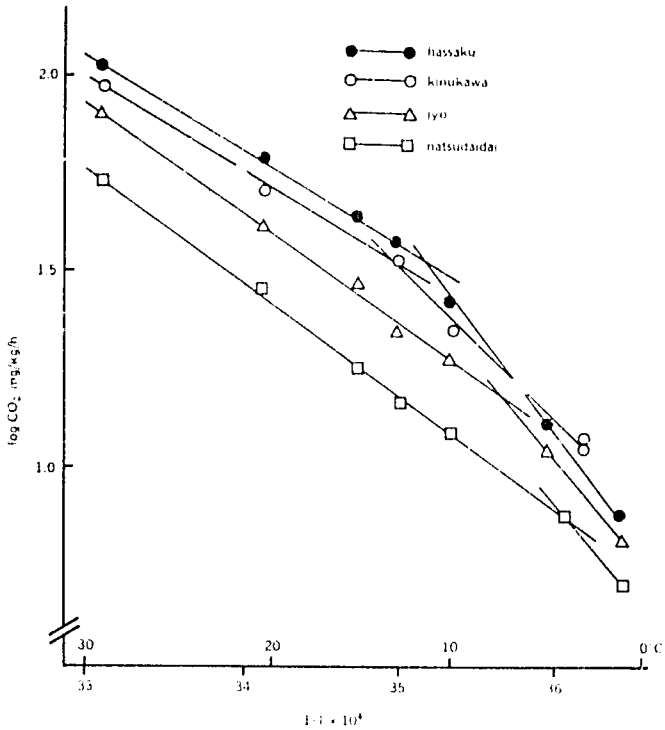

Fig. 2. Arrhenius plots of the respiratory rate of four citrus cultivars, hassaku, kinukawa, iyo and natsudaidai

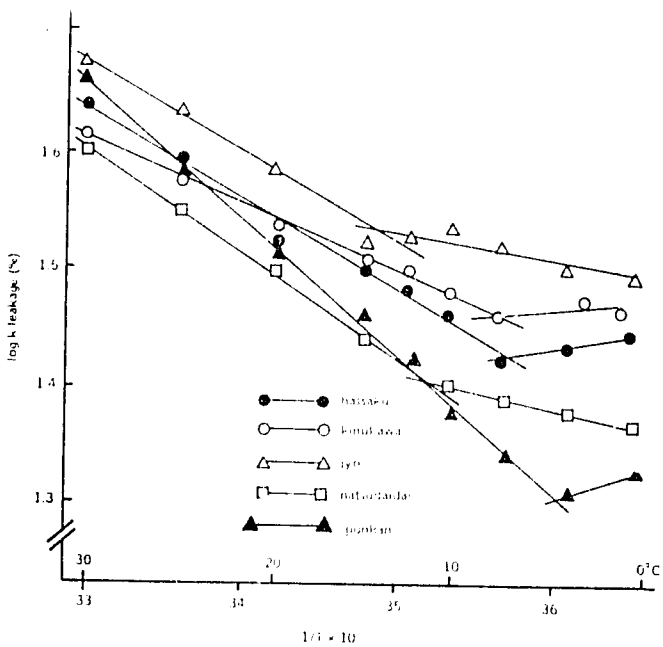

Fig. 3. Arrhenius plots of the rate of potassium ion leakage from rind tissues of freshly harvested iyo, kinukawa, hassaku, natsudaidai and ponkan fruit

One significant result observed in the Arrhenius plots of both the respiratory rate and the rate of potassium ion leakage is that the temperature for the break points in Arrhenius plots corresponds closely with the critical temperature of chilling injury for each cultivar. Any longterm storage of citrus fruit should not be at a temperature below this critical point.

Rate of the Occurrence of Physiological Disorders

The rate of occurrence of physiological disease in different varieties and cultivars of citrus fruit stored for four months at 1°, 5° and 10°C is shown in Table 3. The highest rate of incidence was found in hanayu, navel orange cv. Shirayanagi, iyo cv. Miyauchi, natsudaidai and kabosu stored at 1°C. However, iyo cv. Ohtani and hassaku showed the highest rate of physiological disease when stored at 5°C and 10°C, respectively.

Schiffmann-Nadel *et al.*[20] have investigated the effect of storage temperature, ranging from 2° to 17°C, on the shelf life of Marsh Seedless grapefruit. They obtained optimum results when the grapefruit were stored at 12°C. Chalutz *et al.*[16] have reported that the rate of decay and chilling injury in grapefruit and in orange cultivars Shamouti and Valencia stored at different temperatures varied according to the cultivar. These results indicate that the chilling sensitivity of citrus fruit varies significantly in different varieties and cultivars.

Table 3. Percentage of incidence of physiological disease in citrus cultivars stored at 1°, 5° and 10°C for 4 months

Temperature (°C)	hanayu	navel orange 'Shirayanagi'	iyo 'Ohtani'	iyo 'Miyauchi'	natsudaidai	kabosu	hassaku	Satsuma mandarin
1	85.7	63.5	35.6	25.5	29.4	27.5	24.1	1.0
5	1.0	7.1	71.1	20.5	25.5	5.0	15.4	0
10	0	0	65.7	3.5	19.6	2.0	69.5	0

Effect of Temperature and Humidity during Curing

For the long-term storage of Satsuma mandarin in Japan, the fruit is usually dried after harvest under ambient atmospheric conditions in order to cure it. Suitable curing treatment can reduce the incidence of puffy fruit, and improve fruit quality during storage. Curing is also effective in improving the fruit quality of other citrus cultivars.

Figs. 4 and 5 show respiratory changes in navel orange cv. Morita and iyo cv. Miyauchi during curing. The respiratory rate in both cultivars was inhibited significantly by curing. The same tendency was found in varieties of ponkan, hassaku, natsudaidai and seminole. This inhibition in the respiratory rate from curing was found to continue for considerable periods of storage. This low rate of respiration may result in a decrease in the consumption of the constituents of the juice of the fruit.

Temperature levels during curing may also affect the peel color of citrus cultivars. Figs. 6 and 7 show the effect of temperature and humidity during curing on the peel color of stored iyo cv. Miyauchi and navel orange cv. Morita. In both cultivars, curing at 15°C resulted in the best fruit color after storage, while storage at 1°C or 24°C gave fruit a poor color. The same tendency was found in the fruit of natsudaidai cv. Kawano and hassaku.

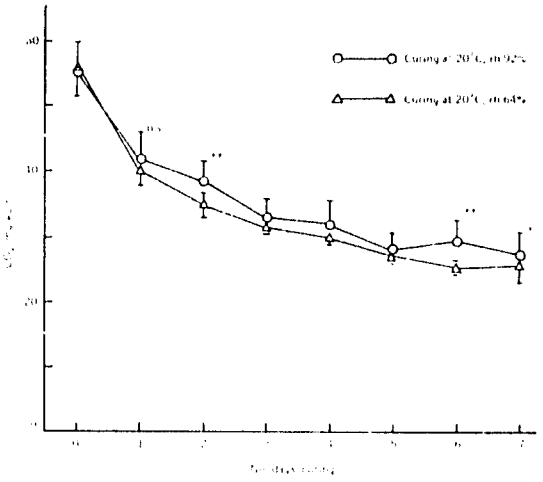

Fig. 4. Respiratory changes in navel orange cv. Morita during curing at different humidities (++: significant difference at 1% level; +: significant different at 5% level)

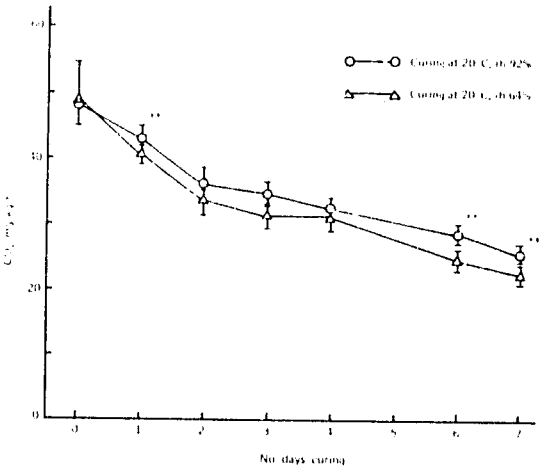

Fig. 5. Respiratory changes of iyo cv. Miyauchi during curing at different humidities (++: significant difference at 1% level)

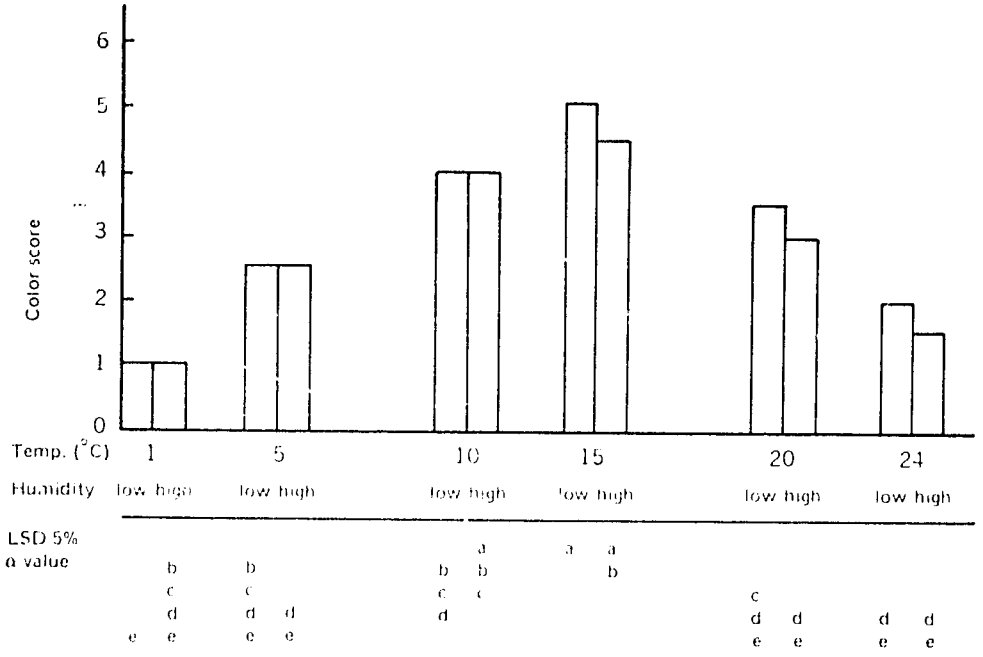

Fig. 6. Effect of curing at different temperatures and humidities on peel color of iyo cv. Miyauchi stored at 5°C. (Dec. 9 — March 10; Color score: 0 = poor, 6 = excellent)

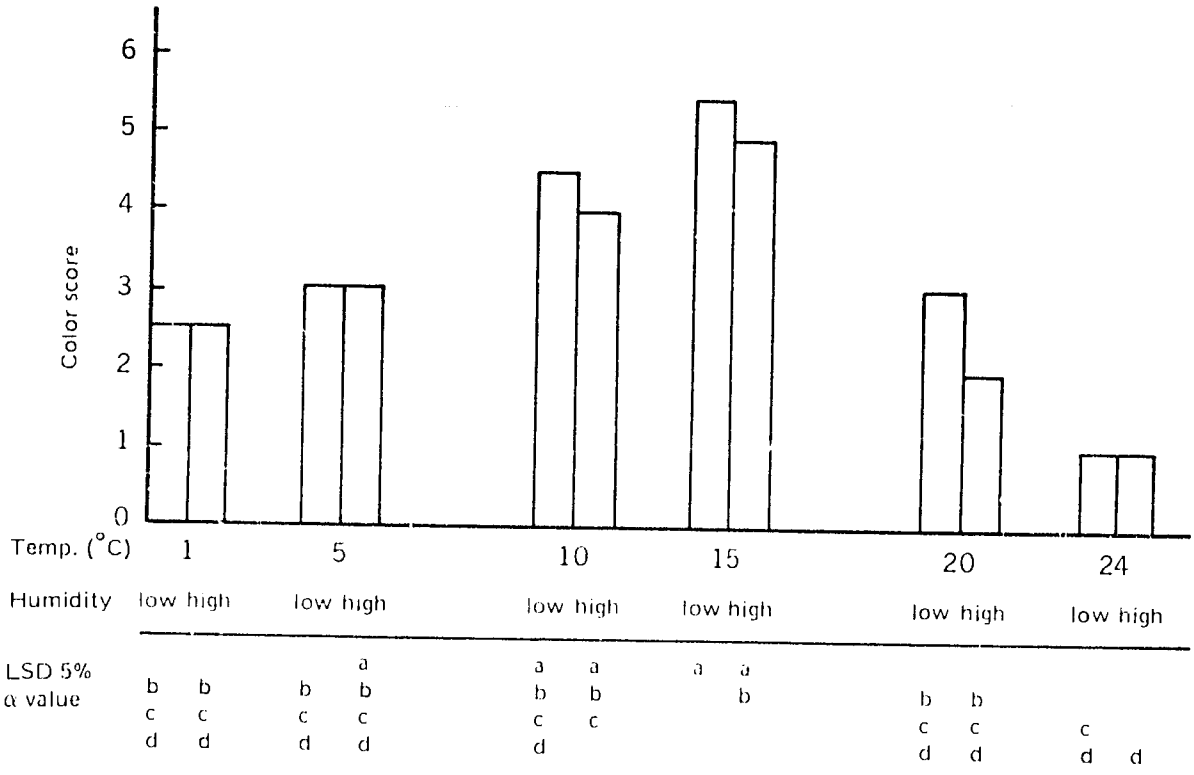

Fig. 7. Effect of curing at different temperatures and humidities on peel color of navel orange cv. Morita stored at 5°C. (Dec. 15 – Feb. 14; Color score: 0 = poor, 6 = excellent)

Acidity in the fruit is also affected by the temperature during curing (Table 4). Ponkan, iyo cv. Miyauchi and hassaku were able to retain a higher acidity content when they were cured at a higher temperature than when they were cured at a lower one. This result is of great interest, because a high temperature generally induces a high rate of respiration and a high rate of consumption of the fruit components. It seems likely that some citrus cultivars have a special pathway of acid consumption at low temperatures.

Effect of Storage Temperature on Color Development

The peel color of citrus fruit tends to influence market quality, because there is some correlation between the degree of orange color in the rind and the sugar and acid content in the pulp.

Figs. 8 and 9 show the effect of storage temperature on color development in the rind of Satsuma mandarin cv. Owari and navel orange cv. Shirayanagi. The value of a/b in the measurement of the Hunter color meter indicates where the fruit lies between red and green: a high a/b value means a high degree of orange color. In the case of Satsuma mandarin, storage at 20°C induced the most beautiful peel color (Fig. 8). However, the most acceptable orange color in navel orange was induced by storing the fruit at 10°C (Fig. 9).

As indicated in Table 5, the optimum temperature for peel color varied for different citrus varieties and cultivars. Lower or higher storage temperatures than the optimum resulted in poor rind color. However, there are several problems in keeping fruit at high temperatures, such as the rate

Table 4. Effect of curing at different temperatures and humidities on titratable acidity in citrus cultivars stored at 5°C, 88 ± 5% RH (% as citric acid)

Cultivar \ Temperature of curing / Humidity	24°C		20°C		15°C		10°C		5°C		1°C	
	low	high	low	high	low	high	low	high	low	high	low	high
ponkan	1.225 b	1.479 a	1.175 bc	1.228 b	1.002 cde	1.088 bcd	0.790 fg	1.063 bcd	0.903 defg	0.924 def	0.736 g	0.862 efg
iyo 'Miyauchi'	2.258 a	2.105 ab	2.056 ab	2.141 ab	2.099 ab	2.225 a	1.990 b	2.077 ab	2.203 a	2.088 ab	1.984 b	1.963 b
hassaku	1.953 d	2.255 a	2.115 bc	2.172 ab	2.124 abc	2.129 abc	2.040 bcd	2.000 cd	2.011 cd	1.975 d	1.900 d	2.007 cd
natsudaidai	2.986 ab	3.005 ab	2.961 ab	3.055 a	2.742 bcd	2.783 abcd	2.631 cd	2.791 abc	2.661 cd	2.713 bcd	2.497 d	2.793 ab

Storage periods: ponkan: Dec. 9–March 14; iyo: Dec. 9–April 8; hassaku: Dec. 22–May 20; natsudaidai: Jan. 17–June 20
Means in the same row with a different letter are significantly different at a 5% level

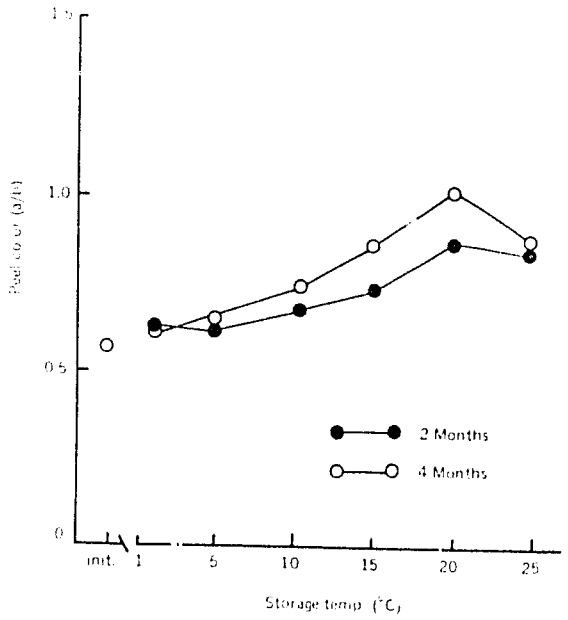

Fig. 8. Effect of storage temperature on color development of the peel of Satsuma mandarin cv. Owari

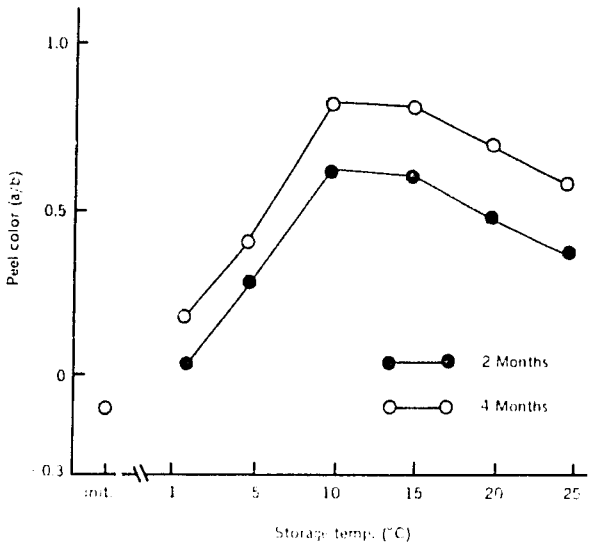

Fig. 9. Effect of storage temperature on color development of peel of navel orange cv. Shirayanagi

Table 5. Optimum temperatures for good color development (a/b) of peel in citrus cultivars

	Cultivar							
	Satsuma mandarin	iyo 'Ohtani'	iyo 'Miyauchi'	hassaku	yuzu	navel orange 'Morita'	navel orange 'Shirayanagi'	natsudaidai
Storage temperature (°C)	20	15	15	15	15	15	10	10

of microbial decay and shriveling. The fruit of sudachi and kabosu fairly acceptable in the market when it is sold with a green color, as both are a sour type of citrus. The chlorophyll content in the rind decreases rapidly if these two cultivars are stored at 15°C, and the peel color turns to pale yellow, so a much lower temperature should be used.

These results indicate that the storage temperature of citrus fruit should be decided according to the relevant factors, which include the variety and cultivar concerned, and the length of the storage period.

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DISCUSSION

Q. (F.W. Liu)

You plotted the respiration rate and ascertained the break point, and then observed the chilling injury. Do these break points show a close correlation with the genetically determined injury development temperature? In your figures, chilling injury appears in the temperature range 0-6°C, while the break point is rather higher.

A. This is a good question. There is some cross correlation between the temperature of the break point and the temperature at which chilling injury occurs, but there is some difference in the actual temperature involved. The break points reflect the respiration rate and thus the total physiological change in the fruit, not just the chilling injury.

Comment: (W. Grierson)

We owe a debt of thanks to Dr. Murata. All of us here have two different lives -- we are working with growers and dealers, who make their living out of these fruits, and most of our papers have dealt with their practical problems. However, as scientists we have to try and find out why these problems occur.

Dr. Murata has touched on a number of things which are very fundamental. The same break points in respiration occur when comparing cold-blooded and warm-blooded animals, as shown in one brilliant experiment carried out by a Californian scientist -- he showed the same gradients that we get in chilling and non-chilling fruit.

This change you demonstrated in respiration rates at different humidities is very interesting. How does humidity have such a profound effect on the fruit? The only effect most people think of is shrivelling, but in your experiments humidity is affecting both respiration and color. In my work on humidity effects, I've chosen to pursue the mechanism of stress, to see whether the changes are being brought about because the fruit is being subjected to various levels of stress. Some of my colleagues are studying the effect of humidity on growth regulators. I think all of us here should go ba to Dr. Murata's paper, and read it with the thought that here someone is forcing us to ask ourselves ..hy these things happen to the fruit we are trying to present so beautifully to the people in the market-place.

Q. (S.C. Tongdee)
When you observed the fruit for chilling injury, did you do this immediately after it was removed from the controlled storage, or did you first keep it at room temperature for several days?

A. The chilling injury was observed immediately after the fruit had been taken from storage.

Comment: (S.C. Tongdee)
I think it possible that chilling injury at low temperatures might occur but not become evident until a few days after the fruit had been removed from storage.

ETHYLENE IN THE POSTHARVEST PHYSIOLOGY OF TROPICAL AND SUBTROPICAL FRUIT

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ABSTRACT

This paper first analyzes the research efforts that lead to elucidation of the biosynthetic pathway of ethylene, a plant hormone which regulates many aspects of growth and development in higher plants. It is followed by a further discussion of some recent progress in this field, which includes: the conjugation of ACC to 1-(malonylamino)cyclopropane-1-carboxylic acid, the formation of cyanide from carbon-1 of ACC during its conversion to ethylene, the regeneration of methionine during ethylene biosynthesis and the purification of ACC synthase from plant tissues. The last part of this paper discusses the role of ethylene in fruit ripening, an important physiological phenomenon common to many tropical and subtropical fruits.

INTRODUCTION

Ethylene, the simplest olefin, is a natural plant hormone that regulates many aspects of plant growth and development. It is produced by nearly all parts of higher plants, and participates in many physiological processes such as breaking of dormancy, seed germination, seedling growth, stress response, flowering, fruit ripening, leaf abscission and senescence.[1] For a long time, ethylene has been a central concern of many postharvest physiologists because of its far-reaching effects on horticultural products. During the past twenty years, significant progress has been made in understanding ethylene biosynthesis and its regulation in higher plants[55]. The biochemical and molecular basis of many physiological processes known to be regulated by ethylene are now also being studied[13]. This paper outlines the background and recent developments in research into ethylene biosynthesis, and discusses the role of ethylene in the postharvest physiology of tropical and subtropical fruit.

ETHYLENE BIOSYNTHESIS IN HIGHER PLANTS – PAST AND PRESENT RESEARCH

Elucidation of the Ethylene Biosynthetic Pathway in Higher Plants

Although ethylene is a rather simple compound, with only two carbons and one double bond, full elucidation of its biosynthetic pathway in higher plants (Fig. 1) was not an easy task.

During the late 1960s, much effort was devoted to determining what might be the precursor of ethylene *in vivo*. This was because there are a large number of compounds which can be converted into ethylene through various chemical reactions. Eventually, methionine gained wide acceptance as the sole precursor of ethylene in higher plants; all other compounds were abandoned due to lack of evidence[50]. Methionine was not only a good ethylene precursor in model reaction systems[26,54], but was also a good substrate for ethylene production in apple tissues[27]. Conclusive evidence was provided by

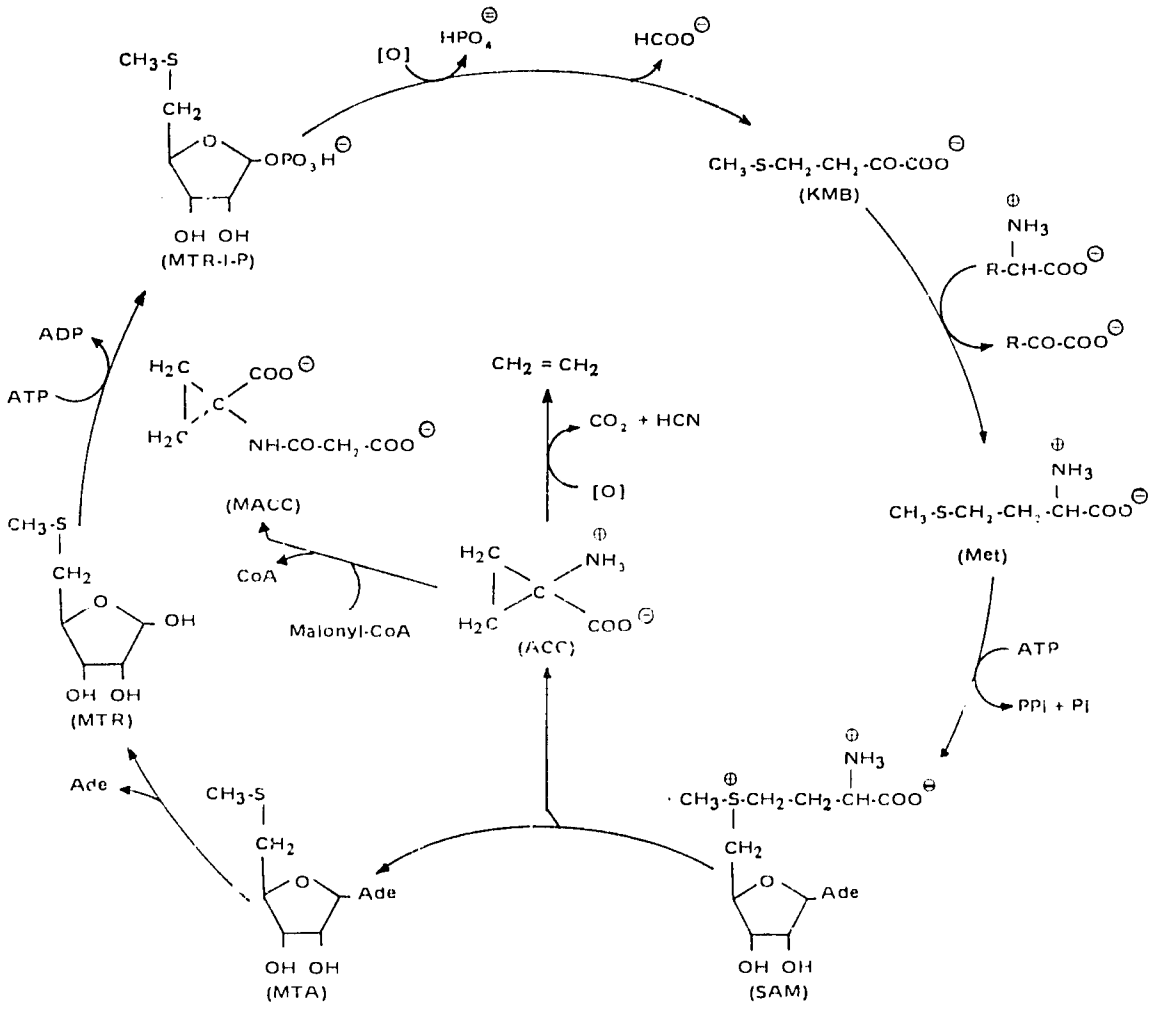

Fig. 1. Ethylene biosynthesis and the methionine cycle (modified from Yang and Hoffman[55], Miyazaki and Yang[33]).

Abbreviations: ACC, 1-aminocyclopropane-1-carboxylic acid; ADE, adenine; KMB, 2-keto-4-methylthiobutyric acid, MACC, 1-(malonylamino)-cyclopropane-1-carboxylic acid; Met, methionine; MTA, 5'-methylthioadenosine; MTR, 5-methylthioribose, MTR-1-P, 5-methylthioribose-1-phosphate; SAM, S-adenosylmethionine.

Baur and his colleagues[8], who demonstrated that the conversion of labelled methionine to ethylene *in vivo* paralleled that found in endogenous ethylene production. Since then, methionine has been shown to be converted to ethylene in many other types of tissue[29].

Although results from model systems suggested a mechanism for the direct conversion of methionine to ethylene via a free radical reaction[9], efforts to isolate a cell-free system that could convert methionine to ethylene were unsuccessful[28]. On the other hand, several *in vivo*

observations suggested that methionine might be converted to ethylene through some intermediate compound(s)[15]. The inhibition of ethylene production from methionine by 2, 4-dinitrolphenol (DNP), an uncoupler of oxidative phosphorylation, implies that ATP may be involved in this process[16]. In 1973, Burg[14] proposed that S-adenosylmethionine (SAM), the ATP-activated form of methionine, might be an intermediate in ethylene biosynthesis. A year later, Murr and Yang[3] proposed a mechanism by which SAM was fragmented into ethylene, CO_2, formic acid, NH_3 and 5'-methylthioadenosine (MTA). It was Adams and Yang[3] who proved conclusively that SAM is an intermediate in ethylene biosynthesis, based on the following evidence.

1. MTA the expected nucleoside fragment from SAM was formed from methyl and sulfur labelled methionine in climacteric apple tissue,
2. The formation of MTA and MTR was observed only in climacteric apples, not in preclimacteric ones,
3. Radioactive labelled SAM could be isolated from a plug of apple flesh fed with labelled methionine,
4. MTA could be cycled back into methionine, so that the sulfur atom was conserved for the continuous production of ethylene in apple tissue, as predicted by Baur and Yang[9] in 1972.

The evolution of ethylene from fruit tissue is oxygen dependent. Burg and Thimann[15] observed that apple tissue stopped producing ethylene when it was kept in nitrogen, but showed an accelerated rate of ethylene production when it was returned to the air. They interpreted this phenomenon as an indication that some metabolite accumulated during exposure to nitrogen which was converted into ethylene rapidly upon transfer to air. This postulated metabolite was eventually confirmed by Adams and Yang[3], who fed U-^{14}C-methionine to apple tissue under nitrogen and found that most of the label was converted into an unknown compound. When this unknown compound was fed to apple tissue in normal atmosphere, it was converted into ^{14}C-ethylene. They went on to identify this compound as 1-aminocyclopropane-1-carboxylic acid (ACC). They also showed that methionine with its methylthio (CH_3S-) group labelled was converted into MTR via MTA under nitrogen. These data together suggest that methionine is first converted to SAM, which is then fragmented into ACC and MTA. ACC appears to be the immediate precursor of ethylene, because it can be converted to ethylene readily by many plant tissues[17]. The biosynthetic pathway for ethylene was thus established as follows[3]:

Methionine → SAM → ACC → Ethylene

Further Progress in the Study of Ethylene Biosynthesis

The Conjugation of ACC to 1-(malonylamino) Cyclopropane-1-Carboxylic Acid (MACC)

Shortly after the discover of ACC as the immediate precursor of ethylene in higher plants, Amrhein *et al.*[5] found that exogenous ACC could be metabolized into a nonvolatile compound by buckwheat seedlings. This compound was identified as 1-(malonylamino)cyclopropane-1-carboxylic acid (MACC). Since this compound forms ACC upon acid hydrolysis, it is considered a conjugate of ACC. The same finding was obtained by Hoffman *et al*[20]. in water-stressed wheat leaves, which produced MACC as an endogenous metabolite of ACC. MACC was later isolated and identified in many other types of tissue[6]. Since MACC is a poor ethylene producer *in vivo*, it is generally thought that MACC is a biologically inactive end product of ACC[21]. However, recent research shows that under certain conditions, MACC can be hydrolyzed back to ACC in some types of tissue[22]. It is now believed that MACC is the major ACC conjugate found in nature, and that it is widely present in plant tissues.

Formation of Cyanide from Carbon-1 of ACC During Its Conversion to Ethylene

It has been soundly established that ethylene is derived from C-3 and C-4 of methionine, which corresponds to the C-2 and C-3 of ACC. The fate of the rest of the ACC molecule, however, was not determined until much later. On the basis of a reaction mechanism in which 1-phenylcyclopropylamine is oxidized to ethylene and benzylnitrile[18], Adams and Yang[4] proposed a similar mechanism for the *in vivo* conversion of ACC to ethylene. By this mechanism, ACC was oxidized to ethylene and cyanoformic acid. Since the cyanoformic acid was unstable, it decomposed into carbon dioxide and cyanide. The formation of these products was eventually demonstrated by Peiser *et al.*[33] in 1984. They fed [carboxyl-^{14}C] and [1-^{14}C] ACC to etiolated mung bean hypocotyls, and found the label to appear in CO_2 and carbon-4 of asparagine respectively. Since it had been shown that in plant tissues, cyanide is rapidly metabolized by an enzyme called β-cyanoalanine synthase to form β-cyanoalanine, which was then converted into asparagine by a hydrolase, it was concluded that cyanide was the initial product of carbon-1 of ACC during its conversion to ethylene. The same results were later reported by Pirrung[39] and Mizutani *et al.*[34]. Since the enzyme activity of β-cyanoalanine synthase is usually one order of magnitude greater than that of ethylene synthesis[32], it is believed that plant tissues have ample capacity to metabolize all the cyanide that is formed during ethylene biosynthesis[38].

In the Methionine Cycle, the Carbon Skeleton of Methionine is Derived from the Ribose Moiety of ATP

It has been shown that the level of methionine in apple tissue is too low to sustain a normal rate of ethylene production, nor are there any volatile sulfur compounds released by the fruit[9]. Because of this, Baur and Yang[9] postulated that the sulfur is being recycled to replenish the methionine pool. Their suggestion was shown to be true when Adams and Yang[2,3] demonstrated that the methylthio group of SAM was conserved in MTA and was later recycled back to methionine. However, the source of the 2-aminobutyrate moiety of methionine was not determined. Since then, it has been found that in some animal tissues and micro-organisms, the ribose moiety of MTA as well as the methylthio group was incorporated into methionine as one unit[7,43]. On re-examining the methionine salvage pathway in higher plant tissues, Yung *et al.*[56] and Wang *et al.*[49] were able to obtain the same result. Thus it is clear that during ethylene biosyntheis, the methylthio group of the methionine molecule is recycled (Fig. 1), and that all the carbon atoms, including ethylene are eventually derived from the ribose moiety of ATP[33].

Purification of ACC Synthase from Etiolated Mung Bean Hypocotyl

Since ACC synthase, the enzyme that catalyzes the fragmentation of SAM into ACC and MTA, is a key enzyme in ethylene biosynthesis, many attempts have been made to isolate and characterize this enzyme. However, despite the fact that ACC synthase activity has been demonstrated in a number of tissues, the enzyme proved to be very unstable, and purification was difficult[55]. Recently, several reports have indicated progress in this field[19,36] and one of them has claimed to have achieved complete purification of ACC synthase with good recovery[47,48]. The purification steps used by this latter group are described here briefly: etiolated mung hypocotyls were ground and mixed with a 1.5 M potassium phosphate buffer (pH 8.0) containing 4.0 mM DTE and 0.5 μM pyridoxal phosphate. The use of a high concentration (1.5 M) phosphate buffer effectively stabilized the enzyme and preserved its activity. The enzyme was purified approximately 1100-fold with 25% activity recovery after the following four steps of purification:

(1) stepwise hydroxyapatite chromatography,
(2) Phenyl-Sepharose CL-4B hydrophobic chro-

matography,

(3) gradient hydroxyapatite chromatography,

(4) Fast Protein Liquid Chromatography (FPLC) with a Mono-Q anion exchanger column.

The purified enzyme showed a single band at 65 kD on SDS PAGE, but had an estimated molecular weight of 125 kD by gel filtration. Therefore, it was concluded that ACC synthase consisted of two identical subunits. It is hoped that this breakthrough in the study of ethylene biosynthesis will soon appear in a formal journal so that its procedures can be followed by other interested people. This will definitely speed up our understanding of the regulation of ethylene biosynthesis at a molecular level.

ETHYLENE AND THE RIPENING OF TROPICAL AND SUBTROPICAL FRUIT

The ripening of fruit may be defined as the sequence of changes in color, flavor and texture which lead to the state at which the fruit is ready for eating[12]. The relationship between ethylene and fruit ripening is probably the most intriguing subject in ethylene physiology.

Generally speaking, fruits from all climatic zones can be classified, according to the pattern of their postharvest drift in respiration, into climacteric and non-climacteric fruit[11]. The term "climacteric" was first used by Kidd and West[24] to describe the rise and decline in respiration of apples after harvest. Accompanying this shift in respiration are visible and dramatic changes in ripening. Recent interpretations of the concept of the climacteric tend to imply, not only an upsurge in respiratory activity, but also physical, chemical, physiological and metabolic changes associated with this increase in respiratory rate[12]. Non-climacteric fruits, on the other hand, show a steady downward drift in respiration and a relatively slow change in the various ripening parameters[11,12]. In Table 1, a number of tropical and subtropical fruits are classified into two groups according to their respiratory patterns. It is obvious that this list is by no means complete, indicating the lack of information in this field.

It has been established that in climacteric

Table 1. Classification of tropical and subtropical fruits according to their respiratory patterns

Climacteric fruit		
Common name	Scientific name	Reference
Avocado	*Persea americana*	1
Banana	*Musa sapientum*	1
Breadfruit	*Artocarpus altilis*	1
Carambola	*Averrhoa carambola*	3
Cherimoya	*Annona cherimola*	1
Chico	*Manilkara zapota*	2
Feijoa	*Feijoa sellowiana*	1
Guava	*Psidium guajava*	1
Jackfruit	*Artocarpus heterophyllus*	1
Mammee apple	*Mammea americana*	1
Mango	*Mangifera indica*	1
Papaw (Pawpaw)	*Asimina triloba*	1
Papaya	*Carica papaya*	1
Passion fruit	*Passiflora edulis*	1
Plantain	*Musa paradisiaca*	2
Sapote	*Casimiroa edulis*	1
Soursop	*Annona muricata*	1
Sugar apple	*Annona squamosa*	4
Non-climacteric fruit		
Common name	Scientific name	Reference
Cacao	*Theobroma cacao*	1
Grapefruit	*Citrus paradisi*	1
Java Plum (Jamblan)	*Eugenia cumini*	1
Lemon	*Citrus limonia*	1
Longan	*Euphoria longana*	4
Lychee	*Litchi chinensis*	1
Mountain apple	*Eugenia malacensis*	1
Olive	*Olea europea*	1
Orange	*Citrus sinensis*	1
Pineapple	*Ananas comosus*	1
Rose apple	*Eugenia jambos*	1
Surinam cherry (Pitanga)	*Eugenia uniflora*	1
Tamarillo (Tree tomato)	*Cyphomandra betacea*	1
Wax apple	*Eugenia javanica* (*Syzygium samarangensis*)	4

Reference: 1. Biale and Young[12]
2. Lizada *et al.*[30]
3. Shiesh *et al.*[45]
4. Unpub. data

fruits, endogenous ethylene serves as the trigger for the rise in respiration and fruit ripening. In non-climacteric fruits, on the other hand, the ethylene requirement is relatively unimportant[12,40]. Usually, a physiologically active concentration of ethylene must first be established within the climacteric fruit tissue before ripening is initiated. This is accomplished either by an increase in ethylene biosynthesis, or by an increase in the sensitivity of tissue to ethylene[2]. The concept of changing tissue sensitivity is the mechanism by which plant hormones work[2,9] is very useful in explaining variations in ethylene concentration and the induction of the climacteric in different fruits. The initiation of ripening is also accompanied by a large increase in ethylene production. McMurchie *et al.*[30] introduced the concept of two systems for ethylene production. System 1 is the ethylene production system that is operating up to the initiation of ripening: System 2 is the ethylene production system induced by fruit ripening. The induction of System 2 ethylene is also called "autocatalytic" ethylene production, because its production is stimulated by ethylene. For climacteric fruits, ripening can be initiated by treatment with exogenous ethylene. This is a very important commercial practice in the postharvest handling of a number of tropical fruits such as banana, avocado and mango[41]. These fruits are usually harvested during the preclimacteric stage, and are treated with ethylene before entering marketing channels. It is also important that ethylene be removed or its synthesis inhibited during shipping or storage, when ripening is not desirable. This is can be accomplished by using ethylene absorbants such as potassium permanganate, ethylene scrubbers, physical methods of inhibiting ethylene synthesis such as controlled atmosphere storage, or chemical inhibitors of ethylene biosynthesis such as AVG and AOA[44,52].

It is now known that the key step regulating ethylene production in ripening fruit is the conversion of SAM to ACC[51]. Hoffman and Yang[19] examined the relationship between ACC content and ethylene production in several types of fruit tissue. Very little ethylene was produced in preclimacteric avocado and the ACC content was very low. As ripening began, there was a parallel increase followed by a fall in both ACC content and ethylene production rate (Fig. 2), indicating a close relationship between the two. Similar results were observed in banana and tomato. The increase in ACC content was due to the development of ACC synthase activity, as demonstrated in tomato tissue by Kende and Boller[23]. The enzyme that converts ACC to ethylene the ethylene-forming enzyme (EFE) is also limited in preclimacteric fruit tissue, but its activity usually starts to increase before the development of ACC synthase[13,55]. The significance of this increase in EFE activity was recently discussed by Yang[53].

Since climacteric and non-climacteric fruits differ in respiration as well as other physiological behavior, it is essential to know to which category a fruit belongs, so that proper handling procedures can be arranged. The previous method of using patterns of respiratory drift to distinguish climacteric fruit from non-climacteric fruit has been found to be inadequate[12]. Currently, it is generally agreed that the two classes of fruit are better distinguished by their responses to exogenous applied ethylene[12,53]. In climacteric fruit, ethylene treatments accelerate the onset of ripening and the accompaning rise in respiration, as well as System 2 ethylene production, without appreciably altering the climacteric patterns or magnitude of respiration. In non-climacteric fruit, the respiratory activity is stimulated as a function of ethylene concentration, but there is no increase in ethylene production nor any distinct ripening changes associated with this rise. A good example of application of the above principles was found in the controversy over the tropical fruit carambola (starfruit). Previous reports had concluded that carambola was a non-climacteric fruit, on the basis that there was no increase in respiration during two weeks of measurement[25,37]. However, when the respiratory activity of carambola fruit was followed very carefully throughout its ontogeny, Shiesh *et al.*[45] found that there was always a climacteric

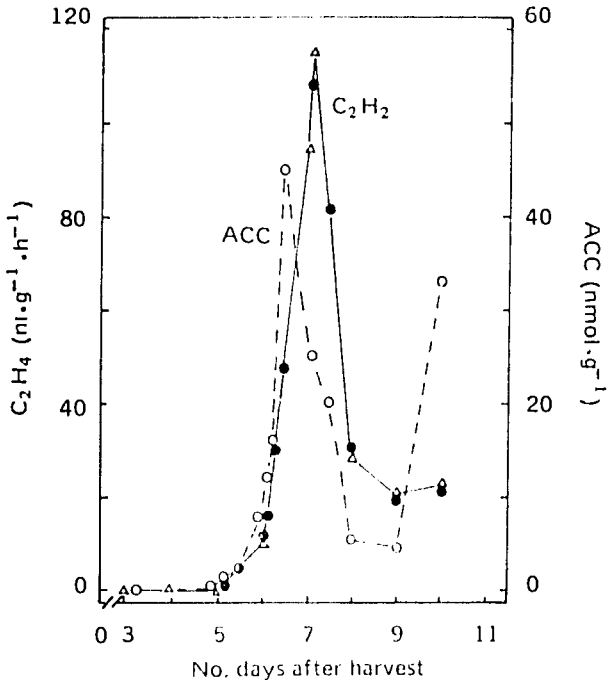

Fig. 2 Changes in ACC content of avocado fruit during ripening
Source: Hoffman and Yang 1980[19]

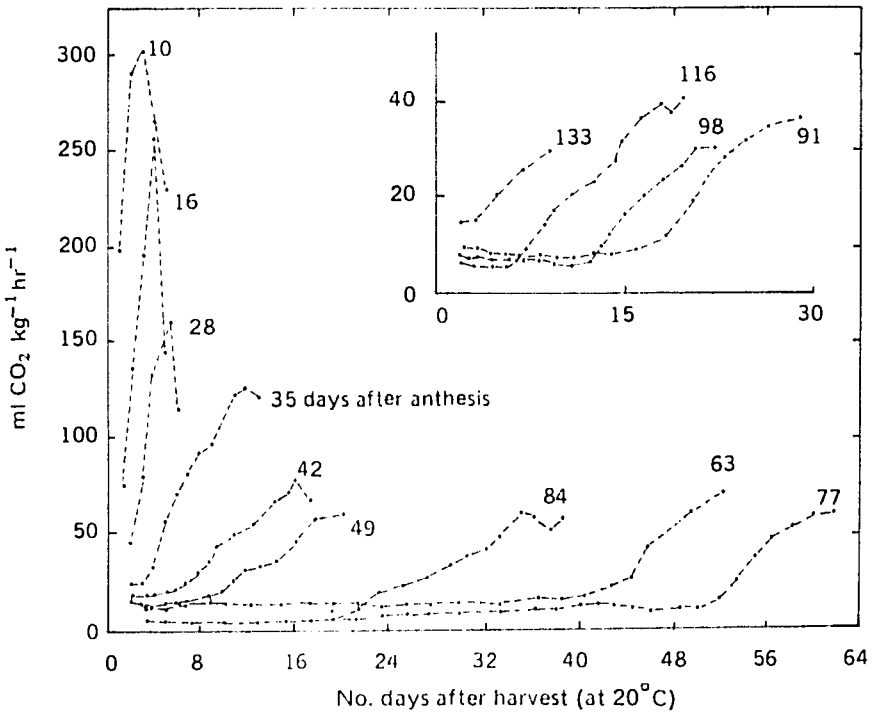

Fig. 3 Respiratory drift of Er-Lin carambola fruit (Starfruit) throughout ontogeny
Source: Shiesh *et al.* 1987[45]

rise in respiration regardless of the age of the fruit (Fig. 3). Moreover, they found that the time required for the fruit to ripen varied with fruit age. The longest preclimacteric period was found in fruit harvested 77 days after anthesis; it took almost 50 days for the fruit to reach the climacteric. Since carambola are usually harvested for the market when the fruit are 90 days old, it is easy to mistake the preclimacteric flat for an indication of non-climacteric fruit. Ethylene treatments shorten the time required to reach the climacteric and stimulated the early production of ethylene (Fig. 4), in accordance with the criteria set by Biale and Young[12]. However, it should be pointed out that ethylene seems to cause autoinhibition in carambola fruit[55], because ethylene production rates decline as the ethylene concentration increases.

Although ethylene does not have any dramatic effects on non-climacteric fruit such as initiating autocatalytic ethylene and ripening, it does have other hormonal effects on such fruit. For example, the degreening of citrus fruit by ethylene treatment is a well-known commercial practice[1]. In citrus fruits such as lemon and Ponkan mandarin, ethylene acts in two ways. Firstly, it promotes the synthesis of carotenoid, and secondly it brings about the degradation of chlorophyll[41]. Another example is the use of ethylene to induce flowering in pineapple[1], which is important in achieving uniform fruit maturity for harvesting.

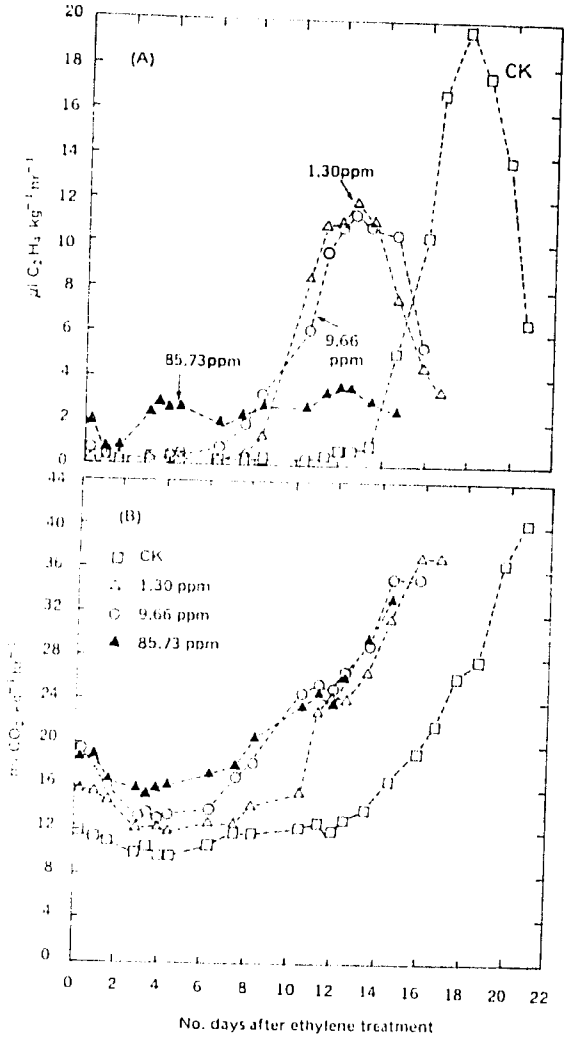

Fig. 4 Effect of ethylene treatment (35 hr, 23°C) on ethylene production (A), and respiration (B) of Er-Lin carambola fruit
Source: Shiesh *et al.* 1987[45]

CONCLUSION

Tropical and subtropical fruits have a very varied genetic background. They differ not only in structure and morphology, but also in physiological and biochemical behavior. In the past, only a few fruits such as banana and avocado were used in model systems for the study of ethylene and postharvest physiology. It is unfortunate that this rich source of research material has not yet been fully explored. As more and more tropical and subtropical fruits are gaining commercial importance, it seems likely that more interest will be focussed on the postharvest physiology of tropical and subtropical fruits. There are still a lot of questions to be answered. For now, we have a good opportunity to work together on postharvest problems in tropical and subtropical fruits, which are of far more interest to us than apples and pears.

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ENERGY-SAVING STORAGE OF CITRUS FRUIT IN JAPAN

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ABSTRACT

In Japan, about 1 million mt of late-maturing citrus fruit is produced each year, and is marketed after long-term storage from February to May. Storage is usually refrigerated, because outdoor temperatures rise to more than 10°C during the latter part of this period. Refrigerated storage has very high energy costs and there is a need for a alternative and more economical storage method.

Some energy-saving storage methods using micro-computers, sites at relatively high altitudes, or abandoned caverns or tunnels, have been studied for this purpose. Of these, particular attention was paid to the use of the 'Ohya' stone quarries, used until 50 years ago to produce ohya tuff stone for building walls, gates and warehouses. These abandoned quarries are good low temperature warehouses, and their climatic conditions were monitored with a view to using the caverns for the storage of citrus fruit. The results obtained indicate that this type of underground warehouse provides a suitable environment for the storage of citrus fruit, and the caverns are already being used in Japan for this purpose.

INTRODUCTION

In Japan, the annual production of citrus fruit is 3.5 million mt, 2.5 million mt of which are Satsuma mandarins. The remaining one million mt consist of late-maturing varieties, mainly natsudaidai (*C. natsudaidai* Hayata), iyo (*C. iyo* Hort. ex. Tanaka), hassaku (*C. hassaku* Hort. ex. Tanaka) and navel oranges (*C. sinensis* Osbeck). Production of all four varieties has increased rapidly during the last decade (see Table 1). They are harvested in late December to early February, stored for 2-5 months, and marketed from February to July.

Refrigeration is not needed for storing Satsuma mandarins, because of the low outdoor temperatures during the storage period (December to March). However, refrigeration is needed for the late-maturing varieties stored during April and May, because the outdoor temperature during this period rises to over 10°C.

Table 1. Production of major citrus varieties in Japan, other than Satsuma mandarins

Variety	Production (mt) 1975	1985
Natsudaidai (*C. natsudaidai* Hayata)	175,000	254,000
Iyo (*C. iyo* Hort. ex Tanaka)	45,000	170,000
Hassaku (*C. hassaku* Hort. ex Tanaka)	157,000	209,000
Navel orange (*C. sinensis* Osbeck)	15,000	63,000

At present, late-maturing varieties are relatively profitable crops for citrus growers. However, profits are likely to become lower in future, partly due to the rise in storage costs.

There is, therefore, a need for alternative cool storage which is energy-saving and relatively cheap. A study was made of the use of microcomputers in storage facilities, storage sites at high altitudes, and abandoned caverns or tunnels. The results obtained were encouraging, particularly for the third alternative, the abandoned caverns, already now in use for storing citrus in Japan.

REDUCING THE ENERGY COSTS OF STORAGE

Use of Microcomputers for Energy-Saving Storage

As the outdoor temperature at night falls below 10°C until mid-April in citrus producing areas in Japan, citrus fruits can be stored without refrigeration by introducing cool air into the storage house at night (Fig. 1). A storage house based on this principle was constructed at Mihamacho, Mie Prefecture in 1983, and 900 mt of Amanatsu oranges (sweet natsudaidai) were stored in it. The storage house was equipped with thermo sensors inside and outside, a microcomputer and ventilators. When the outside temperature is lower than that inside, fresh outdoor air is introduced into the storage house through the ventilators. However, if the outdoor temperature is below -3°C, the storage house is not ventilated to prevent the stored fruit from being damaged by chilling injury. If high outdoor temperatures continue for several days, preventing daily ventilation, the CO_2 concentration inside the house increases to more than 1%. In this case, fresh air is introduced for five minutes every three hours, regardless of the outdoor temperature.

This process is controlled automatically by a microcomputer. As the results were encouraging, another storage house with a capacity of 700 mt was constructed in 1985.

Use of High Altitude Storage Sites

The Asagiri highlands at the foot of Mt. Fuji (3,776 m) are rather cooler than the citrus producing areas. The mean temperature in early May is only about 10°C, so that citrus fruit can be stored there without refrigeration (Fig. 2).

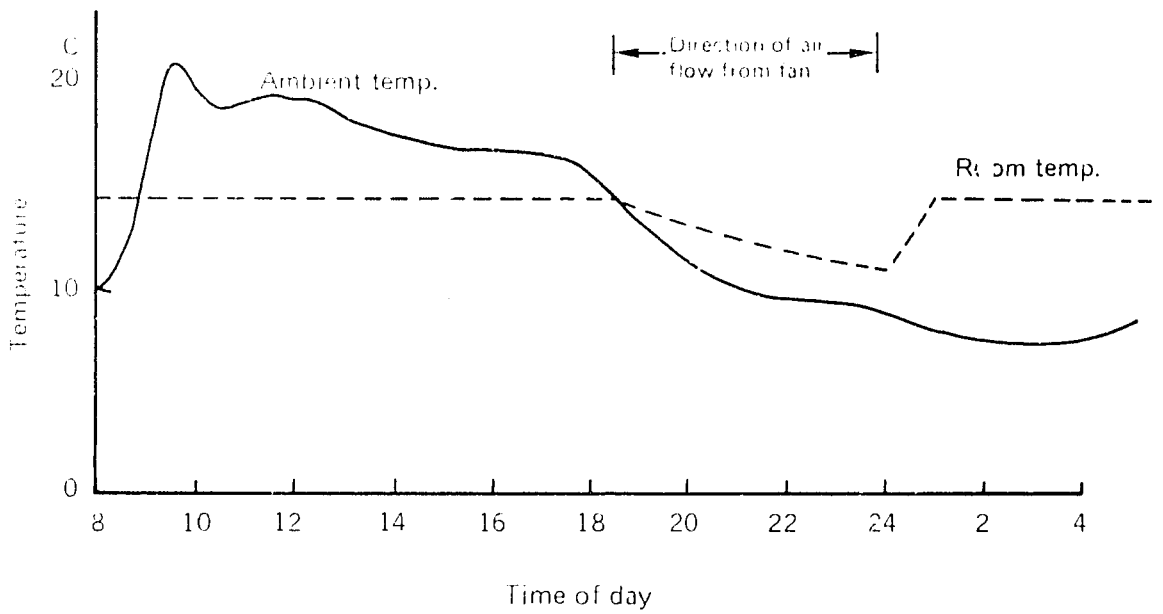


Fig. 1 Diurnal changes in ambient and room temperature in storage house equipped with microcomputer (mid-April, 1981).

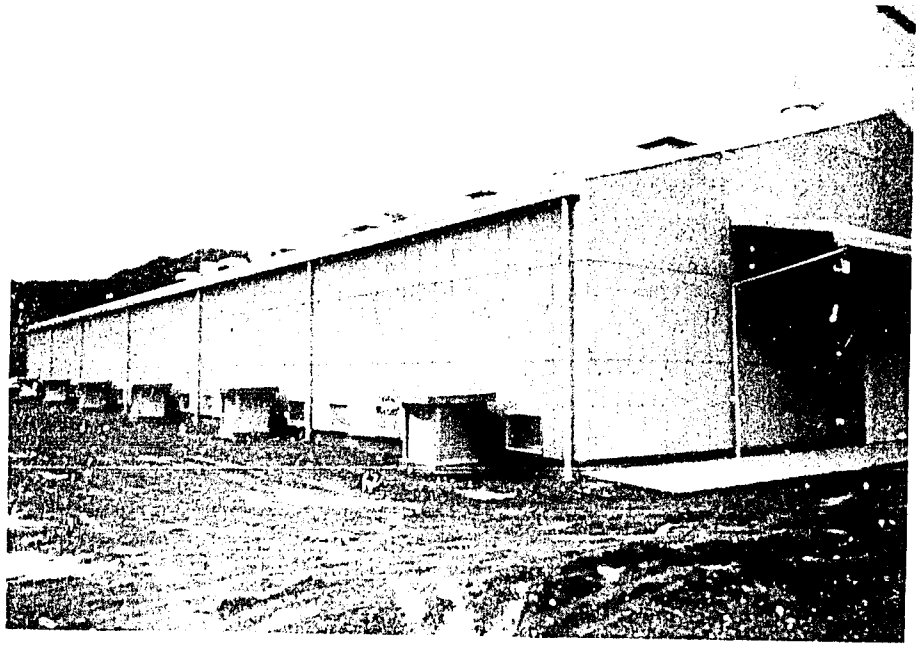


Plate 1. Storage house at Mihama-cho, Japan, with computerized ventilation system

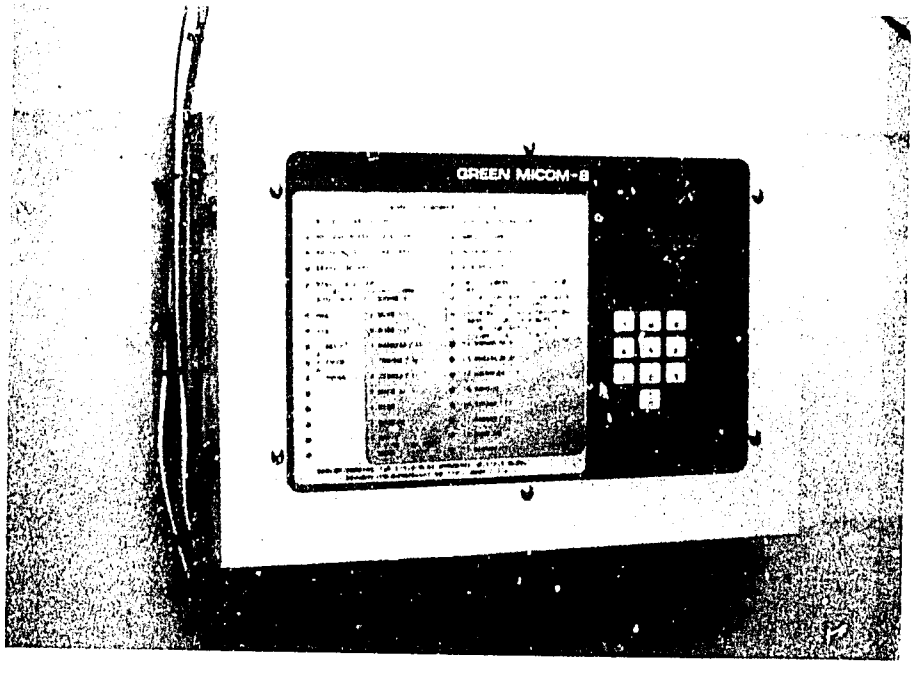


Plate 2. Thermosensor and microcomputer used in storage house above

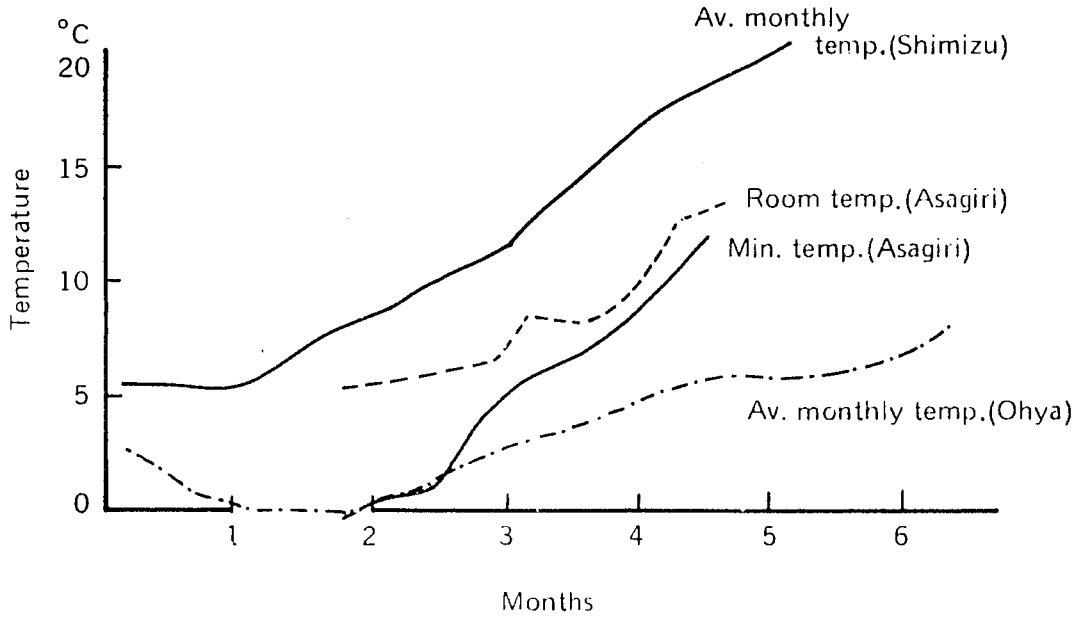


Fig. 2 Changes in temperature in Asagiri highlands, Ohya stone quarry cavern and Shimizu city.

The Misumi Township Agricultural Cooperative has five storage houses (maximum capacity 4,400 mt), the Nishiuwa Agricultural Cooperative has five (3,500 mt), the Tanoura Citrus Cooperative has two (2,000 mt) and Yui Township Agricultural Cooperative has two (920 mt) storage houses in the Asagiri highlands.

The Asagiri highlands are located near Tokyo, a major market. As well as saving energy costs, another benefit of this upland storage of citrus fruit is that shipping can easily be regulated in response to price fluctuations in Tokyo.

Storage in Ohya Stone Quarry Caverns

There are 130 huge underground caverns in the suburbs of Utsunomiya City, Tochigi Prefecture. These are abandoned quarries where Ohya tuff stone, used in building walls, gates and warehouses, was once produced. Climatic conditions inside several caverns belonging to the Byobuiwa Sekizaibu quarrying company were monitored[1], and storage trials were conducted from 1980 to 1984 (Figs. 3 and 4).

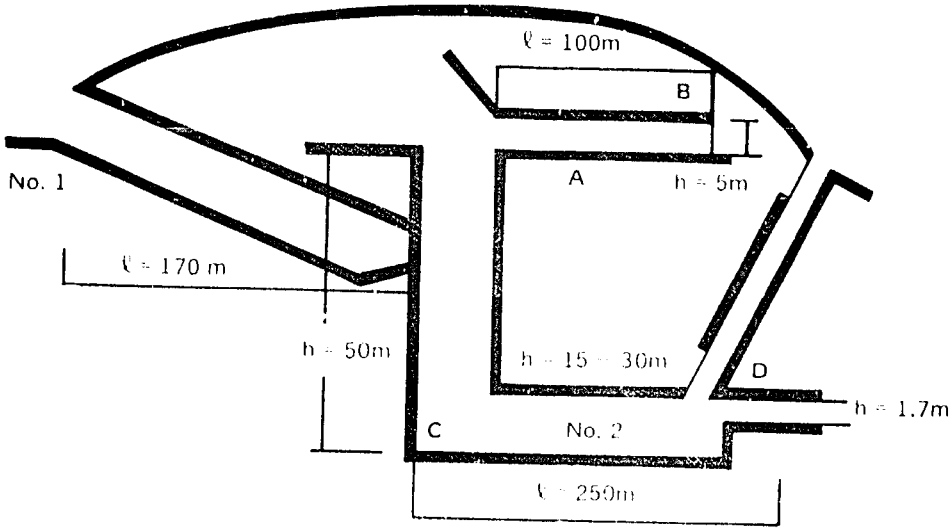
In one cavern (No.1) near the ground surface, atmospheric temperature throughout the year ranged between 3 and 15 C, and the relative humidity ranged from 80 to 90%. In another cavern (No.2), located 50 m below the ground surface, the atmospheric conditions were 2-9 C, with 90-98% relative humidity throughout the year.

The average temperature outside the cavern in June was 22 C, while the base rock inside the cavern at a depth of 25 cm and 90 cm remained constant at 11 C and 9 C, respectively (Figs. 5 and 6).

Generally, underground air temperatures are estimated to be approximately the same as the annual mean outside air temperature. As the annual mean temperature at Utsunomiya is 12.7°C (average of past 30 years at Utsunomiya Weather Station), the temperature inside the cavern was expected to be about the same. However, the actual measured temperature was 2-9°C, far lower than the estimated one.

This discrepancy can be explained in the following way. In winter, the temperature on the ground drops below 0°C at night, and the outside air becomes heavier than that inside

Plates 3 and 4. Fruit storage in disused underground stone quarries, Japan



Source: Iba *et al.*[1]

Fig. 3 Longitudial section of Ohya stone quarry cavern, and points at which temperature and relative humidity were measured. (A,B,C,D).

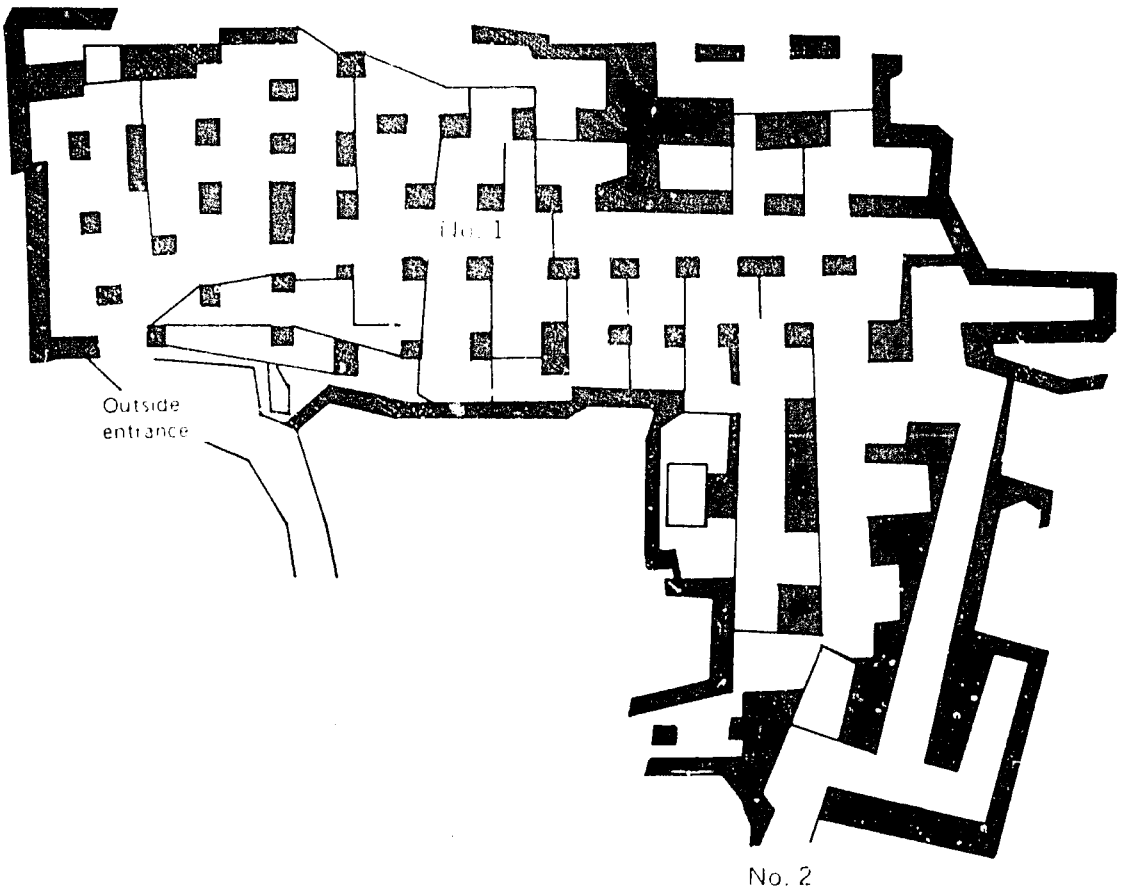


Fig. 4 Horizontal cross-section of Ohya stone quarry cavern.

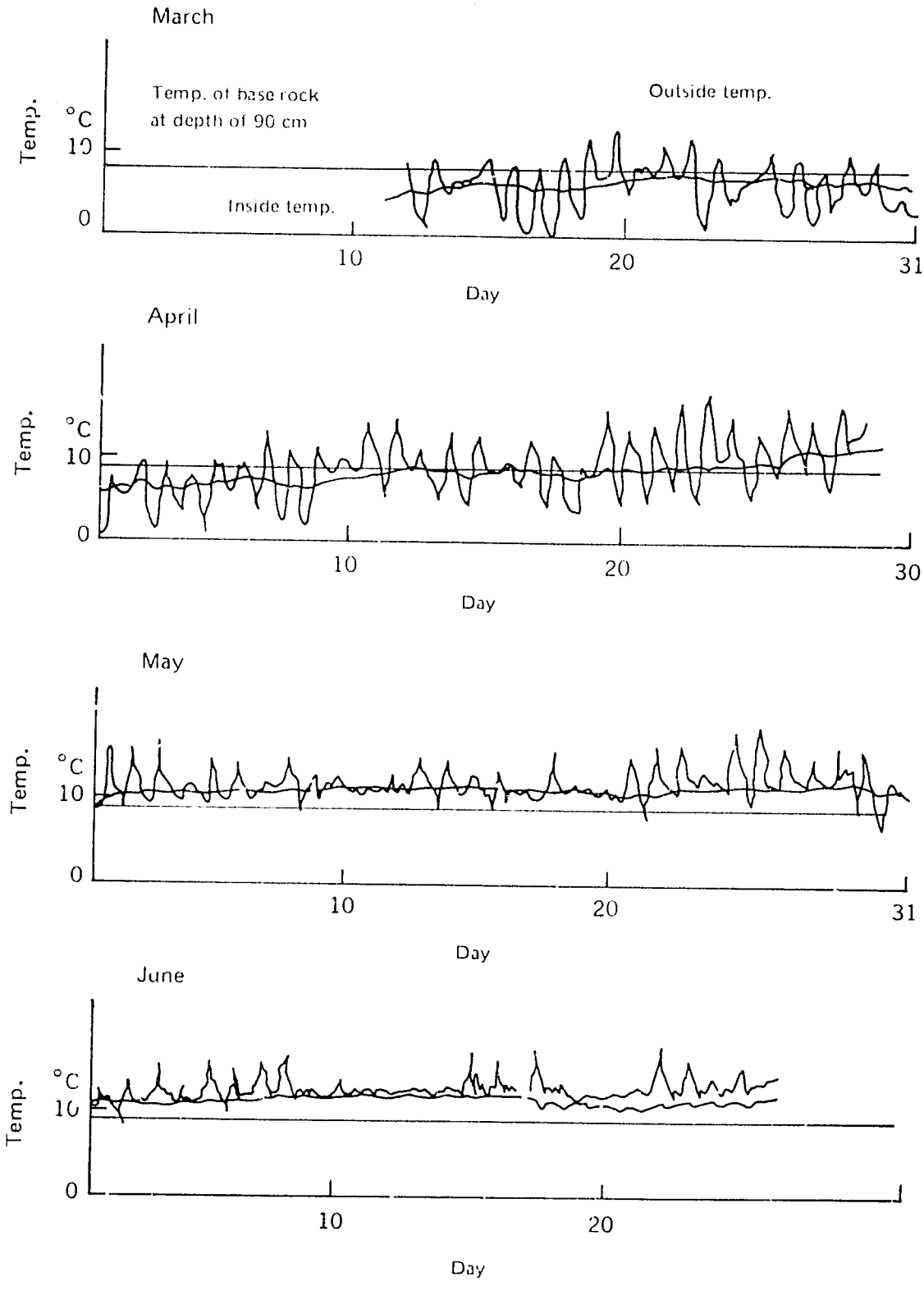


Fig. 5 Changes in temperature outside and inside the cavern and of base rock in Ohya stone quarry cavern. (Iba *et al.*[1])

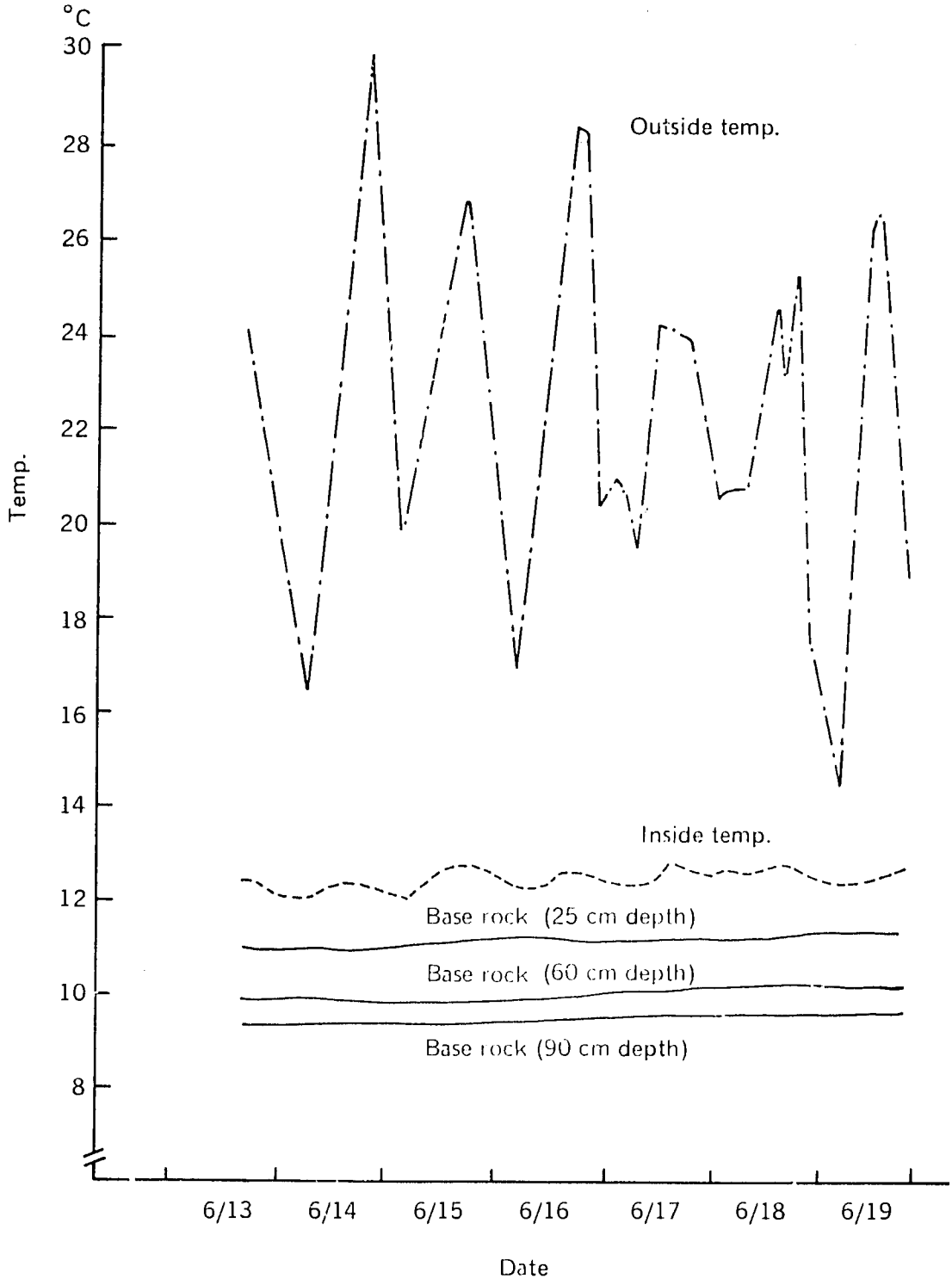


Fig. 6 Changes in temperature outside and inside the cavern and of the base rock at point B (cf. Fig.3). (Iba *et al.*[1])

the cavern. Convection currents move this cold air inside the cavern through vertical pits, so that the inside air temperature drops day by day during winter. Moreover, the cold outside air progressively cools the base rock of the cavern.

On the other hand, air does not move during warm weather because the cool air inside the cavern is heavier than that at ground level outside (Fig. 7). Consequently, heat is not easily transmitted from the ground to the underground caverns, while the base rock cooled during winter works as a kind of large refrigerator in summer. Because of this, the temperature inside the cavern does not rise appreciably even during warm months.

In order to assess the suitability of Ohya caverns as a storage facility, practical storage trials trials were conducted over five years[1,2]. The results obtained are shown in Table 2. It is apparent that there was virtually no difference between the cavern and refrigerated room as to fruit storage quality, storage life and the rate of fruit decay. Accordingly, Ohya caverns can be considered very promising as storage facilities.

Ohya caverns have an additional benefit. In general, Amanatsu oranges are stored in Japan wrapped individually in a polyethylene film bag (0.03 mm thick), to prevent them drying out or being infected by penicillium diseases. However, the laborious process of wrapping was not necessary for storage in the cavern (see Table 3). Amanatsu oranges could be stored

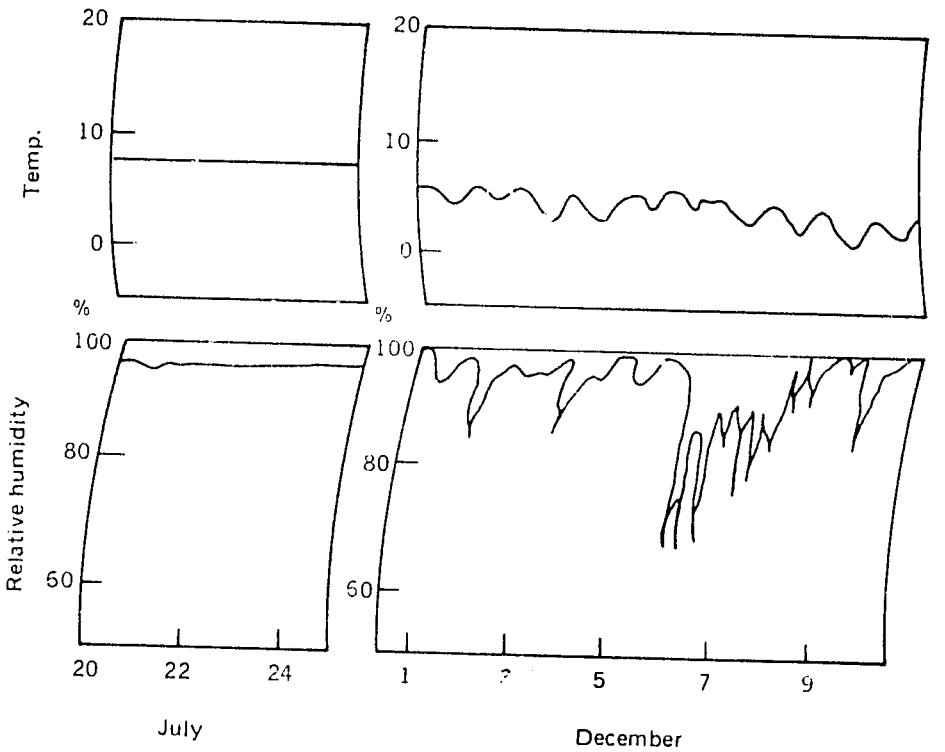


Fig. 7 Changes in temperature and relative humidity at point C (cf. Fig. 3) in summer and winter.

Table 2 Quality and decay rate of Amanatsu oranges stored at Ohya and Okitsu*

(Iba, Y. *et al.*, 1987)

Date of Analysis	Place of Storage	Average Weight (g)	% Flesh	% Juice	Acid Content (%)	Brix Degree	Specific Gravity (g/cm³)	Peel Color	% Decayed oranges at end of storage period
April 20	Ohya	299.1	65.7	67.7	1.11	10.0	0.786	0.63	0.4
	Okitsu*	296.8	65.6	66.7	1.18	9.9	0.778	0.60	0
May 12	Ohya	291.5	63.9	69.4	1.05	9.7	0.775	0.63	0.7
	Okitsu*	295.1	65.5	69.6	1.15	9.7	0.783	0.62	0
June 17	Ohya	297.4	62.3	69.0	0.74	9.0	0.761	0.68	1.8
	Okitsu*	304.4	63.4	70.0	0.93	9.5	0.769	0.66	1.2
August 5	Ohya	298.8	62.8	62.9	0.50	8.2	0.747	0.60	3.5
	Okitsu*	301.4	64.3	65.3	0.62	8.9	0.754	0.63	3.2

* Storage at 5°C under refrigeration.

Table 3 Quality and decay rate of Amanatsu oranges stored in Ohya stone cavern

(Iba, Y. *et al.*, 1987)

Treatment		Average Weight (g)	% Flesh	% Juice	Acid Content (%)	Brix Degree	Specific Gravity (g/cm³)	Peel Color	% Decayed oranges June 21	Junly 21
Plastic Wrapped		305.7	65.3	66.9	0.65	8.8	0.775	0.76	7.3	22.2
Unwrapped		293.2	65.1	67.3	0.68	9.2	0.782	0.76	8.4	14.3
Producing Area	A	292.3	64.5	64.8	0.47	8.0	0.743	0.74	44.8	60.3
	B	232.2	66.4	67.8	0.91	10.5	0.811	0.77	2.3	6.1
	C	310.5	63.0	66.9	0.67	9.0	0.773	0.73	3.1	4.6
	D	265.3	63.4	65.7	0.50	8.5	0.753	0.72	1.7	10.5
	E	278.0	64.5	67.9	0.70	8.9	0.808	0.81	1.7	18.5
	F	333.5	66.6	67.7	0.67	9.2	0.777	0.78	3.3	15.0
	G	324.9	65.9	67.7	0.70	8.7	0.784	0.75	5.1	17.1

well without it. This made a considerable saving in labor.

In addition, storage costs in Ohya caverns are low, as electrical refrigeration is not required. At present, 8,000 mt of Amanatsu oranges are being stored in Ohya caverns. If all these were stored in a low temperature storage house, the refrigeration costs would amount to 25,000,000 yen (US$180,000*). Running costs in the Ohya caverns, for illumination inside the cavern, amount to no more than 1,800,000 yen (US$13,000), one-fourteenth of the cost of refrigerated storage.

* 1 US$ = 140 Yen

In conclusion, this type of underground warehouse provides a suitable environment for the storage of citrus fruits, and is also energy-saving and economical.

Storage in Other Kinds of Underground Facility

After the successful trials in the Ohya caverns, 44 other abandoned mines and tunnels in various parts of Japan were examined as prospective storage facilities. Some of these have now been put to practical use.

In Mie Prefecture, an abandoned mine and a tunnel are now being used to store Amanatsu oranges. A total of 400 mt were stored there in 1986.

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DISCUSSION

Q. (F. W. Liu)
You are using caves or tunnels built some time ago, but are any new ones being built for storing fruit?

A. No -- they are too expensive.

Q. (S. C. Lin)
As your slides showed, you are storing citrus fruit in cartons in a microcomputer-controlled warehouse. Do you check the fruit for decay? If not, how do you control blue penicillin mold?

A. In these high mountain storage facilities where the temperature is controlled by computer, scientists from nearby research stations check the fruit for decay once a month and take samples. If any rot is found, all the cartons are checked.

Q. (S. C. Lin)
Does the wall of the storage room contain insulating material?

A. Yes, the inner wall has a layer of insulation about 10 cm thick. In addition, although air temperatures during the day can be high in the mountains, the computerized ventilators eliminate temperature fluctuations within the storage facility.

Q. (Y. L. Chen)
Have you considered the safety factor? Are these underground storage facilities dangerous?

A. No, they are very safe. Although Japan does have earthquakes, these do not affect the underground storage systems.

Q. (F. W. Liu)
I note that you store the fruit in cardboard boxes. Do the boxes absorb moisture, or are they waxed? What is the humidity of the storage?

A. The cardboard boxes are not waxed, but they are loaded only five boxes deep. Even if they absorb some moisture they do not collapse. If they were to be packed six layers deep, the lowest boxes might collapse if the humidity were high.

VACUUM, HYDRO, AND FORCED-AIR COOLING OF FARM PRODUCE AND THEIR ENERGY CONSUMPTION

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ABSTRACT

Air cooling, hydrocooling and vacuum cooling are all widely used to cool fruit for storage, to maintain quality and prolong the shelf life. This paper looks at the energy costs of the three different systems. Vacuum cooling appears to have the lowest energy cost per unit of produce cooled, because there is no need to move the cooling medium through the system and the vacuum minimizes heat transfer from the environment. The system with the highest energy cost is forced air cooling, while hydrocooling is intermediate between the two. Various ways are suggested of improving the efficiency of energy use.

INTRODUCTION

Forced-air, hydro cooling, vacuum, and room cooling, package ice, and top icing are all cooling methods used to cool farm produce in postharvest handling[1]. The first three are used in precooling. They cool produce within hours or even minutes to maintain better quality and give a longer storage life[2].

Air Cooling

Forced air cooling is suitable for fruits, berries, fruit-type vegetables, tubers, cut flowers and cauliflowers, hydrocooling is suitable for stems, leafy vegetables and some fruits and fruit-type vegetables, vacuum cooling is suitable for leafy vegetables, some stem vegetables, and flower-type vegetables.

Room cooling supplies cold air which moves around containers, whereas forced air cooling forces cold air to move through container vents, thus achieving more rapid cooling as a result of the intimate contact between cold air and warm produce. Room cooling may be too slow for many perishable commodities. Its cooling rate varies extensively according to the load, whether it is on pallets, and the type of container used. Forced-air cooling is more uniform. Usually, forced-air cooling and room cooling are combined in a packing house, the former being used as precooling and the latter as cold storage.

Hydrocooling

Hydrocooling removes field heat from fruit and vegetables at the time of harvest. It also washes away residues, field dust, and dirt from the produce to be cooled. Adding certain chemicals to the cooling water, such as chlorine or iodine solutions, destroys harmful bacteria on the surface of fruit and vegetables.

Hydrocooling is carried out by flooding or by immersion or by a combination of the two. Flooding showers the produce with an abundance of cold water from overhead perforated flood pans. The produce being cooled is either stationary or moving on a conveyor belt. For immersion cooling, packed or bulk produce is submerged in agitated cold water. The flow rate of cold water is about 10 l/s per square meter of distributor pan surface. The conveyor advances the product under the flow of water at a rate of about 30 cm/minute[6]. Cooling is very fast. Uniform cooling can be achieved if the method is properly used, but temperatures may vary widely

and sanitation measures are essential. The product must be able to tolerate wetting, and water tolerant shipping containers may be needed.

Vacuum Cooling

Vacuum cooling is used for certain vegetable crops. It is basically an evaporative cooling process, whereby water is supplied by the commodity being cooled. Absolute pressure surrounding the commodity is reduced, which lowers the boiling temperature of water. If the pressure is lowered enough, water will boil at the temperature of the produce. Sensible heat is given off by the produce to change liquid water into water vapor, and so the produce cools. Mushrooms and leafy vegetables such as lettuce release water vapor rapidly enough for vacuum cooling to be very efficient. Cooling time varies from 0.5 to 1.5 hours. Commodities must have a favorable surface-to-mass ratio for this cooling method to be effective. It causes about 1% weight loss for each 6 C cooled. A procedure is available which adds water during cooling to prevent this weight loss but the equipment involved is expensive and water tolerant shipping containers are needed.

Energy Consumption of Different Cooling Systems

A limited amount of research has been done on the energy consumption of different types of cooling system. An engineering consulting firm has reported that one lettuce vacuum cooler operation had an energy use of 0.25 kwh per carton (a carton of head lettuce weighs about 25 kg, and is typically cooled from a field temperature of about 20°C to about 2°C). This is equivalent to an energy consumption of 0.56 kwh to reduce 1 mt by 1°C (mt/-1°C). Some of the earliest work, on an ice cooled hydrocooler indicated an average energy use of 0.04 melted ice per kg/-1°C of product cooling, equivalent to 3.7 kwh/mt/-1°C[12]. Bennett[1] defined cooling energy use efficiency as the amount of sensible heat removed from the product, divided by the refrigeration capacity of the cooling facility. He found that the efficiency of using hydrocooling for peaches fell in the range of 0.42 – 0.90[1]. Using the same definition, Grierson, Bennett, Soule and others[7,10] have found the energy use efficiency of forced-air cooling to be in the range of 0.17 to 0.58 for oranges, tangelos, apples and grapefruit. Early in 1958, Guillou[8] showed that only 55% of refrigeration in continuous type hydro coolers was used to bring the product temperature down: the remaining refrigeration was spent in supporting the process. The percentage was even lower (23%) for batch type coolers.

This paper summarizes recent research at National Taiwan University and University of California at Davis on the energy use of commercial scale cooling systems. It gives the energy use for the three main types of coolers, forced air cooling, hydrocooling and vacuum cooling. The level of heat input from all sources is analysed, and possible reasons for differences in the energy use of the three systems are identified.

To compare the energy consumption of different cooling systems, Energy Use Coefficient (EC) is used in this paper. EC stands for the sensible heat removed from the product to be cooled, divided by the electrical energy used during the cooling operation.

ENERGY USE IN FORCED-AIR COOLING

Table 1 shows the heat inputs into two commercial cold storage systems on days when fruit packing and precooling were being carried out. Fig. 1 gives a pictorial representation of the same data.

As mentioned above, forced-air cooling systems are usually installed as an integral part of cold storage systems, to cool produce before it is moved into cold storage rooms. It is difficult therefore to distinguish the refrigeration load of the precooling system from that of the facility as a whole. However, some information was

Table 1 Heat input in two commercial cold storage systems during precooling operations[z]

Item	A Storage		B Storage		Ave.
	kwh/31 days	%	kwh/30 days	%	%
1. Heat transmission through walls, floors, and roofs	57,610 (14,500)	18.5 (7.4)	40,000 (10,000)	7.3 (2.6)	12.9 (5.0)
2. Heat from warm air infiltration	967 (800)	0.3 (0.4)	20,000 (16,000)	3.7 (4.1)	2.0 (2.3)
3. Heat from produce	82,598 (70,200)	26.5 (35.7)	230,000 (195,500)	42.2 (50.5)	34.4 (43.1)
4. Heat from people, lights, forklift trucks etc.	7,309 (2,600)	2.4 (1.3)	14,500 (4,900)	2.6 (1.3)	2.5 (1.3)
5. Heat from fans	162,940 (108,700)	52.3 (55.2)	241,000 (191,000)	44.2 (41.5)	48.2 (48.3)
6. Total	311,424	100.0	545,500	100.0	100.0
7. Electrical power consumed during the same period	196,160 (123,960)[y]		582,600 (413,750)[y]		
8. EC (Item 3/ Item 7)	(0.57)		(0.47)		(0.52)

[z] Figures in parentheses are the calculated heat inputs for the forced-air precooling system which was part of each cold storage plant.

[y] 123,160 = 196,160 × 196,800/311,424;
413,750 = 582,600 × 387,400/545,500.

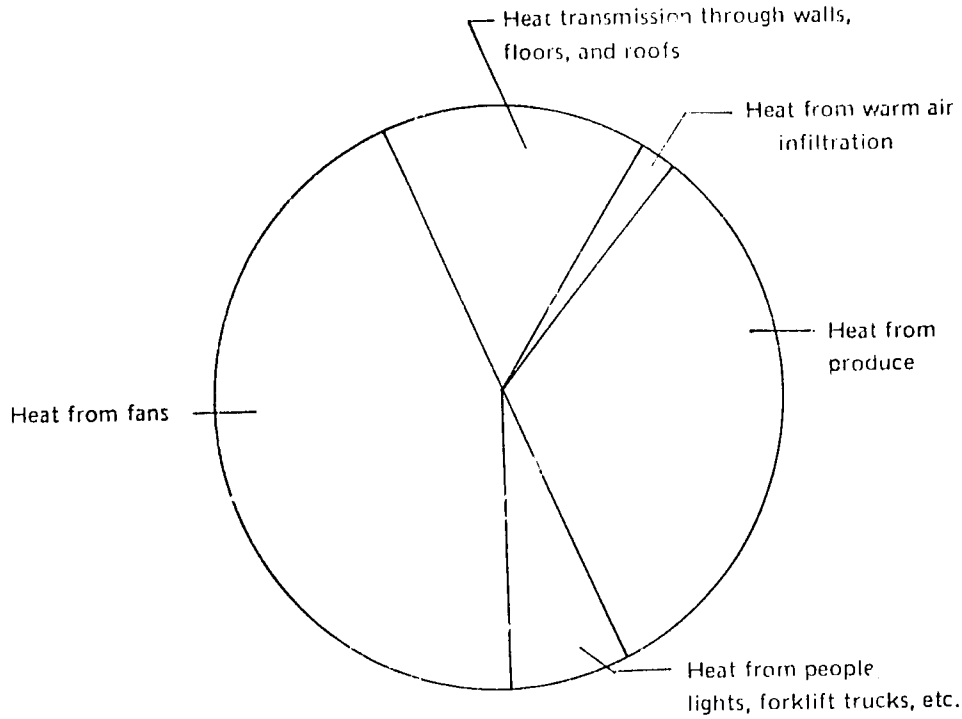

Fig. 1 Relative contribution of five types of heat input to the refrigeration load of a commercial cold storage system, including forced-air cooling.

obtained from a survey of two commercial cold storage systems. It found that:

1) Precooling facilities occupied only about one quarter of the building structure area of the whole storage system.
2) The precooling system was using two-thirds of the total electrical power consumed.
3) The heat of the product in the precooling area was about 85% of the total.
4) Four out of 9 forklift trucks working throughout the whole operation were working in the precooling area, and
5) Six out of 21 lights were located in the precooling area.

If the heat inputs for the cold storage systems are adjusted according to this information, another set of heat input data can be obtained, shown in parentheses in Table 1 and in pictorial form in Fig. 2. The figure gives a clear picture of how the heat inputs of a forced-air precooling system are distributed. Using this calculation, the EC of the two forced-air cooling systems were found to be 0.57 and 0.47, respectively.

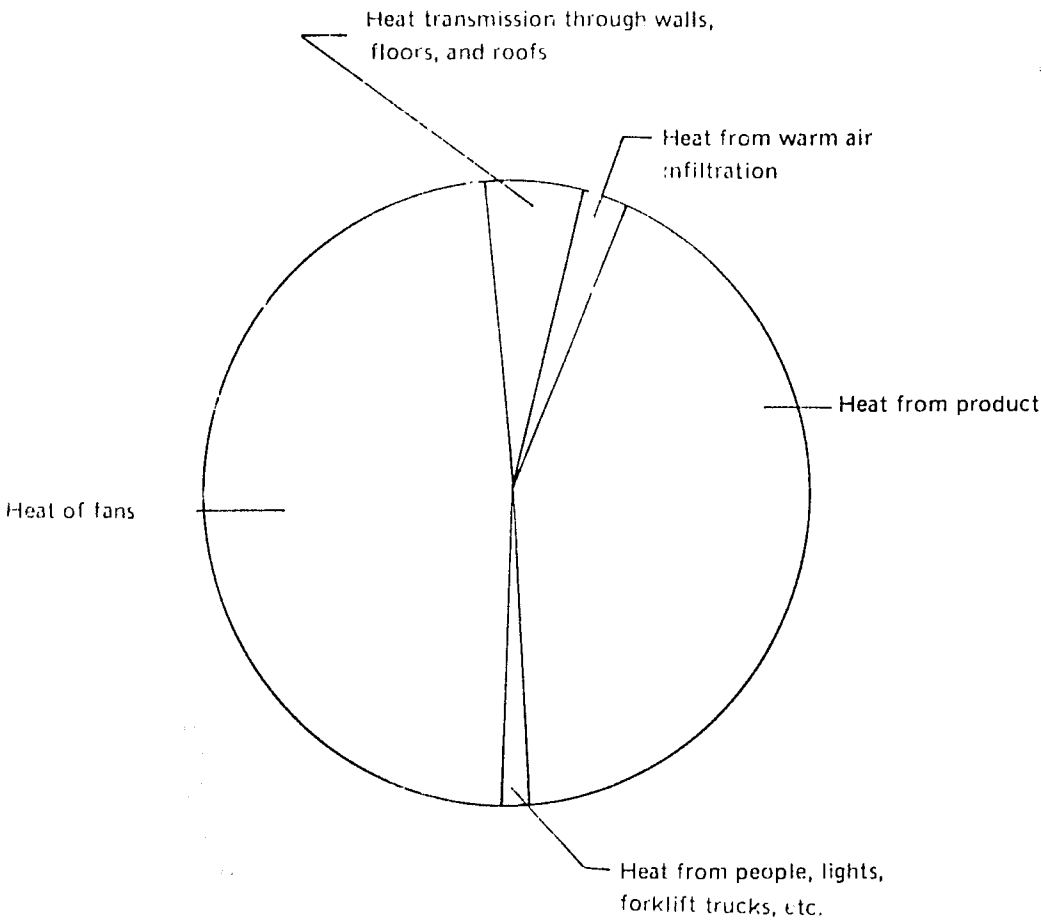

Fig. 2 Relative contribution of five types of heat input to the refrigeration load of two commercial forced-air cooling systems

ENERGY USE IN HYDROCOOLING

Nine runs of peach and plum were cooled in two separate hydrocoolers. On average, 78 minutes were required to cool the produce from 24.1°C to 7.5°C. Energy consumption was 0.90 kwh/mt/1°C, which is equivalent to 1.2 EC[5,11].

Of the total energy consumed, 65.1% was used for running the compressors of the refrigeration system, 22.4% was used to circulate the cooling water, and the remaining 12.5% was used by miscellaneous motors and pumps, as shown in Fig. 3.

The total heat input into the hydrocooler was also measured (Table 2). The heat from the produce was the largest item, which implies that hydrocoolers make more efficient use of energy than forced-air cooling. Heat from the environment contributed 26% of the total. It consisted of all the heat transmitted to the system from the cooler's environment by conduction, convection, and radiation. Heat through the pumping of circulating cooling water contributed 9%, starting up after changing the water was also 9%, while heat from supplementary make-up water contributed 2%.

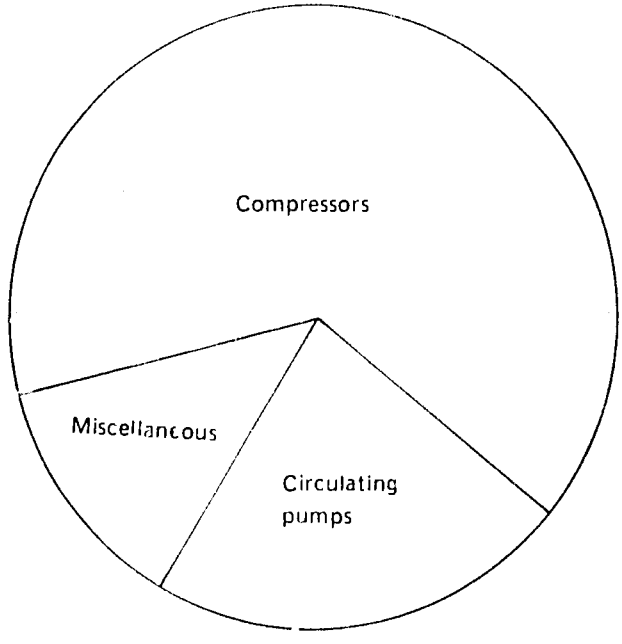

Fig. 3. Energy use distribution in a hydrocooler

ENERGY USE IN VACUUM COOLING

Vacuum cooling performance and energy consumption experiments were carried out for eight runs of lettuce and one run of cauliflower. Less than 30 minutes and less than 0.5 kwh/mt/1°C were required to cool lettuce from 23°C

Table 2. Relative contribution of five types of heat input in a hydrocooling system

Item	% of Total
1. Heat from produce	54
2. Heat from environment	26
3. Heat from pump	9
4. Start-up, change of water	9
5. Make-up water	2
Total Total	100

to 2°C. The average energy coefficient of the coolers were found to be 2.65 for lettuce, and 1.0 for cauliflower[3].

Of the total energy consumed, 67% was used for operating the compressors of the refrigeration system, 22% for operating the vacuum pumps, and the remaining 11% was spent for miscellaneous motors and pumps, as shown in Fig. 4. Heat input to the refrigeration system, on the other hand, was almost entirely from the produce being cooled.

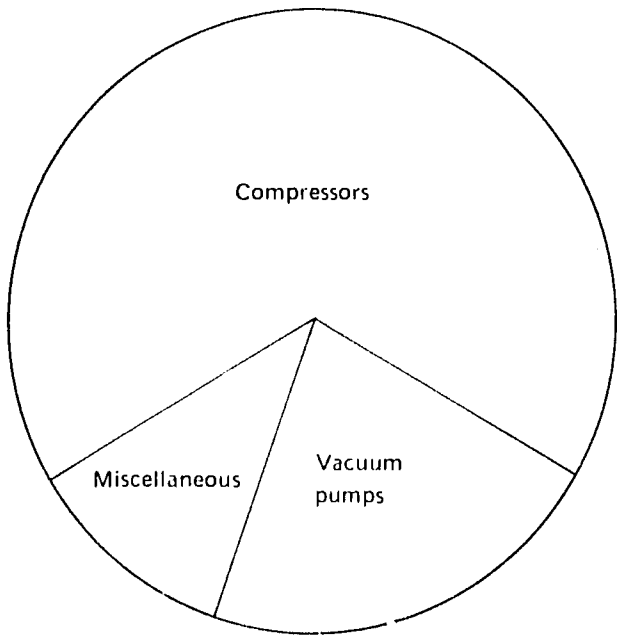

Fig. 4. Energy use distribution in a vacuum cooler

DISCUSSION AND CONCLUSION

The energy use coefficients of forced-air, hydro cooling, and vacuum cooling systems were found to be 0.52, 1.2, and 2.65, respectively.[3,4,5] The differences between the three coolers are mainly due to their different cooling principles, and the nature of the cooling media used. The EC of vacuum cooling is high because it is based on the evaporative cooling principle. There is no need to move any cooling medium through the produce to be cooled, which is why this system requires less energy than forced-air or hydro cooling. The vacuum in the cooling retort minimizes heat conduction or convection between the environment and the produce being cooled. In addition, there are no people, machinery or light within the cooling retort, which makes it even more efficient.

Both hydro cooling and forced-air cooling involve the circulation of a cooling media through the system. Since the heat transfer coefficient and the heat capacity per unit volume are much higher for water than for air, much less energy is required to move large volumes of cold water through the system to cool it. This makes forced-air cooling systems more costly in terms of energy consumption than hydrocooling. In addition, in a forced-air cooling system, forklift trucks are operating *inside* the system, which imposes an additional heat load to the refrigeration system, whereas in a hydrocooling system, the machines

are operating *outside* the cooler.

EC varies between different coolers of the same type. The EC of vacuum cooling systems may range from 1.0 to 3.0[12], that of hydrocooling systems from 0.42 to 2.3[12], and that of forced-air cooling systems from 0.17 to 0.58[8,10].

Two major factors which affect energy use efficiency are the loading of produce within the cooling space, and the kind of produce to be cooled. Cooling a fully loaded vacuum retort could mean a EC of 3.0 for lettuce, whereas a half-empty retort of lettuce would mean an EC of only 2.0. If cauliflower are cooled, the EC can be as low as 1.0.

These two factors also affect the energy use coefficient of hydrocooling. The heat inputs from the environment, from the circulating pump, from the warm water at the start and from the replenishing water during operations, all make up 46% of the heat load to the refrigeration system. This level of heat input will remain much the same as long as the facility is operating, regardless of whether the cooler is fully loaded with produce or not. It is therefore more energy efficient for a cooler to operate at full capacity and with the fewest possible interruptions.

A compact configuration and good insulation are certain to reduce the energy consumption of a hydrocooling system. Heat from the fan(s) is the most important source of heat input in a forced-air cooling system. Proper air flow rate, adequate container venting, neat container stacking, proper refrigeration coil and duct design and good motor and fan selection, will all make a difference in the energy use efficiency of the system. Heat of the produce is the second big item. Even this heat load can be reduced if the produce is harvested at night, avoiding direct exposure to the sunlight before bringing it in for packing and cooling.

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DISSCUSSION

Q. (W. Grierson)
In comparing the energy costs of hydrocooling and forced air cooling, did you check the capital cost i.e. the tonnage of refrigerator capacity that has to be purchased? Usually hydrocooling runs only about eight hours a day, while forced air cooling runs 24 hours a day.

A. No, we only calculated the energy costs. Generally in our operations the commodity was not coming in continuously, but in separate loads of a few tons, arriving at different times. This meant that the cooling system had to be repeatedly stopped and started again.

Section IV.

Disease Control

POSTHARVEST DISEASES OF SUBTROPICAL AND TROPICAL FRUITS AND THEIR CONTROL

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ABSTRACT

Postharvest diseases of fruit are a serious problem in Taiwan, which has a warm, humid climate and produces fruit for export as well as for local consumption. Various methods of chemical control have been developed, and recently there have been promising advances in biological control of citrus mold and anthracnose, using Bacillus subtilis as a postharvest treatment. This paper describes the common postharvest diseases of citrus, banana, pineapple, papaya and mango in Taiwan. It describes the causal organism or predisposing environmental factors which give rise to the disease, and the control methods used.

INTRODUCTION

Postharvest diseases of subtropical and tropical fruits are of great importance, especially in places like Taiwan where climatic conditions are very favorable for disease development. Control of some postharvest diseases can be done in the packing house, but many disease control measures should begin in the field. Good cultural practices and early application of fungicides can reduce losses due to postharvest disease. Controlled temperature, both in transit and in storage, is essential. This paper outlines common postharvest diseases of fruit found in Taiwan, and the control measures used against them.

POSTHARVEST DISEASES OF CITRUS

Common Green Mold and Blue Contact Mold

The most common type of decay found in citrus fruit is generally known as blue mold. This is in fact two separate diseases, common green mold and blue contact mold. The former is caused by *Penicillium digitatum* while the latter is caused by *P. italicum* (Plate 1). In Taiwan, common green mold is the most common cause of decay in postharvest citrus fruit in storage or on sale. Blue mold is much less common. Export fruit is generally treated with a 1-500 dilution of Mertect, with an added 0.5% Potassium alum to increase the effect of the Mertect. In addition, growers are recommended to spray their fruit with 1-1,000 dilution of Mertect in the field four days before harvest, to reduce incidence of decay.

Benomyl was formerly used in packing houses to control blue mold in Taiwan. After continuous use over several years, Yu[14] found a resistant strain of *Penicillium italicum* in 1977. A recent study by Lin, a graduate student of Dr. Tzeng at National Chung Hsing University in Taiwan, showed that *Bacillus subtilis* could inhibit the growth of *P. italicum* and reduce the incidence of rot in citrus fruit in the laboratory. Further study is being undertaken, but the results have not yet been published.

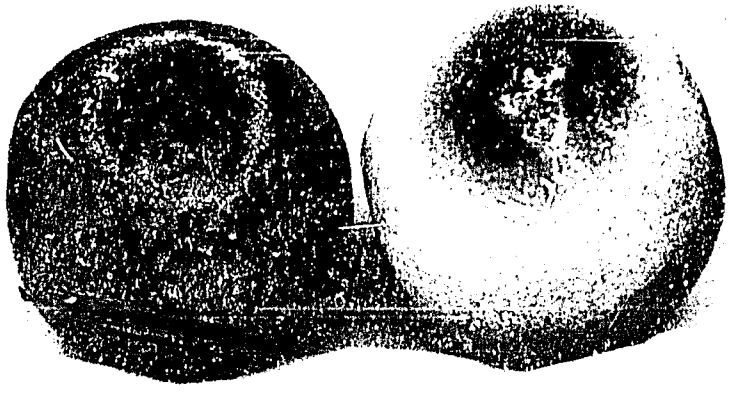

Plate 1. Citrus blue mold (left) and green mold (right)

Diplodia Rot

This kind of rot is caused by *Diplodia natalensis*. The fruit is usually infected at the stem end, but infection may also start at the stylar end or at any place where the skin is injured. The first symptom is a slight discoloration around the button. The fruit soon becomes leathery and pliable, and the rind darkens to brown and then blackish brown. When the fruit has become dry and mummified, it looks like a piece of charcoal, so the disease is sometimes called charcoal rot. Although Diplodia rot can be found in markets or packing houses, losses caused by this disease are not serious. Treating fruit with Mertect could reduce the incidence of this rot.

Phomopsis Stem-End Rot

Phomopsis stem-end rot is caused by *Phomopsis citri*. The perfect stage of this fungus is *Diaporthe citri*, which also incites melanose in the orchard. Phomopsis stem-end rot is a leathery, pliable discoloration of a buff or brown color which encircles the stem-end of the fruit. In the beginning, it cannot be distinguished from Diplodia rot, but later the color of Phomopsis stem-end rot becomes a dull brown or darkish drab brown, while fruit infected with Diplodia rot turns a much darker color over the whole fruit. Phomopsis stem-end rot can be found in storage facilities, but at present it is not important in Taiwan.

Sour Rot

Sour rot is a soft, watery, slimy, contact decay due to *Oospora citri-aurantii*. The disease is also sometimes called Oospora rot. Diseased fruit becomes putrid, sour, dirty and leaking. It is attractive to fruitflies, and eventually turns into a maggot-filled mass of rotten flesh. The fruit finally collapses into a flattened, watery mass.

Citrus Black Spot

This is primarily a field disease caused by *Guignardia citricarpa*, the imperfect stage

of which is *Phoma citricarpa*. The fungus penetrates the fruit at a very early stage, but remains latent until the fruit ripens. Black spot is a very common postharvest disease in the market (Plate 2). Control measures should be taken in the field, beginning a week after petal fall. The following fungicides are recommended: Mancozeb 1-500, Antracol 1-500, Benomyl 1-3000, Delan 1-1000, and Benomyl 1-4000 plus summer oil (Orchex 769) 1-200.

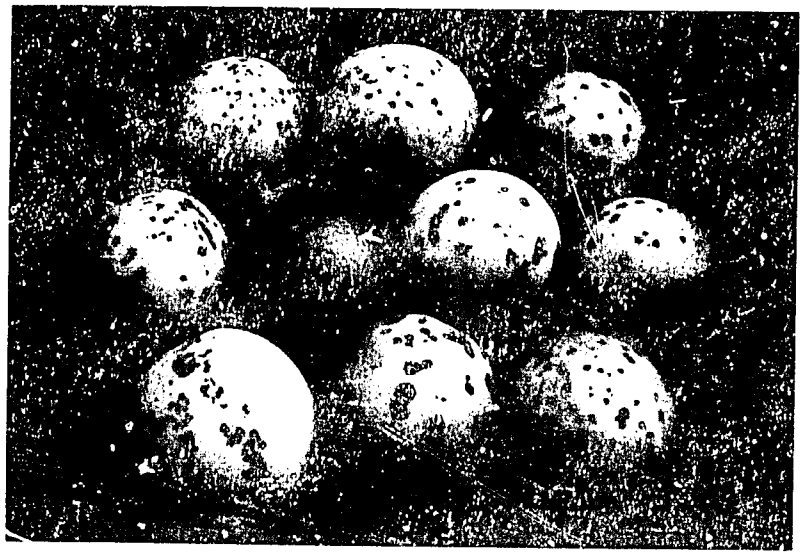

Plate 2. Citrus black spot *(Guignardia citricarpa)*

POSTHARVEST DISEASES OF BANANA

Main Stalk Rot

This was a major in-transit disease in Taiwan when bananas were shipped to Japan in the old days. It was also called crown rot, since the rot begins from the cut surface of the crown tissue (Plate 3). Rotting is first apparent as a softening and blackening of the crown tissue. Greyish white mycelium may be present on the surface of the blackened tissue. Later on, rot may spread inwards towards the pedicles of the fingers, causing finger drop.

No one fungus causes crowns to rot in this way. During the winter season, *Ceratocystis paradoxa* (imperfect stage: *Thielaviopsis paradoxa*) is the usual cause. In summer, *Botryodiplodia theobromae*, *Gloeosporium musarum*, *Verticillium theobromae*, *Fusarium roseum* and some other species can be involved.

Control of main stalk rot was easily achieved with the introduction of Thiabendazole (TBZ) and improved packing and shipping in air-conditioned containers. The TBZ can be applied as a dip, at a rate of 200-400 ppm. Benlate at a rate of 400 ppm is also effective[8,12].

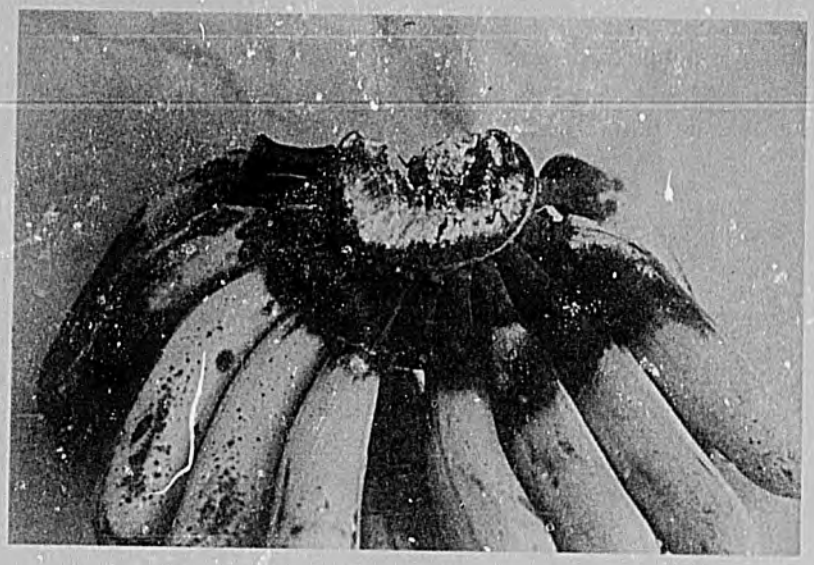

Plate 3. Banana crown rot (photo courtesy Dr. S.C. Hwang)

Anthracnose

Anthracnose is a serious postharvest problem in banana production in Taiwan, since the Cavendish varieties generally grown are highly susceptible to this disease. As the fruit turns yellow in the market, brown spots develop which gradually become sunken and covered with orange or salmon-colored acervuli of the fungus. Under highly humid conditions and high temperatures, a salmon-colored slimy mass appears on the sunken lesion which is the conidia of the fungus. Brown patches are confined to the peel, but as ripening progresses the fungus can invade the pulp, causing a watery rot.

The causal organism of anthracnose is known to be *Collectotrichum musae*, formerly named *Gloeosporium musarum*. Its perfect stage is *Glomerella cingulata*. Meredith (1960) found that the fungus produced abundant conidia on old banana leaves during the dry period, and that spores then become airborne during periods of rainy weather as a result of splash dispersal of conidia from acervuli. Spores deposited on green fruit germinated in a film of water and formed appressoria. After 24-72 hours, penetration pegs below the appressoria pierced the cuticle of the fruit. In green fruit, no further development occurs until the fruit begins to ripen. Simmonds[9] found that the infection hyphae could remain latent for almost five months. Several hypotheses have been put forward about the latent period of infection of banana anthracnose fungus, but it seems most likely that the tannin in the green fruit has an inhibitory effect[1].

Control of anthracnose should begin in the field. Good cultural practices, including removal of the trash leaves, are recommended by Burden[10]. Dipping the fruit with Benomyl or TBZ before packing as recommended by French pathologists is not effective in Taiwan. Since the fungus penetrates the cuticle and forms appressoria during the early stage of fruit development, field application of the following fungicides is recommended: Mertect or Tilt 1-1,000 dilutions, or a Mancozeb 1-400 dilution. Only the bunch of fruit is sprayed, and a polyethylene bag is then placed over the bunch[10].

Freckle or Black Spot

Freckle is caused by *Phyllostictina musarum*, formerly known as *Macrophoma musae*. This is a serious disease of fruit and leaves in the field in Taiwan, since spotted bananas are always rejected for export. Numerous small, slightly raised dark brown spots appear on the green fruit. Each spot consists of 8-10 minute, projecting, black pycnidia, which roughen the peel. The pulp is seldom affected, but spotted fruit have much reduced sales and prices. Cavendish bananas are highly susceptible, while Gros Michel are resistant. Spraying the fruit twice monthly with 1 lb (.45 kg) of Maneb plus 4 oz (.11 kg) sticker-spreader in 100 gal (378.5 *l*) of water reduces the disease incidence[3].

Chilling Injury

Bananas are a tropical fruit which are very sensitive to low temperatures. In the old days, bananas were shipped in vessels which did not have any air-conditioning. Exposure of fruit to winter temperatures while it was in transit from Taiwan to Japan often caused chilling injury. Although ships are now heated, chilling injury still sometimes occurs in transit due to faulty refrigeration in the ship. Placing bananas in an ordinary refrigerator, as people often do, may also cause chilling injury.

If bananas are exposed to temperatures lower than 11°C for several days, underpeel discoloration will appear[10]. If discoloration is severe, the fruit become a dull gray and the pulp is not edible. Chilling in transit of Cavendish bananas can be avoided by making sure the temperature does not fall below 12°C.

POSTHARVEST DISEASES OF PINEAPPLE

Black Rot

Black rot in pineapples is a postharvest disease which is only found after long-distance transport, when the fruit reaches the storage facility or market. The first symptom is a water-soaked spot, which may appear on any part of the fruit but is usually found on the basal portion. This spot gradually enlarges and becomes a dark yellow color. The tissues soften, and the juice which leaks out has a sweet-sour, aromatic odor. Under high temperatures, the disease develops quickly, the flesh collapses and the fiber is exposed. If the diseased fruit is cut open, the diseased tissue will turn black after 24-36 hr in contact with air, hence the name black rot (Plate 4).

Black rot is caused by *Ceratocystis paradoxa*, most commonly known as *Thielaviopsis paradoxa*, the imperfect stage of *C. paradoxa*. The fungus also causes seedling rot and white leaf in pineapple, pineapple disease in sugarcane and crown rot in banana. It is probably the most widespread pineapple fungus of the tropics.

The fungus is a wound invader. Careful harvesting of fruit without bruising the peel is important. Painting the cut surface of the stem end with 0.5% of 50% Captan is also effective in reducing the incidence of black rot[7].

Pineapple Blackheart

Blackheart is a postharvest disease found in pineapple fruit in Taiwan over the winter season (Plate 5). Diseased fruit shows no external symptoms, but when it is cut open, the basal portion of the fruitlets near the fruit core show a brown water-soaked discoloration. In severe cases the flesh around the core becomes dark brown, rendering the fruit entirely useless.

Blackheart is a physiological disorder caused by the low temperatures of Taiwan's winter. Chang and Wu[2] showed that when temperatures fall to 12-13°C or less for several days, harvested fruit will show signs of chilling injury. Sun and Hsu[11] have shown that under low temperatures, the tyrosine in the cytoplasm of pineapple fruit cells is easily oxidized to melanin in the presence of tyrosinase. Melanin is a brown-colored

Plate 4. Pineapple black rot caused by *Ceratocystis paradoxa*

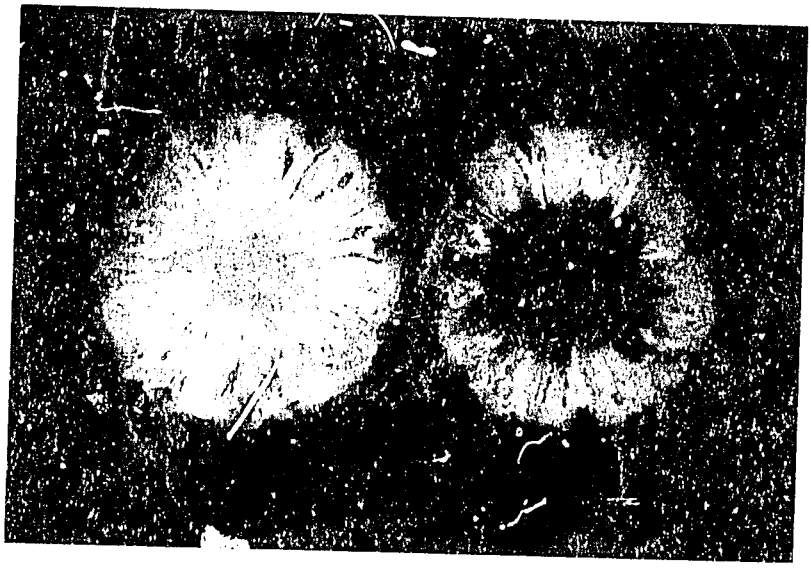

Plate 5. Pineapple black heart (right)

protein which accumulates in the cells giving them a dark brown color. Tsai *et al*[13] reported that 50% of fresh pineapple fruit shipped to Japan in air-conditioned containers (11°C) in 1967 showed signs of blackheart disease when they reached the market.

Pineapple Fruitlet Brown Rot

Fruitlet brown rot is incited in the field, but the disease is found after harvest (Plate 6). When infected fruit are cut open, many fruitlets show a brown discoloration and the flesh is tasteless, with a hard, brittle texture. Diseased fruitlets often show a radiate distribution around the fruit core.

Fruitlet brown rot is caused by *Erwinia ananas*, which is introduced into the fruit during flowering by wasps, bees or ants.

Pineapple Pink Disease

Diseased fruit shows no external symptoms. When it is cut open, the flesh is slightly pink in color. This color becomes deeper if the fruit is heated. Sometimes canning factories suffer severe losses from pink disease, because the canned slices are unacceptable. Pink disease is caused by three kinds of acetic bacteria, *Acetobacter aceti*, *Enterobacter agglomerans*, and *Gluconobacter oxydans*. These bacteria are common saprophytes on the surface of flowers, apples, grapes, and rotting fruit, and are also found in orchard soils. It is postulated that during the flowering stage insects introduce these bacteria into the fruit, causing slight fermentation as the fruit ripens.

POSTHARVEST DISEASES OF PAPAYA

Papaya Anthracnose

This is the most common postharvest disease of papaya in Taiwan. Almost every over-ripe fruit shows signs of anthracnose.

Plate 6. Pineapple fruitlet brown rot

The first symptoms are small round spots which appear on the surface of the fruit. These spots are yellow brown in color and gradually enlarge and sink into the flesh. Under high temperatures and humidity, salmon-colored acervuli grow out of the lesion, which is eventually covered with a slimy pink mass which is the conidia of the causal organisin. The spots may coalesce together, and the fruit rots completely.

Anthracnose is caused by *Glomerella cingulata* (imperfect stage *Colletotrichum gloeosporioides*). The pathogenesis of papaya anthracnose is same as for banana anthracnose, but the latent period of the fungus in papaya fruit is probably due the presence of papain in the immature fruit, which has been shown to be inhibitory to the growth of the fungus. As soon as papain disappears when the fruit ripens, the fungus renews its growth and anthrachose appears.

Although anthracnose is a postharvest disease, its control should begin in the field. At present, no official preventative measures have been recommended in Taiwan. I would suggest that four sprayings of Mancozeb or Delscene-M spray, at a rate of 1-500 dilution, starting after flowering and continuing at 7-10 day intervals, may be helpful. W.C. Lin of National Chung Hsing University has reported that *Bacillus subtilis* had an antagonistic effect on anthracnose fungus, which may possibly be used as a biological control for papaya anthracnose in the future[5].

POSTHARVEST DISEASES OF MANGO

Mango anthracnose is caused by *Glomerella cingulata*. Pathogenesis and control are the same as for papaya anthracnose. The local variety of mango is highly susceptible, but yellow varieties such as Kent are more or less tolerant (Plate 7).

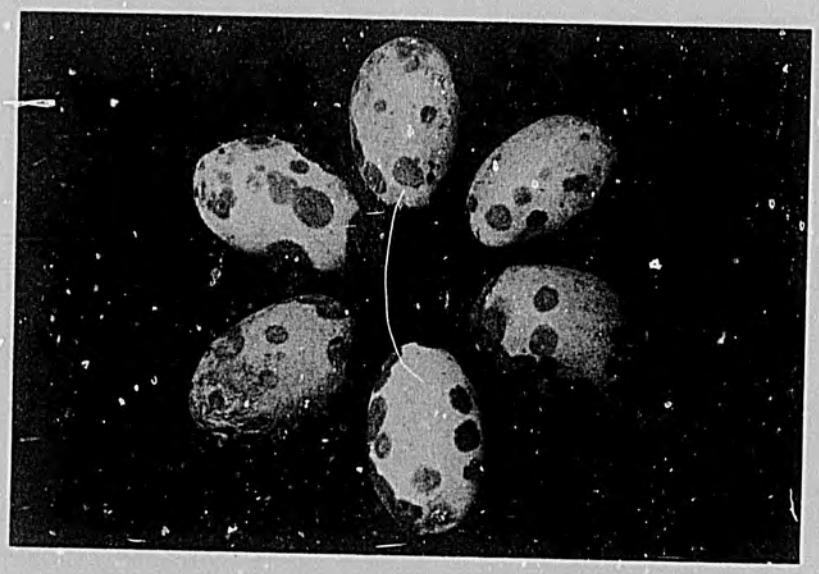

Plate 7. Mango anthracnose

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DISCUSSION

Q. (W. Grierson)
I am intrigued by the use of *Bacillus subtilis* as a control for penicillin mold. Is it applied as a dip?

A. Yes, the fruit is dipped into a suspension of *Bacillus subtilis* The concentration must be very high for the dip to be effective. We have only preliminary results on this treatment as yet.

Comment: (W. Grierson)
It is a wonderful idea – whoever thought of it deserves a crown!

Q. (Y.S. Tsiang)
Our friends from foreign countries may not know that we Chinese prefer bananas with small black spots- we often call them "sesame bananas". We feel that they are sweeter and more fragrant than fruit without spots. Are these black spots caused by anthracnose or freckle?

A. They are probably caused by anthracnose. Cavendish banana in Taiwan are very susceptible to this disease. Blackspot freckle has a different appearance- it protrudes above the surface of the skin, giving it a rough texture.

Q. (Y. Hasegawa)
In Japan, we use Benlate to control *Penicillium* mold in citrus fruit, but we often then note an increase in the occurrence of black rot (*Alternaria citri*). Have you noticed the same effect in Taiwan?

A. The *Alternaria* spore is very thick, and is resistant to manv fungicides, including Benlate. Benlate can inhibit the growth of *Penicillium*, but not *Alternaria*. To inhibit *Alternaria* you need Polyoxin, which is made in Japan.

Comment: (Y. Hasegawa)
Benflan (Iminoctadine) is effective against *Alternaria*, and is usually recommended for use in Japan. It is produced by the Dai Nippon Ink Co. Ltd., Japan.

Comment: (W Grierson)
You mentioned finding strains of *Penicillium* citrus blue mold in Taiwan which are resistant to Benlate but not to Mertect. In our experience, if a strain is resistant to one, it also resistant to the other.

A. Yes, these strains resistant to Benlate are not resistant to Mertect yet, but it is only a matter of time before they are.

Q. (S. C. Tongdee)
Do I understand that the mango varieties grown in Taiwan are resistant to anthracnose?

A. No. There is a very large hybrid variety called "Kent" which is partially resistant, but the local varieties are very susceptible.

INCIDENCE AND CONTROL OF POSTHARVEST INSECT PESTS FOUND IN SUBTROPICAL FRUIT IN TAIWAN

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ABSTRACT

This paper briefly reviews the common insect pests found on the fruit of citrus, banana, pineapple and grape in Taiwan. The control techniques used against oriental fruit fly are given as an example. The sterile-release technique, the male annihilation technique, and fumigation have all been carried out been as part of an eradication program against the oriental fruit fly. Insecticidal applications are commonly recommended to control insect pests on fruit, but integrated insect pest management is to be emphasized in future research, to avoid the overuse of insecticides.

INTRODUCTION

Any evidence of insect damage on a fruit may decrease or destroy its economic value to the producer, even though the food value of the fruit may be the same as if it were undamaged. This forces producers to employ costly and ecologically undesirable means of insect control. The infestation of fruit with insect pests after harvest may also cause them to lose value. This paper reviews the common insect pests of the major fruit crops in Taiwan, citrus, banana, pineapple and grape. These fruits are important for both local consumption and export. It describes in detail the control measures used against one of the most important pests, oriental fruit fly.

INSECT PESTS OF CITRUS

More than 150 species of citrus insects and mites have been recorded in Taiwan. Of these, 15 species are considered key pests in citrus orchards, and must be effectively controlled[6]. The oriental fruit fly, *Dacus dorsalis* Hendel and the chaff scale, *Parlatoria pergandei* Comstock, are important pests on citrus fruit. A number of control techniques are used against oriental fruit fly.

Occurrence of Oriental Fruit Fly in Orchards, and Injury Caused

The population of the male oriental fruit fly was monitored with yellow traps containing poisoned methyl eugenol, which were placed in citrus orchards The results showed that the population density of the male fly fluctuated seasonally, falling to a low level during the cold season from December to March. It then increased from April throughout the rest of the year. The population peak generally appeared some time between June and September. An apparent correlation was observed between the number of trapped male flies and the ripening season of the fruit, as well as the temperature. Although the number of trapped males did reflect the reproductive potential of female flies, a two-week delay was observed between fluctuations in the number of trapped males and the corresponding incidence of injured fruit in the orchard. Because of this, it is suggested that the best time to apply control measures against male flies is the period during

which the host fruit are ripening, particularly from May to November[1].

Use of the Sterile-Insect Technique to Control Oriental Fruit Fly

A field project to control oriental fruit fly by using sterile insects was begun during the autumn of 1975. The sterile pupae were released on the ground in host fruit plantations in central and southern Taiwan. Three years later, the technique of releasing sterile flies by aircraft was adopted, and the area covered was extended to 67,504 ha of orchard.

A field survey was carried out in September 1979 to compare the populations of oriental fruit fly in areas where sterile flies had been released with those where they had not. Yellow plastic traps baited with poisoned methyl eugenol were used. The results showed that the fruit fly populations in Tungshih and Hoping, where aerial release of sterile flies had taken place, remained at a consistently low density compared with the non-release areas of Kukaan. This stable decrease in population was apparently achieved by sexual competition from the released sterile flies, and indicates the efficacy of this technique[4].

Annihilation of Male Oriental Fruit Fly

Efforts were made to develop a more economical and effective means of dispersing poisoned methyl eugenol to control male oriental fruit fly. The results showed that fine-grained fiberboard (2 x 2 x 0.9 cm) soaked with 2 ml methyl eugenol remained attractive for six weeks, while cotton rope (0.7 x 8 cm) given the same treatment was effective for only four weeks. The use of a combination of methyl eugenol with a higher ratio of fenthion gave a more satisfactory result[2].

Fumigation of Fruit Against Oriental Fruit Fly

Quarantine measures are carried out for imported and exported plant materials. A series of studies has been made on the effect of dipping or fumigating fresh fruit with ethylene dibromide (EDB), to eliminate possible infestation with the oriental fruit fly. Such methods proved to be effective for complete eradication of the fly, and were recognized as such by the Japanese government, which then lifted its ban on the import of oranges, mangoes, papayas, and litchi. After EDB was prohibited as a fumigant on September 1, 1984, an alternative to EDB fumigation was developed by the Bureau of Commodity Inspection and Quarantine (BCIQ). This development paves the way for the continued export of fresh fruit and vegetables to Japan, despite the prohibition of EDB[3].

INSECT PESTS OF BANANA AND PINEAPPLE

Seven species of insects and mites are considered to be major insect pests of banana. Of these, the banana mealybug, *Dysmicoccus brevipes* (Cockerell) is an important postharvest pest. The banana mealybug lives mainly on the flower and crown of the fruit, and between the leaf sheath and pseudostem. Bananas are not allowed to be exported if they are infested with mealybugs. This insect was a serious pest in banana in Taiwan before 1970[5], but since then a series of ecological and chemical controls have been carried out. Insecticides such as 50% Diazinon, 50% Sumithion, 50% Fenthion and 50% Carbaryl are recommended as control measures. To avoid chemical injury and residues, insecticides are applied only when the banana hands are half grown. It is also necessary to clear banana fields to destroy mealybugs after harvest. Mealybugs also infest pineapples, and the control method is the same as for banana.

GRAPE INSECT PESTS

A total of 27 species of grape insect pests are recorded in Taiwan. They can be divided into four categories: 1. lepidopterous larvae,

2. coleopterous insects, 3. homopterous insects and 4. other polyphagous insects. Homopterous insects such as scale insects and planthoppers are damaging, not only because they feed on the sap, but also because of the toxicity of their saliva. The citrus mealybug, *Planococcus citri* (Risso) damages principally the young grape, while the scale insect produces honeydew which encourages the growth of sooty mold fungi. An armored scale insect, *Hemiberlesia implicata* Maukell, is injurious to the shoots, stems, and fruit. Both the citrus mealybug and the armored scale insect are considered important insect pests on grapes. Insecticides are recommended to control grape insects. To avoid the overuse of insecticides, researchers are promoting the concept of integrated control in vineyards[7].

CONCLUSION

The cultivation of fruit crops in Taiwan has provided a suitable growth medium for fruit insect pests. To prevent losses in yield, there has been a marked increase in the volume of insecticide applications. This has caused an overuse of insecticides, which in some cases has resulted in the development of insects resistant to insecticides, and has also increased the residues of insecticides on fruit. Many control measures have been used to control or eradicate insect pests, but it is now realized that a combination of techniques can be applied at appropriate times to achieve maxmum control with minimum disturbance of the enviroment. Thus, integrated systems of insect pest management will be emphasized in future research.

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FINAL DISCUSSION

Discussion Panel

S.C. Lin
F.W. Liu
W. Grierson
A. Hassan

1. Postharvest Technology for Fruit must be Time, Location and Variety Specific

In their introduction to the Final Discussion, panel members emphasized the need for postharvest technology to be adapted to specific local conditions and varieties.

(F.W. Liu)

Practical technology is highly time, location and variety specific. One of the central problems in developing efficient postharvest handling systems for fruit is how to select or develop a method suitable for a particular area. As one example, a hydrocooler is a very useful piece of equipment, but if it is installed in the wrong place it is absolutely useless. A hydrocooler in a warm climate is also wasted unless it is part of a continuous cool chain that includes refrigerated transport to keep fruit cool until it reaches the consumer.

(A. Hassan)

With regard to the chilling process in postharvest handling, I should like to cite an example from Malaysia. In the late 1970's, an overseas consultant was called in to advise on the construction of packing houses and cold stores. On his advice a system of 24 very modern storage houses was built, at a cost of US$300,000 to US$1.4 million per unit. They included expensive chilling equipment, and were intended for the long term storage of fruit and vegetables. They are all underutilized, and are in fact now considered white elephants. The fruit concerned has rather a short shelf life, even under optimum conditions – it can be stored for only 2-3 weeks, not 2-3 months. The climate of Malaysia is not sharply seasonal, and so neither is our fruit harvesting season. Even if long-term storage of our fruit varieties were possible, there is little need for it.

(W. Grierson)

We should beware of people who are trying to sell large amounts of imported machinery. Most countries have excellent craftsmen who can do welding and build good equipment. In Jamaica we imported only the pin chain for roller conveyers and local craftsmen made all the rest of the equipment from technical drawings. I think it is best to look first at what local craftsmen can make, and only import what is beyond their capacity. Locally made equipment has the very great advantage that it can easily be maintained locally. Terrible things can happen when complex imported equipment with electronic controls is handed over to an inexperienced farmers' cooperative!

(S.C. Tongdee)

In connection with the use of inexpensive local facilities, I was interested in the use of caves for storing fruit in Japan, and Dr. Liu's account of the same system being used in Mainland China.

(F.W. Liu)

The purpose of building caves for storage is to conserve coldness in rock or soil when ambient temperatures are low, and use this coldness to keep produce cool when ambient temperatures are high. Japan uses underground storage systems that are already there, it is not building new ones. In Mainland China, the labor cost is so low that they can afford to build new underground storage caves. Northwest China has a very heavy clay soil, with a texture that makes it very suitable for cave construction. Some well constructed caves can maintain a temperature 5-6°C lower than the mean temperature at that particular site. In higher altitudes in hotter climates, where nights are cold, building caves can conserve this coldness in the soil.

In a true tropical climate, unless there are cold nights or a cool season, this type of storage is not very useful. In a temperate or subtropical country, cave storage can save energy - the primary cost is labor, so where labor is cheap it can be very useful.

(W. Grierson)

Forty or fifty years ago in Canada, anyone who had a slope on his farm would have what was called a 'common storage' dug back into the hill. There would be vents in the upper side, to trap cold air rolling down the hill, while heat would rise straight up. We have tried to use the same principle to build storage facilities in Jamaica, where an immense amount of cold night air comes rolling down from the hills. It is also used in California, in storage facilities located between the hills and the sea where several million boxes of lemons are kept at a steady 51°C, year in and year out.

2. Fumigation Techniques to Replace EDB

One problem which received considerable attention in the General Discussion was the recent banning by both USA and Japan of the EDB generally used to fumigate fruit against fruit fly. As yet no cheap replacement has been found, and various possible alternative treatments were discussed.

(S C. Lin)

This morning I discussed with Dr. Grierson the possible use of irradiation as an alternative to EDB, but it seems to be too expensive. We have tried irradiating lychee in Taiwan, and found that 15 kilorads was sufficient to kill all fruit flies. However, the cost was too high for us to be able to use the treatment commercially.

(W. Grierson)

One problem in costing irradiation treatment is to achieve sufficient volume. Our tests in Florida have all involved pilot models which handle only a small quantity of fruit. Our first model could handle only two grapefruit! Gradually we worked up to one that could handle a carton of fruit. However, in actual practice we would be dealing with a whole shipload of several hundred thousand cartons of fruit, all needing to be processed within a day or two. A pilot model to handle this volume of fruit would cost US$2 million.

We should note that 15 kilorads were enough to kill fruit flies only when the fruit were laid out in a single layer for exposure to radiation. More kilorads would be needed if the layers of fruit were deeper, and the outside fruit might then get too high a dose.

(A. Hassan)

Apart from the problem of cost, we may have some problems in getting irradiation accepted worldwide – it is a controversial treatment. However, it appears at the moment to be the most promising alternative to EDB.

(W. Grierson)

It isn't fumigation which is forbidden, but EDB. We have been working with methyl bromide, which will kill fruit fly and is still legal. When we had black fly in South Florida but not in North Florida, we used it to fumigate cannery loads of citrus coming from badly affected areas. We have also tried it on avocado, without much success. Fumigation with methyl bromide is effective against eggs as well as live insects, and is accepted as a complete kill by U.S. plant protection specialists. The drawback is that it sometimes softens fruit very badly, and may not be suitable for fruit intended for export. I would suggest that anybody concerned with this problem might check how the particular product they are working with can stand up to methyl bromide, which has not yet been banned.

(T. Murata)

I understand that a group in Florida are working on cold treatment for fruit to kill insect pests. What kind of results are they getting?

(W. Grierson)

Yes, this is being used for both red and white varieties of grapefruit. The fruit have to be subjected to heat stress before they can withstand the cold treatment. We found conditioning at 35°C to be quite successful, but the pre-treatment now being used is to keep the grapefruit for about a week at 20-25°C. The main difficulty is that the temperature has to be maintained within very narrow limits. We don't have storage facilities in Florida which can maintain a constant temperature which fluctuates no more than one or two degrees, nor can most storages on board ship do this. There are some ships with very modern instrumentation which are capable of maintaining a constant storage temperature, and so can carry out cold treatment while the fruit is in transit. However, when we tried it in fruit exported to Japan there was chilling damage due to faulty instrumentation.

The first indication we had that stressing fruit with heat might protect it from chilling injury during cold treatment came from South Africa, where chilling injury experiments were being carried out. They found that fruit treated in Nelspruit was very susceptible to chilling injury and couldn't withstand cold treatment, but that the same fruit was being treated successfully in Capetown. A very helpful message from Mr. L. Ginsburg told me that the fruit had been transported to Capetown across the Karoo desert in unrefrigerated metal box cars, a journey which took several days.

I didn't have any metal box car or convenient desert in Florida, so instead I used a disused metal evaporator housing, up on the roof. I found that keeping grapefruit in this for a few days hardened them against cold. The effect suddenly disappeared when the weather became cooler.

This treatment is now being carried out on a large scale by the U.S. Department of Agriculture, using much gentler conditioning. The conditioning corresponds to a 2% weight loss, but this is an indicator, not a cause. I have stressed grapefruit at high temperatures in 100% humidity so there was no weight loss, and the treatment was still effective.

(S.C. Lin)

According to Mr. Chen, the manager of the Tainan branch of the Taiwan Provincial Fruit Marketing Cooperative, even if the cold treatment is effective it is not suitable for Taiwan. Constructing the cold storage rooms required would be too expensive.

(F.W. Liu)

Many tropical and subtropical fruits are unable to withstand cold. Mr. Huang of the Taiwan Provincial Fruit Marketing Cooperative has mentioned heat treatment – can you describe the current situation in Taiwan?

(E.H. Huang)

Four Japanese experts are now here in Taiwan working on vapor heat treatment for lychee and mango. It has been quite successful used for lychee on a small scale, but we don't know yet whether we can develop the technology to carry out the treatment on a large scale. The fruit has to be heated and then cooled quickly, which is easier to do on a small scale than in bulk. It worked for some varieties of mango, particularly Erwin, but not for others. Kent was one of the mango varieties which did not respond well to the treatment. The fruit of this variety is large, so it takes longer to heat the center. This causes injury, and physiological disorders appear after treatment – the conversion of starch to sugar is incomplete, some enzymes are inactivated – the result is that the fruit does not ripen properly, and has a fermented flavor. Similar reports have been published in the Philippines that sometimes vapor heat treatment is successful and sometimes not, according to the variety. What is the situation in Thailand?

(S.C. Tongdee)

We also had four experts from Japan working in Thailand. We tested vapor heat treatment last year on 23 tons of mango shipped to Japan. The heat treatment itself took only ten minutes at 45.6°C, but the fruit then had to be chilled again, so the chamber had to be kept at -.5°C for one hour forty-five minutes, which meant that the full treatment lasted nearly two hours. Thailand has no facilities of its own for this treatment and had to use equipment imported from Japan. This has given rise to some suspicions as to whether the main purpose of developing this treatment is to buy mangoes or sell equipment!

We also found that the vapor heat treatment had prevented the mangoes from ripening properly. In addition, it sometimes produced jellified tissue at the center of the fruit, and there was a serious anthracnose problem - vapor heat treatment does not control anthracnose. Since vapor heat treatment affects different varieties differently, we are now repeating the trial with other species of mango.

(A. Hassan)

It seems that vapor heat treatment is very recent, and more information is needed before it can be used in a practical way. It may give rise to new problems, since it seems that sometimes the effect may be negative. If it is to be used on a commercial scale, it will probably have to be suitable for a range of fruits. The facilities are very expensive, and the cost will not be justified if they can only be used for mango, which is seasonal and has a harvest period of only one or two months a year.

(W. Grierson)

In fact, vapor heat treatment is not new – it was used against Caribbean fruit fly in Florida in the

1920's, at which time it was the only treatment available. It was used for a few years as an emergency measure for citrus, but unfortunately very few studies were published. The U.S. Department of Agriculture has also used it in Carolina for peaches, to control *Botrytis* and *Rhizopus* rot. I helped set up a large packing house for peaches in 1963, in which the peaches were first given heat treatment and then cooled in a hydrocooler. There were a number of problems — the fruit was so susceptible to damage it had to be handled with tremendous care, using rubber belts. Oddly enough, the first fruit treated in this way also had a blue band round the middle from the sponge rubber rollers which were used without any effect on untreated peaches.

(F.W. Liu)

I should like to make a wild suggestion — since heat treatment takes too long, is there any possibility of using microwaves? Probably fruit being treated by microwave would have to be turned, which would need rather sophisticated technology. Does anyone know if it is a practical possibility?

(S.C. Lin)

I have discussed this with scientists in Taiwan. They feel it is not practicable, because when the microwaves hit the fruit they heat different heat points to different temperatures. Some parts of the fruit will overheat, and some will not reach the desired temperature.

(W.J. Ho)

Oil and water molecules accumulate heat under microwave. The rind of fruit contains less water than the juicy flesh inside, which means that the inside of the fruit would reach too high a temperature and the rind would be too cool. As far as its effect on fruit fly is concerned, most fruit fly are in the rind.

(F.W. Liu)

What effect would the microwave have on the fruit fly eggs?

(Y.C. Lee)

Microwaves were tested as a means of killing insect eggs in grain at North Carolina State University. Since the moisture content of the grain was lower than that of the eggs or larvae, the method was very successful. However, fruit and vegetables have a high water content, and microwaves might cook the fruit before it killed the eggs. It would depend on the frequency used — you might be able to find a frequency that killed the eggs without overheating the fruit.

(W. Grierson)

Since microwaves heat metal, one would have to make sure that the microwaves don't touch any metal part the fruit are going to touch, to avoid burning the fruit.

3. Packaging of Fruit

Sturdy containers of cardboard or plastic greatly reduce the amount of damage done to fruit during transport, but they are also very expensive.

(F.W. Liu)

Every country has a double standard for export and locally consumed fruit. Export fruit receive a great deal of attention and a lot of new technology, whereas not much is done for fruit sold locally. The boxes used in Taiwan for export fruit are very good, but boxes used for local fruit do not have ventilation holes.

(S.C. Lin)

In Taiwan, farmers pack local citrus in cartons without ventilation holes because they earn more money by doing this. The fruit are sold by weight, and if there are holes in the carton the fruit will desiccate in transit and be lighter than fruit packed in a carton without holes. It doesn't really matter - since Taiwan is a small island, there is only a short distance between farms and markets. Fruit can be transported from the extreme south of Taiwan to Taipei right up in the north even on hot days without any ventilation problems.

(W. Grierson)

Where cartons with holes are used, if local transport is non-refrigerated the holes should be at the bottom and top of the carton, rather than at the sides. There is always a temperature differential caused by fruit respiration, with heat rising off the top and cooler air coming in the bottom. Holes in the side do not allow for much circulation of air inside the carton. Of course stacked boxes must be aligned on pallets, with the box vents over the spaces in the pallets.

(W.L. Chang)

Holes in the carton weaken it. The area of the vents should not exceed 5%.

(F.W. Liu)

A Californian expert has just designed a new box with ventilation top and bottom, but using elongated rather than round vent holes. The vents did not weaken the box, but provided excellent ventilation.

(W. Grierson)

With regard to vents and box strength, it is important to have the vents positioned properly. The nearer they are to the corners of the box, the weaker the box will be.

(F.W. Liu)

Obviously many countries share the same problems, which is why an international seminar of this kind is so useful. This meeting has been a valuable opportunity for all of us.

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