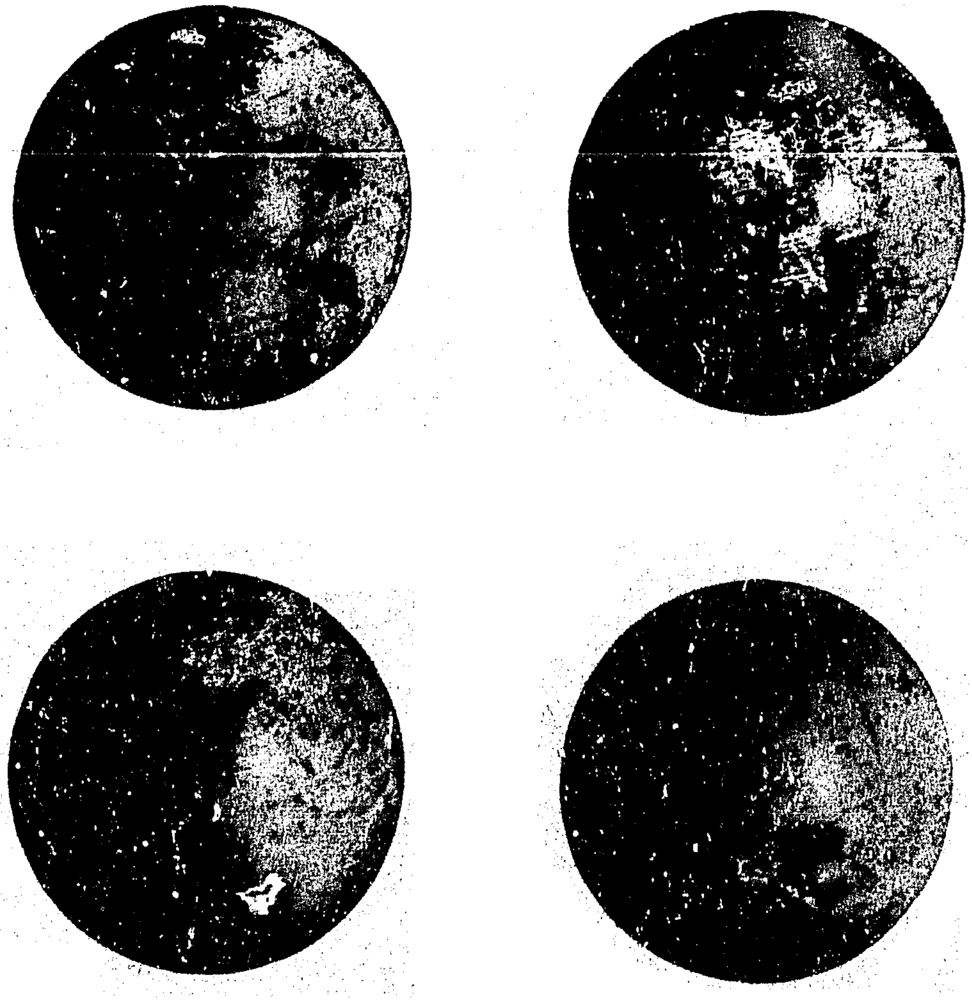

POST HARVEST FOOD LOSSES – THE NEGLECTED DIMENSION IN INCREASING THE WORLD FOOD SUPPLY

Malcolm C. Bourne

Department of Food Science and Technology
New York State Agricultural Experiment Station at Geneva, New York
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York

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WITH modern methods of travel and communication shrinking the world almost day by day, a progressive university must extend its campus to the four corners of the world. The New York State College of Agriculture and Life Sciences at Cornell University welcomes the privilege of participating in international development — an important role for modern agriculture. Much attention is being given to efforts that will help establish effective agricultural teaching, research, and extension programs in other parts of the world. Scientific agricultural knowledge is exportable.

A strong agriculture will provide not only more food for rapidly growing populations in less-developed countries, but also a firmer base upon which an industrial economy can be built. Such progress is of increasing importance to the goal of world peace.

This is one in a series of publications designed to disseminate information concerned with international agricultural development.

Post Harvest Food Losses - the Neglected Dimension...

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by

Malcolm C. Bourne

Professor of Food Science and Technology
New York State Agricultural Experiment Station
Cornell University, Geneva, New York 14456

ABSTRACT

Most international donor organizations have identified the food supply and nutritional status of populations in developing countries as major problem areas and consequently have expended considerable effort in the fields of agriculture and nutrition. The bulk of these efforts has been concentrated on increasing agricultural production and decreasing field losses in order to produce more food. However, increasing agricultural production is not sufficient to improve the nutritional status of poor populations. The increased production must pass safely along the chain that links the farmer to the ultimate consumer and this chain is fraught with perils for the food. Large quantities of food that leave the farm never reach the consumer. Concomitant with the increased efforts in food production there should be increased effort expended in caring for that food so that it reaches the ultimate consumer. This requires a knowledge of food science and technology, storage engineering, entomology and biology.

This paper outlines the nature of the problem of post harvest food losses, discusses the causes of loss, what is known of the extent of losses and where losses occur. It describes briefly the available techniques for preserving food and identifies those techniques that offer the greatest promise for increasing the available food supply in developing countries.

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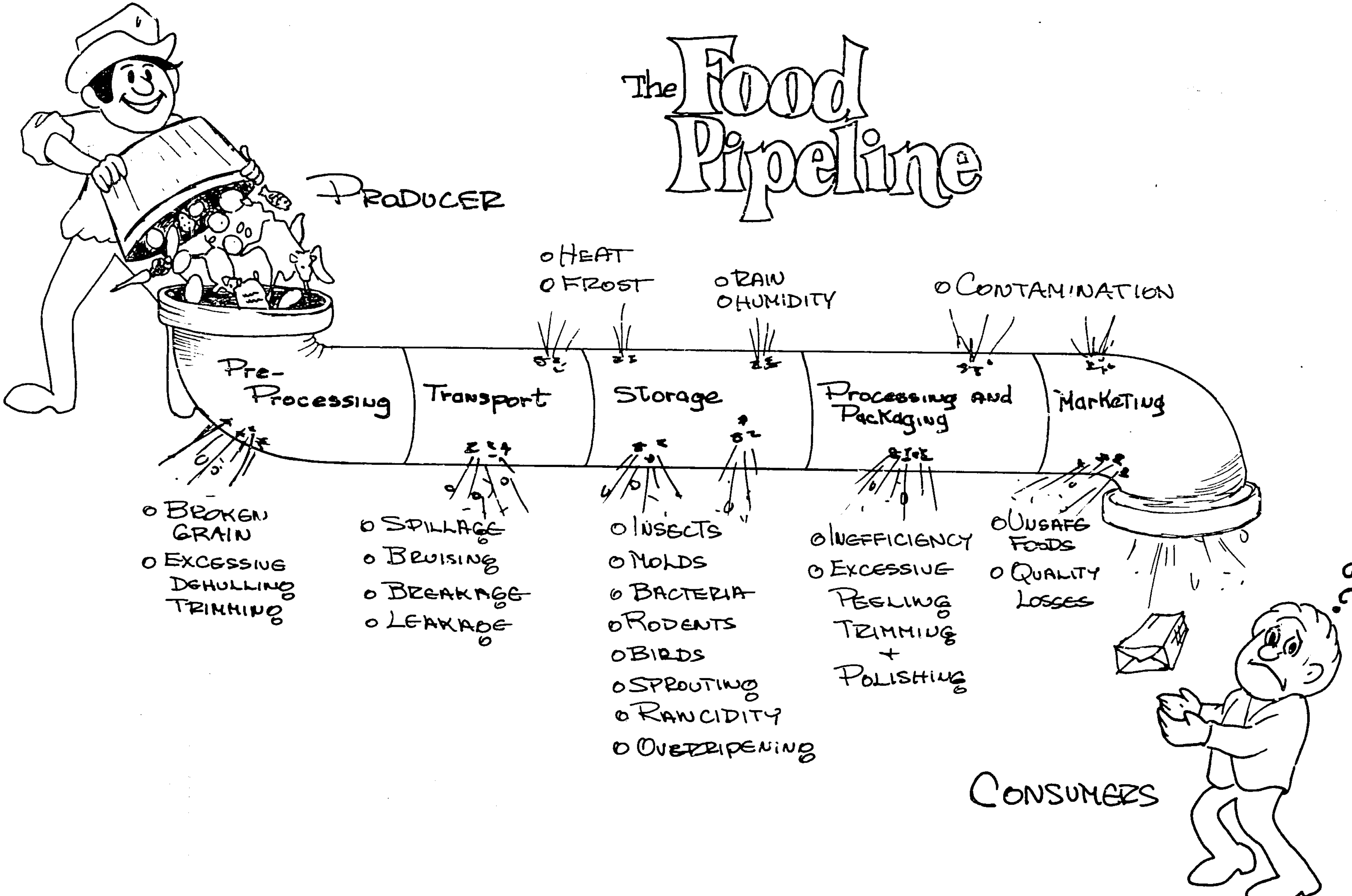
The Food Pipeline



INTRODUCTION

The inadequate supply of food in developing countries has long been recognized as one of the major problems that needs attention in the third world because a population that is not well-fed is prone to deficiency diseases, more susceptible to infectious diseases and does not have the energy to work hard. The problems that result from an inadequate food supply give rise to greatly increased morbidity and mortality rates among the populations of developing countries.

Both multilateral and bilateral organizations have recognized this problem and have devoted a large proportion of their aid efforts to increasing the production of food. It has been recognized that there are three main avenues by means of which the supply of food can be increased:

a) increase the area of production. This includes such activities such as clearing and developing new land, introduction and extension of irrigation systems, etc.
b) increase the yield of crops harvested per unit of area. This includes activities such as the development of new high-yielding varieties, more extensive use of fertilizers, breeding plants and animals that are resistant to diseases, and endeavoring to control field losses resulting from insects, rusts and rodents.
c) produce more crops per year. Multiple cropping systems in which several crops per annum are harvested are activities that fall in this category.

Donor organizations have used all three of these avenues to increase the production of food and there have been a number of successes in each of these fields; however, increasing the production of food is not the real goal of these activities. The real goal is to put more food into the mouths of the people and this requires not only producing more food but moving that food through the delivery system all the way to the point of consumption. Many activities are required to take the raw agricultural product that is harvested in the field and to transport it and convert it into food on the plate ready to eat. In this "pipeline" that takes the food from the farm to the table, there are many opportunities for food to be lost with the result that much of the food that has been produced, including much of the increased production, never reaches the consumer for whom it was intended. It is a waste of effort to increase food production if this increase does not reach the stomach where the utilization of its nutritional value begins. It is now beginning to be realized that the post harvest preservation and storage of foods are subject matters of importance.

The fourth, and hitherto neglected avenue in most attempts to increase the world food supply is the realization that the food must also be delivered to the ultimate consumer through the post harvest system without loss. Spurgeon (1976) has aptly called the reduction of the post harvest food losses the "hidden harvest".

The attention of the world was drawn to the problem of post harvest food losses by the U.S. Secretary of State, Dr. Henry Kissinger at the World Food Conference that was held in November 1974 in Rome. In his keynote address at the opening session of the world food conference Secretary Kissinger said, "Another major priority must be to reduce losses from inadequate storage, transport, and pest control. Tragically, as much as 15% of the country's food production is often lost after harvesting because of pests that attack grains in substandard storage facilities. Better methods of safe storage must be taught and spread as widely as possible. Existing pesticides must be made more generally available. Many of these techniques are simple and inexpensive; investment in these areas could have a rapid and substantial impact on the world's food supply."

The attention of the political world was again drawn to the problem of post harvest food losses by Secretary Kissinger in an address presented at the 7th special session of the U.N. General Assembly on September 1, 1975 in New York. In this address Secretary Kissinger said, "Another priority in the poorest countries must be to reduce the tragic waste of losses after harvest from inadequate storage, transportation and pest control. There are often simple and inexpensive techniques to resolve these problems. Investment in such areas as better storage and pesticides can have a rapid and substantial impact on the world's food supply; indeed, the savings could match the total of the food aid being given around the world. Therefore, we urge that the Food and Agriculture Organization, in conjunction with the U.N. Development Program and the World Bank, set a goal of cutting in half these post harvest losses by 1985, and develop a comprehensive program to this end."

This challenge from Secretary Kissinger was taken up by the U.N. General Assembly in that session and on September 19, 1975 one of the resolutions of the U.N. General Assembly was: "The further reduction of post harvest food losses in developing countries should be undertaken as a matter of priority, with a view to reaching at least a 50% reduction by 1985. All countries and competent international organizations should cooperate financially and technically in the effort to achieve this objective". This resolution has drawn the attention of the highest levels of governments around the world to the problem of post harvest food losses.

There are a number of benefits to be obtained from reducing the wastage of food in the post harvest chain. The first of these is nutrition. Since less food will be lost from whatever cause, there will be more nutrients available for the poor population. The loss of food also represents an economic loss, and the economic loss increases as the food moves down the pipeline because to the cost of food that is lost at each step must be added the cost of storing and handling the food in all the previous steps in the chain. Another important economic aspect is that those developing countries that need to import substantial quantities of food find that the cost of paying for this food places a great burden upon their overseas balance of payments. The reduction of post harvest losses within the country should reduce its dependence upon imported foods and reduce the problems that purchasing this food places upon its overseas currency reserves.

There is yet another important aspect of post harvest food losses and this is the "feed back incentive". In some countries farmers could well increase their production but at present they are unable to store food for any lengthy period of time. There is no incentive to increase production when they know full well that the extra production will spoil before it can be utilized or sold. If the post harvest losses that they suffer at present could be reduced or eliminated there would be more incentive for them to increase production.

The statement that the storage and preservation of food are the neglected dimensions in international aid programs is not intended to be critical of those programs. There were sound reasons for the donor agencies to concentrate initially on increasing food production because these avenues have an "open-end" potential - increases of 50%, 100%, or 200% or more are possible. In contrast, food preservation and storage technology has a "closed-end" potential. For example, if post harvest losses are 15% then the maximum increase that can be obtained from this avenue is 15%. The decision to begin with activities that increase food production was correct. However, now that the machinery for developing and supporting activities that produce more food has developed into mature systems it is time to give increased attention to caring for that food so that it is not lost after production.

WHAT IS A POST HARVEST FOOD LOSS?

If we are going to pay attention to post harvest food losses and devote substantial increases in funding and activities in this area it is important to know exactly what the term, "post harvest food loss" means. A preliminary working definition of this term is set forth below. For the sake of convenience the definition is divided into three parts.

"POST HARVEST" means after separation from the medium and site of immediate growth or production of the food.

Post harvest begins when the process of collecting or separating food of edible quality from its site of immediate production has been completed. The food need not be removed any great distance from the harvest site, but it must be separated from the medium that produced it by a deliberate human act with the intention of starting it on its way to the table. The post harvest ends when the food enters the mouth; it does not cover inefficiencies in human metabolism and utilization of the food.

Three periods of time may be identified during which food may be lost, and each period has its characteristic problems, and means of overcoming these problems.

a. Preharvest are losses that occur before the process of harvesting begins, for example, losses in a growing crop due to insects, weeds and rusts.
b. Harvest losses occur between the onset and completion of the process of harvesting, for example, losses due to shattering during harvest of grain.
c. Post harvest losses occur between the completion of harvest and the moment of human consumption.

Harvest and post harvest losses are sometimes combined into a single loss because there are some elements of common concern between them. A suitable descriptive term for these combined activities would be "post production losses". The following schematic representation shows the relationship among the various types of food losses;

1. Preharvest
2. Harvest } Post Production
3. Post Harvest }

"FOOD" means weight of wholesome edible material that would normally be consumed by humans, measured on a moisture-free basis.

Inedible portions such as hulls, stalks, leaves, skins, bones and shells are not food. Two critical nutrients, oxygen and water, are excluded because they are not normally considered to be foods. Potential food (e.g., single cell protein and leaf protein) are not foods; they do not become food until they are accepted and consumed by large populations. Feed (intended for consumption by animals) is not food.

The method of measuring the quantity of food in the post harvest chain should be on the basis of weight expressed on a moisture-free basis. There will be times when information on losses in nutritional units and economic losses will also be needed but these should not be the prime means of measuring post harvest food losses.

"LOSS" means any change in the availability, edibility, wholesomeness or quality of the food that prevents it from being consumed by people.

Food losses may be direct or indirect. A direct loss is disappearance of food by spillage, or consumption by rodents or birds. An indirect loss is the lowering of quality to the point where people refuse to eat it.

This definition is a people-centered definition. "Food" means those commodities that people normally eat and excludes the commodities that people do not normally eat. If the food is consumed by people it is not lost; if it is not consumed by people for any reason at all then it is considered a post harvest food loss. Appendix A to this report lists a number of specific examples to show how this definition of post harvest food loss works out in practical situations.

NATURE OF THE PROBLEM

Within a given region the daily demand for food is constant over the course of a year (ignoring any changes in population) but the supply of food for that region is very uneven from day to day over the course of the year. Food preservation, storage, and transportation are the mechanisms by which mankind tries to match the very uneven day-to-day supply of food with the even day-to-day demand for food. This problem of matching the uneven food supply to the even demand for food has been one of the classic historical problems that has always faced mankind.

Possibly the only time in the history of the world when there was an ideal balance between daily food needs and food supplies occurred when the children of Israel made their historic 40-year march from Egypt to Palestine across the great desert. During this march their food was provided in the form of manna that fell every night in a quantity sufficient to feed the migrating nation for one day. Manna was a delicious food to eat, "crisp and sweet as honey" and presumably provided all the essential nutrients because the people were free of illnesses at this time. This is probably the only time in the world history that there has been a perfect match between the daily supply and daily need for food. However, it is just as well that the manna rained down from heaven every night because it had poor keeping qualities. After 24 hrs. storage, it "bred worms and stank" (Exodus, Chapter 16).

Although the children of Israel were in an ideal situation in terms of their daily food supply it seems that they did not appreciate how fortunate they were in this respect because they complained that there was insufficient variety in the diet and they demanded changes (Numbers, chapter 11, verses 4 to 6).

The problem with food is that although man harvests or hunts food for his own personal consumption there are many other living organisms that try to use this food for their own use. This includes organisms ranging from large animals, through small forms of life such as insects down to microscopic forms of life such as bacteria. These produce direct losses.

In addition there is a natural tendency for the food, which is built up principally from inorganic carbon and nitrogen sources into complex energy-rich compounds, to degrade again to the simple inorganic compounds from which it was produced in the first place. These biochemical and chemical reactions occur spontaneously and lower the quality of the food. These are known as indirect losses; hence the preservation of foods has been one of the prime concerns of mankind throughout recorded history.

The science of the preservation of food is known as food science and technology and it is based upon the disciplines of chemistry, biochemist microbiology, biology, and engineering. Food science and technology is recognized as a field of study in the US and some other countries. There are many universities that have a department of food science and technology, while many others have activities in this area without recognizing them as a formal department.

All stored foods undergo deteriorative changes during storage resulting in loss of flavor, color, texture or nutritional value. There is no known method for stopping these deteriorative changes. This is a fundamental fact that lies behind all food preservation activities. Food preservation technology can slow down the rate of deterioration of quality but it cannot stop the deterioration. Every food, no matter how well preserved, will eventually become unfit for human consumption if stored for sufficient length of time. However, from a practical view point, we know that cereals and many other dried foods, together with some processed foods can be stored and maintained in good condition for periods of several years provided they have been correctly preserved and subject to good storage conditions and good management practice.

The two most important factors that affect the rate of deterioration of stored foods are 1) temperature and 2) humidity. Most of the deteriorative changes of stored foods result from chemical and biochemical changes and the rate at which these changes occur generally follows an Arrhenius temperature - rate relationship. Most of the developing countries of the world lie within the tropics and the prevailing high ambient temperatures of the tropics makes the problem of preserving the quality of stored foods considerably more difficult than it is in temperate climates because the naturally occurring deteriorative chemical reactions are accelerated in the tropics. In addition, the year-round high temperatures of tropical countries allow pests such as rodents and insects to feed and multiply throughout the year, whereas the cold winters of the temperate climate stop reproduction and reduce the feeding activities of these pests. In very cold climates the cold temperatures can kill many of the pests.

Cereals and other dried foods maintain their resistance against microbial attack because of their low moisture content resulting in a water activity that is too low to support the growth of microbes. Foods must have a water activity higher than approximately 0.9 to permit the growth of bacteria, a water activity above about 0.88 to permit the growth of yeast and a water activity above about .8 to permit the growth of common molds. (Water activity is equal to 1/100 x equilibrium relative humidity, e.g.; a water activity of 0.9 is equivalent to an equilibrium relative humidity of 90%).

The moisture content of grains and other dried foods is such that there is seldom any problem with the growth of bacteria and yeasts but there are frequently problems with the growth of mold. Unless the water activity is reduced to below about .8 molds will grow on any food and since the relative humidity in the humid tropics is generally above 80% almost all dry foods will become moldy when stored in the humid tropics unless the moisture content is reduced to a water activity of less than 0.8, followed by storage that will protect that food from absorbing moisture from the high humidity environment.

Even if the tropical countries had the same per capita income as the developed countries the continual high temperatures at which the food must be stored poses a much more difficult set of problems with the preservation of their food supply than is found in the temperate zones. In the humid tropics the high relative humidity compounds this problem.

The developing countries have a number of problems in their battle to reduce post harvest food losses that are not found in the developed temperate climate countries. a) They have insufficient knowledgeable personnel with the expertise to preserve and protect food; b) they have insufficient capital to provide the necessary handling and storage equipment for food; c) they have insufficient purchasing power to pay for the cost of proper protection (although many food loss reduction activities should pay for themselves because of the food saved); d) they have climatic conditions that favor the growth of insects, rodents and molds, and that accelerate the normal deteriorative changes that occur in stored foods; e) in some countries there is a fatalistic attitude that severe losses in stored foods are inevitable and nothing can be done about it.

CAUSES OF LOSSES

There are many causes of post harvest food losses and they can be grouped under the headings of primary and secondary causes. Examples of loss are given for each cause.

A. Primary Causes

a) Biological and microbiological. Consumption or damage by insects, mites, rodents, birds, and large animals and by microbes such as molds and bacteria.

b) Chemical and biochemical. Undesirable reactions between chemical compounds that are present in the food such as the Maillard reaction, fat oxidation, and a number of enzyme activated reactions; accidental or deliberate contamination with harmful substances such as pesticides, or obnoxious substances such as lubricating oil.

c) Mechanical. Spillages, abrasion, bruising, excessive polishing, peeling or trimming, puncturing of containers, defective seals on cans and other containers.

d) Physical. Excessive or insufficient heat or cold, improper atmosphere.

e) Physiological. Sprouting of grains and tubers, senescence in fruits and vegetables, and changes caused by respiration and transpiration.

f) Psychological. Human aversion, such as "I don't fancy eating that today", or refusal to eat a food for religious reasons.

Some of these causes of losses interact. For example, respiration generates heat which if not dissipated will accelerate biochemical and chemical changes. If the temperature continues to rise the point is reached in stored grains where insects infecting the food move away from the hot spot or are killed. In extreme cases the temperature can rise to the point where the food begins to blacken and eventually burn (spontaneous combustion).

In some cases more than one of these causes may be responsible for food loss. Multiple causes may work simultaneously or sequentially. Simultaneous action is the growth of mold and insects at the same time. An example of sequential action would be first the growth of mold which is stopped by drying, followed by biochemical reaction caused by the enzymes elaborated by the mold that results in unacceptably soft texture, rancid flavor or inferior color.

B. Secondary Causes

Secondary causes are those that lead to conditions in which primary cause of loss can occur. These usually are the result of inadequate or non-existent input. Examples are:

a) inadequate drying equipment or poor drying season;

b) inadequate storage facilities to protect the food from insects, rodents, birds, rain and high humidity;

c) inadequate transportation to get the food to market before it spoils;

d) inadequate refrigerated or cold storage (for perishables);

e) inadequate marketing system;

f) Legislation. The presence or absence of legal standards can affect the eventual retention or rejection of a food for human use.

There are times where it is possible to use a primary cause to offset a secondary cause and vice versa. For example, the problem of an inadequate transportation system can be partially overcome by drying of grain so that it does not become moldy so quickly, or by growing a variety of a tuber that has longer keeping properties. Conversely, insufficiently dried grain can be rushed to market and sold before it molds if good transportation and marketing services are available.

WHERE LOSSES OCCUR

Losses may occur anywhere from the point where the food has been harvested or gathered up to the point of consumption. For the sake of convenience the losses can be broken down into the following subheadings:

A. Preparation. This is the preliminary separation or extraction of edible from nonedible animal and agricultural production, e.g.; the dehulling of grain, slaughtering and dressing of animals, extraction of sugar from sugar cane, and peeling of fruits and vegetables. There is some room for improvement here to reduce post harvest losses, for example; in the dehulling of grain to ensure that grain is not broken or damaged during the dehulling process; in the extraction of sugar to ensure that as much of the sugar as possible is removed from the sugar cane and the minimum is discarded with the bagasse.

B. Preservation is the prevention of loss and spoilage of foods; for example; the drying of grain or fruit; the refrigeration or canning of vegetables or fish, and the prevention of the onset of rancidity in oil. This is the area where the major emphasis in post harvest food loss reduction activities must be given.

C. Processing is the conversion of edible food into another form more acceptable or more convenient to the consumer, e.g., the making of bread from wheat; brewing beer from barley; making sausages from meat, and making instant coffee from coffee beans. The food industry in the developed countries expends its greatest effort in this area because it knows that greater profits can be made by developing some new convenience factor or new flavor to titillate the taste buds of the well fed than by trying to reduce further an already economically acceptable low level of post harvest loss.

Processing should not be an area of major emphasis in developing countries where people cannot afford to buy any great quantity of processed food. In these countries food processing occupies a smaller proportion of the total post harvest food activities than it does in developed countries.

D. Storage is the holding of foods until consumption. For perishable foods such as some fish, meat, and dairy products, the storage life can be very short - a few hours if stored at ambient temperature, up to a week or longer if properly refrigerated. Staple foods such as cereal grains may be stored for several years. Semi-perishable foods such as fresh fruits, most tubers and oil can be stored successfully for periods of one or two weeks to many months if handled correctly.

There is a need for construction of more storage facilities, particularly for durables such as cereals and oilseeds. Large storages are needed by the big cities and the ports, and many small-scale on-farm storages are needed for subsistence farmers.

E. Transportation. Most developing countries need an improved transportation system to reduce the time lag between the site of production and the market.

F. Home Preparation. In developed countries there is considerable loss of food in the home. For example, studies in Denver have shown that the average American household discards approximately 10% of the food that has been purchased (Harrison et al, 1975). It is likely that these in-home losses are low in developing countries because the cost of food accounts for so much of the family budget that food must be of very poor quality to be discarded. In the urban areas of developing countries the homemaker usually makes frequent trips to the food stores and does not hold any great quantity of food in the house thus avoiding the risk of losses in stored foods in the home. This area probably requires minor attention in terms of reducing post harvest food losses in developing countries.

THE EXTENT OF LOSSES

One important question is how much food is lost overall in the post harvest food chain. The honest answer to this question is that nobody really knows. We do know that losses are highly variable depending upon the commodity that is being considered, the country and the conditions in which the food is being handled, and the length of time the food is stored. We would expect to find higher losses in perishable foods than in staple foods, and that the extent of loss would increase with time of storage. It is possible to find individual losses ranging from 0 to 100%, but what is of primary interest is an overall average loss figure and this is not known with any certainty.

dePadua (1975) has estimated the losses of rice in the Philippines to be as follows:

Operation	Range of Losses (%)
Harvesting	1-3
Handling	2-7
Threshing	2-6
Drying	1-5
Storing	2-6
Milling	2-10
Total	10 to 37

These figures give an idea of the amount of losses most frequently found in one of the staple food crops in one country.

A number of figures for the extent of loss are quoted in scientific literature and by the communications media, but much of these data are unreliable because the amount of loss has been estimated and has not been obtained by actual measurements. There is often the temptation to cite "worst case" figures to dramatize the problem. Care must be taken when looking at one lot of food and seeing, for example, extensive infestation with insects not to assume that all of the food in the country is similarly heavily infested with insects. Extrapolation of loss from a limited sample to the entire food of a country is an unsound procedure.

Another problem that intrudes itself is that even some of the figures that have been obtained by careful measurements are manipulated for various reasons. In some cases there is the temptation to exaggerate the figures of loss particularly if there is a prospect that high figures of loss will prompt aid or grants from some donor. In other cases there is a temptation to minimize the actual loss figures in order to prevent the embarrassment of acknowledging the magnitude of losses, or for political, financial and trading reasons.

Another precaution that needs to be taken in assessing overall losses is to see that the arithmetic of loss figures is correctly calculated. In quoting loss figures at various steps along the post harvest chain there is a common error of adding the percent of loss at each stage to obtain the total loss. This leads to overall loss figures that are too large because it assumes that each loss figure is a percentage of the original weight of material. In fact, since each percentage loss is expressed as a percentage of the amount in the previous step, the percentage is being applied to a diminishing base. This problem is explained in Table 1, which shows the apparent loss and the true loss that occurs in 1,000 Kg rice that is ready to be harvested.

Table I. Losses in Post Harvest Rice

	Loss %	Weight loss Kg	Remainder Kg
Start	-	-	1,000
Harvest	15	150	850
Threshing	15	128	722
Transport	10	72	650
Storage	30	195	455
Milling	20	91	364
Distribution	15	54	310
	105%	690 Kg	

Simply adding the percent loss at each step as shown in the first column leads to the conclusion that 105% loss occured. Columns 2 and 3 show what the true loss is at each step. The harvest loss of 15% of 1,000 Kg rice is 150 Kg. but the threshing loss of 15% is 128 Kg because it represents 15% of 850 Kg not 15% of 1,000 Kg and at the distribution end of the chain 15% loss represents only 54 Kg loss. In this example the overall weight loss is 690 Kg or 69%, not 105%. Even this figure of 69% overall loss is high. Almost all the loss in threshing consists of hulls which are inedible material.

The initial weight of 1,000 Kg represents (1,000 - 128) = 872 Kg edible material. The final available weight of 310 Kg leads to a correct estimate of overall loss of (872-310)/872 x 100 = 64% which is very high, but not as high as the 105% figure that results from adding the percent loss at each step.

Another way in which the percent of loss can be unwittingly exaggerated is found in the case of the subsistence farmer who harvests one crop a year and stores it for personal use. If the grain is properly dried most of his losses will come from insect infestation and perhaps rodents. During the first few months of storage the percent of loss is low but as the storage time continues, the number of insects increases exponentially until just before the next harvest season there can be a very high percentage loss. But this high percentage of loss at the end of the storage period is applied to a very small quantity of the year's supply of grain, and the overall amount of loss is considerably less than it would appear to be from looking at the farmer's stored grain shortly before the next harvest.

This aspect of the problem is explained in a hypothetical example in Table 2.

Table 2. Example of 1,000 Kg Grain in Farm Storage

Month	Consumption Kg	Remainder Kg	Loss %	Cumulative Weight Loss Kg
1	100	900	1	1
2	100	800	2	3
3	100	700	3	6
4	100	600	4	10
5	100	500	6	16
6	100	400	8	24
7	100	300	12	36
8	100	200	18	54
9	100	100	26	84
10	100	0	36	120

$\frac{120}{1000} \times 100 = 12\%$ weight loss for year

Suppose the farmer stores 1,000 Kg of grain from his annual harvest and takes out 100 Kg per month for ten months. If the loss during the first month of storage is 1% there is a 1 Kg loss in the 100 Kg he uses. During the second month the loss is 2% and there is a 2 Kg loss in the 100 Kg he uses which, combined with the 1 Kg from the month before, makes an actual cumulative loss of 3 Kg. A 3% loss in the third month gives a

3 Kg loss for the month and a 6 Kg cumulative loss. The highest loss of 36 Kg in the tenth month brings the cumulative loss for the year to 120 Kg.

An inspection of this grain in the second month would show 2% loss which is little reason for concern. By the sixth month the loss of 8% that would be found would be cause for some anxiety while by the tenth month the 36% loss would be cause for alarm. The actual loss of 120 Kg for the year represents an overall loss of 12%.

It is sometimes claimed that increased production can overcome any losses in the post harvest system; however, there must be a greater increase in production (both in total quantity and on a percentage basis) to offset a given post harvest loss as the following example demonstrates. Suppose 100 tons of grain are harvested and that there is a loss of 20 tons (20%) in the post harvest system. There are two ways to regain 100 tons of consumable grain:

a) eliminate the 20% post harvest loss
b) increase production to 125 tons (a 25% increase) so that after losing 20% of the 125 tons there will remain 100 tons for consumption. In other words it requires a 25% increase in production to offset a 20% post harvest loss. Similarly, it would require a 100% increase in production to offset a 50% post harvest loss. This point is explained more fully in appendix B.

An excellent example of close control of post harvest food losses is found in Australia. The Australian wheat industry is organized in such a way that most of the wheat produced each year is delivered to receivers licensed by the Australian Wheat Board, virtually immediately after harvesting operations. Wheat retained on the farms where it is grown is the only quantity of any significance not delivered into the central handling systems. During the 11 crop years from 1961/62 to 1971/72 growers retained wheat to an average extent of 7.6% (total crop production basis). There are no data on the magnitude of storage losses for the 7.6% of the crop stored at the farm level but careful records are kept of the 92.4% that is received by the Wheat Board.

Most of the Australian wheat is harvested during the hot dry summer months and drying the grain is usually not a problem. All the bulk handling authorities employ the pesticide malathion for prophylactic treatment of wheat delivered into their storage facilities. This action, combined with other complementary pest control and hygiene procedures has proved to be extremely successful. Insect damage in central storage and handling systems during the past decade has been insignificant to the point of being virtually unaccountable.

Damage caused by rodents and birds has also been quite insignificant during recent years in Australia. The nature of the storage structures and the practice of handling wheat exclusively in bulk are key factors that have minimized this potential hazard.

The introduction of export grain regulations in Australia in 1963 resulted in considerable improvement of hygiene on ocean-going vessels scheduled to load wheat and also established a standard, which the wheat industry has had to continue to satisfy, regarding freedom of the commodity from insect infestation. At present, all wheat parcels are inspected prior to exportation by government officers and no tolerance is allowed for insects.

Analyses of the receival and outturn figures for the crop years 1961/62 to 1971/72 reveal that the average quantitative loss in storage was 0.249% per annum (total receivable basis) with a range of 0.138% to 0.675% per annum. These figures include waste, dust, moisture loss and total damage caused by any extraneous influence excepting where this can be specifically accounted for and covered by insurance. The total quantity of wheat handled by the Australian Wheat Board, the cost per annum for maintaining the post harvest food loss reduction activities and the cost per ton are shown in table 3.

Table 3. Cost of Post Harvest Food Loss (PHFL) Reduction Activities in Stored Australian Wheat

Year	Production million metric tonnes	Cost of PHFL Activities Australian Dollars $A	Cost of PHFL A cents/tonne
1967	11.954	$1,425,531	11.93
1968	6.732	1,067,640	15.86
1969	14,033	1,319,576	9.40
1970	9.755	1,641,106	16.82
1971	6.936	1,533,773	22.11
1972	7.666	1,480,386	19.31
1973	5.440	1,142,170	20.99
1974	11.199	2,004,810	17.90

(from data supplied by the Australian Wheat Board and the Australian Embassy in Washington, D.C.)

It should be noted that these costs do not include expenditure on the provision of storage facilities which facilitate effective and convenient pest control. The figures quoted are actual for the years concerned. The stock recording and accounting systems are so arranged that losses at individual storage sites as well as total shortages within state systems are recorded and explanations are sought in relation to any extraordinary deficiencies.

The average figure of loss of 0.249% in wheat over an eleven year period in Australia achieved at an average cost of 15.6¢ (Australian) per ton (which is equivalent to approximately 19¢ U.S. per ton) shows that it is possible to reduce post harvest losses to a very low level at an economic cost. These figures serve as an established reference figure for an achievable goal with a major cereal.

AVAILABLE METHODS FOR PRESERVING FOODS

This section briefly reviews the methods available for preserving foods and reducing losses. It identifies those methods that should have a high priority in reducing food losses and those methods that are unlikely to make any substantial contribution to loss reduction in developing countries.

A. Drying

This technique reduces the moisture content of food to the point where molds and other microbes fail to grow, but it does not prevent the growth of insects and higher forms of life such as rodents or birds. Drying has been the major method of preserving and storing mankind's food supply throughout recorded history. Although the technologies of canning, refrigeration, pasteurization, and freezing that have been developed over the last 150 years have relegated drying to a smaller role for perishable foods, drying is still the preferred method for preserving grains and cereal legumes; hence it is still the most important food preservation technique (based on tonnage) in both developed and developing countries.

Since drying is one of the lowest cost methods of food preservation it should be looked upon as the major method for preservation of both stable and perishable foods in developing countries. The proper drying of cereals to prevent mold growth and heating is a well-established practice in the storage of cereals, but drying and dehydration should also be one of the major preservation techniques for many perishable foods in developing countries. The fact that drying of perishables is a labor intensive, time consuming, low capital cost technique that yields a product that requires several hours to prepare for consumption has made it unpopular in developed countries, but these attributes are not serious obstacles in developing countries and they do preserve the food at low cost.

A good sun-drying technology is available in the arctic regions where drying occurs under low temperature conditions that prevent spoilage while the drying is in progress, and in the arid temperate regions where high summer temperatures and low relative humidity cause rapid drying before spoilage can develop. But little technology has been developed for sun drying in the humid tropics where both temperature and relative humidity are high. A research program is needed that will develop a package of technology for drying and storing perishable foods under the conditions of the humid tropics.

The great positive feature in favor of sun drying in tropical countries is the low cost that results from the combination of several factors: 1) the low capital cost of establishing such an operation compared with many other processing methods; 2) the low cost of energy (sunlight is free); 3) it lends itself to many localized small scale operations in production areas; 4) the localization of small sun drying operations places no burden on a weak and slow transportation system. In most developing countries the transportation of perishable food to a large central factory is a major logistical problem. 5) the reduction in weight during drying reduces the cost of transporting the dried foods to market.

Despite these advantages there are two serious obstacles in the way of widespread drying and dehydration in the humid tropics. We need a drying technology that can use either the high intensity of the solar energy of the tropics or energy from locally available fuels to dry the food before it spoils. We also need low cost packaging that will prevent the dried food absorbing moisture from the air to a moisture level that will support mold growth.

B. Packaging and Protective Storage

Since all dried foods (cereals, legumes, and perishables) depend upon their low moisture content to prevent the growth of molds, it is essential that they be kept dry by protecting them from both water and water vapor in the high humidity atmosphere. There also must be physical protection from higher forms of life such as insects, rodents and birds. There is a need for construction of large storages at elevators and terminals, small storages on farms and in villages, and effective retail packaging that will provide effective protection against all forms of life and water and water vapor. The types of storage structures and packages that are needed to protect dried foods are well known. What is needed is the application of existing knowledge on a wider scale and at lowest cost. Many small storages in developing countries should be upgraded to give better protection of the product.

C. Refrigeration and Cooling

Refrigeration and cooling are of particular interest for extending the storage life of perishable foods. In developing countries there is a great need for low cost refrigerating systems for the preservation of perishable foods that is within the economic reach of rural communities. Even though a refrigeration system may not be feasible for the subsistence farmer it might be possible to develop some kind of locker system operated by a storekeeper or cooperative to make cold storage space available to a community. Two possibilities for energizing a low cost cooling system in areas where electricity is not available are the use of solar energy and biogas.

In recent years the proposal has been made that a quantity of grain, possibly of the order of about thirty million tons should be accumulated during years of good harvests and put aside as a world food reserve to be held until those years when there is a severe shortage of grain. It is likely that, if established, at least part of this world food reserve would be stored in those countries that are most susceptible to periodic poor growing seasons.

The technology for storing cereals for periods of several years is well developed in temperate climates, but there is little assurance at this time that cereals can be successfully stored for periods of many years under the conditions of the humid tropics. This is a technical matter that should enter early into discussions about establishing a world food reserve system.

One possibility to be considered for the long term storage of grain in the tropics is the construction of storage centers at high altitudes wher- the prevailing temperatures are lower. Below about 60°F insects practically stop multiplying; mold growth and biochemical reactions in the grain are slowed, and the whole storage problem becomes much easier to manage. There is need for a technical-economic study of high altitude storage for food reserves because the cost of transporting the grain to a high altitude would have to be offset against quality deterioration and possible loss of the grain in storage for long periods near sea level where temperatures and humidities are higher.

D. Chemicals

Fumigants, insecticides, and rodenticides have a well established place in controlling insects and rodents in grain storage systems. The technology of applying these has been well developed. There are also chemical preservatives that can be used to preserve perishable foods. These come close to the ideal method for preservation of foods in the tropics because they are cheap, effective, easy to apply and usually require a minimum of equipment.

The U.S. Food and Drug Administration divides additives into two main groups;

1) Functional additives that are used to improve the color, flavor, texture or nutritional properties of the food. Most of the chemicals in this group do not have preservative action and are of minor interest in post harvest food loss activities.

2) Preservatives that retard the spoilage of foods. There is tremendous scope here for the preservation of foods. A number of chemical preservatives such as benzoic acid, sulfur dioxide, sorbic acid, parabens, fat anti-

oxidants and propionates are used as permitted food preservatives in the United States.

Salt is an excellent chemical means of preserving fish, some meats, and some vegetables. It could be used more widely in tropical countries and the technology for its correct use should be taught provided that a good quality salt is available.

Stored roots and tubers are prone to sprouting and decay. Chemical treatments are available that stop the sprouting of potatoes and onions (Maleic hydrazide, and chlorprofam) and that inhibit rotting in stored potatoes and fruit (thiobendazole, and benomyl). These treatments are permitted and are well established practices in use in the U.S. Their use could quite well be applied to extend the storage life and reduce the spoilage of tubers in tropical countries.

E. Fermentations

Some fermentations that occur spontaneously in foods, notably the alcohol and lactic acid fermentations, develop a natural preservative as a product of the fermentation. The alcohol fermentation is widely used as a means of helping to preserve certain beverages and requires no further comment. The lactic acid fermentation is effective in preserving certain vegetables and in helping to preserve some processed meat and other products. It has potential for low cost preservation of many vegetables, fish and meat and should be encouraged wherever possible. The lactic acid fermentation that is most widely known is the one that converts raw cabbage into sauerkraut. This is a major industry in certain parts of the temperate world. Another product that is preserved by lactic acid fermentation is the kim-chee of Korea. This class of fermentation should be applicable to many other vegetables in tropical climates and lends itself to small scale preservation processes at the home and village level.

F. Canning

The thermal sterilization of food in cans or bottles is one of the best means of preserving perishable foods and maintaining good quality, but it is an expensive process and there is little chance that the cost of the container or the processing technique will be reduced substantially. The high cost of canning disqualifies it for large scale preservation techniques in most developing countries.

A new development in this area is the use of heat-sealable plastic pouches to replace the cans. At this time this technology is even more expensive than the use of cans and until the cost of the plastic pouches can be reduced very substantially it too would not be recommended for large scale preservation among subsistence populations.

There is one possibility for canning activities that would be applicable to certain developing countries. The Ball Corporation of Muncie, Indiana has developed a "home canning center" for developing countries. The concept is to have a community canning center with small scale canning facilities available to all members of the community to be used for the preservation of any excess of perishable foods beyond immediate needs. The center can be used for preserving fish, meat, chicken, vegetables, fruits, etc. The process uses glass jars that are reusable thus reducing the container cost per unit quantity of material preserved. Those villages that have a strong community spirit, effective leadership, and the funds to provide the initial capital cost of a canning center, or the ability to persuade some donor to provide the equipment and the jars to start operations have a potential to use this method of preservation.

G. Irradiation

Twenty-five years ago irradiation promised a convenient low cost method of food preservation that would be of great use in developing countries. Intensive research has demonstrated that under present conditions irradiation is inferior to other means of preservation with respect both to cost and convenience. There are still a few partisans who staunchly continue to proclaim the potential for irradiation but the major consensus of opinion is that irradiation costs more while it is either equally effective or less effective than other methods of preservation.

The disinfestation of insects from grain can be successfully accomplished by means of irradiation, but an analysis of the total costs involved shows that fumigation techniques cost less and are more convenient. The shelf life of many fruits and vegetables can be extended by means of irradiation, but good refrigeration has been shown to extend the storage life better and more cheaply than irradiation (Maxie et al, 1971). The sterilization of food by canning can be done at lower cost and yields a product of equal or better quality than the product that is obtained by irradiation sterilization.

Although there is still a possibility that irradiation will find a niche in the food preservation industry it will probably be for a special set of circumstances that apply only to a minor food item. The prospect for irradiation is that it is unlikely to become a major method of preserving food in developing countries. Of course there is the possibility that new developments will make irradiation attractive as a food preservation technique at some future time. For example, in the event that the Food and Drug Administration bans the use of all grain fumigants or that insects develop resistance to insecticides irradiation might be used to disinfest grain despite its higher cost and inconvenience because it would be better than no treatment against insects in stored grain.

H. Freezing and Freeze-drying

These two techniques give excellent quality in preserved foods but the equipment is expensive, sophisticated and has a high energy requirement. This puts them beyond the reach of low income populations.

I. Pasteurization

Pasteurization extends the shelf life of milk and other fluid foods but it requires sophisticated equipment. On these grounds it is unsuited for most low income populations.

J. Sterile filtration

Sterile filtration and some other advanced techniques are being studied in developing countries but their high level of sophistication and high costs make them unsuited for consideration for preserving foods for low income populations at the present time.

NEEDED ACTIONS

This section can be subdivided into 2 parts, a) the commodities that should be given attention in post harvest food loss reduction programs and b) the activities that should be given consideration.

A) Commodities

The majority of organizations that conduct activities in the area of post harvest food loss reduction devote their efforts largely or wholly to reducing losses in grains and dry legumes. This attitude is probably based upon the fact that the cereals and dry legumes are staple foods and contribute the major part of the calorie and protein intake of populations in developing countries. While this writer agrees that a large part of post harvest food loss reduction funding should be devoted to cereals and dry legumes he is of the opinion that these commodities should not constitute the only commodities that are subject to post harvest food loss reduction activities. There are substantial reasons for considering other commodities in addition to cereals.

There are large areas in the world where roots and tubers are staple items in the diet and provide a large proportion of the calorie intake. It is estimated that the production of cassava, potato, yam, and sweet potato in developing countries exceeds 162 million tons per annum representing 21.3% of the total food production. Since the roots and tubers constitute such an important part of the diet in many developing countries, they should be given some attention in any post harvest food loss reduction program.

Perishable foods have traditionally been given little or no attention in post harvest food loss reduction activities. This is understandable when it is considered that their perishability poses special problems in preservation, transportation and marketing and furthermore, that there are so many perishable food items that the problem of handling all of them becomes almost intractable. The major cereals and dry legumes of the world are less than 10 in number. Likewise the important roots and tubers of the world are less than 10 in number. In contrast there are literally dozens of perishable foods and these represent an extraordinarily wide variety in types of food, chemical and nutrient composition, kinds of spoilage, and methods of preserving and maintaining quality.

It should be pointed out that some of the major nutritional deficiencies in developing countries, especially of the minor nutrients (vitamins and minerals) can only be remedied through greater intake of some of the perishable foods. Deficiencies of the minor nutrients require a longer period of time to produce obvious clinical symptoms than do deficiencies in calories and proteins, but deficiencies in minor nutrients can sap the vigor and increase the morbidity and mortality rates of the population just as surely as do caloric and protein deficiencies.

Extensive nutrition surveys conducted in the Philippines (Quiogue et al, 1969) have shown that the average Filipino obtains 76.5% of the recommended caloric intake and 86.2% of the recommended protein intake. These are important problems that need attention. An increased consumption of cereals would overcome the calorie deficiency and make up a large part of the protein deficiency. However, this survey also showed that the average intake of calcium is 33.7% of the recommended level and of vitamin A, 49.8% of the recommended level. These are nutrients that are provided predominantly by perishables. The deficiences in these minor nutrients are much greater than the deficiencies in calories and proteins.

A recent survey at an East-West Center Workshop (Yang 1976) also revealed that deficiencies of some of the minor nutrients are worse than deficiencies in calories and proteins throughout the Pacific region. This evidence provides substantial reason for including perishable food items in any comprehensive program of post harvest food loss activities.

The number of perishable foods is so great that it would be impossible to cover all of them and it seems difficult to know where to begin. It would be valuable to select for attention a limited number of perishable foods from this great number of items, those that will help overcome the gravest and most common deficiencies of minor nutrients in developing countries. A limited number of perishable foods (perhaps 10 or 12 in number) would reduce the problem to a manageable level and still enable much progress to be made.

Some obvious candidates for inclusion in this limited list of perishable foods would be fish, several fruits such as papaya, mango, plantain, and citrus fruits, and perhaps a limited number of vegetables. Milk would probably be excluded from this list since it is provided every day and there is no need for long term storage. Likewise, chickens and small animals such as goats, lambs and pigs do not pose too great a problem in preservation because consumption can usually be arranged to be completed soon after slaughter. With these considerations in mind a useful apportionment of effort in post harvest food loss funding would probably be approximately as follows:

Cereals and dry legumes	60%
Roots and tubers	20%
Selected list of perishables	20%

This recommended apportionment of post harvest funding might need to be changed depending on local circumstances. For example, in those countries in which tubers constitute a major part of the diet, the proportion devoted to roots and tubers could be doubled while in countries in which tubers are insignificant the proportion could be reduced to zero.

B) Activities

A wide range of activities is needed in any comprehensive program of post harvest food loss reduction activity. The following activities are listed in decreasing order of the level of funding that should be applied to each one.

1. Equipment - There is an obvious need for construction of many food storage and handling facilities in developing countries. This includes grain storages that range in size from small on-farm storages to large elevators and terminals depending on the needs in each particular locality. Construction of general-purpose storage warehouses that can be used for storing commodities other than grains for part of the year is also needed. There is a need for more refrigerated storage capacity in many areas.

The dehulling and milling of cereals are frequently sources of considerable loss of food in developing countries, especially with rice. There is a need to improve the efficiency of dehulling and milling operations in developing countries by means of programs that teach operators how to run their equipment with maximum efficiency, research into improved methods and equipment for threshing, dehulling and milling grain especially in small operations, and assistance in the acquisition of new and more efficient equipment.

In developing countries there are many small food extraction plants that are used for purposes such as extracting sugar from sugar cane and oil from oilseeds such as coconuts and peanuts. In contrast with large operations that usually provide a highly efficient extraction these small scale extracting plants are generally inefficient, extracting only 50% to 75% of the desired food material thereby resulting in considerable loss of good food. There is a need to improve the efficiency of these simple small scale extraction processes. This can be done by supporting research to improve the efficiency of extraction in small plants and providing new or improved extraction equipment.

2. Education - It is significant that methods for controlling post harvest food losses are well known and widely used in developed countries but not in developing countries. Therefore, a major educational effort across the whole spectrum of society in developing countries is needed in order to make their populations aware of the fact that large post harvest losses in foods are not inevitable, that there are known causes for losses and known cures for each cause of loss. In some areas it will be necessary to overcome superstitious and erroneous beliefs such as the one that insects are spontaneously generated in stored foods. The entire population of developing countries should understand that stored food is a living biological system that must be continuously watched in order to maintain its quality and availability, that stored food is not inert like a stockpile of metal or lumber that can be stored and left without care indefinitely. Stored food must be cared for by knowledgeable people who have adequate facilities to take care of it properly. Large storages particularly require trained people for proper operation. Funds must be provided to train and hold managers for these storages and to provide them with essential inputs such as fumigants and electric power for aeration.

Top level governmental officials and their staffs need to be given short training courses to make them understand the needs and importance of proper food storage, the economic costs of storage and the saving that can result from proper care of stored food. It will be difficult for the political process of a developing country to provide the funds for adequate storage and maintenance unless high level government officials have a clear understanding of the general principles of storage, and the costs and savings that are incurred in implementing good storage practices.

College level training is needed in developing countries to provide the teachers and the course material for education services in high school and primary school. A college level course and textbook is needed that will be interdisciplinary in nature and cover food technology, entomology, grain and storage engineering, stored product economics and effects of climatic conditions. Such a textbook should cover the principles of food preservation and storage of cereals, tubers and perishables with particular emphasis on tropical conditions. U.S. Universities and Colleges could also help by offering such a course not only to food technology majors but to all foreign students who are pursuing studies at U.S. colleges and to American students who have any thought of serving overseas. The course should be offered at a level that could be taken by all undergraduate and graduate students who have a reasonable background in science. This would help to increase the number of people in developing countries who are informed of the problems and solutions to food storage and it would prepare many of the future agricultural leaders of developing countries to cope with their food loss problems.

Children in primary and secondary schools in the rural areas in developing countries should be given instruction in the technology of food protection and storage. Even children in grade school can be taught the simple concepts of food protection and practical methods for the preservation of food. It is just as important that these children learn how to preserve their precarious food supply as it is for them to learn how to read and write. Suitable textbooks and teaching materials for both teachers and students should be developed for each target age group. Concepts of rodent biology, entomology and mycology and how these affect the quality of stored food could be incorporated into the science curriculum of schools in developing countries.

The extension services in developing countries can also be involved by bringing to farmers, and the population in general, methods of reducing losses in foods. Both farmers, and children in school can be taught the life cycle of insects and be shown that insects do not spontaneously generate in stored grain. Extension service personnel and some of the better farmers can be trained in procedures of simple fumigation and spraying techniques for the control of insect infestation in small on-farm grain storages.

3. Adaptative research - Although the basic knowledge of food preservation and storage is well known and the technology is well developed in developed

countries there is a need to develop packages of low cost simple technology that will fit right into the existing practices and customs of each country. Most of this work should be country specific, taking into account local customs, local building materials, and the existing incentives for farmers and food handlers to adapt the new package. It is necessary to work out every aspect of the total package in detail and check it out in practice before it is taught on a wide scale. It would be a misuse of everybody's time and money to rush in with some new recommended practice that has not been thoroughly tested under the conditions of each particular locality.

The drying and storage of grains need to be given major emphasis in adaptative research. A great number of small scale storages have been described but more work needs to be done in this area with emphasis on economic factors. Some areas that have interesting possibilities are the aeration of grain in small storages when atmospheric conditions are right, the mixing of fine inorganic dusts in grain as a means of killing insects and methods of removing these dusts before the consumption of the food, the use of oil coatings on cereal grains and legumes to kill insects, the use of large plastic bags for small scale fumigations, water-proofing and rodent-proofing of storages, and simple fumigation techniques that can be used by farmers in rural areas.

Since drying is one of the lowest cost methods of food preservation it should be the subject of considerable research both for the drying of cereals and the drying of some perishables. Some attention needs to be given to the use of solar energy and energy from locally available fuels. The drying of foods in the arid tropics can probably utilize much of the technology of the fruit drying industry of the temperate regions. The drying of foods in the humid tropics poses a difficult set of problems where the technology of sun drying in the temperate and arctic climates is not effective; however, one advantage available in tropical climates is the much higher intensity of solar radiation. This is shown in Fig. where the intensity of solar radiation in a temperate climate (Ithaca, NY) and in two tropical areas, one near the Tropic of Cancer (Honolulu)

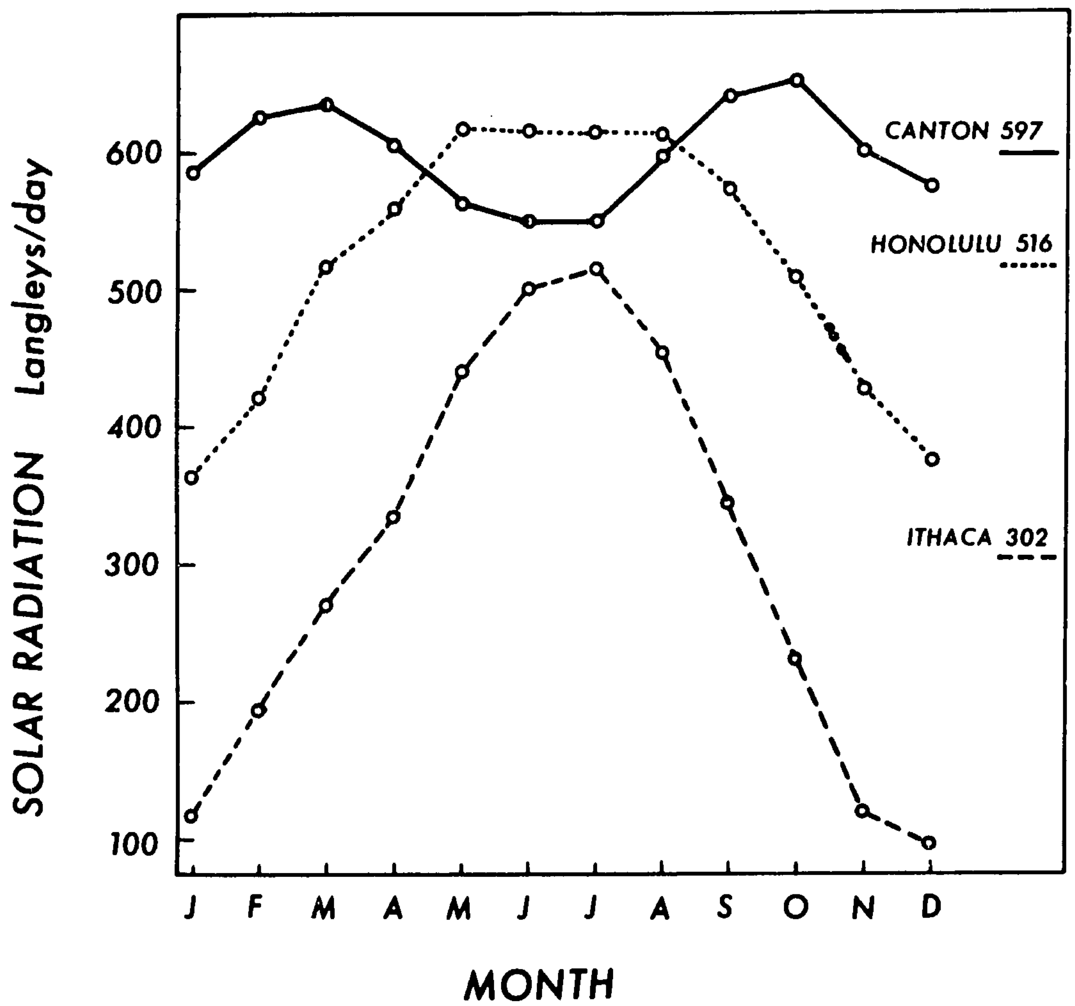


Figure 1. Intensity of solar radiation in a temperate climate (Ithaca, New York), near the Tropic of Cancer (Honolulu), and near the equator (Canton Island).

The numbers on the right hand side list the annual mean daily solar radiation in each location. One Langley of radiation equals one gram calorie per square centimeter.

and the other near the equator (Canton Island) portrays the much greater intensity of solar radiation in tropical latitudes. It should be possible to develop a drying technology for both cereal grains and legumes that will use the high intensity solar radiation of tropical climates in such a way that it will overcome the problems that high ambient relative humidity inflicts upon the products.

Since all dried foods, cereals, legumes and perishables depend on a their low moisture content to prevent growth of mold, it is essential that they be kept dry by protecting them from both water and high humidity surroundings. Adequate protective packaging of dried foods is an essential corollary of the total preservation-by-drying process. Effective packaging and storage of dried foods are essential parts of the total package of practices that is needed for drying.

Adaptative research is needed to develop already known simple low cost methods for reducing temperatures for storage of foods. Even partial cooling will extend the shelf life of many foods and although not so effective as complete refrigeration for perishables it is better than no cooling at all. Some simple methods that can be used to reduce temperatures are: 1) keep foods out of direct sunlight. The high intensity of solar radiation (see Fig 1 above) can raise the temperature of foods by 20 to 30° or more with a resultant shortening of shelf life. It is not a difficult matter to see that all stored foods are shaded. 2) Evaporative type water coolers in regions that have low relative humidity can be effective in reducing the temperature by 20° or more. 3) In those regions that have cold nights and hot days insulated storages that are closed during the hot day and opened during the night should be a low cost method of maintaining reduced storage temperatures.

Most tropical roots and tubers and many tropical fruits have an optimal storage life of temperatures in the range of 50 to 55°F. These commodities are subject to "chilling injury" at temperatures in the range of 32 to 40° as is obtained under normal refrigeration. The simple methods for reducing temperatures listed above should be of particular use for extending storage life of roots and tubers in the tropics.

The judicious use of chemicals can greatly reduce storage losses of many foods. Fumigants, insecticides, and rodenticides already have a well-established place in grain storage systems and their use should be extended to and adapted to the conditions in developing countries. Stored roots and tubers are prone to sprouting and decay. In the U.S. chemical treatments available in the form of maleic hydrazide and chlorprofam are widely used to prevent the rotting of onions and potatoes and would possibly be useful under tropical conditions. The chemicals, thiobendazole and benomyl, are widely used to inhibit rotting in stored potatoes and fruits and could likewise be adaptable for use on similar commodities under tropical conditions.

A number of chemical preservatives such as benzoic acid, sulfur dioxide, sorbic acid, the parabens, and fat antioxidants are used as permitted food preservatives in the U.S. Their use on specific products to reduce spoilage should be explored and extended to developing countries. This is a subject that could well be incorporated in college level courses in food preservation as mentioned above.

One of the best, safest and most readily available chemical preservatives is salt (sodium chloride). It is used in many tropical areas in an attempt to preserve fish and meat and it can be used to preserve some vegetables. Unfortunately the salt in developing countries is usually impure containing rather large amounts of calcium and magnesium salts and sometimes iron. These impurities can cause so many problems in the food that is being preserved by the salt that the net benefit of using salt is small. These problems would not be experienced if salt of higher purity was as readily available as the impure salt.
The technology for producing high purity salt from sea water is well known and effectively used in developed countries. It would be worthwhile to extend to developing countries the existing technology of pure salt production from sea water. The availability of high quality salt as a preservative would be an important advance in the preservation of many perishable foods.

The lactic acid fermentation is an easy method of preserving many vegetables and mixtures of vegetables. There is a need to develop techniques of lactic acid preservation for vegetables and perhaps fruits and fish in developing countries. This is one of the more promising appropriate technologies available for preserving some of the perishable foods under tropical conditions.

4. Basic research - There is a need for basic research in a limited number of areas in order to develop new technologies for special problems of developing countries. This will require long term funding commitments of the order of 5 to 20 years given to a single center of excellence in each area of interest in order to provide important breakthroughs. Some of the areas in which basic research is needed because of their relevance to post harvest food loss reduction potential are:

(i) drying technology for cereals. Since cereals are the major item of interest there should be more basic study on drying, including the use of solar energy and locally available fuels such as hulls, straw, shrubs, bamboo and other combustible material that has no other economic use.

(ii) Another item that needs study is the "ultradrying" of cereals and legumes. The present practice of grain drying brings the moisture level to about 14% in order to stop the growth of molds. However the growth of insects can also be stopped by drying grain to even lower moisture contents of 10% or less. This is an area of insect control that needs to be investigated more thoroughly.

(iii) Dry legumes are notorious for losing their capacity to soften during cooking after several months storage under tropical conditions. The loss of cookability is known to be accelerated by high temperatures and high humidities. It would be uneconomical to store dry beans under refrigeration in order to maintain cookability, but it might be economic to dry the legumes to a moisture content low enough to prevent loss of cookability even when stored at a high temperature. The ultradrying of legumes promises a method both for retaining cookability and preventing insect growth.

(iii) Refrigeration. It is a well established fact that reduced temperature prolongs the storage life of foods, especially perishable foods. There is a need for research to develop small low cost refrigeration systems for developing countries. The evaporation system of refrigeration offers some promise and the use of solar energy or biogas should be considered as a possible energy source for developing low cost refrigeration systems in developing countries.

(iv.) The chemical, propionic acid is extensively used in the United Kingdom and Europe to preserve moist grain intended for cattle feed. Propionic acid is not used on grain intended for human consumption because of its unpleasant flavor but the sodium and calcium salts of propionic acid are permitted to be added without limitation to bread in the United States as mold inhibitors. It is quite possible that a dose of propionic acid applied to moist paddy rice would prevent mold growth for several months and that most of the acid would be removed when the rice was dehulled thus eliminating the flavor problem. The potential additional weeks that moist paddy rice could be stored would ease the problem of overloading the capacity of rice dryers during the harvest season and might even hold the moist paddy until the end of the wet season thus allowing it to be dried in the sun. Another positive feature with propionic acid is that it inhibits the growth of *Aspergillus flavus*, the mold that produces aflatoxin.

The successful development of such a mold inhibitor for moist rice would be of particular value now that the production of a second crop of rice has begun to be adopted in some areas. The cost of the propionic acid would be in the range of $1.00 to $5.00 per ton of treated rice based on the U.S. price of propionic acid. The amount of sodium or calcium propionate added to bread is equivalent to about 2 lbs. per ton. This is sufficient to prevent the bread from molding for a week or longer and its flavor is undetected in the bread. The amount of propionic acid that is added to moist grain for cattle feeding is in the range of 10 to 20 lbs. per ton. This level imparts an off-flavor to the grain (that is not objectionable to animals) and will prevent mold growth for a year or longer. It seems quite likely that some intermediate level of the free propionic acid, or one of its salts, or mixtures of propionic acid with other preservatives can be found that will inhibit mold growth for a period of several months without leaving a residual flavor in the stored grain after preparation for eating. This holds forth the greatest promise for rice where the dehulling of the rice would probably remove most of the propionic acid.

(v) Plant breeding. The keeping quality of tubers, fruits and vegetables is partly dependent on inheritance. For example, in New York the potato variety Ontario has a storage life of about two months while the Pontiac variety has a storage life of 9 to 12 months. Similar differences in keeping quality can be found among different varieties of onions, apples and other horticultural crops. Breeding programs for tubers, vegetables and fruits should include keeping properties as one of the criteria used in selecting new varieties and cultivars for use in tropical countries.

5. Loss Surveys - Since little hard data are available on the extent of losses, the economic dimensions of the losses and costs of reducing losses, it is desirable to have in-country surveys to determine typical figures. This kind of data is a needed prerequisite to the planning of effective large scale intervention programs.

6. Literature Research - In the early days of this country the U.S. Department of Agriculture and the State Experiment Stations gave much attention to the problem of food spoilage on the farm. Simple practical ways whereby farm families could reduce their food losses were developed and brought to the attention of farmers through the extension services. The advent of modern transportation, marketing, and supermarkets has relieved today's American farm family of the task of raising and preserving almost all of their own food. There should be good, practical information buried in some of the older publications of these previously

mentioned agencies that would now be applicable to developing countries. It would be worthwhile to search through this old literature to retrieve it, to bring it up to date in the light of our present knowledge of food science and to apply these techniques to the problems of developing countries.

WORLD FOOD RESERVES

The U.S. Secretary of State, Dr. Kissinger, proposed at the World Food Conference held in Rome in 1974 that a world food reserve of approximately 30 million tons of grain be established to carry the developing countries of the world through critical times of food shortage in future years. The details of this proposal are still being worked out but it seems that at least some of these long term storages will be held in the developing countries. One technical aspect of this world food reserve program that has been given insufficient attention is the ability to store cereals for periods of many years under tropical conditions. We know that cereals can be successfully stored for long periods of time in a temperate climate but there has been little experience with long term storage of cereals under tropical conditions. Some research is definitely needed in this area to determine the length of time cereals can be stored under tropical conditions and the conditions needed for successful long term storage at minimum cost. The studies should include the feasibility of long term grain storage at high elevations where prevailing ambient temperatures are low. These studies should be initiated as soon as possible in order that the results may become available before long term storages are constructed in developing countries.

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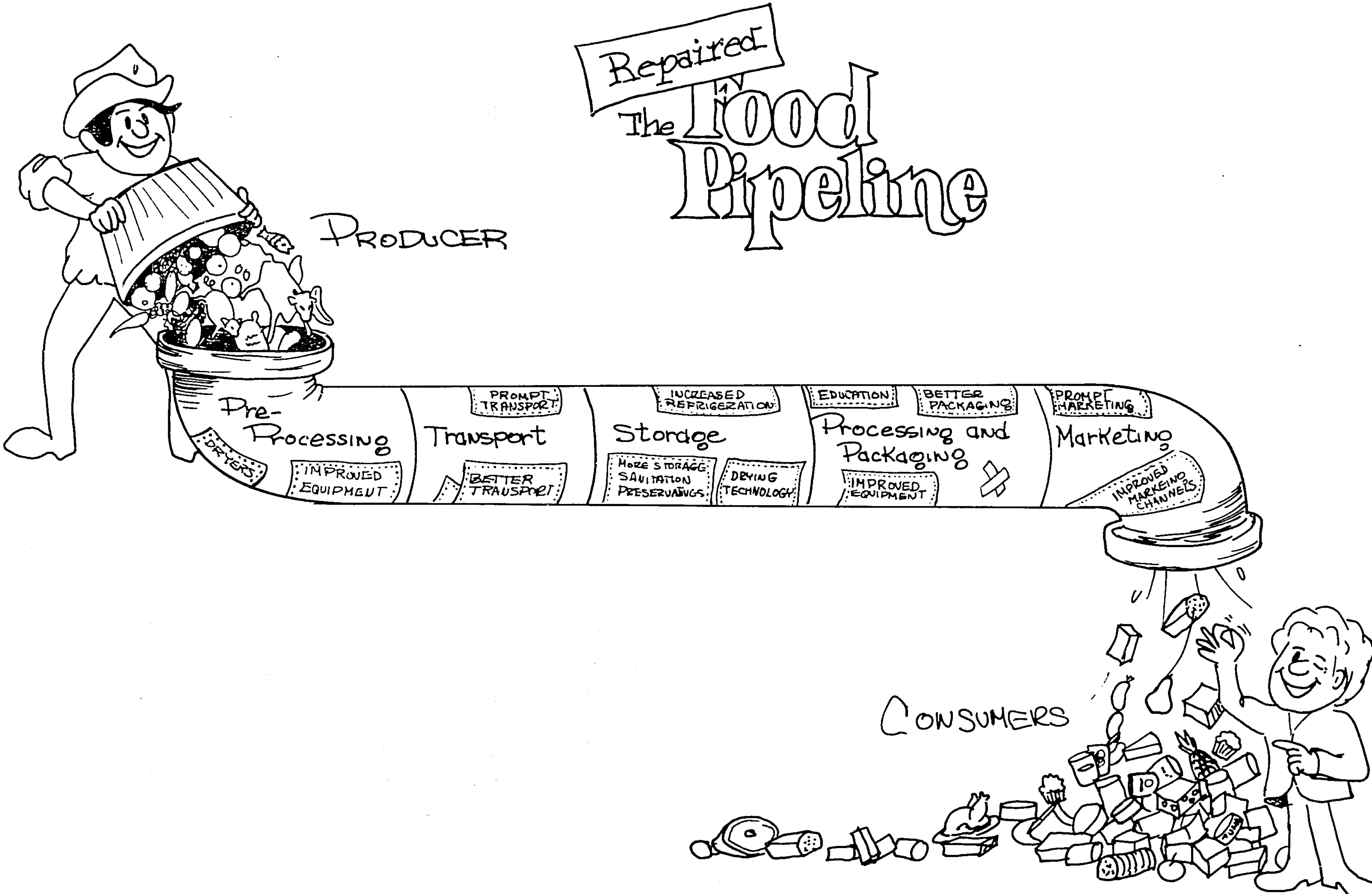

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CONSUMERS

APPENDIX A

This appendix lists a number of specific examples to show how the definition of post harvest food loss (given on page 4-6) works out in practical situations.

1. Grain becomes post harvest after it is separated from the stalks and brought in from the field. It need not be removed from the farm; thus on-farm storage of grain is post harvest, but untouched grain on the stalks in the field is preharvest, and bundles of grain in shocks in the field are in the process of harvest. Ears of corn that are turned down and allowed to remain on the stalks in the field are in the process of harvest. The corn does not enter the post harvest stream until it is separated from the stalks and removed from the field.

2. Animals and birds become food after slaughter and dressing. Losses before slaughter are not post harvest losses. Carcasses that are discarded after slaughter because they are diseased or otherwise unfit for human consumption are not post harvest losses; they were unfit for human consumption before slaughter but the defects were not evident until after slaughter. Carcasses that pass inspection after slaughter, and subsequently develop defects that make them unfit for human consumption are post harvest losses.

3. Fish becomes post harvest after it has been pulled into the boat. A fish escaping through a hole in the net before being landed is not a post harvest loss. If after being landed, an edible fish is thrown back into the water because it is of the wrong kind, size or quality, it is a post harvest loss. If it is thrown back because it is inherently inedible (e.g., a poisonous species) it is not a food loss.

4. Fruit becomes post harvest after it has been picked from the tree and placed in containers. Fruit that falls from the tree and is allowed to rot on the ground is not a post harvest loss because it was never harvested; however, if fallen fruit is picked up and placed in containers for the

purposes of utilization, then it becomes subject to post harvest losses. Similarly vegetables become post harvest after separation from the plant by human intervention; roots and tubers must be removed from the soil to enter the post harvest system.

5. Milk becomes post harvest as soon as it is drawn from the udder unless it is rejected as being unfit for human consumption at the time the animal is milked. Any subsequent losses in milk or products manufactured from milk are post harvest losses.

6. Eggs enter the post harvest food chain as soon as they are separated from the hen by human intervention. Eggs broken by the hens are not post harvest losses. Eggs that are rejected for human consumption because of defects present in the egg when they were laid are not post harvest losses even though the rejection might occur some time after laying (e.g., if candling discloses excessive blood spots).

7. A quantity of rye is found to be contaminated with ergot and is condemned. This is not a post harvest loss because the rye was unwholesome at harvest but this fact was not discovered until later.

8. A quantity of peanuts is condemned because it is contaminated with aflatoxin. If the aflatoxin was present in the peanuts at the time the plants were pulled from the ground it is a preharvest loss. If the aflatoxin developed during the time the peanuts were curing in the field, it is a harvest loss and if the aflatoxin was formed because of faulty storage conditions after the peanuts were brought in from the field it is a post harvest loss. This is one of the difficult cases because it is not always possible to determine at which point the Aspergillus mold grew and formed the aflatoxin. Since the contamination usually occurs during curing in the field, aflatoxin should be considered a harvest loss unless there is strong evidence to show that the mold grew while the peanuts were in post harvest storage.

9. 100 tons of paddy rice are milled yielding 80 tons of unpolished rice. There has been no food loss because the hulls are inedible.

10. 100 tons of paddy rice are milled yielding 60 tons of whole polished grains, 20 tons of broken grains and 20 tons of hulls and bran. The 20 tons of broken grains are a food loss if they are not used for human consumption because this is edible material. The small quantities of endosperm that are rubbed off by abrasion and are removed with the bran are a food loss. The weight of hulls removed is not a food loss. The weight of bran is another difficult case because it contains valuable nutrients and sometimes it is eaten. Since the bran is usually not eaten it should probably be excluded as a food loss, but this is a debatable decision.

11. 120 tons of rice with 20% moisture are dried, yielding 110 tons of rice at 10% moisture. There has been no food loss because the only change was in the moisture content.

12. Food that is condemned because it fails to meet legal standards is a loss if it was in compliance with those standards when it first entered the post harvest system.

13. Theft is not a food loss. The fact that the food moves from legal channels into illegal channels does not alter the fact that the food is, presumably, still used for human consumption.

14. Food that is spilled is a loss unless it is picked up and reclaimed.

15. Food that is consumed by rodents, birds, and other non-domestic animals after harvest is completed, is 100% loss.

16. Grain that is contaminated by insects can range from a small loss to 100% loss because insects cause both weight losses and quality losses. Insects usually consume only a small portion of the food they contaminate. The confused flour beetle larva (a heavy feeder for an insect) is estimated to consume 26 milligrams of food during its development to adulthood. It requires an enormous number of larvae to directly consume a significant quantity of food and occasionally the insect population becomes so high

that significant direct weight loss occurs. However, insects damage much more than they consume. Their frass and webbing can spoil many times the amount of food they actually consume. When the extent of insect infestation is small the food can generally be reclaimed making the loss small. A point is reached in heavier infestations where health, legal, cultural, aesthetic or fiscal factors, or the difficulty of reclamation cause 100% loss, even though only a small percentage of the food has actually been consumed by the insects.

17. 1,000 lbs of field run potatoes are passed through a cleaning & grading plant and yield 800 lbs saleable potatoes, 100 lbs of undersized potatoes and 100 lbs of rocks and dirt left in the washing tank. The reduction in weight resulting from the removal of rocks and dirt is not a food loss. The 100 lbs of undersized potatoes are a food loss even though they have no present economic value and are discarded, because they represent edible food.

18. When the quality of a food deteriorates to the extent that it is considered unfit for human food and it is diverted into animal feed, it should be considered 100% loss. We are concerned with food for humans, not feed for animals. It might be argued that the food returned by the domestic animal should partly offset the food → feed loss. SInce the conversion efficiency of animals is generally less than 10% it seems that writing this off as 100% loss would be the simplest method of handling this situation, and that it would not cause any significant decrease in the accuracy of the bookkeeping. Foods that are produced expressly for animal feed are not food losses since it was the intention to use them as feed from the outset. This example refers to crops that were intended to be used as food but were diverted into feed because of loss of quality.

19. Food that is discarded for minor or major quality defects after entering the food chain is considered 100% loss. Examples of minor quality defects are day-old bread, and fruit with a blemished skin or unusual shape. Examples of major quality defects are food that is burned in cooking, moldy bread, stale eggs, overripe fruit and rotten vegetables and fish.

20. A quantity of apples in cold storage suffers internal breakdown of the flesh after two months when the expected storage life of this variety is six months. Investigation shows that the cause of the problem is calcium deficiency in the orchard. This is a post harvest food loss even though the correction of the problem (better calcium nutrition for the trees) is preharvest because the apples were in a wholesome, edible condition at the time of harvest and there was time for them to be marketed and consumed before the problem of internal breakdown appeared.

APPENDIX B

Crop Production Increases Required to Offset Post Harvest Losses

The following formula shows how to calculate the production needed to supply a fixed quantity of consumable grain after losing a certain percentage in the post harvest system:

$$\text{Production} = \text{amount of consumable grain} \times \frac{100\%}{100 - \%\ \text{post harvest loss}}$$

If the amount of consumable grain needed is 100 tons this formula becomes:

$$\text{required production} = 100\ \text{tons} \times \frac{100\%}{100\% - \%\ \text{post harvest loss}}$$

The table below shows by how much production must be increased in order to offset various levels of post harvest losses.

Post Harvest Loss %	Consumable Grain tons	Production Required to give 100 tons after post harvest loss. tons	Increased Production needed to offset post harvest loss. %
0	100	100	0
10	100	111	11
20	100	125	25
30	100	143	43
40	100	166	66
50	100	200	100
60	100	250	150
70	100	333	233
80	100	500	400
90	100	1000	900
100	100	Infinite	Infinite

When post harvest losses are small a percent increase in production slightly greater than the post harvest loss will make up the deficiency. As the percent loss increases the percent increase in production required to offset the loss increases more rapidly. It requires a 25% increase in production to offset a 20% post harvest loss, a 66% increase to offset a 40% loss, and a 150% increase to offset a 60% loss.

during cooking after several months storage under tropical conditions. The loss of cookability is known to be accelerated by high temperatures and high humidities. It would be uneconomical to store dry beans under refrigeration in order to maintain cookability, but it might be economic to dry the legumes to a moisture content low enough to prevent loss of cookability even when stored at a high temperature. The ultra-