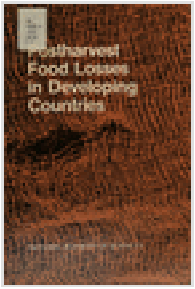

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Postharvest Food Losses in Developing Countries

Board on Science and Technology
for International Development
Commission on International Relations
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1978

This report has been prepared by an ad hoc advisory panel of the Board on Science and Technology for International Development, Commission on International Relations, National Research Council, for the Office of Agriculture, Bureau for Development Support, Agency for International Development, Washington, D.C., under Contract No. AID/csd-2584, Task Order No. 23.

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Comments on this report, especially regarding its usefulness and any initiatives or research it may have induced, would be welcomed by the staff officers: M. G. C. McDonald Dow and John Hurley, National Academy of Sciences-National Research Council, 2101 Constitution Avenue N.W., JH-214, Washington, D.C. 20418, USA.

Contents

Summary

As the world's population grows, increasing the food supply becomes an ever-more-urgent priority. One vital–and neglected–step toward this end is to reduce the food losses that occur between harvest and consumption. Reliable studies indicate that postharvest losses of major food commodities in developing countries are enormous, in the range, conservatively, of tens of millions of tonnes* per year and valued at billions of dollars. Programs for reducing these losses must be based on reasonable estimates of their magnitude, as must evaluations of program effectiveness. Yet it is very difficult to estimate postharvest food losses with precision. Partly, this is due to their inherent variability. But it is also a result of many cultural and economic factors that frustrate the smooth, efficient flow of food through the postharvest system from producer to consumer.

Useful food loss estimates are possible, however, as is improvement in food conservation. This study is devoted to assessing both the potential of food loss reduction efforts and their limitations. It summarizes existing work and information about losses of the major food crops and fish; discusses some of the economic and social factors involved; identifies major areas of need; and suggests various policy and program options for developing countries and technical assistance agencies.

Loss Estimation

Any effort to reduce food losses must begin with a quantitative assessment of the problem. However, loss estimates–unlike production estimates, which are based on the measurable genetic potential of crops–are location- and season-specific to a degree that makes the concept of average levels of loss almost meaningless. The low accuracy of loss-survey techniques on the one hand, and the limitations of extrapolating from even a specific, well-characterized loss situation on the other, make reliable, economic loss esti-

*Tonnes (metric tons) are used throughout the report.

mates very difficult to obtain. There is no doubt that losses can be better understood and assessed, however, and improved methods must be developed and standardized.

Improved loss estimation is essential for making policy decisions about the allocation of resources to reduce losses. Experts resist estimating national or global losses of major food commodities because these figures are impossible to substantiate statistically, except on a limited, controlled experimental basis. When providing "indicative" figures for planning purposes, the experts typically cite minimum overall losses of 10 percent for durable crops (the cereal grains and grain legumes) and 20 percent or higher for nongrain staples (yams or cassava, for example) and other perishables, including fish. Even if these estimates are accepted (with appropriate caveats) only as conservative minimum values in support of allocations for food loss reduction, it is clear that worldwide food losses are staggering and that they justify substantial investment of intellectual and financial resources to better understand and reduce them. This is reflected in the 1975 Resolution of the VIIth Special Session of the United Nations General Assembly, committing member states to reduce postharvest food losses by 50 percent by 1985.

Loss Reduction

The degree of loss reduction achieved will depend ultimately on economic exigencies. Given modern technology and sufficient resources, it is theoretically possible to conserve most food commodities almost indefinitely without loss. The expenditure on food conservation, however, must be justified by particular needs and circumstances. Before programs can be undertaken to reduce losses on a national scale, more data are needed on probable costs and personnel and organizational needs. Actual loss reduction efforts must begin with political commitment by individual countries to carry through the actions required at the national level.

Given the complex coordination required to effect loss reduction, each country requires a national postharvest policy body with a full-time professional staff to assess and monitor overall losses, identify acute loss priorities, and carry out research. This body should also provide decision makers with realistic policy options, so that investment in loss reduction can be made commensurate with the economic and social costs and benefits involved. The postharvest policy group must have access to the highest levels of government, since losses may result as much from disincentives to conservation caused by pricing, taxation, or other governmental regulatory policies as from biological or physical causes.

Regrettably, few countries have postharvest groups responsible for developing and coordinating policy among the ministries involved. Establishment of such bodies is urgently recommended, and technical assistance agencies should be ready to help developing countries with the process.

Current national efforts for food loss estimation and reduction are not only inadequate, but are also heavily biased towards storage losses of cereal grains. Given the seasonal character of grain production and the survival value of grain in many societies, this is understandable. However, the nongrain staples, which are the main source of calories, at least in the diets in many areas, should receive attention commensurate with their importance in the diet; so should vegetables and fruit. This concern should not, however, be at the expense of efforts focused on the cereal grains.

In most societies, so much importance is attached to eating fresh, known varieties of fish (because of the dangers of eating either spoiled or toxic varieties) that increasing consumption of less-conventional varieties or processed fish products (fish flakes or protein concentrate, for instance), is unlikely to reduce current losses. Rather, efforts should be directed to 1) improving storage; 2) assisting fishermen in forming cooperatives, which collectively could justify improved boat-landing and fish-handling facilities; and 3) improving marketing and processing (drying, salting, and smoking) of landed catches of conventional species. Nonconventional fish species should be used, wherever possible, for animal feed and fertilizer.

Social, Cultural, and Economic Aspects

Food losses are related as much to social phenomena as to physical and biological factors. Cultural attitudes and practices form the critical, inescapable backdrop for postharvest operations and loss reduction activities. Even the perception of what constitutes food loss often varies greatly among cultures. The techniques of food conservation are frequently dictated more by traditional beliefs than by immediate utility. The roles of male and female, or relationships among individuals and families, may be reflected in the particular ways in which food is handled or stored after harvest.

Thus, national efforts to reduce food losses cannot rely solely on technology or empirical data. Techniques and information must be culturally and socially acceptable if they are to be useful. Moreover, incentives for the adoption of sound food conservation practice should be emphasized. Incentives are an important aspect of reducing food losses. Producers are unlikely to invest money or effort in loss reduction activities unless they foresee a good return, whether in income, security, or status.

A problem here is that the lack of data about postharvest food losses is particularly acute with respect to economic and social aspects of loss, meaning that the cost effectiveness of food loss reduction cannot yet be adequately demonstrated. Yet there are simple improvements in conservation practices that require little monetary investment and could greatly reduce the risk of serious loss at the farm level. There are also indirect benefits that can derive from investment in postharvest loss reduction. This is true especially in the traditional farm sector of poor countries, where the bulk of the population produces and consumes the larger proportion of the food crops, little of which enters the market sector. Here food loss reduction leads to greater security against lean years. It may also offer possibilities for generating employment and surplus food for marketing, which may pay for an increased flow of goods and services to the rural area. Government action to reduce losses is probably more important in the traditional farm sector than other sectors of the economy, where food commodities are mainly in the hands of commercial entrepreneurs who normally respond to market forces with appropriate conservation measures.

Education and Training

The lack of reliable general information on the extent, nature, and possibilities for reduction of postharvest food losses, combined with lack of recognition that this is a discrete technical area with opportunities for professional career development, has led to a critical shortage of qualified and experienced personnel. This should be overcome by educational efforts at many levels. These efforts should include informal programs to increase public awareness of the need for hygiene in food handling and storage. They should also include training courses for agricultural extension workers (who have a particularly important role to play in the rural farm sector) and administrative personnel, as well as degree and postgraduate training in appropriate biological and engineering disciplines. Particular attention should be given to increasing training opportunities for women, who in many societies play a vital role in harvest and postharvest activities. Existing technical assistance support for national postharvest training programs should be strengthened and should be matched by complementary research and training opportunities in the industrialized countries.

Technical Information and Research

There is little precise published information about losses and loss reduction in developing countries. That which is available concerns mainly grain storage; more information is needed about perishables and the socioeconomic factors affecting food conservation. The literature is scattered widely throughout the technical journals and is often not readily identifiable by title as relevant to postharvest losses. There is need for an international postharvest loss documentation service, continually updated and with facilities for providing microfiche or hard copies of technical papers on a worldwide basis.

Although accurate specific data are lacking, a great deal of general technical and scientific information about various aspects of food loss in industrialized countries is available and should be put to use. There is need for adaptive research to ensure that this information is technically sound and for socioeconomic research to ensure that it is socially acceptable and economically justifiable to apply it to developing country situations. The private sector in developing countries is potentially very important because of its information and experience in the postharvest conservation of commercial and export crops.

Further applied research is needed to improve food processing equipment so that it will work efficiently under tropical conditions. This applies particularly to drying, threshing, and milling equipment, which is often old, inexpertly operated machinery designed for other purposes and the cause of much avoidable loss. There is also a particular need for low-cost, simple cooling equipment, which could dramatically increase storage and marketing life of perishables.

Finally, there is a need for basic research, much of it conducted in cooperation with industrialized countries. Topics for study should include improved, biodegradable pesticides (insecticides, rodenticides, and fungicides) to be used in integrated systems of pest control, replacing toxic chemicals to which many pests are becoming resistant and which may be a threat to the health of people, livestock, and wildlife. The international agricultural crop research centers and national crop breeding programs should also consider the postharvest characteristics of new varieties when selecting crops for introduction to developing countries.

Our study confirms that there is no known simple, inexpensive technology that can, by itself, make a profound impact on postharvest losses. On the contrary, postharvest food conservation can be achieved only through a combination of location-specific organization, problem identification, training, information, and adapted technology. Good conservation practice must be applied on a sustained basis, with continual refinement in response to new information. Significant worldwide reductions in food losses will result as the aggregate of these sustained national efforts, which should be given all possible support by the bilateral and international technical assistance agencies.

Chapter 1

Introduction

By the year 2000, it is projected that world population will increase from 4 billion to between 6 and 7 billion. Since estimates indicate that between 450 million and 1 billion people do not have enough to eat now, this number is likely to increase with the population (NRC, 1977).

To cope with current and future food demand, governments have traditionally emphasized two lines of action: reducing future demand by slowing population growth, and augmenting food supplies by expanding production.

A third vital complementary measure, however—reducing the loss of food during and after harvest—has not been adequately emphasized.

In developing countries enormous losses result from spillage, contamination, attack by insects, birds, and rodents, and deterioration in storage. Conservative estimates* indicate that a minimum of 107 million tonnes of food were lost in 1976; the amounts lost in cereal grains and legumes alone would provide more than the annual minimum caloric requirements of 168 million people.

Billions of dollars have been invested to help developing countries produce food, but this has not been matched by investment—or by an awareness in developing countries of the need for it—either to determine what could be done to reduce losses, or to initiate measures to reduce loss.

Increased food production causes strain on existing methods of handling, storing, and processing crops, and increased food losses will result unless developing countries and donors of economic assistance can a) establish and maintain adequate harvesting, storage, and handling practices, particularly in rural areas, and b) create efficient policy and administrative infrastructures.

Neither the total magnitude of postharvest food loss nor the extent to which it is avoidable are reliably known. Losses vary greatly and are a function of crop variety, pests and pest combinations, climate, the system of harvesting, processing, storage, handling, and marketing, and the social and cultural setting. The importance of losses in particular localities varies accord-

*See Chapter 8.

ing to the availability of food and the purchasing power of the various sectors of society.

Experts involved in the preparation of this report resisted extrapolating postharvest loss estimates to national or global levels because general estimates cannot be supported with statistically significant data. For planning purposes, however, 10 percent is cited as an average minimum overall loss figure for cereal grains and legumes, and about 20 percent as the minimum for perishables and fish. It is clear that food losses are important to poor countries in terms not only of quantity, but also of nutritional and economic loss.

Many observers believe that a 50-percent reduction in postharvest food losses in developing countries would greatly reduce, or even eliminate, the present need of some countries to import large quantities of food. This reduction has been set by the VIIth Special Session of the United Nations General Assembly in 1975 as a target to be achieved by 1985. Annual production of cereals by that time is projected to reach 450 million tonnes, and projected minimum losses might amount to at least 45 million tonnes, valued at 7.4 billion 1976 U.S. dollars. Calculations for perishables and fish project minimum losses in 1985 valued at over $4 billion for a total food loss in developing countries valued at more than $11 billion.

Food losses are highly locality-specific, not only in amounts, but also in their impact: this means they must be evaluated in the context of the relative economics of food production and of the relationship between food production and population growth. There is no doubt, however, of the importance of loss reduction to governments and technical assistance agencies as a means of increasing food availability at a time when constraints on production (decreased land availability and rising costs of fertilizers and pesticides) are continually increasing.

Substantial postharvest losses also occur in developed countries. These losses appear to result from somewhat different causes than those in developing countries, however. For instance, many stem from consumer demand for a widely varied diet. Because of strict quality regulations and consumer preferences, a large amount of food is thrown away due to slight changes in quality or appearance. Similarly, requirements for uniform packaging procedures result in heavy losses of discarded irregularly shaped fruits and vegetables.

Charge and Objective

The United States Agency for International Development (AID) has identified postharvest food loss reduction as a key problem area to receive attention. In order to pinpoint the most appropriate ways to allocate AID funding, the Agency requested the Academy to undertake a study of postharvest food losses.

The objectives of this study are:

1. To summarize existing work and information on food losses;
2. To discuss some of the social and economic factors involved in food loss and food conservation; and
3. To identify the need for food loss assessment and food conservation and to suggest alternatives for food conservation policy and programs for developing countries and development assistance agencies.

The study does not prescribe conservation projects or practices applicable to all developing countries, since remedies must depend on each country's particular circumstances and priorities. Rather, the study reviews alternative possibilities for reducing losses, presenting them in a way that may help decision makers to better assess the possible consequences of various courses of action.

The report is aimed primarily at the decision maker—in both industrialized and developing countries—who is responsible for resources that might be allocated to food conservation and who seeks a comprehensive overview of the postharvest system in developing countries. We have, therefore, included background and basic technical, socioeconomic, and cultural information.

The report is also designed as a basic introduction for the technical person not familiar with the field. References and suggested reading are included to indicate further sources of information.

To initiate and direct the study, the Academy appointed a Steering Committee whose members have experience with both the technical aspects of postharvest food conservation in developing countries and the broader scientific, social, and economic context.

The Steering Committee met three times. At the first meeting, participants agreed on the outline of the study and identified key issues. With these guidelines established, compilation of a bibliography was begun and information solicited from large numbers of experts throughout the world.

For the second meeting, an international group of experts was invited to join in an examination of the key issues and the roughly assembled study material. On the basis of these discussions, a final draft was prepared by NAS staff members for discussion at the third meeting, with subsequent review under the Academy's report review procedure.

Scope of the Study

Throughout this report, emphasis is given to the major food crops, identified on the basis of estimates of their levels of production in 1976 (FAO, 1977). The study focused on the basic categories of foods–cereal grains and grain legumes, nongrain staples, and perishables and fish–in rough proportion (60:20:20) to their relative importance and the amounts of information believed to be available about their postharvest problems.

Since Congress has directed AID to devote its main attention to the poorest people in developing countries, the study focuses on the needs of rural farms. Morover, emphasis on the farm sector is logical in terms of production patterns; a large portion of all food crops in developing countries remains on farms and in rural villages and never enters the commercial market.

TABLE 1:1 Major Food Crops, World and Developing Country* Ranked in Order of Estimated Production (from FAO, 1977)

WORLD			DEVELOPING COUNTRIES		
CROP	TONNES (in thousands)	PERCENT	CROP	TONNES (in thousands)	PERCENT
Wheat	417478	15.67	Paddy	186230	21.36
Paddy	345386	12.97	Cassava	103486	11.87
Maize	334014	12.54	Wheat	95048	10.90
Potatoes	287554	10.80	Maize	73328	8.41
Barley	189654	7.12	Banana/ Plantain	55199	6.33
Sw. Potatoes	135855	5.10	Coconuts	32664	3.75
Cassava	104952	3.94	Sorghum	31173	3.57
Soybeans	62117	2.33	Yams, Taro, etc.	28777	3.30
Grapes	59204	2.22	Potatoes	26909	3.09
Banana/ Plantain	56805	2.13	(Pulses)**	25997	(2.98)
Sorghum	51812	1.95	Citrus	22040	2.53
(Pulses)**	51522	(1.93)	Millet	21452	2.46
Millet	51461	1.93	Barley	20775	2.38
Citrus	50843	1.91	Sw. Potatoes	17630	2.02
Tomatoes	40802	1.53	Soybeans	13842	1.59
Coconuts	32895	1.23	Groundnuts	13502	1.55
Yams, Taro, etc.	29530	1.11	Tomatoes	12755	1.46
Rye	27660	1.04	Grapes	12720	1.46
Groundnuts	18495	0.69	Mangoes	12556	1.44
Dry Peas	13427	0.50	Watermelon	10436	1.20
Dry Beans	12580	0.47	Dry Beans	8537	0.98
			Onions	6474	0.74
Percentage of Total World Food Crop Production		88.14	Percentage of Total Developing Country Food Crop Production		94.39

*Developing market economies as defined in the FAO Production Yearbook (1977).
**Pulses–total legumes except soybeans and groundnuts.

As a corollary to the emphasis on crops grown and consumed in the poorest farm sector, it was agreed to exclude primarily commercial food crops—the beverages (tea, coffee, cocoa) and other plantation and export crops such as bananas and sugar cane. These commodities are largely the province of private enterprise; presumably, the entrepreneurs give postharvest loss appropriate attention, at least by comparison with the nonmarket food crop sector.

Meat and dairy products have also been excluded from the study. It was agreed that they pose special kinds of loss problems related to the provision of a storage and distribution system. If such a system exists, it operates more or less efficiently with pasteurization and refrigeration; if it does not, there is little incentive for production beyond immediate, usually modest, needs and the products (except for cheese) are consumed quickly with minimal loss.

The study is directed toward losses occurring either in unprocessed food or in food commodities that have undergone "primary" processing. Primary processing is a series of steps (taken mainly on the farm, with women taking much of the responsibility) by which the raw foodstuff is converted into a basic edible commodity by being treated or separated from inedible constituents. Rice, for example, is harvested, dried, stored as paddy, hulled and polished, or parboiled. These steps involve weight loss that may or may not include food loss, depending on definition. (Rice hulls are not losses because they are not food, but rice bran may be.)

There are further "secondary" processing steps such as baking, brewing, or canning in which the basic edible commodity is converted into other forms before being consumed. The study concentrates on the losses occuring from harvest through primary processing rather than on secondary processing, a decision made for two reasons:

- Secondary processing takes a large variety of forms. Keeping track of the commodity as it moves through various stages in this part of the food chain makes the estimation and quantification of losses a daunting prospect.
- In secondary processing, the commodity is normally in the hands of commercial, village, or domestic processors. Losses are likely to be relatively small (compared to storage losses, for example), and to the extent that commercial enterprise is responsible, they are probably minimized as much as the available resources and economic incentives warrant.

Although meat and dairy products are excluded from the study because of their perishable nature and urgent storage demands, fish is included. This decision was made because of the importance of fish in the world diet (to which it supplies 17 percent of animal protein consumed) and because losses after "harvest" are similar to losses in other perishables resulting from problems of rapid deterioration, preservation and drying technologies, and storage.

Definitions and Boundaries

Certain key words must be defined to avoid confusion. Perception of loss is highly subjective and location-specific and the formulation of unambiguous definitions difficult. The definitions that follow are the consensus of a large number of knowledgeable individuals who recognize the need for bringing some uniformity to the use and meaning of commonly used terms. The definitions are based on those articulated by Bourne (1977).

Food

Food is any commodity produced or harvested to be eaten by a particular society. It is measured by the weight of edible material–calculated on a specified moisture basis–that has been harvested, gathered, or caught for human consumption and that is consumed by the population of the area under consideration. For the purpose of this study, primary attention is focused on the major food crops–cereal grains, grain legumes (the "durables"), and root crops, with secondary consideration given to perishables and fish.

Harvest and Postharvest

Harvest is the single deliberate action to separate the foodstuff (with or without associated nonedible material) from its growth medium–reaping cereals, picking fruit, lifting fish from water–and all succeeding actions are defined as postharvest actions.

The postharvest period of time thus begins at separation of the food item from the medium of immediate growth or production. It is defined here as ending when the food enters the process of preparation for final consumption. This period also corresponds to the agricultural marketing and distribution period in which "crop protection" activities have ended, but before meal preparation activities begin.

Fruit becomes postharvest after it has been picked. Fruit that falls from the plant and is allowed to rot on the ground is not a postharvest loss because it was never harvested. However, if fallen fruit is collected for use, it becomes subject to postharvest loss assessment.

Loss and Damage*

Loss is measured as a reduction in weight in the amount of food available for consumption. We are concerned here only with losses that could

*For a fuller discussion of this topic, see Chapter 3.

be avoided or reduced given the right conditions under the constraints of the society in which they occur. Economic considerations may lead to situations in which it is not desirable to reduce loss that could technically be avoided. For the purpose of this report, therefore, the food would not be considered lost.

Damage is physical spoilage, often a partial deterioration or one subjectively judged and very difficult to measure; it is usually reported as a percentage of the food sample. Damage of a crop sample is not usually the same as weight loss and is usually not as useful or precise a loss indicator as percent weight loss.

Foods that are taboo and therefore not consumed are not held to be lost; neither are foods used in ceremonial or religious rites. Nonutilization and underutilization of items not now recognized as food are not considered lost, though this is an important area of study that should be addressed elsewhere.

It is important that loss definition be location-specific. Cultural differences create problems in defining loss; what is considered edible, a delicacy even, in one area (fermented bean curd, for example) may not be viewed as food in another. Loss definition may even be time-specific, with items rejected in times of plenty consumed in times of want.

Assessment, Measurement, and Estimation

These terms are used in the literature to describe different kinds of processes that determine losses with varying degrees of confidence. They are used here as follows:

Assessment is used to denote the rough quantitative approximation of food loss or to characterize the relative importance of different points of loss in a particular food chain. Implicit in the use of this term is subjective judgment required because of insufficient information.

Measurement is a more precise and objective process by which quantitative facts about a loss situation are calculated. Implicit in this process is the belief that the same procedure applied by any observer under the same circumstances will yield the same result. This does not mean that the accuracy of the result is necessarily higher than that of an assessment—the accuracy will depend on the method of measurement itself, while the accuracy of an assessment can only be borne out by subsequent measurement.

Estimation is used to describe the process of interpretation of a number of scientific measurements, and thus requires that experience and judgment be brought to bear on the factual information under consideration.

Waste

Waste or wastage are terms included here because they are commonly used in other reports. However, they cannot be precisely defined since they involve subjective and even moral value judgments and depend on the context in which they are used. They should not be used as synonymous with loss and are probably better avoided.

Bibliography

The need for a survey of bibliographic material was recognized, and this is included in the study's terms of reference.

As collection of postharvest technology references proceeded, it became evident that, contrary to expectations, a large amount of material exists that in some way touches upon loss estimation, food preservation, or storage technologies.

This material was organized by major categories: food commodity loss estimation, conservation technology, and loss vector. The limited time available and the volume of material precluded extensive cross-referencing, but country and author indexes are appended.

The present bibliography of some 2,100 entries and 300 pages is recognized to be a working document. Two hundred and fifty copies have been distributed to institutions actively pursuing research on postharvest technology. Additional copies are available through the National Technical Information Service (NTIS). The information has also been entered in the FAO AGRIS computerized information store and can be obtained from AGRIS catalogs; it is also available from Kansas State University (see p. 173).

To serve the needs of readers who may desire an overview of particular aspects of the postharvest food loss problem but who have neither the time for nor the interest in examining large quantities of information of uneven relevance or quality, selected reading lists have been provided at the end of the major sections of the report. These lists represent the opinion of experts on the various topics as to the items in the literature that are informative, comprehensive, and well-written.

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Chapter 2

Cultural and Socioeconomic Aspects

This report emphasizes the technical aspects of postharvest food losses. Much of the discussion, following the mandate of the study committee, concerns the methodology of loss reduction, the technology of primary food processing and food storage, and the body of knowledge on food pests and the physiological deterioration of food. The study committee is fully aware, however, that prevention of postharvest food losses necessarily involves more than technical issues. Cultural, economic, and social factors strongly affect the nature and magnitude of food loss and the attitudes of farm families and governments to food conservation. Past experiences with agrarian reform have demonstrated that programs must be sensitive to the cultural, socioeconomic, and political characteristics of a society and that the technical and scientific components of change cannot be divorced from the social context within which they are applied.

The resources available to the committee did not permit a systematic examination of knowledge about cultural change and the conditions that facilitate it. This discussion does not represent, therefore, a thorough examination of the social, economic, and educational issues that need to be considered in an approach to food conservation. It is intended, rather, to emphasize the importance of these issues, to point out some of their implications, and to stress the immediate need for planning to conserve food.

Cultural and Social Factors in Food Conservation

The causes of food loss are linked in many complex ways to beliefs and attitudes that underlie traditional ways of managing the postharvest system and that complicate change. These factors must be carefully examined and understood before new conservation technologies and practices can be successfully introduced.

Under traditional farming conditions, the postharvest system of storing and handling crops is suited to the type and level of crop production in which it has evolved, often through a harsh process of natural selection. The levels of production and conservation of food are constrained by the resources available to the farm family, and there may be limitations on the time or labor available on the farm or in the village for incorporating changes in the established seasonal cycle of events. Furthermore, change may be perceived as a threat, and resistance to it may be strong. In many societies, for example, there may be much reluctance on the part of individuals or groups to relinquish established controls over food storage and other practices that are linked to security and status. Traditional practices, therefore, are not likely to be abandoned unless it can be demonstrated both that new technologies and methods will be effective improvements and that they will not result in intolerable strains on social structures, income levels, and distribution.

Despite understandable–and justifiable–conservatism about established postharvest practices, change is inevitable. Population increase, for example, may strain food resources and lead to introduction of new crops, new varieties, or other inputs for production. Such changes will strain the existing food-handling capacity, creating possibilities for increased levels of loss at all stages of the postharvest system. Thus, food production increases should go hand in hand with plans for postharvest conservation techniques and incentives.

The conditions that foster the incentives necessary to stimulate change vary over time and among cultures. Past experience suggests, however, that certain conditions can turn people against technical "improvements" to food conservation. Typically, these include:

- Price depression resulting from increased availability of food;
- Taxation, especially tithes on amounts of food stored;
- Fixed quotas for commodities to be purchased after harvest;
- Inadequate means of storing or marketing surplus production; and
- Obstacles to reaching larger markets, such as lack of feeder roads or inadequate transportation arrangements for fish and perishables.

Conditions that mitigate against food conservation draw attention to the importance of national policies. Past experience suggests that the effectiveness of intervention depends on adequate communication between central governments and local communities. Governments must have adequate information for planning and decision making. It is for this reason that the committee places special stress on the need for national policy bodies concerned with postharvest food losses. Such bodies can take account of the broad range of local interests involved and can examine the technical and scientific considerations in the light of local conditions and attitudes. This would aid national governments in deciding how postharvest losses rank in terms of national priorities.

The decision to act to reduce losses involves not only complex social considerations, but also economic considerations, some of which are discussed below.

Economic Factors in Food Conservation

Postharvest losses can arise from a number of causes. These fall into three main categories, each of which has economic implications:

- Physical loss that can be measured by weight;
- Loss of quality (including presence of contaminants), with changes in appearance, taste, or texture that may cause the food to be rejected by potential buyers; and
- Loss of nutritional value.

These losses may affect the subsistence farmer, the farmer who produces food for sale, and the consumer. Although any losses will ultimately be felt by society as a whole, individual groups are likely to experience the economic consequences to different degrees. Further, strategies to prevent or reduce food losses have economic effects not only on consumers, producers, or owners, but also on other groups involved in food preservation and processing.

Many kinds of costs may be associated with postharvest losses, and it is important to assess these costs as thoroughly as possible for an accurate picture of possible economic consequences.

Individuals or private organizations normally make decisions about dealing with food losses on the basis of economic consequences alone; governments, however, are faced with decisions about losses that involve not only economic consequences but also social responsibility and national development goals. Clearly, there is no simple, "right" answer for complex and changing situations, but understanding of the economic consequences of postharvest food losses can help illuminate feasible answers and eliminate unsuitable ones. These consequences differ at the production, or farm, level and the broader social level; both contexts will be discussed below.*

Economic Loss at the Farm Level

For the individual farmer, economic loss is usually expressed in monetary terms and may result when physical, qualitative, or nutritional loss occurs.

*Discussions on economic losses are based on their treatment by Harman in Adams and Harman (1977).

For example, a farmer may store grain to sell at a later date; if a portion is eaten by rodents or is damaged and becomes unsalable, the farmer loses income he would otherwise have gained. (It should be noted, however, that the example just given could result in an economic *gain* where the general availability of a commodity declines and the price rises as a result; in such a situation the total income of some individual farmers may be increased.) In a similar storage loss situation, a subsistence farmer might be forced to buy extra food to replace his lost supplies and the cost of this food would be a loss. His diet would also suffer if the food lost nutritional value.

It is also possible for the farmer to avoid an economic loss even though his commodity has suffered a loss of quality or nutritional value. If such losses are not detected or the consumer, for whatever reason, is willing to purchase the commodity at prices unaffected by the qualitative changes, the farmer experiences no loss of income.

For the farmer, costs related to postharvest food loss may be considered as direct or indirect and these costs are discussed in Note 2-1.

Economic Loss at the Social Level

Food loss also has implications, of course, for the buyer and the consumer and thus affects the society or the nation as a whole. (Strictly speaking, the economic implications spread throughout the entire world, but they are generally analyzed at the national level.)

For purposes of this discussion, losses at the national level are defined as social losses. Although the economic implications of postharvest losses will be considerably more difficult to appraise at the social level than at the farm level, the causes and consequences of social loss must be recognized.

The difference between postharvest loss consequences for the individual farmer and for the society as a whole can be shown through examples used earlier. A farmer may not suffer economic loss, for example, if he sells his crop at normal prices even though nutritional value has been reduced, but society incurs a loss through the possibility of poorer health and lower productivity resulting from nutritionally inferior food.

Conversely, society may benefit when the individual farmer bears an economic loss. Farmers could, for example, take steps to improve grain storage that involve substantial costs to each farmer. In the short term, there could be a surplus of grain and a lowering of prices so that the farmers, individually and collectively, would lose while consumers benefited. There may also be effects on secondary groups other than farmers and consumers: e.g., basketweavers making storage containers may be displaced by the introduction of metal bins.

Social gains or losses also fluctuate in relation to external influences, notably the world market price for the commodity and the availability of food from external donors on concessionary terms.

Evaluation of Economic Costs

This report emphasizes the importance of knowing as much as possible about the actual quantitative or qualitative extent of postharvest food losses in any given situation in order to make reasonable decisions about corrective action. The requirement for intelligent decisions is knowledge about the costs involved in various losses; to the extent practicable, loss situations must be carefully evaluated in economic terms.

Farm Level Costs

Some illustrations of economic evaluation at the farm level may be helpful.

A subsistence farmer may become short of food before the next harvest and be forced to buy it for sustenance. The money spent or the goods bartered for the purchased food are a direct cost. If the money to buy food comes through a loan, the interest paid is also a direct cost. If food has been damaged in storage and the farmer must sell when the price is low because he lacks alternative storage, he incurs a direct cost equal to the price he would normally have received less the price received from the forced sale. In some instances, a farmer who runs short of food may be helped by donations from friends or relatives. Although his own direct costs may be negligible as a result, the cost to the donors must be included in a complete evaluation.

Costs incurred through loss of quality in a commodity may be difficult to identify. If the loss of quality causes complete market rejection, then the extent of the loss is reasonably clear. In less clear-cut situations, the analysis may be aided if the crop happens to be graded, with different prices for different grades. In the case of quality loss in animal feedstuffs, costs will vary depending on the value of the substitute feeds used or available.

Nutritional losses due to deterioration of food that is nevertheless still consumed are difficult to evaluate in economic terms, although it is recognized that they can have an adverse effect on health and productivity. It is possible to assess the protein and vitamin content of certain harvested crops in their premium or undamaged condition and assess later decreases against the premium standard. An evaluation of this nature, however, is essentially subjective, and interpretations based on such data should be presented separately from other aspects of a loss evaluation.

Social Costs

One farmer's postharvest loss will have little social consequence, but the total of all farmers' losses can represent a significant social cost. Typically, evaluation of these social costs follows an approach similar to that used for an individual farmer: the consequences of loss are analyzed as thoroughly as possible and appraisals made on that basis.

The values assigned to postharvest food losses can be based on the prices (using international exchange rates) at which the commodity could be traded by the country concerned. If production of the commodity has been great enough to meet internal or domestic demand, then a surplus is available, at least in theory, for export. Losses that occur can be calculated to have cost the amount of foreign exchange sacrificed by the reduction of exports.

Conversely, if a commodity is not produced in sufficient quantities to meet domestic demand, some amount of the commodity, in theory, will need to be imported. Losses can be valued at the cost in foreign exchange of importing quantities of the commodity equal to the losses.

Just as individual farmers bear indirect costs in coping with or trying to prevent postharvest losses, indirect costs also can be incurred by society. Measures taken to prevent food losses, rather than those resulting from actual losses in a particular season, have indirect costs. The costs of extension staff who advise on improved postharvest handling and storage of crops are an example of indirect costs, as would be the costs involved in inspecting and grading produce to reduce losses. Indirect costs to society can present problems in economic evaluation, however, because they frequently involve multipurpose activities and the costs cannot be attributed solely to loss prevention purposes.

Cost-Effectiveness Analysis

To the extent that prices can be attributed to postharvest food loss prevention or reduction activities, cost-effectiveness analysis can be a useful technique for evaluating the cost of reducing a unit of food loss and the quantity of units that can be affected within a fixed budget. This analytical approach can indicate which activities could affect the most units within a fixed level of resources. An example is given in Note 2-2.

While cost-effectiveness analysis can be a useful analytical tool when reasonably good information is available on costs and anticipated results, it is only one factor that policy makers and program planners must consider. Other elements that must be included in the decision-making process are the sociocultural acceptability of possible programs, overall national development priorities, and the impact of possible programs on social and economic matters beyond postharvest food losses. The next section discusses some of these additional impacts.

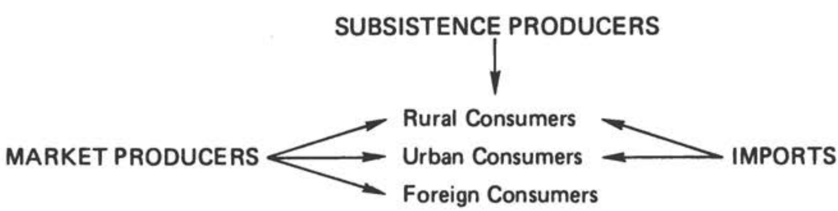
A Special Approach to Cost-Benefit Analysis

In a background paper commissioned for this report, Martin Greeley demonstrates the way in which social cost-benefit analysis supports concentration of loss reduction in the rural traditional part of the postharvest system.

Greeley points out that differences exist in measuring costs and benefits for a private entrepreneur and for the public sector for an investment in loss reduction. The entrepreneur is concerned with private profitability. For public sector investment, the purely financial considerations are only one aspect of evaluating the investment.

In the public sector, investment in food loss reduction programs must be considered in terms beyond the primary objective of loss reduction and increased food supply. The secondary–but vitally important–objectives may include effects on employment (including employment of women who are often displaced by mechanization), income distribution, nutrition, social stability, and balance of payments. These factors necessarily require that the financial cost of achieving a given level of postharvest loss reduction be only one element of evaluation. Poorly conceived programs of loss reduction can impose social costs that negate the benefits derived from the saving of food. Well-conceived programs, on the other hand, may not only save food but also help to provide jobs and distribute income more widely (thus increasing food purchasing power) as well as saving foreign exchange by reducing food imports. In such cases, the social benefits can often be of greater weight than the investment in loss reduction activities.

The postharvest food sector is depicted in the following diagram:



As shown, there are three major sources of food and three major types of consumer. Each arrow represents an element or sector of the total postharvest system.

The sectors are not always independent in physical and operational terms; a rural miller, for example, may have as customers both subsistence and market producers. The sectors do, however, provide a useful division into target groups for program planning purposes.

According to Greeley, the entire postharvest system has often been neglected in resource allocations and there is a need to improve operations at all levels.

For planning purposes it is helpful to establish priorities among the six sectors, which can be defined by the movements of food. These are discussed in Note 2-3.

The use of social cost-benefit analysis suggests that, in general, governments should give greater emphasis to food conservation programs for the traditional sector. In many countries (especially in Asia), this sector has both the largest population and the highest total food production, meaning that with widespread food conservation techniques, substantial savings of food can be made even when percentage losses are relatively low. Furthermore, the producers and consumers in this sector comprise the largest poverty-level group in many countries, and therefore can provide a focus on the poor in national development activities. Because loss reduction activities may require some capital investment and must be perceived to provide practical benefits, governments may need to demonstrate the value of these efforts and to subsidize them. At the village level, good opportunities exist for using local raw material, labor, and artisan skills in loss reduction activities; these elements of a country's resources are relatively cheap and abundant, yet the opportunity cost—their value in alternative investments—is relatively low. Use of these rural resources, moreover, provides direct social benefits by generating employment and distributing income, in addition to reducing food losses for the benefit of poor farm families and consumers. Increased food availability in this sector can also provide the poorest farmers and farm women with access to, and perhaps integration into, the urban and export markets.

Thus, a persuasive case can be made that careful social cost-benefit analysis will support an increased emphasis on food conservation programs for the traditional sector. At the same time, it must be recognized that other demands will frequently have to be given short-term priority. Losses that affect urban food supplies, for example, are highly visible, often affect local political elements, and must be addressed with urgency. Other short-term imperatives can take on equal priority. Moreover, in those countries where the majority of farmers are involved in market-oriented activities, a focus of postharvest food loss interventions in the subsistence or traditional sector assumes less importance.

Despite these cautions, social cost-benefit analysis is an important analytical methodology for evaluating postharvest food loss reduction activities in economic terms, whether or not those activities are directed toward the traditional sector. The results of such activities must be appraised in terms not only of the reduction in food losses and the costs of achieving those results, but also in terms of the effects of those savings on the beneficiaries and of the secondary and lasting impact on the country's overall development.

Conclusions

Food losses are related to social phenomena, and ways should be found to incorporate government concern for a country's food supply with the sociocultural implications of food loss and food loss prevention. Because food conservation bears similarities to other types of intervention into rural practices, the problems and successes of rural health delivery, agricultural extension, and other community development interventions at the village level should be studied by those who plan for food loss reduction.

The need to integrate new practices and revised technologies into village economies calls for a better understanding of traditional practices and, generally, of the conditions that facilitate or hinder corrective measures. Thus, there is a need for more research into the links among economic and cultural practices and food losses.

More understanding is needed of the effects of government financial policies (subsidies, price controls) on postharvest losses and incentives to reduce losses. Specific case studies are also needed to illuminate village-level problems, such as the impact of subsidies on the motivation to adopt new or changed technology.

There is a particular need for data on the costs of increasing the availability of food commodities through loss reduction. Such economic evaluation is essential for comparing food loss reduction strategies with other types of interventions as an aid to more effective decision making and planning of development programs.

NOTES

2-1

In the examples given in the section, the losses are direct; the farmer has suffered a decrease in the quantity available for sale, his own consumption, or barter. In all these cases a monetary value can be applied to the loss. Physical or qualitative losses may also cause other direct costs to be incurred by the farmer. A damaged grain crop, for example, may have to be rebagged or resieved at additional cost.

Indirect economic costs result from measures taken to prevent physical losses. If a farmer takes steps to prevent future losses, he will normally make an investment of money and time in the expectation of a positive return. Or a farmer may prefer to plant an improved crop variety because of its good yields or marketing characteristics. If he is obliged to produce a different variety, however, because the improved variety does not hold up as well in storage, he may suffer some loss in satisfaction, which should be valued if possible. Indirect costs and losses are more difficult to estimate than direct losses and should be considered separately when evaluating food loss situations.

2-2

In country X, assume, for example, that the national postharvest policy unit wishes to know how to achieve the maximum amount of loss reduction for rice, working within a limited budget. Assume further that a program of introducing new rice milling machinery might reduce annual losses by 600 tonnes, on average, in each province affected, while a particular type of improvement in village cooperative rice storage facilities might reduce annual losses by 400 tonnes in each province. If the total budget available for loss-reduction activities is $2 million, and if the improved storage program costs $200,000 per provincial project and the milling machinery program costs $400,000 per province (assume equal rates of amortization), then cost-effectiveness analysis would favor the storage program. This program could be used in ten provinces, reducing total losses by 4,000 tonnes, while the milling machinery program could be used in only five provinces, reducing total losses by 3,000 tonnes, as the table shows.

Cost Effectiveness of Food Loss Reduction Options

Program	Loss Reduction per Province	Cost per Province	Provinces Affected Using Budget*	Program Effectiveness**
Storage Facilities	400 tonnes	$200,000	10	4,000
Milling Machinery	600 tonnes	$400,000	5	3,000

*Total funds available = $2 million.
**i.e., tonnes of food saved.

2-3

The sectors of the postharvest food system in order of importance for resource allocations are:

1. Subsistence producers to rural consumers. This can be called the *traditional sector*, in which the rural consumers are also producers themselves and labor and service employees are paid in kind. Inputs of capital are typically very low, and this sector is characterized by on-farm operations of crop processing and storage.

In many places in the developing world, however, there is an increasing trend toward market-oriented agricultural production, and many regions or countries have no identifiable subsistence or rural nonmarket sector in the strict sense. While small farmers may consume much of what they produce, they generally also market some portion to meet other requirements, often as barter. Even when farmers produce one crop entirely for their own use, they usually produce a second crop for the market. "Traditional," therefore, may be a more useful description of this socioeconomic situation than "rural nonmarket."

2. Market producers to rural consumers. This sector, called the *rural private market sector*, involves large-farmer commercial activities oriented toward monetary profit rather than subsistence food. More off-farm operations are involved than in the previous sector, and buying agents, millers and other processors, and wholesalers and retailers participate in the activity. Consequently, quantitative and qualitative food losses may be higher because of the additional transport and handling.

3. Market producers to urban consumers. This *domestically produced urban sector* represents the flow of surplus food from the rural production. In developing countries, distribution activities here are often dominated by public corporations. Buffer stocks of foods are held within this sector, and their size is a key variable determining the level of activity for the sector. Moreover, if the stocks are on occasion too large in relation to management capability and facilities, losses are likely to increase.

4. Market producers to foreign consumers. The export sector is generally the smallest of the six divisions and varies from small to nonexistent, depending on the season and the country. Its importance is in the export of commodities to generate foreign exchange. The postharvest operations are generally similar to those of the domestically produced urban sector.

5. and 6. Imports to urban consumers and imports to rural consumers. Together, these two divisions are called the *import sector*. Food imports can be highly variable, and the organization of the required transport and handling facilities for imports may be redundant in times when they are not necessary. Long-range projection for the mix between domestic and imported production thus requires high-level policy decisions based on risk calculations and other factors.

Reference

Adams, J. M., and G. W. Harman. 1977. *The Evaluation of Losses in Maize Stored on a Selection of Small Farms in Zambia with Particular Reference to the Development of Methodology*. Report G-109. Tropical Products Institute, London. 149 pp.

Chapter 3

Postharvest Food Loss Assessment and Estimation

In 1975, the United Nations General Assembly, reflecting international concern with ways to increase the world's food supply, called for a 50-percent reduction in overall food losses by 1985. Progress toward this goal can be judged only through reasonable quantitative estimates of actual food losses. Loss estimation is also essential for establishing the programs that will reduce loss; at the national level, politicians and administrators must have reasonably accurate information for their decisions on food conservation investment.

Yet, while the committee understands the need for quantitative estimates to justify budget allocations, we caution against undue emphasis on this aspect of the problem. Food loss estimation is a complex process yielding results of limited accuracy. Reliable average figures on losses for a region, nation, or period of time may be impossible to support with sound statistical evidence, for reasons to be discussed later in this chapter. Part of the problem is that standard methodologies for measuring and estimating loss are lacking for most kinds of food. A variety of estimation techniques do exist for grains, but considerable care must be taken both in choosing the descriptive terminology and estimation technique appropriate for a given situation and in using it.

Above all, care must be taken in extrapolating loss estimates from one situation to another, particularly in attempting to arrive at general national or global estimates. The dubious accuracy of food loss observations and their limited general applicability support use of an extrapolated average figure for loss estimates only under carefully described conditions.

In many cases, it may be unnecessary—or impossible—to make scientific estimates of loss. The sophistication of measurement required will vary widely in different situations, and assessment by experienced observers is often sufficient to justify loss reduction measures. In the commodity sections of this report, the opinions of qualified observers about average losses are included; these figures are conservative judgments of the specialists and should be used with caution.

In many developing countries, the greatest loss assessment need is for a coordinating body at the national level, provided with an operating arm to identify where postharvest food losses are occurring and to undertake detailed loss assessment using standard methodologies. This structure will permit continuing review of the resources that should be allocated for reducing losses.

The personnel needed to carry on programs of food loss estimation in developing countries do not all require a high degree of technical skill. At the planning and supervisory level, however, it is important that responsible persons have a thorough grasp of the complexities of postharvest food processing and distribution, along with sufficient knowledge to call on the various disciplines essential to loss estimation programs.

Prior to a more specific discussion, there are two general aspects of food loss estimation that deserve somewhat fuller treatment: the difference between "damage" and "loss" and the utility, or applicability, of loss estimates.

The distinction between damaged and lost food is often difficult to make. The subjective term "damage" denotes a condition that is not objectively measurable. It refers to apparent evidence of deterioration, and its importance to the consumer depends upon his economic level and cultural background. A poor family often has no alternative but to consume a certain amount of damaged food in its diet, whereas more affluent neighbors may be in a position to exercise selection.

With perishables, damaged portions of root crops, fruit, or vegetables may be cut off and lost for consumption. However, there will be stages of deterioration at which the consumer decides that the whole item should be discarded. It is clearly impossible to define the general conditions under which a certain type of damage should be considered partial or complete. This is a culture-dependent decision.

"Loss," on the other hand, denotes disappearance of food and should be directly measurable in economic, quantitative, qualitative, or nutritional terms, as follows:

- Economic loss is the reduction in monetary value of food as a result of physical loss.
- Quantitative loss involves reduction in weight and, therefore, can be readily defined and valued.
- Qualitative loss, although difficult to assess because it is frequently based on subjective judgments (like damage), can often be described by comparison with locally accepted quality standards.
- Nutritional and germinative losses, which may be a combination of loss of quantity or quality, are also difficult to measure.

Loss of food quality through deterioration, contamination, and changes in the composition of nutrients is important, and needs to be much better understood and measured. At present, however, quantitative food losses—from whatever causes—are of more immediate signficance, since opportunities already exist for alleviating the factors responsible for these losses.

As mentioned earlier, quantitative food losses should be determined on the basis of the food's moisture content. Quantitative estimates of losses can be used to evaluate the potential of conservation activities in the following ways:

- To provide a basis for decisions made by developing-country governments and international agencies about the allocation of resources for food production and for postharvest activities such as storage, processing, and marketing;
- To furnish information necessary for determining the locations and types of activities that may be effective in reducing losses; and
- To increase knowledge and understanding of food supplies.

Relationship Between Accuracy and Usefulness of Loss Assessment

Despite the limitations inherent in the identification of food losses, properly selected estimation methods can provide the information essential for reducing losses. Widespread sampling procedures can be used, for example, in which untrained observers gather information according to a prescribed format. Although the accuracy of the individual loss estimates may be low, large numbers of such observations can provide a useful basis for more general estimates and for decisions involving extended geographical regions or a substantial number of food stores.

Large-scale surveys raise the question of how much accuracy is necessary to make loss estimates that are generally useful. The answer depends upon the purpose to which the estimates are to be put. With survey procedures, the range and level of confidence of the individual result is less important than the overall picture that emerges. If, however, the objective is to determine losses in specific large-scale food storage or processing facilities and to institute conservation measures affecting large amounts of food over a number of seasons, then the accuracy of loss assessment should be as high as possible. Technologies exist to store almost any food indefinitely, but economic, social, and political factors influence the selection of the technology for a particular commodity and place. Often the type of storage—and the consequent amount of loss—represents a compromise among factors of storage cost, desired food quality, and the anticipated storage period required.

On another level of assessment, for traditional on-farm storage situations the degree of accuracy of loss estimates is likely to be low, as are resources for available corrective measures. Here loss estimation is limited by the variety and dispersal of storage facilities among families and villages in a given area and by problems both in sampling procedures and in making generalizations based upon individual observations.

These problems are likely to be exacerbated by the reluctance of farmers to provide accurate information and by the efficiency of the traditional storage methods. Experienced observers agree that in many developing countries storage losses of grain stored at the farm level are often relatively low, perhaps on the order of 8-10 percent. If losses at the farm-storage level are of the same order or smaller than the accuracy achieved by reasonable estimation procedures, it is obvious that good estimates for a region or a sector of agriculture cannot be made with any degree of precision by generalizing from farm data until the number of observations becomes large and is taken over carefully sampled areas. As the amounts of grain stored increase, the potential accuracy also increases and there is less need of subjective judgment.

The limitations of food loss estimation at the farm level lead to the concept of sound conservation practice, which says that, although it may not be economically sound or practical to determine precise food losses, certain food conservation practices are nevertheless justifiable on the basis of common sense. These could include such efforts as making sure storage bins are completely cleaned out between seasons, or providing shade and appropriate containers for transporting and marketing perishables.

Food is such a vital resource in a world of growing population that reasonable measures to conserve it should be taken even though detailed information on exact losses may be lacking. Furthermore, although losses at the individual farm level may be relatively low, in the aggregate the savings that result from improved food conservation can be considerable.

The complexity of procedures used in estimating food losses should be in relation to the risk of loss and the quantities of food involved in the situation under study. Existing data and the opinions of experienced observers may be useful in formulating a "commodity loss profile" in which loss problems for a particular commodity are approximated. The approximation can also help identify areas where losses are higher than would be expected with sound conservation practices and that therefore require detailed attention.

We have been describing some of the limitations and choices involved in the estimation of food losses. However, a considerable effort has been made to develop specific loss estimation methodology and procedures. The remainder of this chapter will examine what is known, what is in the process of being developed, and, finally, what still needs to be done.

Loss Estimation Methodology

The production, processing, and distribution of food involve a system of movement that is always locality-specific and usually very complex, consisting of many stages. Regardless of the nature of the system, however, certain food losses always occur.

Often there is a clearly apparent need to estimate food losses. It may be readily seen, for example, that rodents or insects are attacking stored grain, and the general extent of loss must be determined to decide whether pesticide treatment is warranted. In many other situations, however, observation may indicate that food is being lost in the system, but the quantities, causes, and specific weak points are not known.

The more that loss estimation is analyzed, the more it is apparent that there neither is nor can be a simple technique, method, or procedure that can be universally applied. The movement and storage of commodities between production and consumption is seldom an easily analyzed flow. Irregular movement and mixing of various batches in postharvest operations make sampling procedures and generalizations difficult. Yet, sampling procedures must be defined precisely according to the particular situation.

Loss estimation in a given situation should be designed so that the methodology is meaningful, economic, and culturally appropriate. Analysis of the results should be directly applicable to decisions regarding loss reduction. *It is important, therefore, to integrate the process of reducing losses with the process of loss assessment.* At the farm level, for example, the limited resources available for estimation should also be applied to reduction to be credible to the farmer; estimation must not be seen as an end in itself.

For a variety of reasons, more techniques have evolved for the estimation of grain losses than for other major food categories. These reasons will be examined in greater detail in subsequent chapters on specific commodities; suffice it to say here that these techniques reflect the importance of grains as staple foods, the relative physical uniformity of specific grains, and the ease of storing grain.

Grain loss estimation methodology has recently been the subject of a manual prepared by Harris and Lindblad (1978) for the American Association of Cereal Chemists and the League for International Food Education, supported by funds from the Agency for International Development (AID). The manual is designed to be widely used in developing countries to encourage standarized loss assessment procedures so that results from observations carried out in different locations can be more easily compared. This valuable document has been written in consultation with grain loss experts involved in the major national and international programs around the world, many of whom were also involved in the preparation of the present study. Thus, these two AID-supported projects are complementary—the manual designed for those directly involved in grain loss estimation, and this study designed to cover a wider range of subject matter for a more general audience.

A number of useful techniques and approaches have been developed for handling problems of food loss estimation. These techniques can be applied in situations ranging from a broad analysis of where losses occur and at what rough levels of magnitude to sampling and estimation procedures yielding rather precise loss figures. The techniques, described in the following paragraphs, include *a) overall assessment of the commodity movement system, b) field investigation of losses, and c) loss measurement (or "experimental estimate").*

The following pages describe the major methodological aspects of loss assessment, including inherent problems and limitations and future needs. Those seeking more detailed information on procedures for grains should consult the Harris-Lindblad manual directly.

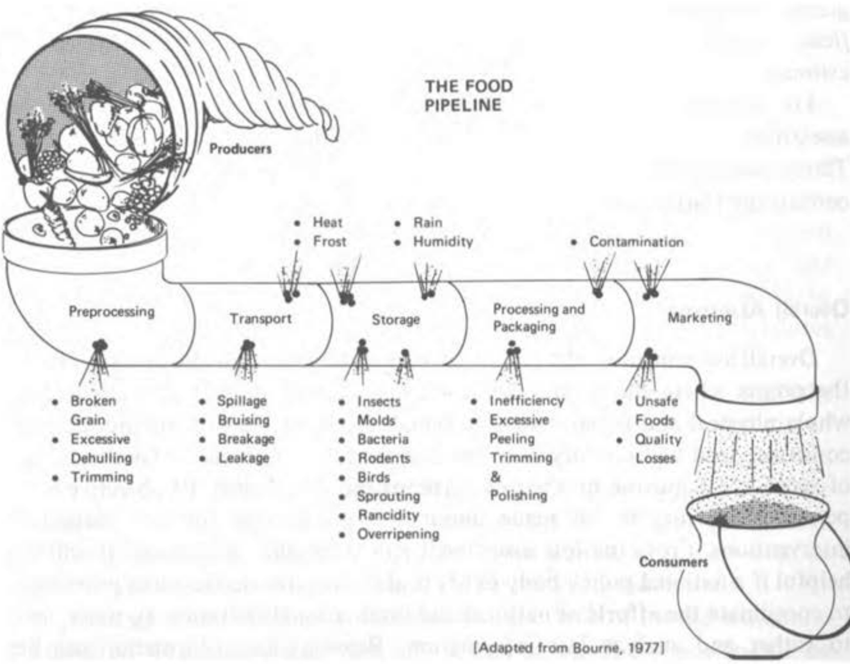
Overall Assessment

Overall assessment of the commodity movement system means a search for the points where the most acute food loss occurs. It implies study of the whole physical and social system in which the food moves from producer to consumer, and will identify how the commodities are handled (size, number of steps, etc.) and the number of participating middlemen. Its objective is to permit judgments to be made about the possibilities for loss reduction interventions. From the loss assessment and reduction perspective, it will be helpful if a national policy body exists to deal with postharvest loss problems, to coordinate the efforts of national and international assistance agencies, and to gather and analyze loss information. Relevant loss information can be obtained from a variety of sources: ministries of agriculture, central statistics organizations, university faculties of agriculture and economics, transportation agencies, marketing boards, commercial organizations, and farmers' cooperatives.

Locality- and commodity-specific information is needed to develop a "commodity loss profile" describing the movement of a commodity through the system and highlighting points of potential or actual food loss.

The figure below depicts the "food pipeline" and the physical and biological ways in which some losses occur. It must be emphasized, however, that the actual movement of food from harvest to consumer may be simpler, or may involve a much more complex system than that represented. Movement can be irregular or can be halted for long periods of time; batches of a commodity can be divided and routed through the system by very different paths and schedules; infusions of a commodity into the system can be made from different sources.

The "pipeline" also has a number of different kinds of materials. There are the human and the mechanical parts of the pipeline, the chain of hands and the line of the transport vehicles through which food passes with greater or lesser efficiency, speed, and ease. The food in the pipeline is propelled by socioeconomic and political forces; regulations and other bureaucratic procedures slow down or accelerate the food's passage from producer to consumer.



Despite the complexities of the system of commodity movement, experienced professionals can make useful estimates of losses and identify possibilities for loss reduction. Simple observation, for instance, of such visual indexes as insects, mold, or leaking roofs may be all that is necessary. Further, such factors as the use of pesticides or the type of storage facility can provide a knowledgeable person with a basis for judging where losses occur and in what magnitude.

The ultimate use of a commodity also bears on loss estimation. Harvested grain may be divided into several lots for different purposes, with each receiving different treatment—some dried and stored for long periods as seed and some held only for short-term storage and consumption or movement off the farm. Different loss risks would be involved for the different uses; for instance, farmers frequently consume their low-quality grain first, since it is known to be subject to the most rapid loss.

These observations enable the trained observer to develop a commodity loss profile for a particular commodity. Such a profile would indicate the final uses of the commodity, the channels through which it travels to final use, the points at which losses occur, and rough estimates of the relative magnitude of the losses at these points. It should be mentioned that complete information on food handling frequently is not collected, but the data is critical, i.e., the number of handling steps involved, the number of middlemen handling the food (with inevitable losses) at each step. It is only this kind of complete information that will enable the expert to judge with confidence what should be investigated and where priorities are to be assigned.

Field Investigation of Losses

Field investigation typically results from analysis of critical points of potential or actual loss in the commodity loss profile.

The first step is to develop methodology for the particular objectives of the investigation. Loss assessment projects frequently have suffered from poorly defined objectives and from lack of experimental control. In addition to objectives, the project must have a pattern that is replicable so that loss comparisons can be made. Comparisons must be statistically valid and must be undertaken within a logical framework of field investigation and scientific measurement.

There are two aspects to field investigation: the survey and the sampling procedure.

First, a *survey* is made of farms, villages, or areas to determine the locations at which the loss assessment will take place, the parts of the postharvest system to be investigated, and the farms or villages from which samples will be taken. A recognized statistical procedure should be employed for selecting farms or villages if it is intended to apply the resultant loss data to an estimate of loss over the area as a whole. Adams and Harman (1977), for example, recommended stratified random sampling in connection with their assessment of losses of maize in Zambia.

The method of *sampling* a commodity is the way in which the sample is removed from the location under investigation, such as a farm or village store. Specifications of sampling procedures are frequently missing from the postharvest literature, yet are a critical dimension of loss estimation procedures.

If the purpose of sampling is to estimate the loss in all the produce in a store at a particular time—for example, during one or two visits in the season—then the sampling must be carried out on all the produce in the store. If sampling is undertaken at regular intervals over a season, on the other hand, then each sample should be taken only from produce being consumed between samplings; to remove other samples would disturb the natural process of loss.

The size of a sample is limited by practical considerations, including whether or not the sample is being removed for analysis and return to the store. (With maize, for example, Adams and Harman (1977) suggest samples of 10 cobs or 1 kg as a reasonable quantity.)

Sampling of stored grain also must take into consideration removal of the commodity from the store for normal consumption or sale. Large losses quoted in the literature often reflect heavy damage to a small amount of residual stored commodity at the end of a season, while in fact total weight loss of the entire crop may be much smaller.

Estimation of Total Losses

After calculating losses in commodity samples, the investigator still faces the problem of estimating total loss in the entire lot under scrutiny. In making such estimates, it is important to relate losses to the pattern of consumption. If, for example, food is left untouched throughout the storage

Sampling stored grain, People's Republic of China (Courtesy E. S. Ayensu) period and at the time of removal the estimated loss is 10 percent, then this represents the total loss over that period. However, in most cases food is removed at intervals during the storage period, and each quantity removed will have suffered a different degree of loss since it will have been exposed to deterioration for a different length of time. The total loss over the season can be obtained by accurately weighing all the grain in and out of the store and comparing the totals. This does not, however, indicate the relationship between loss and time; that is, whether the loss reached a peak or whether it was related to a particular part of the season.

Clear distinction, obviously, must be drawn between observations of loss made at different stages of the system, whether they are made on the same lot of grain experiencing all the losses cumulatively, on different lots, or on a mixture, as grain is added or withdrawn (see Note 3-1). Sophisticated methods are available to deal with these kinds of loss estimation problems for grains (Harris and Lindblad, 1978); they do not yet exist for perishables. The whole area of deterioration over time of stored perishables in developing countries, and the implications for costs of loss reduction, need priority attention.

Interpretation of Results

As Adams (1976) points out, it is clearly impossible to avoid approximation in estimating storage losses of subsistence farmers unless enumerators can be used within each village to check and weigh each removal of stored grain. In most cases, provided the same method of estimation and similar approximations are used for a well-selected sample, the loss estimates will be comparable and will enable decisions about loss reduction activities. The pattern of loss and the factors influencing it should also be recognizable. If possible, loss reduction activities are to be evaluated effectively using accurate weighing of food quantities, replication, and simulation of normal usage. The data for this evaluation should cover the whole storage season and can best be obtained from the type of general loss survey described in the previous section.

Food loss estimation in developing countries is plagued by the inverse relationship between accuracy and extrapolation. At one end of the scale, the few trained observers who have the time, experience, and the trust and cooperation of the farmers whose losses are being estimated can obtain results of reasonable accuracy, but with limited extrapolation to other situations. At the other extreme, large numbers of poorly instructed, untrained observers are likely to produce representative information of low accuracy and little value.

The inherent variability in postharvest food losses renders extrapolation of estimates from one loss situation or from one time period to another difficult, if not impossible, without being so misleading as to be counterproductive. At present, available information is so limited, even in the case of the cereal grains that have received most attention, that experienced observers agree it will not substantiate the use of single "average" or "representative" values for losses of food commodities at national, regional, or global levels. The available values for losses in particular situations should be used only as indicative of the particular kinds of losses in highly similar situations.

Until much more research and loss assessment is undertaken by trained observers on a planned, systematic basis using well-conceived standard methodologies, aggregate estimates of loss that can be substantiated by statistically sound observations will not be possible. In the interim, where these values are required for planning purposes the conservative judgment of experienced observers familiar with the local situation is the only basis for arriving at a particular figure. This figure is apt to be meaningful to the extent that it can be related to particular situations and backed up by experimental data. Again, it must be emphasized that there is great danger that these "best judgment" figures will be taken out of context and quoted as authoritative, as has so often happened in the past.

The committee is persuaded that the magnitude of losses of all commodities justifies additional efforts to gain knowledge about their nature and extent, thus providing an information base that can lead to improved conservation of food. This is particularly so for losses of perishables, about which there is an almost total lack of reliable scientific data.

The committee, therefore, recommends that additional resources be allocated by developing country governments and technical assistance agencies to improving knowledge of a) the movement of food from source to consumer, and b) the locus, nature, and extent of postharvest food losses. Priorities for these efforts should be assigned in proportion to the importance of the food in the local diet. This should not be interpreted to mean that the committee recommends the diversion of resources from existing efforts directed at cereal grains and legumes to efforts concerning other crops but, rather, the committee's recommendation aims at redressing the imbalance of effort that so far has been aimed primarily at the durable crops.

The critical shortage of trained observers for identifying and estimating food losses should be alleviated by appropriate short- and long-term training programs. Innovative approaches, such as use of rural high school and university students as observers under appropriate supervision, should be considered by the responsible national body as valuable supplementary resources for loss estimation and reduction studies. One source of expert skill sometimes found in a country lies within the marketing organization for valuable export crops such as cocoa, copra, coffee, etc. Diversion of some of these valuable skills to the subsistence economy should be encouraged.

Additional information on methodologies of estimating grain loss resulting from particular causes is given in Note 3-2.

Postharvest loss estimation methodology for perishables (including fish) is much less advanced than for cereal grains and legumes. The development of a standard methodology is complicated by a number of factors intrinsic to the nature of the commodities. Differences such as the following must be taken into account:

- The high moisture content of the harvested perishable material, which makes estimation of weight loss on a dry matter or defined moisture-content basis difficult, if not impossible.
- The lack of uniformity in weight and shape of individual perishable food items as compared with rice, wheat, or other grains and legumes.
- The potential in perishables for partial loss. In the case of fruits and vegetables, the size of the food and its susceptibility to deterioration at different rates in different parts make it possible to divide the edible parts of an individual yam or banana, for instance, into acceptable and unacceptable portions; grains, by and large, are either edible or not.
- The rate and consequence of spoilage in perishables, which in fish is particularly rapid and potentially dangerous to the health of the consumer, but is also important in other perishables.
- Differences in the relative value of each food unit, individual perishable items being more valuable than individual grains. The value is not only economic, but nutritional, particularly in the case of fish.

At present, all that can be reasonably recommended to bring some order to the estimation of postharvest losses of perishables–a new field–is that research workers be as explicit as possible when reporting what they are measuring. For example:

- For roots and tubers, weights should indicate whether the observations were made on fresh, cured, or aged material; whether with or without skins; and whether vegetative reproductive parts have or have not been removed.
- For fruits and vegetables, weights should specify whether observations were made on fresh, whole material or whether skins, peels, cores, etc., were removed.
- For fish, the situation is complicated to an extraordinary degree by the unique characteristics of the "harvesting" process and the many ways in which the fish harvest can be measured. The differences between total-catch live weight and landed catch on the one hand, and the weight of edible portions of individual live, gutted and deheaded, or dried fish on the other, must be clearly distinguished in reporting and discussing loss.

With the nongrain staples, there is particular need for case studies of different crops and situations to develop methodology for estimating losses of commodities on a standardized basis. Establishment of locality-specific standards of quality for perishables is also urgently needed.

Notes

3-1

For example, rice loss estimates for Southeast Asia are reported (De Padua, 1974) as follows:

Harvesting	1- 3 percent
Handling	2- 7 percent
Threshing	2- 6 percent
Drying	1- 5 percent
Storing	2- 6 percent
Milling	2-10 percent

The possible range of weights of food lost as the grain passes through these stages is not the same as the simple sum of the percentages of loss, since the weight of a given lot of grain is reduced at each stage. Assuming that there is no removal of grain other than through loss and no dilution of the lot by addition of grain, the sum of losses in the example given above would be calculated as follows for a 100-kg lot of paddy:

Stage	Loss Percentage	Grain In (kg)	Grain Out (kg)
Harvesting	1–3	100	97–99
Handling	2–7	97–99	90.21–97.02
Threshing	2–6	90.21–97.02	84.80–95.08
Drying	1–5	84.80–95.08	80.56–94.13
Storing	2–6	80.56–94.13	75.73–92.25
Milling	2–10	75.73–92.25	68.16–90.41

Where there is withdrawal of grain at any of the stages, or dilution of the original lot with added grain at any stage, appropriate adjustments in the observations and calculations must be made.

3-2

Specific Crop Loss Assessment Considerations

The following paragraphs outline the procedures involved in the loss assessment of different cereal and legume commodities. It should be kept in mind that there is a need to distinguish between crops that are cultivated and place a major demand on available labor, such as rice, as opposed to those grown as a minor activity. The differentiation is significant in determining the relative importance of the crop in terms of postharvest loss reduction. The input labor cost is a decisive overall factor in which, in particular, the role of women on the farm is important and frequently overlooked.

On the basis of major review papers, original published material, discussions with experts, and firsthand field and laboratory experience, Harris and Lindblad (1978) conclude with regard to techniques for measuring cereal grain losses:

> All of the U.S. Food and Drug Administration-generated procedures, which are employed as standard methods of loss measurement in the USA and other countries, are too time-consuming, require a laboratory setting, require judgements that are difficult to standardize, use sample sizes that are too small, or have too variable a relationship to grain weight loss to make them suitable for use in developing countries.

This results from the very different conditions under which losses occur and are estimated in developed, as opposed to developing, countries. The same sequence of food movement, storage, and marketing occurs in both kinds of countries: the degree of loss at different stages differs markedly and the commodity loss profiles are different.

In the highly mechanized agricultural production typical of developed countries, losses, generally speaking, are proportionally greater during the harvesting process; smaller during processing, storage, and handling; and greater again during marketing; consumers demand variety and high quality of products, and this, together with government standards and regulations, leads to high "shelf" losses at the market level as well as at the table.

In developing countries, on the other hand, while many components of the commodity loss profile are similar, losses tend to be low during harvest, where the crop will be mainly handpicked, high where processing involves primitive procedures (threshing grain with animals), high during storage, and somewhat lower after marketing.

Thus, the FDA-developed tests (and by analogy other equivalent developed-country procedures) are largely designed for completely different conditions, that is, for monitoring large-scale modern storage rather than for use under field conditions, and may require expensive laboratory-based apparatus and procedures that are time-consuming and difficult to standardize.

Discussion follows of grain losses due to insects, fungi, vertebrate pests, and handling and primary processing.

Losses Due to Insects

Examinations for insects on the surface of the grain, weighing insect frass, and various procedures to detect visually damaged grains and count or weigh them have been given field trials in developing countries. There is a positive correlation between damage, insects, and frass with some loss quantification possible and Harris' (1972) report to the World Bank suggests their use in making *rapid* assessments. This information may be useful in developing a commodity loss profile and in quick comparisons to identify likely points of acute loss in the system.

Some confusion exists concerning the application of these procedures in quantifying actual losses. Their use in test situations and positive correlations to weight losses have been taken by some to indicate that they can be used with some degree of precision to determine weight losses. In fact, they cannot be used for this purpose unless the biological and physical characteristics of each estimation situation are completely understood.

All of the procedures, however, are of value in assessing a situation and coming to a personal judgment. Their precision as indicators of actual losses depends upon the expertise of the user. This is also true of the so-called gravimetric techniques in which a comparison is made between the actual weight of a sample and the weight it would have had in the absence of damage.

For reliable testing, then, Harris concludes that loss in weight can only be determined by comparison weighing such as "before" and "after," equal volumes "with" and "without" treatment, and other methods for various causes of loss as summarized for cereal grains by Adams and incorporated into the manual prepared by Harris and Lindblad (1978).

However, although comparison weighing is necessary for weight-loss estimates, it is more complicated than simply weighing appropriate samples at successive intervals on a balance of appropriate accuracy because the moisture content varies throughout the year. The following paragraphs will serve to illustrate the complexity of the procedure required to compensate for changes in moisture content, without repeating the excellent technical treatment given in the Harris-Lindblad manual.

> Losses of grain prior to secondary processing are mainly due to insects and molds. The insects bore into the kernel and feed on the surfaces, removing food (sometimes selectively), permitting increased uptake of moisture by the grain from the atmosphere and encouraging the growth of microorganisms.
>
> There are two ways in which the weight loss can be measured: by weighing a measured volume of grain—in which case the change in weight in successive samples tested over a period of time is a measure of their losses (and possibly other factors—the cause has to be determined)—or by separating damaged from sound kernels in a given volume and measuring their comparative weights calculated in terms of the whole sample.
>
> In the first case it is necessary to express the weights of grain in terms of a constant moisture content—usually the dry weight. While it is relatively simple to measure moisture content with a moisture meter, the

volume of the grain changes slightly with changes in moisture content, so it is necessary to measure, by experiment, the weight of the standard volume of grain at different levels of moisture. Then the weight of subsequent samples taken at the prevailing moisture content can be corrected to the original moisture content for weight change to be calculated independent of moisture.

Because different varieties of grain have different characteristics, graphs of weights of the standard volume of grain at different moisture levels are necessary for each variety. The procedure also is based on the assumption that the grain is homogeneous; if it is not, as in the case of lots of grain of mixed varieties, then a separate baseline graph is required for each lot.

The baseline graph is prepared by taking a bulk sample of approximately 5 kg from each store under consideration (or for each variety). The bulk sample is sieved and its moisture content measured; it is then divided into five sub-samples to correspond to five points on the weight/moisture content graph. Since the normal range of moisture content in stored grain is from, say, 8 to 18 percent, it is necessary to select five points within that range. The original 5-kg sample will have a moisture content somewhere between these two extremes; the other four sub-samples must be dried down or wetted up to the selected percentages to complete the required range, which in itself is a procedure requiring care and time.

Three replicate standard volumes of grain taken with a chondrometer (the test weight container) according to the instructions provided by the supplier are then weighed to the nearest 0.1 g and the mean weights of the five samples converted to dry weight plotted on a graph against moisture content. This graph can then be used throughout the sampling period to measure the dry weight of samples at any moisture content. The sample whose weight is to be measured is sieved (the weight of sievings being considered as losses if they are not used as food or calculated back to the weight/volume if they are), its moisture content is measured, and sub-samples are taken three times with the chondrometer. The samples are weighed, dry weight is calculated from the graph, and the weight change calculated by comparison with the original sample at the beginning of the test period.

Error is introduced by factors affecting variation in packing and, hence, the volume of the chondrometer-sampled grain. These factors include high levels of damage, which increases packing, and presence of insecticide dust, which reduces it, so that treated and untreated grain should not be compared.

The comparative weights of undamaged and damaged kernels gives percentage weight loss directly on the assumption that the undamaged portion is completely undamaged. The disadvantages of this method become apparent at high and low levels of damage: hidden infestation results in underestimation of loss, because grains that have lost weight are included in the undamaged group. At high levels of damage it may be difficult to identify and count damaged grains accurately among the debris. It also assumes that insects choose grains at random, which for maize is not the case. Nevertheless, particularly for unshelled and mold-damaged grains, it provides a useful means for estimating loss at moderate levels of infestation with a minimum of equipment.

Other methods are variations of these procedures. The chondrometer method is the preferred method as it has the highest accuracy when properly carried out. It is neither simple nor rapid, however, and requires a fairly high level of experience, if not of training, and a variety of ancillary equipment not readily assembled outside a laboratory.

Losses Caused by Fungi

The methods for estimating loss from insects are also applicable to fungal damage. However, when mold occurs, a considerable proportion of the grain rejected by the farmer is often discarded or used to feed animals, since the presence of infected grain causes a drop in quality grading. The impact of fungal infection on loss can be estimated by including the separation of mold damage from other types of damage during the analysis.

The quantification of "weight loss" when the loss is due to fungal damage will depend on local practices in the use of the damaged material. People accept or reject damaged kernels as local custom and hunger dictate. It is desirable to make measurements in one country, or region of it, that can be compared with measurements made elsewhere; in each situation, acceptance-rejection limits should be defined in terms of a widely used language. Despite the difficulty, these limits, based on information from interviews, must be quantified.

It seems likely that methodology for fungal damage estimation will need to be somewhat separate from that for insect loss, but since the two are frequently interrelated and interacting, the degree of separation needed is currently unclear, and likely will be situation specific. In sampling, allowance must be made for differences in moisture content of infected and uninfected samples.

The hidden or socioeconomic effects of moldy grain that may be consumed are more difficult to assess; they are related to the possible presence of toxins and the tendency for repeated consumption of infected grain to cause chronic illnesses. This will lead to a reduction in work output by an affected person and may be likened to the effects of nutritional loss.

Losses caused by fungal contamination can arise through:

1. The rejection of food because of visible fungal contamination or fungal damage.
2. The rejection of food (which may well *not* be visibly contaminated with mold) because of its mycotoxin content.

   The mycotoxin contamination of food can arise from:

   a. The direct fungal contamination of the food.

   b. The consumption of mycotoxin-contaminated feed by animals leading to contaminated animal products (e.g., meat and milk). Rejected food is often used as animal feed.
3. A decrease in the yield of food.

The ingestion of contaminated feed can reduce the productivity of animals (e.g., a decrease in milk yield). Sufficiently high doses of mycotoxin can result in death.

4. Acute and chronic illness caused in humans by the ingestion of contaminated food.

Because of the increasing awareness of the mycotoxin (especially aflatoxin) problem, there is a corresponding likelihood of increased food rejection. A rapid method exists for observing aflatoxin in maize (utilizing the BGY fluorescence) and groundnuts are routinely sorted using electronic color sorters. Established assay procedures also exist for the analysis of a wide range of foods and feeds for aflatoxin and other mycotoxins.

Recent examples of food rejection, after analysis, include the rejection of large quantities of corn in Zambia and of shipments of wheat in Pakistan and Bangladesh.

In some West African countries the groundnut crop contributes greatly to the GNP of the country, and therefore food and feed losses can represent severe economic losses.

Losses Caused by Vertebrate Pests

Losses caused by vertebrates such as rodents and birds are difficult to assess directly, since they result in the removal of grains from the store. The usual method of estimation is to blame vertebrate pests for all losses that cannot be accounted for in any other way. It is difficult to obtain an accurate estimate without accurate weighing of the grain throughout the season.

Another method is based upon an estimate of the pest population, usually by trapping and then conducting consumption trials with captured animals to obtain a figure of daily food intake. However, allowances need to be made for situations in which the store is not the only source of food; one must also account for the difference between unlimited food supply in the consumption trial and the foraging required in the field situation.

Studies carried out under warehouse and village conditions have shown that rodent populations can probably best be estimated by combining a number of techniques, including rodent sign survey, trap-release-trap, and estimating consumption of poison baits. In captivity the roof rat (*Rattus rattus*) has been found to consume 8-12 g/day of food grain; the house mouse (*Mus musculus*), 3-5 g/day; and the bandicoot rat (*Bandicota* spp.), 25-30 g/day. While eating, the rats also contaminate an estimated 10 times more food than they eat with urine, feces, hair, and saliva (Yashoda *et al.*, 1977).

These estimates are difficult to extrapolate with confidence because they neglect the fact that rodents often hoard amounts of food many times greater than they actually consume. Thus, predictions of losses from rodent population estimates are likely to underestimate actual food losses (Frantz, 1972).

Postharvest losses due to rodents have been summarized by Hopf *et al.* (1976). Estimates of damage are quite variable and range from 0.5 percent to 60 percent. Amounts are given in some cases, with India reporting approximately 11 million tonnes lost annually with a value estimated at over $1,000 million.

Postharvest losses due to birds are likely to be of relatively minor importance compared to preharvest losses to birds and postharvest losses to other factors. Exceptions occur where grain is left in the field after harvest or spread in the open to dry for long periods, or where stores allow birds access. Other than figures of weighing before and after, including all sources of loss, there is little information on postharvest loss to birds *per se.* Guggenheim (1977) reports distinguishing bird damage from insect and rodent damage in millet on the cob by observation of the marks on the ear.

Losses Due to Handling and Primary Processing

These are losses that may occur at the following stages of the grain postharvest system:

- threshing
- drying
- bagging, or placing threshed grain in other containers
- transport from field to storage
- transport to mill
- milling, which may involve several processes and stages
- transport from mill to storage or market.

These losses should be determined by weighings before and after the particular step or by weighing the amount of grain or grain products in food and nonfood categories. In many cases, appropriate methodology will have to be developed to meet particular local handling procedures, as grain is moved from field to store, mill, and home by different methods. Steps in the process are points of potential loss to be investigated.

There is very little published information on postharvest grain losses during transportation. Yet, any transfer of grain from one stage to another implies the possibility of loss.

There are three ways in which transportation losses may particularly occur:

1. During handling of crops between harvest, threshing, storage, and milling.

2. In connection with transportation allied to storage—"moving storage"—during which loss may occur, for example, due to continued deterioration of bagged grain in transit; to spoilage of bagged grain exposed to rain during transportation; or to spillage due to container damage or inefficient transference of the grain. The use of hooks to handle sacks of grain in port facilities is a frequent glaring example of loss caused by handling during transportation, but the use of old sacks from which grain leaks, and which permit access by pests, is perhaps even more important.

3. As a result of the absence or inefficiency of transportation facilities and of limited access to alternative market possibilities.

As we concluded earlier, it is probably not productive to pursue maldistribution as a source of postharvest loss of grain, since this involves many nontechnical factors whose effects reach beyond the postharvest environment. Maldistribution is more relevant to postharvest losses of perishables due to the overriding importance of moving the commodity to market as quickly as possible after harvest.

The limited information available about these aspects of transporting food provides little specific wisdom regarding food loss. But it is obvious that attention should be given to transportation problems in the interest of overall security and efficiency of delivery of food supplies.

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Chapter 4

Cereal Grains and Grain Legumes

The knowledge about the nature and extent of postharvest losses, as noted earlier, is much more extensive for cereal grains and grain legumes than for other commodities.

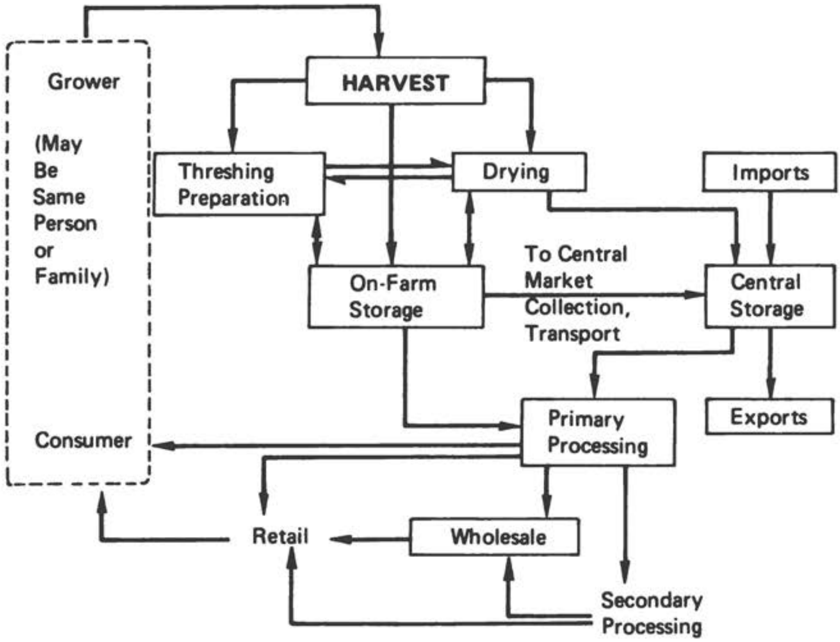
There are a number of reasons for this. In most societies, the durable commodities are (or have been) the most important in terms of quantity produced. They are traditionally stored, and security or survival has depended on keen attention to this process. This has been less true in the case of the nongrain staples. It is easier to protect dormant dried grain from external attack by insects or rodents than it is to prevent physiological deterioration or fungal attack of perishables. Perishables are often seasonal crops that provide a relatively constant supply of a variety of fruits and vegetables without storage. Many grow with minimum attention; their husbandry is therefore much less important and demanding than that of durable staples.

The bulk of harvested cereal grains and legumes passes through a fairly well-defined series of steps–the postharvest system. After harvest, the crops are threshed or shelled, dried, stored, and finally processed. Each commodity has its own variations in this process and some have additional steps that enlarge the system (rice parboiling, for example), but there are enough similarities in the flow of durables through the system to enable generalization about loss problems. The first part of this chapter is concerned with these problems; the second part will be a discussion of loss factors specific to the individual commodities.

General Causes of Postharvest Grain Loss

Preharvest Factors

The genetic characteristics of a grain variety greatly influence the postharvest losses it is likely to incur. Traditional varieties are generally well adapted both to their usual environment and to postharvest handling. The



The grain postharvest system

grains that survive storage and are used in subsequent seasons have evolved characteristics that favor their survival. These may include, for instance, lower moisture content in the ripe grain, which then dries more readily, and thicker seed coat for repelling insects and rodents.

Introduction of varieties selected for high yields has resulted in greater postharvest losses where the new varieties are not as well adapted to the postharvest conditions as traditional varieties. This problem should be a consideration both in selecting high-yielding varieties and in providing for their postharvest treatment.

Damage to the growing crop may affect its postharvest characteristics, as may crop protection treatment prior to harvest. In particular, insect infestation of a maturing crop may increase its vulnerability to loss after harvest; however, residual insecticide may reduce the extent of postharvest insect damage.

Harvesting Factors

The time at which harvesting occurs has an important effect on the subsequent storage quality of the grain. Typically, the harvest may be begun before the grains are fully ripe and may extend until mold and insect damage are prevalent and shattering has occurred. Grain not fully ripened contains a higher proportion of moisture, and will deteriorate more quickly than mature grain because the enzyme systems are still active. If the grain remains in the field after maturity, repeated wetting from rain and dew at night, along with drying by the hot sun by day, may cause grain to crack (particularly long-grain paddy) and may increase the likelihood of insect damage (especially in maize, paddy, and pulses).

Crops standing in the field after maturity become more liable to harvest losses. Ripened grain is more likely to be shattered onto the ground during harvesting. Maize loss may result from the loosening of the husk after it is ripe and subsequent mold infection or insect attack. The probability of insect infestation in the field is also likely to increase if the crop stands too long, as is loss to rodents, grain-eating birds, and other vertebrates.

Threshing and Shelling

Traditional methods of threshing to separate grains from the plant, such as use of animals to trample the sheaves on the threshing floor—or the modern equivalent using tractor wheels—may result in loss of grain not separated. This method also allows impurities to become mixed with the grain, which may cause subsequent storage problems. The use of flails to beat the grain from the stalk may also damage the grains or kernels and is not always effective.

Threshing and shelling will contribute to losses if carried out in a manner that results in cracking of grains.

Modern devices for threshing and shelling may be used incorrectly, or for a crop for which they were not intended, with excessive breakage of grains.

Traditional threshing with ox-drawn "norag," Lebanon (FAO photo by G. Tortoli)

Drying

Drying is a particularly vital operation in the chain of food handling, since moisture may be the most important factor determining whether, and to what extent, grain will be liable to deterioration during storage.

Drying is used to inhibit germination of seeds and to reduce the moisture content to a level that prevents the growth of fungi and bacteria; it can also retard attacks on the grain by insects and mites.

In developing countries, the methods available to farmers for drying crops are often limited, usually to a combination of sun and air drying, although supplemental heat is frequently employed. In many cases, seed grain may be treated separately from food grain and with greater care. Drying is a complex process requiring considerable skill and effort on the part of the farmer; the success with which the grain is preserved over shorter or longer periods depends to a great extent on the care and attention given to the drying and subsequent storage. Drying is often complicated by the introduction of high-yield varieties that mature and must be harvested during wet seasons or by production of a second, irrigated crop ("double-cropping") that must also be harvested during the rains. In these cases the grain requires artificial

Sun drying rice, central Java (FAO photo by Jack Ling) drying. The increased production of high-yield varieties and their differing characteristics may also tax the farmer's ability to handle the grain properly by traditional methods. Consequently, a new drying and storage procedure must be adopted or the crop must be sold undried. The alternative may be to forego the new variety.

Overdrying–which can easily occur in arid regions or after excessive exposure to sun or other heat–can cause breakage, damage to the seed coat, bleaching, scorching, discoloration, loss of germinative power, and nutritional changes. Too-rapid drying of crops with high moisture content also causes damage; for example, bursting (or "case-hardening"), which causes the surface of the grain to dry out rapidly, sealing moisture within the inner layers. Underdrying or slow drying (a problem in humid regions) results in deterioration due to fungi and bacteria, and, in extreme cases, leads to total loss.

Solar technology for artificial drying is receiving attention because of its negligible running costs in comparison with traditional fuels, which are becoming not only expensive but, as in the case of firewood (increased consumption of which is causing deforestation in many areas), are adversely affecting the environment. However, the fundamental problem with solar devices is that they do not operate effectively when they are most needed–to dry grain that must be harvested during a wet spell or during the rainy season.

The Peace Corps-VITA manual, *Small Farm Grain Storage* (Lindblad and Druben, 1976), contains descriptions and instructions for constructing a variety of improved grain dryers–a pit oil barrel dryer, an improved maize drying and storage crib, a simple batch-type rice dryer, and a number of simple solar dryers.

Clearly, methods of drying must be selected for the particular climatic, economic, and social circumstances in which they will be used. This is especially true where existing drying methods have evolved over long periods of time to meet community and family survival needs. Alternative methods should not be recommended without awareness of all possible consequences to the farmers. Problems affecting the selection of drying methods are discussed in the second half of this chapter, in the context of individual commodities.

Storage Losses

The extent to which deterioration and loss occur in storage depends on physical and production factors, the storage environment, and biological factors. Physical factors which contribute to storage loss have been discussed in the previous section.

In addition, physical damage to the crop during harvest may also affect storage. Undamaged cowpea pods, groundnut shells, and the husks of paddy grains also afford the crop a noticeable degree of protection from infestation by most insect species, though the space occupied reduces the volume that can be stored.

Storage Environment

Storage conditions have much to do with the rate of deterioration. High temperature and humidity encourage mold formation and provide conditions for rapid growth of insect populations. Deterioration is minimal in cool, dry areas, more marked in hot, dry ones, high in cool and damp conditions, and very high in hot, damp climates. Climatic conditions during and after harvest affect the ease with which natural drying may be carried out and may dictate the need for artificial drying. Seasonal and diurnal temperature differences between stored grains and the surrounding environment can result in moisture translocation or migration among quantities of bulk or bag-stored grains or in condensation of moisture on the grain. Concentration of moisture in grain can lead to conditions favorable to the development of fungi.

Some climates lessen the residual activity of certain pesticides and can reduce the effective life of storage containers and structures. Certain structural materials may alter the effectiveness of different formulations of a given insecticide.

Deterioration is also related to storage method and management. For example, cob maize stored in open-sided cribs takes up moisture more rapidly during the rainy season than shelled maize in mud-walled cribs, so that conditions for rapid insect development are produced earlier in the storage season. On the other hand, properly designed open-sided cribs will allow relatively rapid drying of unhusked ears of maize and reduce losses due to mold. Traditional pest control methods are often effective in keeping down infestation levels. For example, some farmers storing pulses and larger grains will admix a smaller seed or sand with the grains to fill the intergranular spaces. This effectively inhibits the development of bruchid beetles. Other farmers use a fire under their storage cribs to repel insects, either through the effect of the smoke or by keeping the grain dry. The admixture or overlay of ashes derived from burning various woods or dried animal dung is another method affording protection against insect attack.

Biological Factors

The principal biological agents of deterioration during storage are insects and mites, fungi, and rodents.

Losses Due to Insects and Mites. Insect pests are a greater problem in regions where the relative humidity is high, but temperature is the overriding factor that influences insect multiplication. At temperatures of about 32°C, the rate of multiplication is such that a monthly compound increase of 50 times the present number is theoretically possible. Thus, 50 insects at harvest could multiply to become more than 312 million after 4 months.

The nutritive requirements of insects are much the same as those of vertebrates. Crops with the highest nutritive values for man are also those most susceptible to insect damage. In certain cases, farmers may keep only small amounts of a nutritious crop such as beans because they believe damage and loss to be inevitable. Furthermore, insects often select the most valuable portion of seeds. For example, four important pests of maize attack the embryo and reject the starchy endosperm, thus removing the most nutritious part of the grain as well as destroying the power of germination.

Weight loss is of economic as well as nutritive importance and, in the absence of effective control measures, insect attack on cereal grains and beans can be so severe as to reduce the commodity to empty husks and dust. Large numbers of insects can be expected to produce heavy weight losses, and the resulting contamination by dead and live insects and their excreta can be sufficient to make the commodity completely unpalatable and unacceptable in the market.

Termites in a grain store can weaken the structure, leading to its collapse. They will also readily attack the grain.

Table 4:1, prepared by entomologists of the Tropical Products Institute, shows the main insects and mites that attack and damage stored cereal grains and pulses in developing countries. The U.S. Department of Agriculture has recently published a useful compendium of information on stored-grain insects (USDA, 1978).

Control measures, whether or not insecticides are available, depend first on storage hygiene. Storage containers must be checked and cleaned as carefully as possible. Old stored grain should be checked and, if necessary, redried and cleaned to control existing infestation. New dry grain should be kept separate from old stored grain because of the risk of cross-infestation. Similarly, stores should be as remote from the field as possible to reduce the risk of infestation. In addition to store pests, it must be assumed that new grain is infested from the field and control must include a regular system of inspection and deterrence to maintain storage hygiene and take control measures where infestation is observed.

Traditional pest-control systems not involving insecticides are adapted to local circumstances. Use of local herbs, mixing ash with grain, and smoking are effective and should be encouraged. As previously stressed, every effort should be made to build on traditional technology and innovations should be undertaken with understanding of the social and economic implications. This is particularly important in the case of insecticides that present severe health hazards or have other environmental, ecological, economic, and social implications (such as overoptimistic expectations that new technologies will solve all problems and remove the need for traditional efforts).

TABLE 4:1 Storage Pests of Grains and Pulses

Order	Family	Name	Commodities
Coleoptera	Dermestidae	* *Trogoderma granarium* Everts	Cereal grains and products
	Anobiidae	*Lasioderma serricorne* (F.)	Cereal grains and products
	Bostrichidae	* *Rhyzopertha dominica* (F.)	Cereal grains and products
	Trogossitidae	*Lophocateres pusillus* (Klug)	Cereal grains
		Tenebroides mauritanicus (L.)	Cereal grains and products
	Nitidulidae	*Carpophilus dimidiatus* (F.)	Cereal grains
	Cucujidae	*Cryptolestes ferrugineus* (Steph.)	Cereal grains
		C. pusillus (Schoen.)	Cereal grains
	Silvanidae	*Ahasverus advena* (Waltl)	Cereal grains
		Cathartus quadricollis (Guer.)	Cereal grains
		Oryzaephilus mercator (Fauv.)	Cereal grains
		O. surinamensis (L.)	Cereal grains
	Mycetophagidae	*Typhaea stercorea* (L.)	Cereal grains
	Tenebrionidae	*Alphitobius diaperinus* (Panz.)	Cereal grains and products
		A. laevigatus (F.)	Cereal grains and products
		Gnatocerus cornutus (F.)	Cereal grains
		G. maxillosus (F.)	Cereal grains
		Latheticus oryzae Waterh.	Cereal grains and products
		Palorus ratzeburgii (Wissm.)	Cereal grains and pulses
		P. subdepressus (Woll.)	Cereal grains and pulses
		* *Tribolium castaneum* (Hbst.)	Cereal grains, grain products and pulses
		* *T. confusum* Duv.	Cereal grains, grain products and pulses
	Bruchidae	* *Acanthoscelides obtectus* (Say)	Pulses (esp. beans)
		* *Callosobruchus chinensis* (L.)	Pulses (esp. peas and grams)
		* *C. maculatus* (F.)	Pulses (esp. peas and grams)
		* *Zabrotes subfasciatus* (Boh.)	Pulses (esp. beans)
	Anthribidae	*Araecerus fasciculatus* (Deg.)	Cereal grains
	Curculionidae	* *Sitophilus granarius* (L.)	Cereal grains
		* *S. oryzae* (L.)	Cereal grains
		* *S. zeamais* Motsch.	Cereal grains
Lepidoptera	Gelechiidae	* *Sitotroga cerealella* (01.)	Cereal grains
	Pyralidae	* *Corcyra cephalonica* Staint.	Cereal grains
		* *Ephestia cautella* (Wlk.)	Cereal grains and products
		E. elutella (Hbn.)	Cereal grains and products
		E. kuehniella Zell.	Cereal products
		Plodia interpunctella (Hbn.)	Cereal grains and products
Acarina	Acaridae	*Acarus siro* L.	Cereal products
		Tyrophagus putrescentiae (Schrank)	Cereal grains, grain products and pulses

*Major pest species.

Many insecticides are becoming widely available in developing countries as their application is encouraged by suppliers and extension services. Some are more hazardous to humans, and potentially so to the enviroment, than others, but all should be used with great care. Some can be used on seed grain in high concentrations that would be dangerous where used on food grain.

The grain-storage insecticides are of two main types:

- Contact poisons such as dusts, dispersible powders, and emulsions. Some insecticides, such as BHC, are quite stable and have long residual action; others, like malathion, usually have little residual action and are used where human consumption of the grain precludes use of longer-acting chemicals. Some compounds may be mixed with grain at the time of storage, while others are used for spraying storage containers or bagged grain. The level of application and its timing in relation to expected human consumption are major problems for extension services seeking to improve insect control in rural grain storage.
- Fumigants, which are gases, can penetrate bulks of grain and kill insects and their larvae living within grains. The negative factors are that all fumigants are safe only when used by trained personnel and that they have no residual action to protect grain from subsequent reinfestation. A first requirement is improvement of the methods of application and more careful monitoring of insecticide use to achieve maximum control of infestations. Reports of insect resistance to chemical insecticides are frequently encountered. Awareness about the drawbacks of chemical use is also increasing and there has been renewed interest in traditional nonchemical control techniques and in developing alternative approaches to pest control.

The principal methods of coping with insect infestations involve cultural control or manipulation of the environment to make it less favorable to the insect; breeding resistant crop strains; using natural enemies of insects such as parasites, predators, and disease vectors; sterilizing insects to interfere with normal reproduction; and using attractants and repellants.

Cultural control and inbred resistance are not new techniques. Traditional methods of controlling insects in storage involve mixing sand, limestone, ash, or herbs with the grain; in addition to forming a barrier against movement of the insects through the grain, they abrade or absorb the wax coating of the insect's protective cuticle, causing a loss of body moisture. In many areas insects (and rodents) are repelled by smoke from small fires, used either within granaries to decontaminate them between harvests or under granaries constructed of permeable materials such as woven plant fibers. The fire also assists grain drying *in situ*. In other areas, stored grain is inspected frequently and is redried in the sun if insects are observed. Hermetic storage, with grain sealed in impervious containers, is highly effective in excluding insects.

However, the system is difficult to maintain for large quantities and is usually confined to relatively small amounts of seed grain. (See Note 4-1.)

Along with investigations of newer possibilities for nonchemical biological control, traditional methods of cultural control should receive greater attention to increase understanding of their underlying biological basis. The knowledge gained about both approaches can form the basis of more effective and safer methods. Since the methods are dependent on manipulation of the ecology to the detriment of the insects, they are highly location-specific, which increases the need for research and adaptation of techniques to local circumstances. This will require long-term study, making it unlikely that there will be alternatives to replace or greatly reduce insecticide use in the near future.

Losses Due to Fungi. Fungal attack in storage generally occurs when drying has been inadequate, when large numbers of insects are present, causing a temperature rise in the grain, or when the stored crop is exposed to high humidity or actual wetting. Fungal development does not normally take place when the moisture content of the commodity is below that moisture content in equilibrium with a relative humidity of 70 percent. In recent years, attention has been given to the toxic products of certain fungi, such as aflatoxin and zearalenone, which are metabolites, respectively, of the fungi *Aspergillus flavus* and *Fusarium moniliforme*. Mycelia penetrate the endosperm of grains, removing nutrients. In many cases the embryo is attacked first and eventually destroyed.

Fungal spoilage is more serious in those regions with a permanent high relative humidity or where a season of high humidity coincides with the time when grain is being dried or kept in store. Microorganisms may multiply and create heat that can increase in unventilated grain to the point of complete destruction. However, losses due to fungi are reduced as a result of improvements in drying and storage technology and do not need to be treated separately.

Losses Due to Rodents. Rodent damage to stored food can occur in a number of ways. The animals not only consume the food (damage to maize grains is characteristic in that the embryo is usually removed first), but also foul a large amount with their excretions (which may carry microorganisms pathogenic to man), destroy containers by gnawing holes that result in leakage and wastage of grain, and paw into and scatter grain while they eat. This scattered grain, along with that which leaks from gnawed holes, is subject to contamination and admixture with impurities. Damage to grain stored in bulk may be much less than to grain stored on the head or in bags because rodents are unable to burrow into the bulk.

These problems have recently been reviewed by Hopf *et al.* (1976) in a report prepared by the U.K. Centre for Overseas Pest Research and the Tropical Products Institute. This report analyzes extensive information provided by a number of governments. It concludes that in most countries very little is known about the extent of the problem, although some countries with high losses, such as India, have considerable expertise in this area and allocate large resources to rodent control.

The three main species of rodent are:

- *Rattus norvegicus*, the Norway, common, or brown rat;
- *Rattus rattus*, the roof, ship, or black rat; and
- *Mus musculus*, the house mouse.

Other species, such as the bandicoot rat (*Bandicota bengalensis*) are important pests in particular areas. Locally, other species can assume greater importance.

Control of Rodents. Techniques for rodent control fall into the following broad categories:

- Rodent exclusion efforts in store construction;
- Improved sanitation, including removing food and harborage from the surroundings or reducing it as much as possible;
- Poison baiting, including use of the anticoagulants such as chlorophacinone, warfarin, coumarin, diphacinone, and coumatetralyl, and acute poisons such as zinc phosphide, barium carbonate, red squill, and vacor;
- Fumigation with phosphine or other gas;
- Trapping and hunting;
- Use of cats and dogs; and
- Rodent repellents.

Estimates of the effectiveness of these techniques are mixed, sometimes even contradictory within the same country. Results depend on the thoroughness with which the control technique is applied and the length of time it operates. Control usually is more effective when a combination of methods is used, particularly those that prevent access to food. The persistence of the rodent problem is obvious in a report from Israel, where it is fully recognized and control is vigorous and well organized but where the estimated loss to crops in the field remains at 5 percent. The problem must be approached with the recognition that store rodents cannot be controlled unless field rodents are also controlled.

Observations from the People's Republic of China indicate that well-organized rodent exclusion, together with sanitation and field control, may have been rather successful; no published figures are available. Traditional and modern granaries are reported to be protected by detailed attention to cleanliness, by physically isolating the granary, by laying concrete on the

Hygienic rice store, People's Republic of China (Courtesy E. S. Ayensu)

area around and underneath the granary (which introduces aspects of behavioral control), and by providing rat barriers at points of potential access (Ayensu, 1977).

New rodent-control technologies, even simple ones, may meet considerable resistance at the farm and village level. For instance, local acceptance of baffles fitted to traditional storage containers has been slow, at best. In this and similar cases, more research may be needed to determine whether such unpopular solutions to problems are the most effective. There are reports that rodents are becoming resistant to rodenticides, although there is little evidence from tropical regions and research on this aspect of control is also indicated.

Although many countries fully recognize the seriousness of food loss caused by rodents–including India, China, and Israel, as we have seen–the editors of the report of the Centre for Overseas Pest Research conclude that "the one single fact which emerges most clearly from the survey is the widespread ignorance of the magnitude of the rodent problem, and of means to control it."

We have discussed the physical, environmental, and biological causes of grain losses during storage. Discussion follows of methods of reducing storage losses, with a brief description of storage practices.

Reduction of Storage Losses

In developing countries, storage on the farm is an important part of the traditional farming system (the subsistence or nonmarket sector and the semisubsistence or farm-to-village market sector). It is essential both for conserving seed for the next planting and for stockpiling staples to feed the farmer, his family, and his livestock until the next harvest.

Sound storage practice has three elements:

- Proper preparation of the grain for storage, including drying and, where possible, separating out any infested or spoiled grain and other impurities;
- Sound storage structures that provide protection from moisture (rain and ground moisture) or excessive drying and a barrier against insect and rodent pests and theft; and
- An appropriate system of monitoring the quality of the stored grain and treating and handling it while it is in the store.

Traditional Storage Practices

Traditional systems have evolved over long periods of time to satisfy storage requirements within the limits of the local culture. Grain for seed is frequently sealed in gourds or clay containers and kept in the house. Larger amounts of grain for human and animal consumption are stored in containers constructed of plant material, mud, or stones, often raised off the ground on platforms and protected from the weather by roofing material. The design and materials vary according to local resources and custom.

However, with the exception of sealed containers (including underground pit stores in drier areas that control insects by limiting the supply of oxygen), the traditional structures provide only limited protection against insect and rodent damage, particularly in areas where the climate is warm and humid or where grain is stored for extended periods.

These traditional grain storage systems have evolved slowly by natural selection and provide reasonable storage security for the traditional farmer. This does not mean that losses are necessarily low; it does mean that the risk of large-scale losses is minimized under traditional decentralized storage systems.

Subsistence or traditional farming systems are being improved by the introduction of high-yielding varieties of grain, which farmers are encouraged to grow. However, as a consequence of increased production the traditional storage system is proving inadequate not only in capacity, but also in protecting grain from damage, since the new varieties may be more susceptible to insect attack.

There are three approaches to solving traditional storage system problems:

- Improving small-scale on-farm storage;
- Centralizing grain storage with efficient collection, drying, and large-scale stores; and
- Breeding new varieties that are less susceptible to loss in storage.

Of these approaches, the last two are important long-term possibilities with political, social, and economic implications that are largely outside the scope of this report. They will require expanded research efforts, particularly on socioeconomic aspects of centralizing storage.

New On-Farm Storage Practices

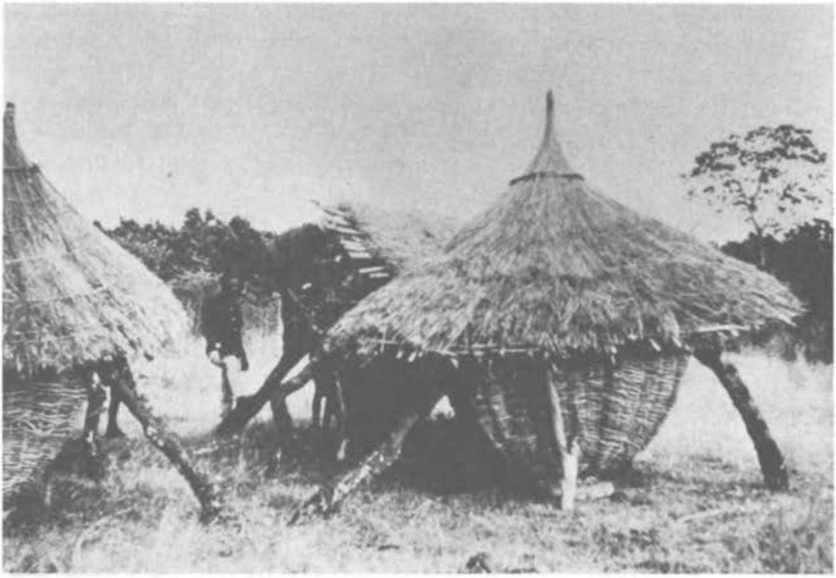
In recent years, this aspect of postharvest technology has been receiving considerable attention. In East Africa, adaptations have been made to the traditional design, for example, by fitting "rodent baffles" (Kenya and Malawi) or mud-plastering cribs for the storage of shelled grain (Zambia and Malawi).

In Guatemala, India, and Swaziland, prefabricated corrugated or plain (flat) metal tanks have been in use for storage for a number of years. These tanks permit fumigation of the grain with hydrogen phosphide tablets, reduce the probability of reinfestation by insects and rodents, and reduce the rate of uptake of moisture. In Swaziland at least 40 percent of farmers were using them by 1976.

Introduction of improved grain bins has not met with the same success in Ghana and Zambia, where concrete stores proved unacceptable to farmers because of rising costs, the shortage of materials, and difficulties in construction. A more recent approach, adopted in Zambia, is to produce a cheap, easy-to-construct container using readily available materials. The container, known as the "ferrumbu," incorporates the features necessary for safe grain storage and should be affordable by emergent commercial farmers.

In Southeast Asia, metal storage containers have been introduced on a fairly wide scale. Problems have been encountered, however, with drying rice adequately before storage, providing adequate ventilation, and preventing stored rice from taking up moisture from the humid atmosphere. These problems were assigned high priority in reducing losses of stored rice in Southeast Asia.

Small-scale on-farm grain storage technologies have been compiled by Lindblad and Druben (1976) in a useful compendium that has been made widely available to developing countries through the U.S. Peace Corps and Volunteers in Technical Assistance (VITA).



Traditional "gottera," Ethiopia (particularly well made with a good roof cover) (Crown copyright, Courtesy TPI)

Muddied (left) and unmuddied (right) traditional nkhokwc, Malawi. Note the mud rat guards on wood framework. (Crown copyright, Courtesy TPI)

Improved dry-store hut, Séhoué young farmers' club, Bénin (FAO photo by Banoun/ Caracciolo)

1-2 tonne metal grain tank, Swaziland, The tank is raised above ground to prevent bottom corrosion and shaded to minimize moisture migration. (Crown copyright, Courtesy TPI)

The Lindblad-Druben manual includes discussion of the advantages, disadvantages, and construction of various grain-storage methods, including:

- Traditional basket storage;
- Bagged storage;
- Airtight storage–underground pits, including "Thailo" (ferrocement-lined traditional Thai grain silo), plastic sack storage, metal drums and bins, and sheet metal silos;
- Earthen structures–mud brick silos; and
- Cement and concrete structures–cement stave silos and village concrete silos.

The selection of storage methods depends on the commodity, the climate, and the social and economic characteristics of the particular situation. While improved storage is a prerequisite for sustaining production increases without increased postharvest losses, the improvements must be carefully attuned to economic, social, and cultural realities.

Losses During Processing

Primary processing losses occur during:

- Threshing and milling;
- Parboiling; and
- Further processing (baking, brewing, canning, packaging), in which the losses are important but are not central to the focus of this study.

There is a tendency for processing losses to increase as larger amounts of a crop are produced and strain the capacity of the traditional processing system. Maize normally shelled by hand, for example, may be placed in sacks and pounded with a stick to detach the grains from the cob. Mechanical processing is generally less efficient than manual processing, both because it is incomplete and because of damage to grains due to their variation in size or poor adjustment of the machinery. The manual processing efficiency may be used as the standard against which the efficiency of machinery is measured.

Processing losses are generally specific to particular crops and will be dealt with under each commodity. There are, however, some general loss problems resulting from processing. Attitudes towards broken grains vary from society to society; acceptability of off-color grain due to poor parboiling or drying varies. In many cases, this simply means that the poorer members of society have the broken grains and dust, or otherwise lower-quality grain, and there is little loss. In Pakistan, the Council on Scientific and Industrial Research has experimented with reconstituting "whole" rice grains from broken grain and rice powder with good acceptance.

In many societies central milling facilities process grain brought in by farmers for a price determined by the initial unmilled volume or weight, and there is thus little incentive for mill operators to reduce subsequent losses due to poorly adjusted equipment or leakage and spillage. Payment may also be in kind, with part of the milled product or the milling by-products going to the miller.

Where the society is affluent enough that grain adversely affected by processing is not consumed, the loss is comparatively unimportant to the central focus of this study.

Individual Crop Loss Problems

Among the hundreds of food crops grown around the world, some two dozen of them account for approximately 90 percent of all the food produced. Table 1:1 shows the reported production of major food crops worldwide, and in the developing countries (according to FAO figures and definitions).

The cereals and legumes, the focus of this chapter, account for more than half the world's production of food crops and have received most of the attention in worldwide attempts to reduce postharvest losses. In the main, developing-country cereals are rice, maize, wheat, sorghum, millet, and barley. In this section they will be discussed as separate commodities in terms of the food losses connected with them.

Rice

Loss Estimates

Losses of rice in the postharvest food system in developing countries (Table 4:2) are probably as well characterized as losses for any crop. Yet, though there are reports of much serious work, there is still uncertainty as to the magnitude of postharvest losses of rice because of variation in situations being assessed and because of differences in methodology and definition.

Yet these estimates may be approaching the level of accuracy with which it is possible to assess losses on a large, nonexperimental scale. There is also a fair level of consistency from country to country in rice loss figures from similar situations. These are summarized for Southeast Asia by De Padua (1974):

Harvesting	1- 3 percent
Handling	2- 7 percent
Threshing	2- 6 percent
Drying	1- 5 percent
Storage	2- 6 percent
Milling	2-10 percent

These figures, widely quoted, give a loss range of from 10 percent to over 30 percent (see Note 3-1).

Limited observations on rice in West Africa do not yet specify detailed loss estimates broken down by stage; however, the overall figures are consistent with those from Asia (FAO-ECA, 1976). Table 4:2 shows rice weight losses by percentages for a number of developing countries or areas.

TABLE 4:2 Reported Losses of Rice within the Postharvest System (Based on FAO, 1977b, Figures Unless Otherwise Indicated)

Region and Country	Total Percent Weight Loss	Reported National Production ('000 Tonnes)	Remarks
West Africa	6-24		Drying 1-2; on-farm storage 2-10; parboiling 1-2; milling 2-10 (van Ruiten, 1977)
Sierra Leone	10	580	
Uganda	11	15	
Rwanda	9	5	
Sudan	17	7	Central storage
Egypt	2.5	2,300	(Kamel, 1977)
Bangladesh	7	18,500	
India	6	70,500	Unspecified storage
	3- 5.5		Improved traditional storage (Boxall and Greeley, 1978)
Indonesia	6-17	22,950	Drying 2; storage 2-5
Malaysia	17-25	1,900	Central store 6; threshing 5-13;
	c.13		Drying 2; on-farm store 5; handling 6 (Yunus, 1977)
Nepal	4-22	2,404	On-farm 3-4; on-farm store 15; central store 1-3
Pakistan	7	3,942	Unspecified storage 5
	2- 6		Unspecified storage 2 (Qayyum, 1977)
	5-10		Unspecified storage 5-10 (Greaves, 1977)
Philippines	9-34	6,439	Drying 1-5; unspecified store 2-6; threshing 2-6
	up to 30		Malaysia workshop (FAO, 1977c)
	3-10		Handling (Toquero *et al.*, 1977)
Sri Lanka	13-40	1,253	Drying, 1-5; central store 6.5; threshing 2-6
	6-18		Drying 1-3; on-farm store 2-6; milling 2-6; parboiling 1-3 (Ramalingam, 1977)
Thailand	8-14	14,400	On-farm store 1.5-3.5; central store 1.5-3.5
	12-25		On-farm store 2-15; handling 10 (Dhamcheree, 1977)
Belize	20-30	2	On-farm storage (Cal, 1977)
Bolivia	16	113	On-farm 2; drying 5; unspecified store 7
Brazil	1-30	9,560	Unspecified store 1-30
Dominican Republic	6.5		On-farm store 3; central store 0.3

Rice is relatively difficult to process by hand or with simple manual equipment, and processing, unlike that for most grains in developing countries, is widely organized on a collective or centralized basis.

DePadua indicates that because of the complexity of the system, reduction of losses will require a combination of increased efficiency at each step in the postharvest system and improved drying, threshing, and milling technology.

Rice postharvest technology is described in detail in the widely available publication of that title (Araullo *et al.*, 1976) published by the International Development Research Centre (IDRC). Details of the stages of processing are described insofar as they relate directly to postharvest losses and loss reduction.

Harvesting

The bulk of rice produced in Asia and Africa is still grown on small farms and harvested by hand. Combine harvesters of the type used in Europe and the United States are unsuited to small farms, and even the smaller Japanese models have not gained wide acceptance due to high cost, exacting field requirements, and the high field losses which they cause.

Some major losses are connected with the timing of the rice harvest, that is, with the maturity of the crop and the effects of postponing the harvest under certain dry or wet conditions. Delay in harvesting a mature rice crop leads to lower yields because of lodging and shattering and the exposure of the ripe grain in the field to birds and rodents. It also leads to postharvest losses by lowering milling yields and recovery of head grains.

Introduction of new quick-maturing varieties, in major part due to the breeding and management research carried out at the International Rice Research Institute in the Philippines, has permitted double-cropping (two crops per year).

The summer or dry-season rice crop does not have to be dried quickly; if it is left in the windrows after reaping in good weather, there is little damage to the grain. However, if semidried grain is remoistened by rainfall or a heavy dew, it may crack and high milling losses will result.

The rainy-season crop creates much more difficulty. To avoid significant loss, the wet harvest must be threshed, cleaned, and dried within 24 hours unless predrying facilities are available. It cannot be left in windrows or stacked in the field, since this results in mold, fermentation, and even germination. De Padua reports that some farmers in the Philippines are becoming reluctant to plant wet-season crops because of the threshing and drying problems (TPI, 1978).

Threshing

Traditional threshing techniques are a frequent cause of loss. They include:

- Beating the straws against slats through which the grain falls into tubs or buckets; and
- Threshing by trampling with feet–human or animal–and occasionally by using tractor wheels or (in Thailand) a tractor-drawn roller.

The Japanese drum thresher–an adaptation of the paddle wire loop thresher–is widely used and has been the first step toward mechanization in India, Bangladesh, and Burma.

The dry-season crop is frequently dried in the field in windrows or stacks (such as the large rice stack, the "mandola," used in the Philippines) and can readily be mechanically threshed when relatively dry. A variety of mechanical threshers and cleaners is found in developing countries, especially in Asia, frequently based on adaptations of U.S. or Japanese combines.

Rice-threshing, Indonesia (Courtesy A. A. C. Huysmans)

The wet-season crop tends to choke many conventional mechanical threshers. Further, the wet conditions make it difficult to bring threshing machines to the field. Development of satisfactory mechanical wet-season crop threshing equipment is a priority IRRI research activitiy; a number of double-drum threshers have been shown to work satisfactorily and are being introduced commercially. In many areas the capital cost of these threshers, and the training and organization their use entails, limits their widespread use, although Samson and Duff (1973) have demonstrated the cost effectiveness of mechanical threshing, drying, and milling over traditional methods in the Philippines. Wet-season rice losses due to delayed threshing are likely to be reduced as mobile mechanical threshers become more widely available.

Drying

Rice grain at time of harvest varies in moisture content from low levels to over 30 percent, depending on the season. This must be reduced to 13-14 percent if the rice is to be stored for any length of time. Inability to do this quickly leads to rotting of the grain and reduction in milling quality because of high breakage. It also causes discoloration and loss in quality due to fermentation and heat damage. Mold attack, including possible aflatoxin production, may also lead to loss in quantity and quality.

Traditional sun drying of spread-out grain is an effective means of reducing moisture in the dry season. Wet-season crops require forced-air drying with heated or ambient temperature air. Commercial driers are designed either to dry grain in batches, in deep or shallow beds in which the grain may be stationary or mechanically circulated, or continuously in stages as the grain flows through the drier. The physical design and operating characteristics,

Field-drying paddy, Indonesia (Courtesy A. A. C. Huysmans)

Winnowing paddy, Hmawbi, Burma (FAO photo)

including such factors as air volume to grain volume ratio and air temperature, influence the rate of drying and quality of the dried grain.

The mechanical characteristics of driers vary for different kinds of grain, and great care must be exercised in using a drier for a grain other than the one for which it was designed. This is particularly important in the case of rice, which is much more sensitive to thermal stress than other grains and is eaten as whole kernels. High temperature and low-volume air movement, while rapidly removing moisture, result in fissuring and a high proportion of broken grains in milling. The same rate of drying may be achieved at lower temperatures with greater air flow–the important characteristic being the vapor pressure differential between the drying air and the grain–at less risk of damage to the grain.

Other characteristics of drying equipment to be considered include the time required to dry grain from high moisture content and the peak volumes that must be handled during the harvest season. The strength of the construction material is important, as paddy rice is highly abrasive and rapidly wears through sheet metal. Some parts of rice-conveying systems in the People's Republic of China are frequently constructed of glass, which both counters the wear and permits visual inspection of the rice flow.

In spite of the evident need for them, driers have not received wide acceptance in Asia and Africa. Factors mitigating against them include:

- The high capital cost of both imported and locally constructed driers since the limited market has not led to the large-scale manufacture that would reduce unit cost;
- Unsatisfactory performance of some models and lack of experienced operators, which has resulted in poor milling of dried grain;
- Disparity between drying capacity and threshing, milling, and transportation capacities (with large-capacity central driers only a partial solution, since they may not be adaptable for many different varieties and grades received); and
- Delays in harvesting, threshing, and transportation that reduce the benefit of mechanical driers, since drying spoiled grain does not pay for the investment.

For these reasons, it is agreed that the most immediate equipment need is for low-cost batch-type farm driers fabricated locally from locally available materials. This simple equipment, properly used, gives dried grain of good milling quality with a minimum of delay, particularly where the drier can be moved from the storage or milling plant to the farm to reduce the time between harvest and drying.

In certain situations, these small batch driers can be used to complement large central drying plants, particularly at the peak of the harvest season when the grain has very high levels of moisture. They can be used to dry the grain partially to about 18 percent moisture level, at which level the grain can be kept for several days without significant bio-deterioration before being centrally dried to the 13–14 percent moisture level required for storage and milling.

The level of sophistication of the farm-level batch driers can vary according to need, capital resources, and construction and operating experience available. Very simple driers can be built that are also designed to burn rice husks, thereby reducing operating expenses.

The necessary credit for the farmers to purchase the driers and the infrastructure to support their use and maintenance must be available. This may include pricing policies which encourage production of better quality grain; the profit incentive will stimulate adoption of the improved technology.

Larger driers can be purchased commercially or designed and constructed with expert advice from engineers of national agencies or international organizations such as FAO, IRRI, or the West African Rice Development Association (WARDA).

Research on the use of rot retardants and natural ventilation drying may yield useful alternative or supplementary practices (Note 4-2).

Milling

Because rice is mainly consumed as intact grains, rice milling, in contrast to processing of other cereals, is a complicated process; a large number of operations are required to produce white polished rice grain from harvest paddy. (Rice is widely called "paddy" prior to milling, and "rice" after milling, a convention followed here to distinguish between the two forms.) These operations are parboiling, precleaning, hulling, husk separation, paddy separation, and whitening and polishing.

At each stage, losses are incurred due to the inherent efficiency limits of the process and, of course, due also to inefficient operation. These losses–and the processes themselves–are reported to be priority areas for attention and improvement and are described in Note 4-3.

Storage

Much of the traditional rice-growing area of the world lies in the humid tropics, with a climate characterized by high average temperatures (around 30°C) and relative humidity (around 85 percent).

Under these conditions, grain (whether stored as paddy or as milled rice) at equilibrium tends to absorb moisture from the atmosphere at the more humid times of day. Unless the storage is adequately ventilated, spoilage may result from increased respiration of molds in the grain, accompanied by local heating and possibly fermentation.

Traditional rice-storage houses, Laos (FAO photo by H. A. Wirtz)

Improved traditional paddy storage, India (Courtesy A. A. C. Huysmans)

In closed structures, there can be a problem with condensation of moisture, which may be given up by moist grain at the hottest part of the day and condense on the walls during the night, causing local wetting of the grain. Aeration (forced ventilation) permits equalization of moisture content throughout the stored grain and also reduces the temperature of the grain by evaporation. The drop in temperature also tends to reduce respiration and spoilage.

Paddy is commonly stored either in the form of bundles of panicles, in sacks or plastic bags, or in bulk storage. The sacks or bags provide a means of separating varieties for specific milling requirements. However, they deteriorate with use and allow access to insects and rodents, particularly if not properly stacked, if handled with hooks, and if the store hygiene is not adequate. Bulk storage, if properly organized, is efficient and relatively inexpensive. However, its efficient operation requires considerable capital investment and trained manpower, both of which may not be available.

Storing rice as paddy has advantages over storing milled grain, particularly where storage facilities are less than completely adequate. The protection afforded the kernel by the husk against insect, fungal, and even rodent attack, as well as the problems of storing poorly milled rice, accounts for the fact that the bulk of harvested dried paddy is stored in this form before milling, although this depends to some extent on the local economic situation and supply and demand for paddy and milled rice at different times in the season.

"Kanduch" lath and clay rice store, Chasemabad District, Gilan Province, Iran. Note the log-disc rodent baffles. (FAO photo)

Washing Losses

Rice is commonly washed prior to cooking, and in Korea, Cheigh *et al.* (1977) estimate weight losses due to washing local varieties of polished rice at over 2 percent. While it can be argued that this is not, strictly speaking, a postharvest loss as such losses are defined in this report, since the food is in the hands of the final consumer and loss takes place immediately prior to consumption, it has postharvest loss implications. The loss of nutrients accompanying the total solids loss is similarly not a postharvest weight loss, but is clearly important. The authors suggest that improved postharvest handling that delivers sanitary rice to the household and makes washing unnecessary could minimize these substantial losses.

Economics of Improved Processing

Studies have been made at IRRI on the magnitude and nature of field grain losses in paddy production. Samson and Duff (1973) indicate different levels of loss between varieties, wet and dry seasons, and varying moisture contents at time of harvest. A related series of trials investigated losses ascribable to handling, bundling, stacking, and field drying. Total paddy losses are given as approximately 1-3 percent for the harvest operation and 2-7 percent for the intermediate handling steps.

A comprehensive survey of rice milling and field level operations was undertaken in three regions of the Philippines, including 180 rice mills and approximately 600 farms. Based on the results, a series of pilot trials was undertaken to assess the impact of different systems of technology at the farm and rice mill level.

These trials compared the traditional methods commonly employed by farmers (threshing manually and sun-drying prior to storage and milling) with various systems of improved technology: mechanical threshing, batch-drying, and combinations of each with manual threshing and sun-drying.

Losses from manual threshing were found to be three times greater than losses from mechanical threshing. Increases in yield of about 12 percent were observed using either the drier or thresher in combination with traditional methods, and using both in sequence gave the greatest increase in output. A large part of this increase is ascribed to the reduction in time between harvest and threshing.

The improved technology also increased the quality of the grain, largely by reduction of broken, fermented, discolored, and immature grains due to the improved drying and reduction in the time between harvest and drying. Total expenditure per tonne was estimated to be twice as high for traditional methods as for the improved methods evidently much favored by farmers.

Maize

Loss Estimates

FAO-published figures (1977b) report average maize losses from 9.6 percent to 20.2 percent, mainly in storage (either unspecified or on-farm as opposed to central storage) and due primarily to insect damage, followed by fungus and rodent damage. However, the data is markedly inadequate, and as the FAO report concludes, "the estimates of losses of durable commodities and the methods by which they are derived were inadequately refined." Much painstaking work that has been published on farm-level maize storage is of limited use in determining weight losses because of the difficulty of measuring and interpreting losses due to "insect damage" reported as a percentage of damaged grains. Adams (1977) notes the lack of information from Central and South America in contrast to the considerable attention paid to cereal losses in most regions of Africa.

Maize presents particular problems of loss estimation because it can be stored either on the cob or shelled, affecting the subjective evaluation of what is edible. Storage on the cob enables a process of selection at the time of shelling; individually damaged grains may be separated as the grain is shelled, or the cob may be considered so heavily damaged that it is rejected, good kernels and all. The correlation between visible insect damage and weight loss varies according to the type and length of infestation. Accurate estimates of losses are impossible unless clear definition of these factors accompanies the numerical data.

The preferred methodology for determining maize losses involves weighing standard volumes of shelled grain. Losses would be measured on a dry-weight basis and reported on a typical moisture content that is acceptable in the marketplace. This moisture content should ideally become a "standard" that would be widely adopted.

Table 4:3 gives an indicative compilation of reported estimates in different countries.

Harvesting Factors

Postharvest losses are influenced by harvesting practice and field infestation by pests.

In many areas, standard practice includes turning down the ripe ears on the stalk, where they are left to dry further before collection; in traditional varieties, the corn husk completely encloses the grain and protects it from insect attack. The husk also protects the ear from exposure to moisture after it is turned down.

Resistance to field infestation by insects is low in many high-yielding varieties. Increased grain production on the cob generally results in both more and larger grains that may be incompletely covered by the corn husk and are more susceptible to field attack by insects and birds. The effects of these attacks may be carried over to the storage phase.

Shelling

Damage in shelling is proportional to the moisture content of the grain. Maize shelling is traditionally accomplished by hand and this method, though hard, tedious, labor-intensive work, is efficient in stripping the cobs and in minimizing damage to the grains; it also permits hand separation of damaged or infested grain from sound grain. Increased production increases the amounts of grain to be shelled and this can strain the capacity to shell the dried cobs by

TABLE 4:3 Reported Losses of Maize within the Postharvest System (Based on FAO, 1977b, Figures Unless Otherwise Indicated)

Region and Country	Total Percent Weight Loss	Reported National Production ('000 Tonnes)	Remarks
Benin	8-9	221	Traditional on-farm storage; 6 months improved silo storage (Harris and Lindblad, 1978)
Botswana		62	Insect damage
Ghana	7-14	395	(Rawnsley, 1969)
	15		8 months storage (Hall, 1970)
Ivory Coast	5-10	120	12 months stored on cob (Hall, 1970; Vandevenne, 1978)
Kenya	10-23	1,360	4-6 months central storage
	12		Hybrid maize, hotter regions, 6 months (De Lima, 1973)
Malawi	6-14	1,200	Drying 6; on-farm store 8 (TPI, 1977; Schulten, 1975)
	min. 10		Hybrid
Nigeria	1-5	1,050	On-farm storage
	5.5-70		6 months on-farm storage (FAO: ECA, 1977)
Rwanda	10-20	60	On-farm storage
Tanzania	20-100	1,619	Unspecified storage
	9, 14, 67		3, 6, and 9 months (Mushi, 1978).
Togo	5-10	135	6 months central storage (Tyagi and Girish, 1975)
Uganda	4-17	623	
Zambia	9-21	750	On-farm storage (Adams and Harman, 1977)
India	6.5-7.5	6,500	Central storage, 7.5 (Agrawal, 1977)
Indonesia	4	2,532	
Pakistan	2-7	70	
Belize	20-30	20	Traditional on-farm storage (Cal, 1977)
Brazil	15-40	17,929	Farm storage
Dominican Republic	19	49	Farm storage, 15; processing, 1
Honduras	20-50	289	Traditional storage, poor facilities (Balint, 1977)
Mexico	10-25	8,945	
Nicaragua	15-30	201	
Paraguay	25	290	(Martino, 1977)
Venezuela	10-25	532	

hand. Methods of shelling quantities of cobs include beating bagged cobs with a stick, which results in increased loss due to incomplete stripping of the cobs and damage to the grain. Mechanical shelling losses are relatively low when the equipment is adjusted and operated competently and grain moisture levels are low. Wooden hand-held maize shellers developed by the Tropical Products Institute (Pinson, 1977) offer an efficient intermediate-level technology to

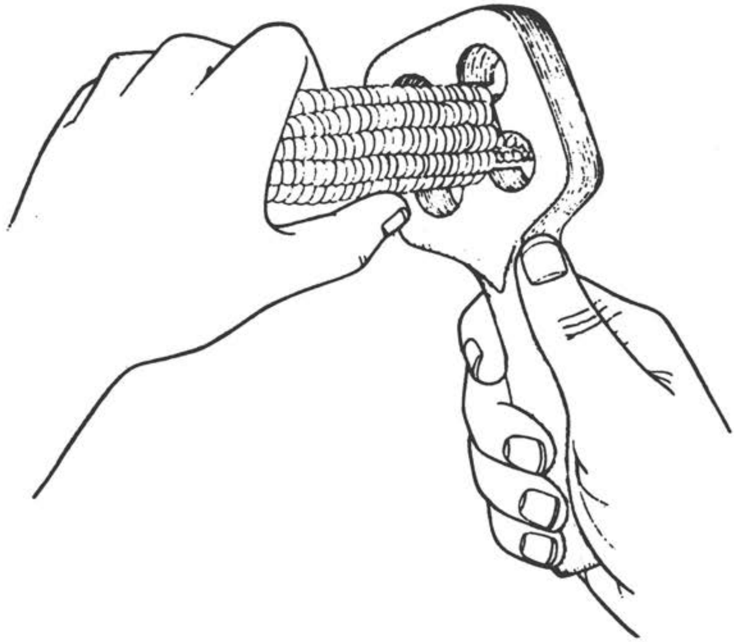
Corn-husking, N'Kolbisson, Cameroon (FAO photo)

increase manual shelling capacity. The dry maize cob is held in one hand, the sheller in the other, as illustrated. As the cob is pushed into the sheller, the ridges pull out the grain.

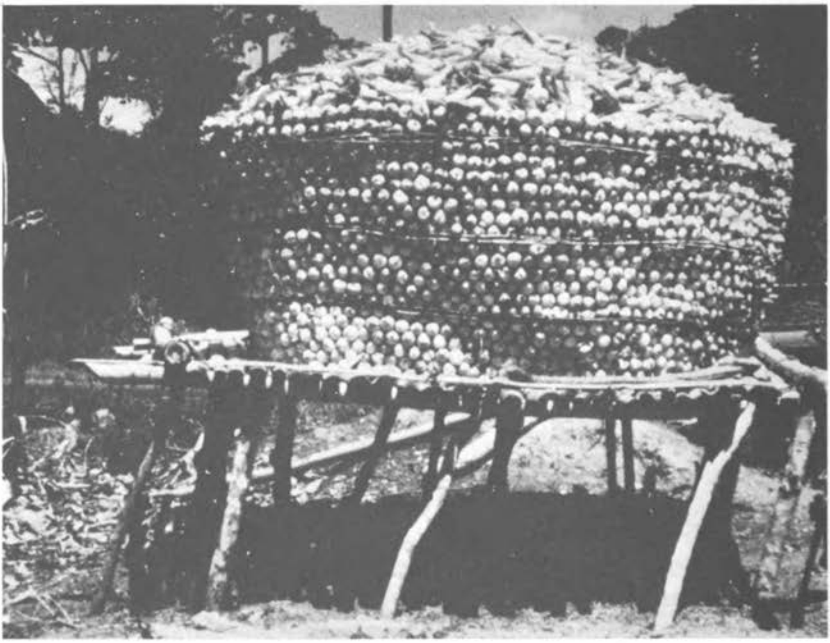
Drying and Storage

Harvested ears of corn are normally stored and dried at the same time and these two functions should be considered together.

In developing countries there are a number of on-farm traditional methods for drying and storage of maize.



Wooden, hand-held, maize sheller (Crown copyright, Courtesy TPI)



Ewe barn, Ghana (Crown copyright, Courtesy TPI)

In Ghana, for instance, these include the Ewe barn, a raised circular platform on which ears are piled up to form a cylinder and roofed with thatch, and the Ashanti crib, a raised rectangular structure of wood or bamboo that is also thatched. Losses are estimated at 7-14 percent over 3-6 months (Rawnsley, 1969).

In a number of places in West Africa and elsewhere, ears are hung to dry from horizontal poles protected from the rain or from branches of trees.

In Kenya and Tanzania, stores for shelled grain are constructed from woven branches and the basket structure supported by a strong platform raised on poles or stones. In humid areas the maize is stored in a special loft or crib over the cooking fire, which deters insects and reduces humidity.

In a number of countries storage baskets may be plastered with mud. Sometimes they are completely sealed to exclude infestation, in which case it is usual to open the store periodically and redry the grain in the sun.

The use of hessian sacks for storing shelled grain is widely reported. A limitation is that the sacks are vulnerable to insect, mold, and rodent damage

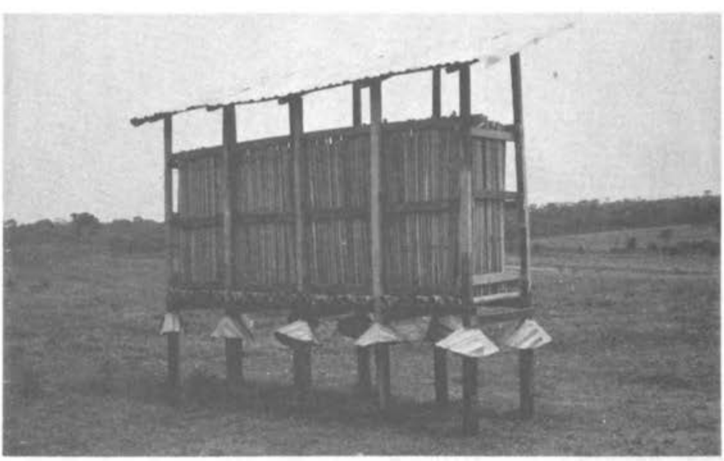
Traditional mud-walled stores of the low savannah zones, West Africa (Courtesy W. Boshoff) when left on the ground in the corner of a hut for extended periods, although this may be prevented by frequent inspection.

Other containers commonly used to store small quantities include gourds, pots, tins, and small baskets.

In general, the traditional methods of storage work well as long as they are in balance with the rest of the farming system. The inherent quality of local maize varieties (including hardness of the endosperm and low moisture content), along with storage on the cob with husk intact, help to protect the grain from insect attack. A long process of natural selection has led to the survival of varieties that provide a reasonable return to farmers for their farming and storing efforts. This can be seriously disrupted by introduced changes; in addition to new crop varieties with their different grain properties, the amount of grain to be stored generally increases and may place a strain on the traditional storage facilities or on the time available to the farmer and his family for processing it.

Improvements to Traditional Drying. Drying is often a problem, particularly when, as in West Africa, the crop matures during a period of high humidity and the effectiveness of natural drying of large quantities of maize is uncertain.

The African Rural Storage Center at Ibadan, Nigeria, recommends the construction from locally available materials of improved drying cribs designed to make best use of free ventilation drying effects. (Note 4-2.) About 4 months of crib drying of dehusked maize, to which insecticides are applied externally, is the technique recommended over field drying or the storage of shelled grain immediately after harvest. Crib drying reduces losses due to both fungi and insects to about 2 percent after 4 months' storage. There is no evidence to show that small-scale mechanical driers are a better answer to



Conventional crib with rat guards (Courtesy W. Boshoff)

Crib constructed entirely from local materials (Courtesy W. Boshoff)

Large conventional crib constructed mainly from local materials (Courtesy W. Boshoff)

TPI ;ommended mesh-sided crib, Swaziland. Note the corrugated iron roof and metal rat guards. (Crown copyright, Courtesy TPI)

drying needs, and the fuel supply from firewood or fossil fuels makes this method environmentally and economically less attractive than free ventilation methods for farm- and village-level drying.

Nyanteng (1972) notes the problems of organizing cooperatives to carry out drying and storage and the difficulties of introducing improvements through grain marketing cooperatives in Ghana. The problems stem partly from inappropriate technology and partly from poor management.

Reduction in losses due to insects has been reported when properly dried maize is stored shelled. This controls *Sitotroga* by restricting its movement through the bulk of the grain and its opportunity to deposit eggs. In the shelled grain, damage is confined to the exposed surfaces. *Sitophilus* is readily controlled by insecticides suitable for direct application to grain, such as malathion. Crib drying with insect control, followed by storing shelled grain in impervious containers, has been reported as a successful combination for reducing losses in humid regions of West Africa and Zambia.

Wheat

The production of wheat continues to increase in the main producing countries–India, Pakistan, and Mexico–and the problems of harvesting, threshing, transport, marketing, storage, and processing have increased proportionally. However, these have been accompanied by extensive efforts to improve the postharvest system in these countries, and research, training, and infrastructure are relatively sophisticated compared to those in other countries.

Loss Estimates

Relatively few loss problems suffered by all grains are specific to wheat. Loss reports for wheat average 10 percent, with the major causes being insects, rodents, and mold during storage, particularly where overproduction has strained storage facilities to their limits. As noted, rodents are a major problem in India.

Milling losses are not reported to be a serious problem. As with rice, they result from inefficient operation or maintenance of machinery, often due to inexperienced operators or difficulty in obtaining spare parts. The roller milling of wheat grains is a highly complex technical process that must be carefully adjusted to achieve efficient milling of wheat grain to flour of various qualities, plus yielding germ and bran. Wheat milling differs from rice milling in that the product is ground flour rather than intact kernels and grain breakage is not a major issue. Unlike rice processing, wheat processing is not reported to be an area where substantial postharvest loss occurs or that requires priority research in developing countries.

With wheat, the primary need is careful precleaning prior to milling to remove all damaged, spoiled, or infested grains and dirt and debris. This ensures high-quality flour and protects the machinery from damage.

Threshing

Threshing and winnowing are still done in open yards rather than in combines. The grain is exposed for an extended period; considerable losses due to birds, rodents, and spillage occur, and losses due to high moisture, molding, and fermentation may result if it rains. Inefficient operation of mechanical threshers breaks the grain and makes it more susceptible to insect attack or threshes it incompletely.

Storage

In addition to storage problems common to all harvested grains, wheat may be rendered unfit for malting or bread making because of spoilage during storage, particularly due to mold. Indian government reports on storage losses of wheat (Krishnamurthy, 1972) give figures of approximately 2.5 percent loss due to rodents and a slightly higher percentage due to insects. Small-scale farm-storage losses vary, but are typically around 10 percent.

Processing Losses

Use of wheat and wheat products is increasing in developing countries in response to the demand for bread. However, wheat flour is put to other uses besides bread. In a number of countries, unleavened bread ("hubus," "chapattis," "puris," etc.) is made from varying grades of flour.

While white flour technically comprises about 63-80 percent of the whole wheat grain, practical milling considerations in current mills require an extraction rate of about 75 percent to produce a white flour suitable for western bread making. More widespread use of higher extraction brown flour (such as the 95 percent "atta" in India) would reduce milling losses.

Barley

Barley is produced in cool, upland areas and is a major crop in Korea, China, India, Iran, Syria, Turkey, and Ethiopia. Its processing is similar to that of rice. An important use of barley is for sprouting (malting) and fermentation to produce beer and other alcoholic beverages, and considerable quantities are imported by developing countries for this purpose.

Drying of the grain prior to malting must be done carefully to ensure that germination and malting are not affected.

There are few reports in the literature of losses of barley in developing countries, and it appears that there is no special problem peculiar to barley. This may reflect, in part, the fact that it is mainly produced in the cooler countries, the care with which the brewing industry handles the crop, and the relatively few stages of processing it requires.

Millets and Sorghums

Millets and sorghums are grown in semiarid regions, and although their annual reported production, approximately 20 million and 30 million tonnes respectively (FAO, 1977a), represents only 6 percent of total cereal production, they are the main staple in drier regions of Africa, the Middle East, India and Pakistan, and China.

In developing countries, most millet and sorghum production is still at the farm and village level, and postharvest technology is unimproved compared with that for the major cereals.

TABLE 4:4 Reported Losses of Wheat and Barley, Millets, and Sorghum within the Postharvest System (Based on FAO, 1977b, Figures Unless Otherwise Indicated)

Commodity and Country	Total Percent Weight Loss	Reported National Production ('000 Tonnes)	Remarks
WHEAT			
Pakistan	5-10	8,500	On-farm storage 5-10; milling 2; central store 5 (Qayyum, 1977; Greaves, 1977; Chughtai, 1977)
	12		Unspecified storage
India	8-25	24,000	(Amla, 1977; Agrawal, 1977)
	2-52		Farm storage to 45; threshing 1; central storage 8
Rhodesia	10	2,571	On-farm storage (Howden, 1977)
Sudan	6-19	880	
Bolivia	16	833	Store 7; drying 3
Brazil	15-20	906	Storage 1-4
BARLEY			
Pakistan	9	130	Unspecified storage 7; processing 2
Bolivia	14	80	Drying 2; unspecified store 6; transport and distribution 4
Sudan	17	–	Central store
MILLETS			
Mali	2-15	804	On-farm store 2-4; central store 10-14 (Guggenheim, 1977)
Nigeria	0.1-0.2	3,200	On-farm storage
Rhodesia	10-15	564	On-farm storage (Howden, 1977)
Sudan	14	450	Central store
Zambia	10	30	On-farm storage
India	7-10	9,600	Drying 2-5; farm storage 5 (Chaturvedi, 1977; Agrawal, 1977)
Pakistan	7.5	503	Storage 5; processing 2.5
SORGHUM			
Nigeria	0-37	3,680	On-farm over 26 months (Hall, 1970)
Rhodesia	25	716	On-farm store (Howden, 1977)
Sudan	6-20	1,800	Central storage
Zambia	0-10	46	Local varieties, negligible; high-yielding varieties 10 (TPI, 1977)
India	7.5	544	Unspecified storage
Indonesia	4.0	–	
Pakistan	7.0	621	Storage 5; processing 2

Loss Estimates

Postharvest losses of millets and sorghums have received relatively little attention. Reported losses have often cited damage rather than weight loss. Loss estimates have indicated relatively moderate levels occurring during storage, 1-5 percent (Spencer *et al.*, 1975). Other losses occur during harvest and as the grain dries in the field.

Harvesting

Because harvesting is carried out under dry conditions, millet and sorghum crops are commonly left standing in the field to dry for a period. Sorghum stalks may be tied together at the top in threes or fours to prevent the dry stalks from lodging.

This field-drying period may extend for a considerable time, during which the grain is exposed to bird, rodent, and insect attack, including termites. Although in many cases these may be considered as preharvest problems, depending on local variations in handling, the results affect postharvest deterioration of stored grain.

Threshing

Millet and sorghum grain is frequently stored on the head and threshed as required, except for seed grain, which may be threshed and sealed in small containers to be kept in the house for special security. In other cases, however, seed grain is kept unthreshed and hung from the roof.

Millet Storage

Guggenheim (1977) and Spencer *et al.* (1975) describe traditional and central warehouse storage of millets in Mali and Senegal and report losses averaging 2-15 percent. Losses in traditional stores were lower than in the central warehouses.

The difference between estimates of loss under traditional and central storage results from a number of factors. In Mali, farmers may be assigned a quota of grain that they must sell to the government; they are prepaid for

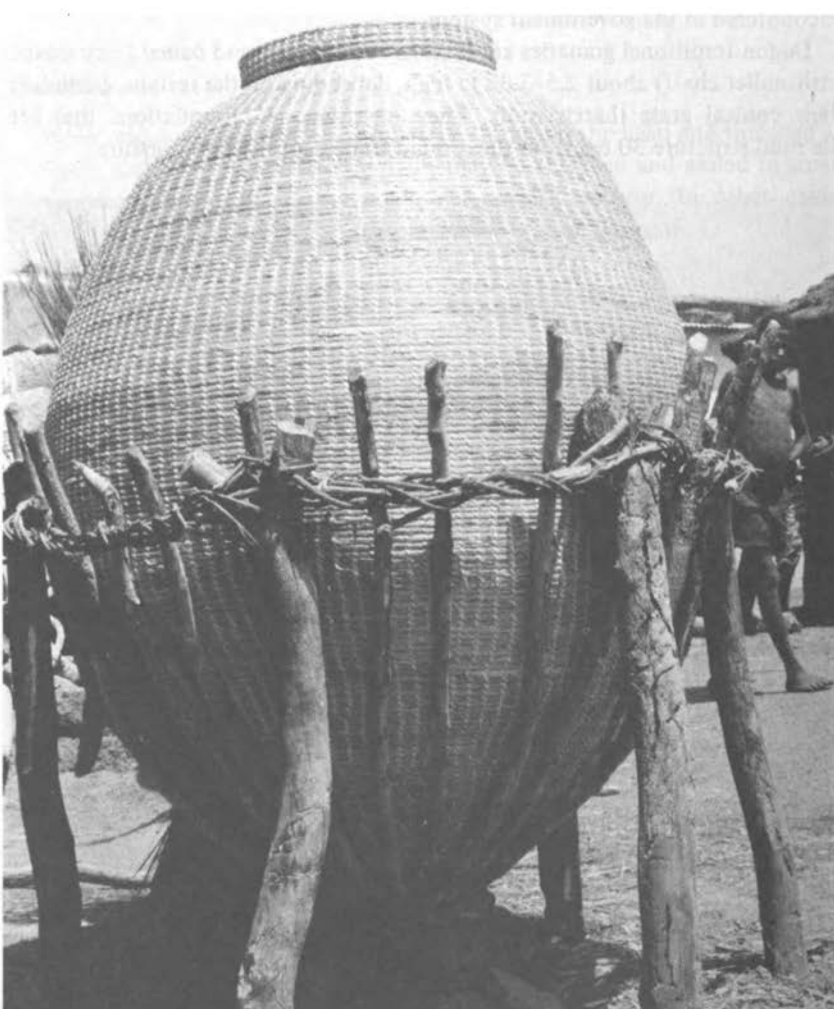
Sun drying millet, southern India (Courtesy A. A. C. Huysmans)

their quota and provided with empty sacks in which to deliver the shelled grain, but since they are not paid for the transportation, there is no incentive to speed the delivery of the bagged grain to the collection centers. The collection centers themselves have insufficient, often ill-designed space; even specially designed stores may be poorly constructed. The bagged grain may be left uncovered on open ground or kept in old storerooms or school buildings or the extension agent's residence, together with his animals. And since the grain that farmers sell to the government is commonly the oldest available, or of a quality they do not wish to store themselves, it may not be very durable at the outset. As a result, comparatively high losses (10-15) percent are encountered in the government system.

Dogon traditional granaries are built of rock, wood, and *banco* (clay mixed with millet chaff) about 2.5-3.33 m high, depending on the terrain, excluding their conical grass thatch roofs. They have wooden foundations that lift the mud structure 30 cm from the ground to protect it from moisture.

Dogon granary and pounding millet, Mali (Courtesy H. Guggenheim)

Good management of granaries is fundamental to keeping postharvest losses low. Millet heads are roughly classified during harvest: very poor and aborted grain is not cut; poor grain is cut but kept apart; good grain is prepared for storage. The grain to be stored is spread on the flat terraces of the houses for drying. The very best is reserved as seed, usually kept under the kitchen roof, protected by smoke against insect attack. The remainder is moved to the granary 6 weeks to 3 months following harvest, in December or January, by which time it is very dry–typically below 10 percent moisture.



Grain storage basket, northern Ivory Coast (FAO photo by A. Tessore)

Rodent damage in the field and in storage is difficult to differentiate, as is bird damage in the field and while the grain is drying on roofs or terraces of houses. The grain-eating weaver bird (*Quelea quelea*) is responsible for heavy losses of early-maturing varieties of millet, and wild pigeons cause major damage to grain during drying.

Fungal damage appears to be negligible when millet is stored on the head for up to 4 years; in bulk with the addition of ash, the grain is reported to keep up to 5-7 years. However, this grain is thought to lose its flavor, perhaps as a result of biochemical deterioration.

Traditional mud and straw grain store, N'Djamena, Chad (FAO photo by J. C. Abbott)

Traditional methods of fumigation, such as smoking with burning millet chaff mixed with pepper, appear to be effective. Leaves of plants such as *Andropogon* (grasses) and *Combretum* (vines), whose odor is thought to repel both insects and rodents, are placed with the grain. More important is the use of ash of *Boscia senegalensis* and millet stalks, a mixture scattered on the floor and rubbed into the walls of the granary. It is also mixed with the threshed grain.

Sorghum Storage

Annual production of sorghum in developing countries was estimated to be 31 million tonnes in 1978 (FAO, 1977a). Little investigation of losses has been reported, and generalization from the few reports is obviously risky.

Storage is similar to millet. Reports by Giles (1964) of storage in northern Nigeria, Nyanteng (1972) for northern Ghana, and Spencer *et al.* (1975) in Senegal indicate the existence of storage problems similar to those for millet in Mali, discussed above.

Losses are reported to be relatively low in storage of traditional varieties of sorghum. Insect damage from *Sitotroga, Sitophilus*, and *Rhyzopertha dominica* occurs particularly in newer high-yielding varieties in central stores. Estimates of 1-20 percent losses are reported.

Dusting the stored grain on the head with BHC is reported to be effective in controlling insect infestation in mud granaries for up to 18 months (TPI, 1977).

Grain Legumes

The grain legumes or pulses occupy an important place in global food and nutrition, with a current annual production of about 50 million tonnes (FAO, 1977a). Half of them are produced in developing countries, where they are a disproportionately important dietary constituent of many people, supplementing cereal diets with essential amino acids and improving nutrition where animal protein is scarce.

Substantial amounts of grain legumes are consumed, particularly in Africa and Asia, after milling to dehusk and split live grains or after other types of processing. Many commercial technologies are either obsolete or inadequate for this purpose as they cause heavy losses due to breakage and powdering; research and development in a number of countries, particularly India, has been devoted to developing improved technologies.

Grain legumes are more difficult to store than cereals and suffer greater damage due to insects and microorganisms. Damaged grain also suffers higher milling loss.

Yields of grain legumes are low compared with cereal grains, averaging from 200 to 1,500 kg/ha, and total production has remained roughly constant over the past 10 years. This was the subject of discussion at a special seminar organized by the Protein Advisory Group of the United Nations in 1972 (FAO, 1973), which emphasized the importance of developing new varieties of grain legumes to resist pests, diseases, and drought, and of developing improved technologies for processing and conserving them.

Nomenclature

There are some 36 major species of grain legume grown and consumed as food. All have common or local names, some of which are given to more than one species.

Table 4:5 lists both common and botanical names alphabetically.

Loss Assessment

Most grain legumes are harvested after a preharvest period of field drying. During this drying period, the pods and grains are exposed to attack by birds, rodents, and insects, and preharvest losses result not only from the food these pests consume but also because they cause shattering of the seeds.

The harvested legumes may carry a field infestation, mainly by bruchid beetle species, which lay their eggs on the maturing pods (Prevett, 1961). Although the infestation at harvest may be as low as 2 percent (Booker, 1967), this may provide an insect nucleus sufficiently potent to cause serious losses after several months of storage.

Taylor (1977) reports that in Nigeria field infestation often causes farmers to dispose of a crop as soon as possible after harvest. Although this passes the storage problem to middlemen, it also imposes on the farmer the necessity of buying back needed legumes later in the season when the price has increased and the quality decreased. Grains may change hands many times before consumption, making loss assessment and control more difficult.

Studies have been directed mainly to assessing losses in storage and processing. The loss assessment problems of cereal grains also apply to legume losses and are compounded by the large variety of legume species and their traditional production as supplements to, or in rotation with, cereal grains. The fact that they are produced and stored in comparatively small quantities has increased the difficulty of loss estimation. High variability is shown by the reported figures, attributed to the variety of storage systems and containers and the progressive consumption during the season, which lead to a high proportion of damage and loss in the residue at the end of the season. Losses are reported from 2 to 3 percent to as much as 50 percent; many of the reports give damage assessments rather than weight losses. Representative

TABLE 4:5 Nomenclature of the Grain Legumes

Common Name	Botanical Name
Arhar	*Cajanus cajan*
Bambara groundnut	*Voandzeia subterranea*
Beans, dry	*Phaseolus subterranea*
Bengal gram	*Cicer spp.*
Black gram	*Phaseolus mungo*
Black-eyed cowpea	*Vigna unguiculata*
Broad beans	*Vicia faba*
Chick peas	*Cicer spp.*
Congo pea	*Cajanus indica*
Cowpeas, dry	*Vigna unguiculata; V. sinensis*
Feijao	*Phaseolus* spp.
Garbanzos	*Cicer spp.*
Golden gram	*Vigna radiata; V. aureus*
Green gram	*Phaseolus aureus*
Groundnut	*Arachis hypogaea*
Haricot bean	*Phaseolus vulgaris*
Horse gram	*Dolichos biflorus*
Kidney bean	*Phaseolus vulgaris*
Lentils	*Ervum lens; Lens* spp.
Lima beans	*Phaseolus lunatus*
Lupins	*Lupinus* spp.
Masur dhal	*Lens* spp.; *Ervum lens*
Mung beans	*Vigna radiata; V. aureus; Phaseolus aureus; P. radiatus*
Mungo bean	*Phaseolus mungo*
Navy bean	*Phaseolus vulgaris*
Peanut	*Arachis hypogaea*
Peas, dry	*Pisum* spp.
Pigeon peas	*Cajanus* spp.
Pinto bean	*Phaseolus vulgaris*
Redagram	*Cajanus cajan*
Snap bean	*Phaseolus vulgaris*
Soybeans, soja	*Glycine* spp.
Urd	*Phaseolus mungo*
Velvet bean	*Mucuna pruriens; Stozolobium* spp.
Vetch	*Vicia sativa*
Windsor bean	*Faba vulgaris*
Winged bean	*Psophocarpus tetragonolobus* (humid tropics); *Tetragonolobus purpureus* (European)
Yam beans	*Sphenostylis stenocarpa*
Yellow dhal	*Cajanus indicus*

Botanical Name	Common Name
Arachis hypogaea	Groundnut, peanut
Cajanus cajan	Pigeon pea, Arhar, Redagram
Cajanus indicus	Pigeon pea, Congo pea, Yellow dhal
Cicer arietinum; C. miotinum	Chickpeas, Bengal gram, Garbanzos
Dolichos biflorus	Horse gram
Ervum vulgaris	Lentils, masur dhal
Faba vulgaris	Windsor bean
Glycine max; G. hispida; G. soja	Soybeans, Soja
Lathyrus sativus	
Lens esculenta; L. culinaris	Lentils, masur dhal
Lupinus spp.	Lupins
Mucuna pruriens	Velvet bean
Phaseolus angularis	Dry bean
Phaseolus aureus	Mung bean, Green gram, Golden gram
Phaseolus lunatus	Lima bean
Phaseolus mungo	Mung bean, Mungo bean
Phaseolus radiatus	Mung bean, Green gram, Golden gram
Phaseolus vulgaris	Haricot, Kidney, Navy, Pinto or Snap bean, Feijao
Pisum angularis; P. arvense; P. sativum	Dry peas
Psophocarpus tetragonolobus	Winged bean (humid tropics)
Sphenostylis stenocarpa	Yam beans
Stizolobium spp.	Velvet beans
Tetragonolubus purpureus	Winged bean (Europe)
Trigonella foenum graecum	
Vicia faba	Broad beans
Vicia sativa	Vetch
Vigna aureus; V. radiata	Mung beans
Vigna sinensis	Dry cowpeas
Vigna unguiculata	Black-eyed cowpeas
Voandzeia subterranea	Bambara groundnut

figures are given in Table 4:6, but the degree of variability makes it impossible to arrive at an average figure. Experienced observers agree that losses are normally somewhat greater than for cereal grains.

Preharvest Loss Control

The extent of field infestation by insects has led to preharvest prophylaxis in legumes to reduce storage loss. In food for human consumption, prevention is clearly preferable to postharvest control measures. Effective preharvest control involves making the grain inhospitable to the insects. This may be achieved, to some extent, by breeding resistant varieties and by treating the crops with insecticides before harvest.

TABLE 4:6 Reported Losses of Legumes within the Postharvest System (Based on FAO, 1977b, Figures Unless Otherwise Indicated)

Country	Total Weight Loss (Percent)	Reported National Production ('000 Tonnes)	Remarks
Ghana	7-45	11	Shelled beans, 1-5 months; unshelled beans, 22 (Rawnsley, 1969)
Nigeria	5.4	932	Cowpeas (Caswell, 1968)
	1-2		Cowpeas stored 3 months in shell (Boshoff, 1975)
	4.5	350	Groundnuts (Howe, 1977)
Kenya	30	280	On-farm storage (De Lima, 1973)
Rhodesia	5	706	On-farm storage (Howden, 1977) groundnuts
Sudan	4-27	980	Groundnuts, central store
Swaziland	5		Groundnuts, insects and mold
Uganda	9-18.5	220	Groundnuts, mainly insects and mold
Zambia	40	600	Cowpeas (TPI, 1977)
India	8.5	12,956	Pulses, central storage
Indonesia	5	900	Unspecified storage (Sumartono, 1977)
Pakistan	5-10	785	Pulses (Chughtai, 1977)
Thailand	10-30	1,008	Soybeans, drying 15-17; farm store 12-15; handling 10 (Dhamcharee, 1977)
	0.25-68		Soybeans, central storage
	0.25-16	1,347	Groundnuts, central storage
Belize	20-50	1	Kidney beans, on-farm storage (Cal, 1977)
Brazil	15-25	1,923	Drybeans
Costa Rica	24		Drybeans (Mora, 1978)
Honduras	20-50	48	Drybeans, on-farm storage (Balint, 1977)
Nicaragua	10-35	54	
Paraguay	15	8	Soybeans (Martino, 1977)

Harvesting

Harvesting problems arise where the crop does not mature evenly or where harvesting must be done when rain prevents satisfactory drying of the crop on the mature plant. Uneven maturing is less of a problem on small farms, where mature dry legumes can be picked over a prolonged period. Larger plantings that have to be harvested at a particular time may contain pods with more than 13-14 percent moisture and will need to be dried before or during storage to prevent mold and discourage insect attack.

Losses can be minimized by good hygiene of stored legumes, by storing only whole pods and shelling the rest for sale or immediate use, by attention to drying the crop properly, and by carefully excluding insects and rodents in the transition between field and store.

Storage

Major losses of grain legumes occur during storage.

The bruchid beetles breed rapidly in stored legumes, preferring relatively high temperatures and humidity. Most subspecies show preference for particular legumes and will not necessarily thrive on any variety of pulse.

Dehusked and split stored pulses may be infested by insects such as *Rhyzopertha, Trogoderma*, and *Tribolium* spp. from other stored products. In addition to physical damage, contamination by insect excreta and fragments are extensive–guanine and uric acid are the most abundant substances. They are found in greater concentration in legumes than in cereals.

Treatment of Harvested Grain Legumes

Because legumes are so prone to insect damage, special measures are often taken to protect them after they are harvested.

Physical Treatment

In many areas grains are spread in the sun to disinfect crops, possibly the only economical treatment currently available to farmers in developing countries, although experimental uses of cold, heat, and radiation have been tried.

Blockage of intragranular spaces using smaller grain such as millet (*Eleusine coracana*) or other inert material restricts movement of bruchids through stored grain and limits ovipositing. Steaming and parboiling, which cause hardening and gelatinization of the grain starch, have also been tried. As in the case of cereal grains, the use of inert materials to abrade and absorb cuticle wax and dehydrate insects is reported to be very effective.

Lemon oil has been shown to be effective in controlling cowpea weevils in black-eyed peas (Su *et al.*, 1972), and a number of other oils and terpenes have insecticidal properties. Recently, work at IITA (1976) showed that groundnut oil added to cowpeas at 0.5-1.0 percent prevented insect attack for over 6 months. Castor, mustard, coconut, and sesame oils also are reported to be effective (CFTRI, 1977).

Biological Control

Various predators and parasites have been recorded as attacking and killing storage insect pests. A predacious mite (*Pyemotes* [*Pediculoides*] spp.) has been observed to attack and kill eggs, pupae, and adults of *Acanthoscelides obtectus* and *Callosobruchus maculatus*. Adults and larvae of the hymenopteran *Pteromalus schwenkii* feed on the larvae of *C. chinesis*, the bean weevil that attacks the mung bean. *Dinarmus laticeps* is a very common parasite of bruchids. However, though predators may locally reduce populations of pests, they cannot be considered an effective overall method of control.

Juvenile hormone analogs have been reported to block embryonic development of the cowpea weevil *C. maculatus* (El-Tantawi *et al.*, 1976). A new pheromone that can act as an inhibitor of oviposition is reported by Yamamoto (1973). These methods are still only experimental.

Chemical Control

Malathion is a contact insecticide commonly applied to pulses that appears to give satisfactory control of store pests for extended periods.

Because of the infestation of storage facilities by infested crops brought from the field, fumigation of harvested crops has been widely employed. Fumigants have included carbon disulfide, ethylene dibromide (EDB), methyl bromide, and aluminum phosphide. Aluminum phosphide proved better than EDB because of better penetration; however, excellent control of bruchids was accomplished with EDB absorbed in chalk tablets and used to fumigate small quantities of pulses in airtight containers. Some eggs and larvae are tolerant to phosphine and require increased concentration of fumigant or fumigation time (Muthu, 1973).

From reports, it appears that the pulses are more difficult to store at the farm level than cereal grains and that the structures and treatments for legumes perform better at private and government warehouses than on farms. Several factors may enter into this, including greater field–and hence farm–infestation; greater difficulty in controlling infestation in the larger grains without chemical insecticides or fumigants; and the fact that legumes may receive more attention in commercial or government storage because of their higher unit value.

Processing

Dried food legumes go through a variety of primary processing steps before the consumer can prepare food from them. These procedures include dehusking, puffing, grinding, splitting, and sprouting.

They are practiced at different levels of sophistication in different countries and regions, from hand-operated farm and home methods to small-scale cottage industry to major industrial processing similar to that of the rice and wheat industries in India and Southeast Asia.

Dehusking. Dehusking or hulling is the removal of the fibrous seed coat, or husk, of the legume. This upgrades the quality of the grain by improving its appearance, texture, palatability, and cooking properties as well as the digestion and absorption of nutrients after it is eaten. The simplest method involves grinding the heated or sun-dried grain in a mortar and winnowing off the husks. The husk may also be loosened by soaking the grain and then removed by wet grinding stones. In large-scale operations, husks may be removed by either wet or dry methods or a combination of them. In the wet method, the grain is soaked and sun dried or mixed with small amounts of water. In the dry method, the grain is sun dried after application of small amounts of oil or moisture, or both. In some cases, simple sun drying may be sufficient.

In removing the husk, care must be taken to remove as little of the edible kernel as possible. Several factors must be considered: variety of legume, which influences thickness of husk; thickness of the gum layer binding the seed-coat to the kernel; shape, size, and uniformity of the grains; hardness of the grains; texture and waxiness of the seed-coat; and age of the grain. Because of the variation in hulling characteristics dependent on these factors, there is no standard procedure for hulling a given variety of legumes, and different combinations of methods are empirically employed.

Removal of the husk is commonly done in small machines, including both hand- and power-operated under-run disc-shellers or blunt-plate mills. In many cases, hulling is accompanied by splitting the cotyledon; the husks are removed by aspiration while unhulled grains are easily separated from the split cotyledons by sieving. Roller mills are also used, but cause loss of kernel by scouring of the surface of the dehusked grain, which also leads to loss of surface proteins. These losses are particularly high if the grains are not well graded by size.

Moisture affects hulling and splitting of the grains; lower moisture content helps the dehusking process, while higher moisture assists in splitting. Losses are reduced if these operations are done separately.

Splitting also causes loss of the embryo (amounting to 2-5 percent of grain weight) and breakage of the edges of the cotyledons. No widely used method satisfactorily permits dehusking without splitting and loss of the embryo; this is an area where opportunity exists for technology to improve the processing yield of edible grain and to make an important contribution to nutrition. Improved milling technologies are being developed at the Central Food Technological Research Institute, Mysore, India. Separate methods are used to loosen the husk by heated air, followed by tempering and husk removal by abrasion in a pearling machine, with each method adjusted for the particular legume. These combinations are reported to give impressive experimental yields of over 95 percent dehusked grain in a single operation. They are being introduced for commercial operation, and three automatic plants with capacities of between 0.5 and 2 tonnes per hour are in production. Other existing mills are being converted to the new technology. The process has been standardized for pigeonpeas, chickpeas, mung beans, black gram, lentils, cowpeas, soybean, horse gram, and kidney beans (Kurien, 1977).

These methods are suitable only for improving large-scale commercial milling. Nevertheless, they offer possibilities of conserving considerable amounts of legume yield and thus of high-quality protein. Kurien estimates that possible additional yields of at least 8 percent could be achieved by adopting improved technology, which would amount to 800,000 tonnes additional milled pulses per annum, containing approximately 240,000 tonnes crude protein (flour from the peripheral layers of seeds contains about 30 percent crude protein) and costing approximately US$290 million. Kurien indicates that further improvements are needed, including:

- Increased milling efficiency of the dehuskers;
- Adjustment of machines to the needs of individual legume varieties;
- Better separation of husks from unhusked grain;
- More detailed knowledge about the nature of gums and mucilages and their influence on grain milling;
- Improved efficiency in splitting pearled grains under all conditions with minimum losses; and
- Improved recovery of edible portions of byproducts.

Larger varieties of legume are easier to mill, give higher yields, and are preferred by millers, while the smaller varieties like pigeonpeas, black gram, and mung beans require repeated and severe premilling treatments that often cause high scouring and splitting losses. In wet milling methods, water-soluble nutrients are lost. The development of milling technologies that reduce these losses can, therefore, enable additional yields of protein to be achieved.

Puffing. Legumes may be puffed by subjecting them to high temperatures for a short duration. At the farm and home level, this may be done by gentle heating to around 80°C, followed by moistening with 2 percent water, which is absorbed overnight. The following day the grain is toasted with hot sand at 250°-300°C, at which point the cotyledons puff and split the husk, which is then removed by gentle abrasion. At the cottage industry level, puffing is accomplished with husk-fired furnaces and large toasting pans operated by a number of people. More recently, fully automated continuous oil-fired or electric toasting or parching machines have been introduced. Chickpeas are the most common puffed legume, although puffed peas and cowpeas are also found in many countries. Puffing expansion is low—1.5 compared to the 8–10 times expansion of puffed cereals. Losses are not mentioned in the literature, and presumably are relatively low in view of the simple processing technique.

Grinding. In a number of countries, whole legumes or dehulled splits are ground dry or wet into flour or batter; this is used for a number of sweet or savory preparations, either alone or in combination with cereal grains or oilseeds. The quality of these products depends on the composition of the flour, fineness of grinding, relative proportion of ground particles of different mesh grades, and method of preparation. Chickpeas, peas, black gram, and cowpeas are the most commonly ground pulses. The grinding may be done in mortar or stone grinders, with or without sifting, or in plate or hammer mills. Although the dry flour is easier to handle, in some countries wet-ground preparations are preferred to dry-ground flour mixed with water. Mechanized mortars are available for this purpose where larger quantities are handled.

Cooking. Legume seeds, either whole or split, are commonly cooked in the traditional way: for extended periods of 1–4 hours following overnight soaking. This is necessary to produce a tender, edible product and to extract (if soak water is discarded) or inactivate antinutritional factors such as antitrypsin and hemagglutinins. As in the case of rice, the precooking washing and soaking, as well as the prolonged boiling, lead to losses of total solids and other nutrients. While these are not defined as postharvest losses in the strict sense, postharvest technology prior to cooking that reduced the need for these severe treatments would constitute, in effect, a loss reduction.

A variety of these processes has been developed. Precooked, quick-preparation legumes have been developed, using flaked splits, pressure-cooked and dehydrated beans, and beans that have been soaked in solutions of inorganic salts, which penetrate the beans under reduced pressure (the "Hydravac" process, Rockland *et al.*, 1974). These techniques require careful quality control to retain the appropriate flavor and texture of the end product. While these technologies are somewhat remote from the main focus of postharvest loss reduction in this study, they have the potential for increasingly important savings of food as more centralized storage and processing becomes feasible for a greater proportion of the harvested crop. Research and development in this area is encouraged.

The loss of cooking properties of legumes after storage is an important problem; some legumes toughen and do not become tender regardless of the amount of cooking, a result of as yet unknown changes occurring during storage.

Notes

4-1

Considerable research is in progress on the use of controlled atmosphere (inert gas) storage, but its application to date has been limited to a few installations in developed countries and the People's Republic of China. Though a simple concept, in practice it requires a high level of management and constant monitoring by professional storage scientists.

4-2

Alternative or supplementary practices that should be investigated involve 1) the use of preservatives to retard spoilage, and 2) naturally ventilated drying methods. Preservatives such as propionic acid applied to wet paddy may retard spoilage during a critical period of several days while drying capacity is overloaded. After subsequent drying, the propionic acid remaining (much of it will volatilize) will be on the husk and removed during milling. Research is needed to determine appropriate level of application, economics, and management of this method in field situations.

In theory, even wet-season paddy or panicles should be possible to dry under cover with natural ventilation in similar fashion to the method developed for maize by the African Rural Storage Centre, Ibadan, Nigeria. The method depends on the phenomenon that grain with a moisture content of more than the minimum required for safe storage—13-14 percent—will give up moisture to moving air with a relative humidity of 60-75 percent. This has enabled drying cribs to be designed in which maize can be stored and dried using natural ventilation. The only design limitation is the thickness of the crib, which should not exceed 50 cm to permit penetration by the ventilating air. Even during the most humid periods, the relative humidity drops during the warmer part of the day to levels that apparently permit drying to continue. Supplemented with insecticide applied to the outer surface of the crib and its contents, this method has reduced losses to fungus and insects to about 2 percent after 4 months' storage.

With paddy or rice panicles, the limitation to naturally ventilated drying may be the area of surface of rice that must be presented to the moving airstream. The paddy, being denser than maize cobs, may require large numbers of trays of relatively shallow layers to permit drying to take place sufficiently quickly. This may necessitate considerably more complicated construction than wire-netting, pole, and thatch maize cribs.

4-3

The following pages describe the various stages of parboiling and processing paddy to produce white milled rice grains.

Parboiling. Rice milling involves the removal from paddy of the hull germ and bran (a mixture of pericarp, seedcoat, and part of the aleurone layer of the grain), with the intention of leaving as much of the kernel as possible in its original shape. Some varieties of rice do not yield much head rice (defined as a "grain" of rice, with at least 75 percent of the length of the original unbroken kernel). Even under optimum processing circumstances, certain varieties of paddy produce a low head rice yield because of poor milling characteristics inherent in the genetic composition. To counteract this problem, premilling treatments have been developed in a number of countries.

Since early times, particularly in India, paddy has been soaked for varying lengths of time in hot or cold water and dried before being milled. This may have originated as a method of cleaning the threshed grain, but its effect on the hardness of the grain and improved milling qualities must have become apparent, and it is now widely practiced.

The changes occurring with parboiling result from its effect on the structure of the paddy grain kernel, in which the endosperm is composed of loosely packed polygonal starch granules and intergranular spaces filled with air or moisture. The spaces, together with any cracks or fissures that may have resulted from handling, are the source of weakness from which broken grains result during milling. By soaking the paddy in water, the starch granules swell and absorb moisture, particularly if heat is applied. In this case, some of the granule structure may be weakened, permitting more moisture to penetrate and irreversible swelling, known as gelatinization, to take place. At the end of this process, the paddy may have 45-50 percent moisture and must be dried before further processing. Gelatinization takes place at or above a critical temperature specific for each variety of rice. It may be achieved either by soaking in hot water at or above the gelatinization temperature or by soaking in water below the gelatinization temperature and then heating to expand and fuse the starch granules irreversibly. The most convenient heat source for this purpose, since it must be moist heat, is steam.

Another reason for parboiling rice is to avoid loss of nutrients which, other than carbohydrates, are mainly found in the outer layers of the rice kernel. These are lost during milling, but water-soluble nutrients may be absorbed to some extent into the kernel during the parboiling process.

Parboiling generally conveys the following advantages to the paddy:

- Hulling of paddy is easier because the husk is split during parboiling.
- The gelatinization of the starch helps to reduce grain breakage during milling.

- A higher proportion of amino-acids, vitamins, and minerals is retained than in the same variety of raw milled rice.
- Because the grain is harder, it is more resistant to insect attack during storage.
- In cooking, there is less loss of solids to the cooking water, and overcooked rice suffers less damage than the same variety of raw rice.
- The parboiled rice bran contains up to 10 percent more oil than raw rice bran, and the quality is higher because the heat treatment destroys the rice limase that hydrolyzes the oil.

However, parboiling also has certain disadvantages:

- Parboiled rice does not store as well. Heat treatment destroys natural antioxidants, and parboiled rice develops rancidity more rapidly in storage than white rice.
- Parboiled rice may have taste, texture, flavor, color, or odor that does not satisfy local preferences.
- Under the moist conditions of parboiling, molds may develop and produce harmful mycotoxins.
- Parboiled rice must be dried from a moisture content of 45-50 percent, as opposed to 25-28 percent for paddy, which adds to fuel costs.
- Parboiled rice is more difficult to polish because it is harder, which reduces milling capacity and increases cost.
- The higher oil content of parboiled rice bran may cause it to clog the polisher screen.
- Parboiling requires additional capital expenditure.

In spite of these disadvantages, when parboiling is properly carried out, the higher efficiency of milling and the 1-2 percent greater yield of total rice and head rice increases the total value of the product to a point where it is reported to be possible to produce parboiled rice more cheaply than white rice (Kisan Krishi Yantra Udyog, 1972).

Drying parboiled rice differs from drying paddy. If the rice is dried slowly to remove the large amount of moisture, microorganisms grow and may spoil the rice to some extent. If it is dried quickly, on the other hand, cracks may develop and the milling quality will be low. The rate of drying is the main factor controlling the breakage. Research (Bhattacharya and Indudhar-aswamy, 1967) indicated that breakage does not occur equally throughout the drying process: drying can safely take place quickly down to 18 percent, but from that point the moisture content must be reduced slowly to avoid breakage. As the grain is dried, a moisture gradient develops between the center and surface of the kernel, which stresses the kernel and at a certain stage causes cracking. The cracks appear 2 hours after the drying is completed.

Sun drying and hot-air drying are the two most common drying methods. In India, the parboiled paddy is dried in the sun for 4-5 hours, with continual stirring and turning. This reduces the moisture content to 18-20 percent, after which the rice is heaped and covered with mats or straw and tempered for 2-3 hours to allow moisture in the kernels to migrate. It is then spread and dried for a further 1-2 hours to complete the drying to 14-16 percent moisture. Average milling yields of sun-dried paddy are 72.5 percent. Average losses due to birds, insects, and rodents during the drying process are estimated to be 0.2 percent in calculating the drying cost (Bal *et al.*, 1974).

Simplified machine-drying technology using a Louisiana State University continuous-flow drier fueled by rice husks has been successfully used to generate steam both for the parboiling and the heat-exchanger hot-air generation. The drying is carried out in two passes with a tempering period of 8-10 hours, which seems to produce good milling yields. Drying may also be carried out in the paddy heating vessel by applying vacuum, stirring, and indirect heat (Gariboldi, 1974).

Traditional parboiling methods give rise to a variety of problems. Most of these result from fermentation due to prolonged soaking or delayed drying, with concurrent development of fungus and mycotoxins and discoloration to the grains, which acquire an unpleasant odor and flavor. Handling and drying conditions are often unhygienic, and losses to birds, rodents, and insects may be high. Some research has been carried out on improving the traditional methods by such steps as adding sodium chromate to the soak water to retard fermentation.

The International Rice Research Institute has recently conducted successful research on a "dry" parboiling process in which the threshed paddy is dried at high temperature by being mixed with sand at 200°C. This process evidently causes gelatinzation of the kernel starch with the moisture in the kernel as it is being dried, without the need for prior soaking or steaming and without excessive breakage. If such parboiling proves economic, it may offer an attractive alternative method of handling wet paddy.

Precleaning. Prior to the actual milling, it is necessary to clean the paddy received from the farmer to remove large and small impurities in order to protect the milling equipment and improve the quality of the milled grain. Cleaning is normally done in large mills by sieving to remove impurities of different size from paddy grains. Dust is usually removed by aspiration.

Hulling. The hulling process removes the outer husk from the grain, and the objective is to do this with minimum damage to the bran layer and without breaking the brown rice grain. The process requires that a certain amount of friction be applied to the grain surface to remove the husk, and some damage and broken grain is unavoidable. As we have already seen, damage is particularly high when the drying grain has been exposed to moisture and has cracked. The amount of damage also depends on the design and construction of the huller, the skill with which it is adjusted, operated, and maintained, and the uniformity of the grain being milled. For example, one of the most common types of huller, the under-runner disc huller, consists of two horizontal cast-iron discs, partially coated with an abrasive layer. The grain is fed centrally down a sleeve through the top disc, which is fixed between it and the rotating lower disc, and the clearance between them determines the efficiency with which the grain is hulled and not broken. The quality of the abrasive coating and the accuracy with which the discs are "dressed" or kept flat and level are also important. As hulling continues, the discs become worn and periodic redressing is required. Because there is no flexibility in the discs and the gap between them is fixed, the machine is sensitive to the size of the grain. Proper operation should include provision for pregrading to minimize both breakage of the outer layers and the proportion of small, unhulled grains.

Another type of huller is the rubber roll huller, in which two rubber-covered rollers, mounted horizontally and parallel with clearance between them smaller than the thickness of paddy grains, rotate in opposite directions at slightly different speeds. The grains, fed onto the rollers from above, are caught between the rollers, and because of the difference in speed, the husk is stripped off. Wear on the roller is considerable, reducing its diameter and thereby the speed of the surfaces, which in turn reduces the efficiency of hulling. Although the dehusking performance of roller hullers is superior to disc hullers, the efficiency of the rubber rolls in tropical countries is not good for a number of reasons: the rollers wear quickly because of the high temperature and humidity; they are expensive to replace; and the design of the machinery (usually Japanese) is for short-grain varieties of rice, whereas in tropical countries the grain is often long or medium and wear is greater.

Husk Separation. The output from the huller is a mixture of brown hulled rice, paddy, husks, bran, dust, broken grain, and immature grain. It is necessary to separate the husks from this mixture before it passes to the paddy separator. The dust and bran can either be carried off with the husks or separately aspirated. There are many designs of separator; some operate from hullers, others incorporate into the huller. All of them operate by aspiration of the mixture, and their efficiency depends upon the experience of the operator and adjustment and maintenance of the equipment. When a machine is not operating correctly, it is possible that some broken and immature grains will be lost with the husks. Such grains are a potentially avoidable loss.

Paddy Separation. Following separation of hulls, broken and immature grains, bran, and dust from the hulled brown rice and unhulled paddy, the rice and paddy can be separated. The amount of paddy varies according to the efficiency of the huller, normally between 80 and 95 percent. If the efficiency of the huller is 80 percent, 20 percent of paddy will remain unhulled, and 80 percent will be hulled, yielding 64 percent brown rice and 16 percent hulls. The output of the huller (without the hulls) requiring separation will therefore be a paddy/hulled rice mixture containing 24 percent paddy. With typical minimum-efficiency hulling, therefore, separators must be capable of separating a maximum of 25 percent paddy from the input feed.

This paddy is then returned to the huller or a special "returns huller." Final separation is accomplished by taking advantage of the different physical characteristics of the paddy and brown rice kernels. The weight of a given volume of paddy on average is less than that of the same volume of brown rice; paddy grains are more buoyant, longer, wider, and thicker than brown rice. Separation is carried out on oscillating trays with indentations the size of brown rice grains that retard their passage while permitting the paddy to flow across.

Problems are encountered with this type of separation when the grain is not of the length for which the trays were designed or when wet or dirty grains are processed.

Whitening and Polishing. The whitening process removes the silver skin and bran layers and, in most cases, the germ, while the polishing process imparts a slight polish to the whitened rice grain.

There are three kinds of whitening machine: 1) the vertical whitening cone, 2) the horizontal abrasive whitener, and 3) the horizontal friction whitening machine. The *vertical whitening cone* is a cast-iron, cone-shaped cylinder with an abrasive coating that rotates inside a wire-mesh screen. The mesh of the screen and the distance between the cone and screen are selected according to the size of the rice. The screen is divided at intervals into segments by adjustable rubber brakes. The brown rice is fed into the center of the machine and distributed over the surface of the cone; the rubber brakes impede its flow and press the grains against the abrasive coating and the wire screen, and the friction removes the bran coating, which then passes through the screen. The partly whitened rice falls out at the bottom of the cone and passes onto the next processing stage.

Adjustment of the distance between cone and screen, usually at around 10 mm, and periodic replacement of the rubber brakes and worn sections of screen are necessary to ensure good operation and avoid excessive grain breakage. Regular maintenance of the equipment is also necessary to ensure that it runs without vibration, which also causes breakage. The effectiveness of the whitening process depends on the friction between the grains themselves, the cone, and the screen. If too much heat is generated during this process, there will be excessive broken grains. For this reason grain whitening is increasingly accomplished by passing it through the cone several times, a process known as "multipass whitening" in which the bran is removed more gently, the grain spends less time in the machine, and the clearance between cone and screen is increased so that less heat is generated.

This does not require much additional investment, because the capacity of a single-pass whitening cone is much lower than a multipass system. The multipass system can be composed of several smaller cones with capacity equivalent to one large single-pass cone.

The Japanese *horizontal abrasive whitener* consists of a cylindrical abrasive roll that rotates at high speed in a cylindrical whitening chamber perforated with slots. Rice is fed in between the roller and slotted cylinder and held by an adjustable valve in the outlet so that slight pressure is built up and the grains forced against the abrasive drum. As it circulates, adjustable steel brakes along the length of the cylinder wall control the orientation of the rice grains and the efficiency of the whitening process. The adjustment of these brakes depends on the variety of rice being whitened, and breakage losses depend on the experience of the operator. The rolls wear out and have to be replaced, which creates a supply problem. Another disadvantage is that the clearance cannot be adjusted.

The *horizontal friction whitening machine*, which is often used for the final separation of bran from grain, consists of a horizontal, partly hollow, perforated shaft on which a cast steel rotor with friction ridges is clamped. Perforated screens surround the rotor and rice is fed into the gap between the rotor and the screen, while a strong, adjustable stream of air is blown through the shaft and the rotor and then into the rice. The air cools the grains, separates the loosened bran from the rice, and blows it out of the machine. The friction in the gap imparts a slight polish to the grain, and the air keeps the grain cool. The machine is designed mainly for short-grain varieties; with medium and long varieties, there is considerable breakage of grains and wear on the screens and cylinder, which are expensive to replace.

The vertical polishing cone is similar in construction to the vertical whitening cone; however, the cone itself is made of wood on which leather strips are nailed and there are no rubber brakes. As the rice is fed into the machine, it is gripped by the leather strips and rolled against other grains and the screen. The remaining bran particles are removed and the rice becomes more shiny and translucent. The horizontal polisher or refiner works on the same principle. Both of these simple machines need little adjustment and operate without significant breakage, and the leather strips can be readily made locally and replaced as required.

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Chapter 5

Perishables

The main perishable staples are cassava, yam, sweet potato, white potato, taro, banana and plantain, and breadfruit. In the developing countries, these staples and the major vegetables and fruits comprise over 39 percent of food crops consumed (see Table 1:1). However, their importance in the diets of many peoples is disproportionately greater than this because they are the major source of carbohydrate and energy and supplement otherwise monotonous cereal-based diets with vitamins and minerals.

From the perspective of postharvest losses, the perishable staples present a very different set of problems from the durable commodities, the cereal grains and grain legumes. They have relatively high moisture content–from 50 percent upwards–and are difficult and expensive to dry and hence to store as dry products. Furthermore, the dried product is very different from the fresh and is often less acceptable. Lacking the hard texture of cereal grains, the perishables bruise easily. Although they are nutrient-storage and reproductive parts of plants, even those that are organs of dormancy (such as yams) are metabolically much more active than the seeds of durable staples and seldom have prolonged dormant periods. Roots and tubers continue to respire and metabolize, at a low level compared with the growing plant but at a much faster rate than in cereals, since they maintain the life of the plant through the nongrowing season. This characteristic limits their extended storage possibilities.

The edible parts of most fruits and vegetables are not the seeds, which are often discarded, but fleshy tissues whose natural function is to support the germination and growth of the seed when the fruit falls or to attract birds or other agents by which the seeds can be spread. The edible tissue is meant to perform these functions when it is ripe, not to serve as a food store in the dry condition, and its storage life may be only days.

Estimates of Loss

There are few accurate figures available for losses of perishables measured by a described methodology. Even those loss figures that have been obtained by direct measurements are of limited value because they cover the loss for one specific commodity, in one location and for one specific set of conditions, and the extent of loss in perishable products can vary greatly within a short time. Further, the figures presumably indicate total weight loss and do not normally distinguish between loss of food *per se* and loss of moisture during storage or due to metabolic processes that continue after harvest.

The high moisture content of perishables seriously affects loss estimation, since it is difficult to express weight loss on a constant moisture basis and loss of moisture over short periods may be taken to be loss of nutrients. The length of time from harvest to observation is much more critical to percentage loss estimation in perishables than in durables; losses tend to increase rapidly, often becoming total within days. In future critical work, the age and state of the commodity needs to be indicated.

Table 5:1 and Table 5:2 (from FAO and other sources) lists figures for losses in horticultural produce. The very wide range of loss cited and, in a few cases, the improbably precise narrow range of loss given in this table reveal the inadequacy of data on losses of perishable products. Nevertheless, the opinions of a group of professionals (NRC, 1978) with long experience with some of the commodities in developing countries produced the following figures as being typical of the normal ranges of loss experienced under usual marketing conditions:

White potatoes in Chile, Peru, and Venezuela	25-30 percent
Cassava in Venezuela, Colombia, Ecuador, Dominican Republic, and Central America	15-25 percent
Tomatoes for fresh market in most developing countries	50 percent
Yam in Nigeria and Ghana	10-20 percent

Although specific examples of loss can be found that lie above or below the ranges cited above, the experienced professionals who provided these figures believe that they represent a fair overall assessment of current losses in the commodities named and are sufficiently realistic to be used as a basis for future planning. They nevertheless consider it worth further effort to obtain more and better figures in order to identify the specific areas where loss reduction activities would be most effective. Most important, there is unanimous opinion that these levels of loss warrant substantial intervention.

Causes of Loss

Mechanical Injury

Perishables are much more susceptible to injury than durables because of their shape and structure, the relatively soft texture associated with their high

TABLE 5:1 Nongrain Staples, Vegetables, and Fruit Losses Reported by Region and Country (From FAO, 1977b, Unless Otherwise Indicated)

Region/ Country	Roots/ Tubers (Percent Loss)	Fruits/ Vegetables (Percent Loss)	Remarks
AFRICA			
Ghana	10-20	30-35	
Nigeria	15-60		Yams, Olorunda (1977)
	10-50	10-50	
Rwanda	5-40	5-40	
Sudan		50	Lack of transport to market
ASIA/FAR EAST			
Sri Lanka		20-40	
Thailand		23-28	
Indonesia	10	25	Cassava
		15-25	
Philippines		10-50	
Malaysia		20	
India		20-30	
Jordan		2-3	Lack of cold storage
Iran	5-100	5-10	Frost in potatoes, Steppe (1976)
		14-28	Subtropical fruits
LATIN AMERICA			
Dominican Republic	24-26	25	Except plantain–10; tomatoes–13; green beans–12
	17		Cassava, Tejada (1977)
Chile	30	30	Potatoes
Brazil	5-30	8-10	Cassava–10; potatoes–5-30; pineapple–8; banana, tomatoes, orange–10
Bolivia	24	17-30	Potatoes–24; citrus–27; tomatoes–30; pineapple–17
Peru	20-50		Potatoes, Werge (1977)

moisture content, and the need for more frequent specialized handling. Injury can occur at almost any point in the postharvest system and results from poor handling and packaging, from transportation and storage conditions, or from damage in the marketplace.

Physiological Losses

Physiological losses consist of natural losses due to endogenous respiration, losses of moisture from wilting or transpiration, and abnormal losses that may arise from exposure to heat, cold, or otherwise unsuitable environmental conditions.

Losses Due to Disease

Possibly the greatest single cause of postharvest loss in perishable produce is decay caused by microorganisms. This usually occurs from initial infection

TABLE 5:2 Nongrain Staples, Vegetables, and Fruits
Losses Reported by Commodity

Commodity	Production in LDCs* ('000 tonnes)	Estimated Loss (Percent)	Remarks
ROOTS/TUBERS			
Carrot	557	44	Thompson, in Coursey (1971)
Potatoes	26,909	5-40	8% in cold store; 20-40/ on farm; FAO (1977b)
Sweet potatoes	17,630	35-95	Thompson, in Coursey (1971); Hall (1970)
Yams	c.20,000	10-60	FAO (1977b); Olorunda (1977)
Cassava	103,486	10	Indonesia, Brazil, FAO (1977b)
		15-25	(see text)
VEGETABLES			
Onion	6,474	16-35	Thompson, in Coursey (1971); Steppe
Tomatoes	12,755	20-50	(1976)
			Thompson, in Coursey (1971); Steppe
		5-16	(1976); Olorunda (1977)
Plantain	18,301	35-100	In transport only, Rawnsley (1969)
Cabbage	3,036	37	Olorunda (1977)
Cauliflower	916	49	Thompson, in Coursey (1971)
Lettuce		62	Thompson, in Coursey (1971)
			Thompson, in Coursey (1971)
FRUITS			
Banana	36,898	20-80	Olorunda (1977)
Papaya	931	40-100	Olorunda (1977)
Avocado	1,020	43	Thompson, in Coursey (1971)
Peaches, apricots, nectarines	1,831	28	Steppe (1976)
Citrus	22,040	23-33	Steppe, Iran (1976)
		20-95	Olorunda, Nigeria (1977)
Grapes	12,720	27	Steppe (1976)
Raisins	475	20-95	Steppe (1976)
Apples	3,677	14	Steppe (1976)

*Less developed country figures taken from FAO, 1977a.

by one or more specific pathogens, which may then be followed by secondary infection by a broad spectrum of biodeteriogens saprophytic on the dead or moribund tissue remaining from the primary attack (Coursey, 1971).

Attack by rodents or stored-product insects are usually of relatively minor importance in comparison to decay from microorganisms, although these factors may be important in particular instances.

Preservation, Storage, and Conservation

Preservation and conservation of nongrain staples is very different from drying and storage of the durables. In many developing countries there has been no interest in trying to reduce these losses because of abundant cheap supply. Political awareness of the need has also been slow because of predominant interest in export and commercial crops or grains and legumes.

The nongrain commodities cover a wide range of roots, tubers, fruits, and vegetables. Their storage life may be as little as a day or two or as long as several months. Although there are perhaps more differences than similarities among them, there are a number of common storage problems; these will be outlined briefly before individual categories of perishables are discussed.

Storage Problems

Storage deterioration is brought about by endogenous physiological processes or by attack of pathogens (fungi and bacteria), both of which may be aggravated by physical damage to the crop. The main causes of storage loss in perishables are:

- Fungal damage, influenced by the lack of rigidity of perishable crops as compared with grains and the ease with which they are damaged during harvest or handling;
- Sprouting at the end of the natural period of dormancy, which affects roots and tubers; and
- Insect damage, usually a relatively minor problem of perishables stored fresh, occurring most frequently while the root is still in the ground or the fruit or vegetable is still attached to the plant and relevant mainly in that it aggravates fungal problems by providing additional points of entry.

In general, losses due to physical, physiological, and pathological damage are minimized by care in harvesting and appropriate storage treatments and conditions. In many cases, however, harvest lesions caused by separation of the organ from the plant are unavoidable. When they occur, roots and tubers can be "cured" to reduce the effects of minor harvesting damage by being kept at high ambient temperature (35°–40°C) and relative humidity (85 percent) for a few days. Under these conditions suberization occurs, a healing process in which a callus is formed over the damaged areas, minimizing the risk of fungal infection. Lowered temperature generally prolongs storage life, although it is characteristic of many crops to suffer low-temperature or "chilling" damage when subjected to temperatures below about 10°C.

Cooling and Refrigeration

Refrigeration is undoubtedly an important means of prolonging the storage life of high-quality fresh tropical produce, but it has a number of limitations for reducing food losses in developing countries, including the following:

• Many tropical horticultural products are liable to low temperature injury–physiological deterioration at temperatures near, but above, freezing.

• Many of the commodities are currently too low in unit cost to bear the cost of mechanically refrigerated storage.

• The capital cost–and the not-inconsiderable cost and organization of efficient and continuous maintenance of significant amounts of mechanically refrigerated storage–is likely to continue to be a major limitation for the foreseeable future.

In the long run, economies of scale will undoubtedly increase the importance of large-scale cooled storage. Other simpler and less costly approaches are necessary in the short run. The provision of simple shade can make a great difference to the storage life of perishables; exposure to the tropical sun can raise the internal temperature to 45°C when ambient temperature is only 30°C. Simple low-cost cooling systems, as distinct from mechanical refrigeration, could make possible great improvement in holding and marketing perishables; reducing the temperature even a few degrees might make a difference. This area requires priority research, with respect to both technology and to the physiology of deterioration.

Handling and Packaging

Major reduction in the amount of loss can undoubtedly be accomplished by improved handling and packaging at all stages of the movement of

Pak Chong market, northeast Thailand (FAO photo by G. H. Ward) perishables from harvest to consumption. Delicate produce is often handled in the same way as the durable crops, and the mechanical damage greatly increases the rate and extent of both physiological and microbiological deterioration. Improvements in packaging and handling also may often be accomplished at little cost. They may require nothing more than ensuring that the produce is handled in smaller quantities and in shallower containers; for instance, in rigid wooden crates or cardboard cartons rather than sacks or in loose bulk. These improvements are normally so situation specific that a detailed discussion is beyond the scope of this report. Proper packaging and handling is so important, however, that it should be among the first aspects of food loss to be investigated.

Improvement in transportation and marketing systems, to reduce the time between harvesting and consumption, can greatly reduce loss.

Perishable Crops

The remainder of this chapter deals with the major categories of nongrain staples and with some of the more important individual crops.

Roots and Tubers

Roots and tubers provide the staple food for an estimated 400 million-500 million people in the tropical world, and of the estimated 1976 world production of 558 million tonnes, 177 million were produced in tropical and semitropical regions (FAO, 1977a). Table 5:3 shows estimated production of the main species by region in 1975 (the last year FAO production estimates were so reported). Cassava production in developing countries (105 million tonnes in 1976) made it the second most important crop after rice (Table 1:1).

TABLE 5:3 Production of Root Crops in the Developing World (after FAO, 1976) ('000 tonnes)

	Cassava	Potato	Yam	Sweet Potato	Taro	Miscellaneous Root Crops*	Total
Africa	42,844	2,039	19,279	5,539	3,569	1,466	74,716
Latin America	32,201	8,951	291	3,379	–	811	45,633
Near East	1,128	4,706	260	94	59	–	5,747
Far East	27,643	8,445	30	8,764	90	1,674	46,646
Other	0,221	6	700	560	262	390	1,639
Developing World Total	104,037	23,647	20,060	18,336	3,980	4,321	174,381

*Includes *Xanthosoma*, arrowroot, arracacha, yam beans, oca, and olluco.

Coursey and Booth (1972, 1975) estimate that 23 percent of the total production of root crops is lost due to an inadequate understanding of storage needs. Most storage problems are related to the physical characteristics of the stored root crop. Roots and tubers are living, actively metabolizing organs that continue to respire and transpire at much higher rates than the dry, dormant grains of durable crop products after harvest. Unlike the food grains, they are high in moisture content and are essentially perishable commodities susceptible to mechanical damage, physiological breakdown, and attack by fungi and bacteria.

This fact has long been recognized in developing countries, where cassava is usually left in the ground until needed; once harvested, the roots are either used immediately or processed into dried products with longer storage life. Occasionally, yams are also left in the ground until needed, but usually they are stored hanging on supports, stacked on racks, or kept in boxes that allow the air circulation necessary to the metabolism of the detached tuber.

The traditional system allows cassava to be harvested over a long period, but Ingram and Humphries (1972) estimate that the practice of leaving cassava in the ground until required unnecessarily occupies 750,000 ha of agricultural land. In addition, losses due to pathogens can increase when the roots remain too long in the ground. Further, as the roots continue to grow with the plant they become more fibrous and woody, with a decrease in both nutritional value and extractable starch content.

Investigations at CIAT, the Centro Internacional de Agricultura Tropical (1973, 1974; Booth, 1976, 1977), identify two types of postharvest deterioration, termed primary and secondary, as follows:

1. Primary deterioration usually makes the roots unacceptable for consumption and is initially manifested by blue-black streaks in the vascular tissue. It is generally associated with mechanical damage, especially a harvest lesion where the roots are separated from the plant. The possible role of microorganisms at this stage has not yet been clarified. The discoloration spreads and causes a more general, brown discoloration of the root tissue.

2. Secondary deterioration involves a widespread invasion of the tissues by any of a number of destructive fungi, which are not, however, primary pathogens.

Factors responsible for storage losses in root crops have been reviewed by Coursey and Booth (1972) and Booth (1974). Five principal factors operate to bring about the deterioration:

1. *Physical processes.* Purely mechanical damage to the produce is common, such as lesions produced at harvesting, crushing or breakage, and spillage or loss from faulty containers. Such damage causes further storage

problems by stimulating physiological changes and enabling penetration by pathogens.

2. *Autolytic processes.* Chemical or biochemical changes may arise as a result of processes in the produce that are either purely internal or that occur in reaction with the environment.

3. *Insect attack.* Durable produce in store often becomes infested with insects or other arthropods, causing both actual loss (disappearance) of the produce and partial or complete spoilage of what remains. With most root crops insects are of minor importance, except in roots stored in dried form, which then behave like durable crops.

4. *Microbiological attack.* Many species of fungi and bacteria, whose initial invasion may occur either pre- or postharvest, have a deleterious effect on stored root crops, and in some cases–especially in tropical climates–can cause serious losses.

5. *Rodent attack.* The damage done to stored crops by rodents, and occasionally by other vertebrates, is well known. Conventional control measures developed for grain storage can be applied.

Cassava (*Manihot esculenta*)

The commercial processing of cassava has been inhibited by storage problems; substantial deterioration can occur even during the few days that buffer stocks of fresh roots are being held at the factory to await processing. Where the crop is marketed as a fresh vegetable, considerable losses occur at all stages in the marketing chain, especially where the market is some distance from the farm. Booth and Coursey (1975) speculate that cassava may differ from other root crops such as yams, potatoes, and sweet potatoes as a result of its evolution, and suggest that "the swollen edible roots developed as an artifact of domestication by man in the comparatively recent past rather than as a response to any climatic stimulus." The cassava root thus appears not to be an organ of dormancy, which may explain its inherently poor storage qualities.

The rate at which deterioration occurs appears to differ considerably between cultivars (Montaldo, 1973; Booth, 1976), beginning from 0 to 7 days after harvest. This rate may also be related to the differences that exist between cultivars in ease of harvesting, with resultant differences in amounts of mechanical damage. Selection of cultivars for good storage and handling properties is being undertaken at a number of centers, particularly CIAT and IITA. Recent studies have suggested that plant growth regulator systems are involved, and that deterioration may be inherently associated with detachment of the root from the plant.

Curing. Curing has been widely used for enhancing the storage life of a number of root crops such as potatoes, yams, and sweet potatoes, but not so far for cassava. At relatively high temperatures and humidities, wounds are healed and subsequent deterioration is delayed or limited. Booth (1975, 1976) reports that at a relative humidity of 80-85 percent and temperatures between 25°-40°C, suberization occurs in cassava in 1-4 days and a new cork layer forms around wounds 3-5 days later. At 40°C and above, primary deterioration usually takes place before the wound can heal. Curing delays the onset of primary deterioration and reduces both secondary deterioration and moisture loss. Curing arrests only previously acquired damage, and if the produce is handled again recuring is required to inhibit further deterioration; thus, the number of times roots are handled should be minimized.

Storage Techniques. Traditional techniques exist for storing small amounts of fresh roots that are successful for several days or even weeks, including reburial, coating with mud, placing under water, or piling in heaps and giving a thorough daily watering. Ingram and Humphries (1972) cite several cases of successful storage of larger quantities of fresh cassava roots for longer periods using various simple techniques such as burying, with success considered due to resultant curing of the roots. Successful trials of pre-storage curing followed by storage in simple field clamps or in boxes packed with moist material have been carried out at CIAT (Booth 1975, 1977). The experience indicates that successful clamp storage of quantities up to 500 kg per clamp can be achieved for periods up to 3 months under relatively cool, moist conditions, whereas during hot, dry conditions, almost complete loss of roots occured after 1 month. This may result from rapid deterioration inside the clamp where the temperature has exceeded 40°C, and appropriate ventilation should be included where this is likely to occur. Although excess moisture should also be avoided to prevent rotting, small amounts of moisture help to keep the clamp cool. Clamp design therefore needs to be highly location specific.

Packing freshly harvested cassava roots in moist sawdust in boxes is also reported to be very effective in storing them for 1-2 months. Moisture content and temperature appear to be critical; if conditions are too dry, curing does not occur and primary deterioration results; if too wet, secondary root development and rotting occur. Local ambient temperature under shade (around 26°C) appeared most satisfactory. The sawdust packing method, which also provides a simple and relatively inexpensive means of transporting and marketing the roots without further handling, appears particularly suited for farmers producing for commercial markets some distance from the farm.

Waxing cassava is reported (IIT, 1973) to extend life of cassava to 30 days by reducing the rate of gas transfer between tissues and the atmosphere; this approach should be pursued further.

These techniques appear to be a major contribution toward solving the problem of longer-term storage of fresh cassava, offering simplicity for both curing and storage in a single operation and an acceptable weight of usable produce after storage periods of weeks or even months. However, the factors involved are not fully understood and storage is not always successful. Further location-specific, adaptive research is needed.

Storage of Dried Cassava Products. A variety of dried cassava products is prepared in Africa, Asia, and Latin America according to local needs, traditions, and tastes. There has been comparatively little research into the storage of these products, perhaps because they are of relatively low commercial value and improved storage technology may be considered uneconomic.

The problems of dried cassava storage are similar to those of grains. Drying below a critical moisture content of 12–13 percent is the first essential for successful storage, and insect attack, rather than endogenous or pathological processes, is a major cause of storage loss. The principal losses in storage resulting from the activities of insect pests are tabulated by Ingram and Humphries (1972).

The main products of dried cassava are chips, flour (ground from the chips), and several kinds of granular meal.

Cassava Chips. To make chips, roots are washed, peeled, and chipped or sliced into suitable sizes and then dried. Sun drying, usually the only process that is economic, takes 3–10 days, depending on the weather. When the moisture content is reduced to 12–13 percent, the chips have good storage qualities, but if stored too long they are subject to insect attack, atmospheric moisture absorption leading to mold, and souring. If properly dried, chips will usually keep from 3 to 6 months before becoming excessively insect infested; if necessary, as a result of wet weather, chips can be redried. Chips made from bitter cultivars are said to store best. Delayed drying after harvest adversely affects storage qualities of the chips.

When properly prepared, the chips are crisp and white and break easily without crumbling. They have a comparatively low density, which means they require relatively large storage facilities.

Parboiled chips, commonly made in India, are reported to have a longer storage life than ordinary chips; however, this may reflect greater care in storage rather than inherent properties. Bags lined with polythene reduce moisture uptake and insect infestation. Chips are readily attacked by insects, and losses in exports from Tanzania some years ago were reported at 10–12 percent. Conventional insect control using a variety of chemical sprays and fumigants, combined with careful disinfestation of warehouses before storage, is generally effective.

Any fungal infection of chips usually begins during the drying period, particularly if this is extended on account of wet weather. It can be controlled to some extent by steeping the chips in sulfurous acid (Ingram and Humphries, 1972).

Cassava Flour. Grinding or pounding the chips produces cassava flour or meal. This presents a different set of storage problems, and the product is

Selling fermented cassava flour wrapped in banana leaves, Kinshasa market, Zaire (FAO photo by J. C. Abbott)

recognized to be more difficult to store in bulk. Fortunately, some insects that attack chips do not thrive in flour and suitable bags can provide a barrier to those that do. Flour takes up moisture and becomes sour more readily than chips.

Cassava Granules: Gari and Farinha da Mandioca. Two important dried cassava products are the West African *gari* and the similar Brazilian *farinha da mandioca*. There are local variations on the method of preparation, but basically the method is to wash and peel the roots, which are then grated and the mash allowed to ferment spontaneously. (Brazilian *farinha* is not fermented, or only for a very brief period; West African *gari* is fermented from 2 to 5 days.) The water is squeezed from the residual mass and the granular product prepared by drying and partial gelatinizing, usually in a metal pan or plate over an open fire. Well-prepared *gari* will keep for several months, but it is subject to fungal attack if not properly dried: moisture levels of 12-13 percent are the maximum for safe storage. *Gari* is normally consumed soon after production and is not stored for long, as it takes up atmospheric moisture rapidly and molds easily.

Yams (*Dioscorea* spp.)

Yams, like most staple food crops, are not all consumed immediately after harvesting; they are a highly seasonal crop and the tubers must be stored at least for several months, from the end of one harvest to the beginning of the next. This is possible because the tubers, being organs of dormancy, have inherently longer storage life than most perishable foods.

Storage Practice. Being largely crops of farmers with small holdings, yams are generally stored in limited quantities, rarely more than a few tonnes and often less. Storage in markets is usually of short duration as stocks are turned over rapidly, with reserves of yams being held by the farmers and sold off gradually throughout the year. A substantial proportion of the yam crop is used for subsistence and never even appears in local trade.

Yams are sometimes simply left in the ground until they are required for food or sale, especially in some of the remoter parts of West Africa, but better storage methods are used in most districts. After lifting, they may be simply piled into small heaps of only a few dozen tubers, sheltered from sun or flooding in such places as crevices in outcrops of rock or between the buttresses of large trees. Alternatively, yams may be stored without any special arrangements or precautions in ordinary storerooms or in sheds or huts either not in use or specially constructed for this purpose. Small, thatched, mud-block or wattle-and-daub huts are sometimes built for yams, or the space under houses on piles or stilts can be utilized. The importance of good ventilation in such stores, even under the subtropical conditions of the southern United States, has been emphasized by Young (1923), and the need for shade has been emphasized by Coursey and Nwanko (1968).

Throughout most of West Africa, the world's largest yam-growing area, the usual type of store is the "yam barn". Yam barns vary considerably in design and construction between regions, but all consist, in principle, of an approximately vertical wooden framework 2 m or more high to which the yam tubers are individually tied. The length of the frames depends on the amount of material to be stored. The vertical poles of the frame are frequently of timbers that will take root and sprout when set in the ground, e.g., *Dracaena, Gliricidia, Ximenia*, or *Gmelina*. This reduces the danger of termite attack or decay and, after the poles have sprouted, they provide some of the shade necessary for successful storage. The cross-members of the frame may be of lighter timber, bamboo, or palm-leaf midribs. A palm-thatch roof may be provided, and two or more frames are often erected alongside each other and the whole barn surrounded by a fence or hedge for security.

In practice, these structures are highly effective. The tubers receive adequate ventilation and are protected from termite attack and danger of flooding. The construction materials cost little, and are often simply cut from the forest as required.

Rather similar structures ("huttes-greniers") are used in parts of Oceania, consisting of platforms of light poles supported above ground level or vertical poles that also carry a roof of straw or thatch. The yams are stacked vertically on this platform, and further horizontal poles fixed around the platform to prevent them from falling off.

Experiments in Nigeria on storing yams in clamps like those used for potatoes in Europe (Waitt, 1961) gave somewhat variable results, with some cultivars storing better in clamps than in barns, while for others the reverse was true. Clamp storage has not been adopted in practice, but further investigation would be of interest.

Experiments on the storage of yams in underground pits have also been undertaken but have not proved very successful, since the fundamental requirement of yam storage—ready availability of air—was not satisfied. Similarly, storage in hermetically sealed containers or silos, which has proven very satisfactory for grain and legume crops, has not worked well with yams.

Storage Loss Estimates. The opinion has become widespread among agriculturalists that "yams store well," probably arising from the fact that storage deterioration of yams usually manifests no immediately obvious defects. There is no doubt that, compared with most nongrain staples, yams have an inherently long storage life. However, there are great variations of storage suitability between species and cultivars, or even within cultivars, influenced by such factors as conditions of growth, time of harvest, and fertilizer treatment. Gooding (1960) quotes loss after 4 months' storage as between 7 and 23 percent in different *Dioscorea alata* cultivars. Farmers are usually well acquainted with variations in storage quality among forms grown in their area.

Yam tubers are sometimes suspended individually on strings from horizontal poles, themselves supported above ground level on forked sticks set in the ground. This has the advantage of affording protection against rodent attack, as well as providing ample ventilation and security from flooding.

Yams, nevertheless, suffer serious losses in weight during normal storage, as is indicated in the results of the experiments summarized in Table 5:4. These observations suggest that weight losses of 10–15 percent are normal during the first 2 months' storage, while after 6 months the losses may be as much as 30—or even 50—percent. Allowing for the proportion of the crop that is stored and that which is consumed shortly after harvest, it has been estimated that in West Africa alone about a million tonnes of edible yams are lost annually in storage (Coursey, 1965). These weight losses are not from desiccation, but are, at least in part, losses of food material arising from the metabolism of dry matter to carbon dioxide and water. Yet many varieties of yam may nevertheless be stored for long periods without significant reduction in quality. Although the quantity of food has been diminished in storage, what remains (unless pathogenic invasion has occurred) is nutritionally and physically comparable with fresh material.

Factors Responsible for Storage Losses. In stored yams, all five types of loss—mechanical, metabolic, insect, microbiological, and rodent damage—occur to some extent. The most important of these are metabolic or autolytic

TABLE 5:4 Summary of Information on Weight Losses in Stored Yams*

Country of Origin	Species	Percentage Weight Loss During Storage						
		1 month	2 months	3 months	4 months	5 months	6 months	8 months
Puerto Rico	"Guinea yams," presumably	1	3	8	(sound tubers)			
	D. cayenensis	2	6	11	(tubers slightly infected by rot)			
Trinidad	Not stated	–	–	14-5	–	–	–	
Trinidad	*D. alata*	–	–	–	–	–	–	**30-40
Nigeria	*D. rotundata*	–	–	–	–	–	50 (at Abak)	
		–	–	–	–	–	67 (at Umuahia)	
		–	–	–	–	–	33 (at Abakaliki)	
Trinidad	*D. alata* (various cultivars)	–	–	–	7-23	–	–	–
Nigeria	*D. rotundata*	5	7	12	20	29	(at Bori)	
		4	6	10	14	21	(at Abakaliki)	
		3	6	14	23	30	(at Umuahia)	
Nigeria	*D. cayenensis*	6	17	29	39	48	–	–
Ghana	*D. rotundata*	1	5-7	15-17	26-27	34-40	–	–

*(From Coursey, 1968).

**Treated with methyl alpha-naphthyl acetate to inhibit germination.

processes and attack by fungi or bacteria. A sixth source of damage, chilling, also occurs and, with the other causes of loss, is discussed below.

1. *Mechanical damage.* Yam tubers are readily injured during harvesting, especially the large-tubered forms; tubers are easily cut or bruised and are awkward to handle. To reduce the risk of damage, wooden spades or digging sticks are often used in yam harvesting in preference to normal iron tools. A strong positive correlation exists between tuber size and extent of harvest damage. The incidence of severe damage ranged from less than 5 percent in the smaller tubers examined to over 50 percent in the largest. Bruising and abrasion of the tubers also occurs during transportation, especially when they are moved by vehicle over the rough roads of many tropical countries.

2. *Metabolic damage.* Yam tubers are still living, if dormant, systems in which the basic metabolic processes of the plant continue, although more slowly than in the active growing phase. The most important metabolic process is respiration, resulting in the conversion of the carbohydrates of the tubers into carbon dioxide and water, which are lost by evaporation. Respiration has been more thoroughly investigated in temperate crops such as the potato, but little direct respirometric evidence is available in the case of the yam. Passam and Noon (1977) have shown variation in respiration patterns during storage, and Passam *et al.* (1976a) illustrate the physiological factors associated with wound repair in yams and demonstrate the correlation of respiratory changes with carbohydrate loss.

3. *Insect damage*. Insect attack is generally of little importance in the storage of unprocessed yams for sale (ware yams). Scale insects do infest them occasionally, but cause comparatively little ware yam loss, although they may affect the viability of stored seed tubers.

The yam beetles *Heteroligus* and *Prionoryctes* spp. are preharvest pests, but the damage they cause before harvesting may render the crop more liable to invasion by rotting organisms during subsequent storage. *Paleolopus* is an occasional postharvest pest of yams in the Caribbean.

Yams in store are occasionally attacked by termites, especially if they are stacked on the ground. In barns, termite attack can easily be avoided by simple attention to hygiene, with any tunnels built by termites on the supports of the barn being regularly destroyed.

Nematodes can cause postharvest loss of yams. Thompson *et al*. (1973) showed that nematode populations increased during storage. Fumigation was not successful, and although hot water treatment reduced the numbers, damage still occurred to the tubers. Nematode infections also increased susceptibility of tubers to storage rots; Ekundayo and Naqvi (1972) show their association with dry rot disease.

4. *Microbial damage*. Apart from metabolic processes, storage rots are the main factors responsible for the deterioration of stored yams. Several fungal species have been identified (Table 5:5) as associated with tuber rots, including hard, brown, dry rots and wet, slimy rots (Ogundana *et al*., 1970, 1971; Ogundana, 1972).

Various bacterial infections have also been observed in yams. Pathogenic invasion of the tubers is greatly facilitated by mechanical damage by acciden-

TABLE 5:5 Some Rotting Organisms Associated with Stored Yams

Organism	Country where Isolated	Reference
Botryodiplodia theobromae Pat.	Ivory Coast	Miège, 1957
Botryodiplodia theobromae Pat.	Ghana	Dade and Wright, 1931
Botryodiplodia theobromae Pat.	Nigeria	Anon, 1962; Okafor, 1966
Lasiodiplodia sp.	Ivory Coast	Miège, 1957
Rhizopus nodosus Namyslowski	Ivory Coast	Baudin, 1956
Sphaerostilbe repens B. ct Br.	Ivory Coast	Baudin, 1956
Fusarium oxysporum Schlect ex Fr.	Ivory Coast	Baudin, 1956
F. bulbigenum Cooke et Massee	Ivory Coast	Baudin, 1956
F. solani (Mart.) Sacc.	Ivory Coast	Baudin, 1956
Rosellinia bunodes (B. et Br.) Sacc.	Jamaica	Smith, 1929
Rosellinia bunodes (B. et Br.) Sacc.	Jamaica	Larter and Martyn, 1943
Hendersonula toruloidea Natrass	Nigeria	Okafor, 1966
Macrophomina phaseoli (Maubl.) Ashby	Nigeria	Okafor, 1966
Penicillium sp.	Nigeria	Okafor, 1966
Serratia sp.	Nigeria	Okafor, 1966
Aspergillus, etc.	Nigeria	Ogundana *et al.*, 1971

tal cutting or bruising or by preharvest nematode attack. In some producer countries it is a common practice to treat cut or bruised portions with an alkaline material, such as limewash or wood ash, to reduce the probability of infection. Coursey (1961) has shown that limewashing and other fungicidal treatments reduce weight loss during the first 2-3 months of storage, but may be ineffective over longer periods. Losses due to causes such as wound pathogens, weight loss, and respiratory loss, are reduced by "curing" or storage at low temperature (Gonzalez and Collazo de Rivera, 1972; Rivera *et al.*, 1974; Martin, 1974; Passam *et al.*, 1976b). Thompson *et al.* (1977) have summarized the use of fungicides in the storage of yams.

Quite beyond the loss of acceptability that occurs when yams decay, infection leads to greatly enhanced weight loss. Sound tubers that later become rotten lose weight faster than those that remain sound, suggesting that pathogens actively contribute to weight loss even before symptoms of decay are visible. This agrees with the observation by Coursey *et al.* (1966) that the respiration rate of apparently sound yam tissue is reduced by antibiotics.

5. *Rodent damage*. Yams are occasionally attacked in store by rodents. Although the quantities actually consumed are generally small, the damage done to the tubers predisposes them to decay. In West Africa, most damage is probably done by the large cane-rat or "cutting-grass," *Thryonomys swinderianus* (Peters) and the giant rat *Cricetomys gambianus* (Thomas and Wrongton). Conventional control measures can be applied with good effects.

6. *Chilling damage*. Yams, like most crops cultivated in tropical countries, suffer physiological damage at temperatures well above freezing. Young (1923), discussing yams as crops for the southern United States, points out that in storage freezing temperatures must be avoided and suggests that 12°-16°C is the optimum range.

It appears that cold storage is unsuitable for yams, but the possibility exists of using cooled storage, probably around 15°C, at which no chilling damage will occur but at which the rate of metabolic processes, and hence the storage losses, will be substantially reduced. Extensive research will be needed if this principle is to be applied to practical storage on a commerical scale, as each species, and probably many different cultivars, doubtless have differing optimum storage temperatures.

Effects of Inhibitory Treatments. The storage behavior of potatoes and other temperate root and tuber crops can be improved considerably by the use of sprouting and respiration inhibitors, and some have gained widespread commercial acceptance. Similar techniques have not as yet been applied to yams on a practical, farming scale. Experiments to date with chemical sprout inhibitors are inconclusive and more research is needed.

Yam Flour. This staple is manufactured in quantity in parts of West Africa, and to some extent elsewhere; it is virtually the only processed food product made from yams. Yam tubers are sliced, usually parboiled, and the slices peeled and dried in the sun to a moisture content of only a few percent. After drying, the yam pieces are ground in mortars or milled in corn mills to yield a coarse flour. The flour is reconstituted by stirring into boiling water to form a pasty dough.

Yam flour is usually manufactured from yam tubers that are of inferior quality or peculiar shape, that have been badly damaged in harvesting or heavily attacked by yam beetles, or that are partially rotten and would not store well.

The storage of yam flour or dried pieces of yam presents entirely different problems from storage of fresh yams. Insect attack is a serious threat; several stored-products insects infest yam flour (Cornes, 1964), of which *Araecerus fasciculatus* De G. (Coleoptera, Anthribidae) and *Sitophilus zeamays* Mots. (Coleoptera, Curculionidae) are by far the most common. Pieces of dried yam arriving at mills are often riddled with holes caused by the first species, and stores where yam flour is kept in normal sacks are usually heavily infested with one or both types. However, insect attack can be fairly easily controlled, first by milling the dried yam pieces shortly after preparation, before any infestation has a chance to build up, and second by packing the flour immediately after preparation in insect-resistant containers such as polythene bags or polythene-lined sacks. Infested material can be fumigated by normal methods, for example with methyl bromide.

Rodent attack may also be severe, but can be prevented by good storage hygiene and conventional control measures.

Potatoes (*Solanum tuberosum*)

In 1976, the annual production of potatoes in developing countries approached 27 million tonnes (Table I.1, FAO, 1977a), contributing over 3 percent of major food crop production. The potato is the staple crop of many poor farmers in the tropical highlands of Latin America and is increasingly important in the highlands of East and North Africa, Bangladesh, India, Korea, and the People's Republic of China.

Losses. Like other tubers, the potato is subject to postharvest weight loss due to its continuing metabolism, to damage during harvest and handling, to rotting, drying, and shriveling, and to sprouting. As with all nongrain staples, losses may be considerable after extended periods of storage, although very few loss estimates have been made in developing countries. In the Dominican Republic losses have been estimated (Mansfield, 1977) at 7.5 percent weight loss due to dehydration and infection over a 24- to 48-hour period, 31 percent total loss in less than 15 days (not including harvesting losses), and greater losses over longer periods. Coursey and Booth (1972) give a global postharvest potato loss figure of 25 percent.

Present modern storage technology in the United States, employing intermittent ventilation with 9°C air containing 95 percent humidity, reduced weight loss to 6.3 percent and total potato loss to 12.7 percent after 11 months (Sparks, 1973). This represents probably the lowest loss attainable with good conservation practice.

Preharvest Causes of Loss. The planting variety is an important element in potato loss. Those varieties with thicker skins are less likely to suffer mechanical damage during harvest. Those with long dormancy will suffer less from sprouting during storage. During growth in the field, potatoes are subject to infection by light blight, pink rot, and brown rot, and the presence or absence of disease (influenced by varietal selection, chemical spraying, and cultural practices) will affect postharvest storage properties. The Centro Internacional de Papa (CIP) is beginning research on resistance to soft rot caused by *Erwinia carotovora* and is selecting resistant varieties.

Harvesting Losses. Physical damage during harvest is a major cause of subsequent storage losses since it facilitates fungal infections and stimulates physiological deterioration and loss of moisture. Mechanical harvesting permits rapid, relatively gentle digging and movement of potatoes to storage and marketing and significantly reduces harvesting loss. However, since mechanical harvesting is unlikely to be widely employed in the poorer countries for some time, attention should be focused on reducing losses by harvesting when the crop is mature and the outer skin thick; by careful digging and handling of the dug potatoes; by protecting newly harvested potatoes from exposure to wind and sun; and by prompt curing and storage.

Storage Practices and Losses. Storage of seed potatoes and those for food or sale in Peru has been the subject of detailed investigation by Werge (1977), who classifies storage into three main types: house, outbuilding, and field. House storage is convenient and secure, and appears related to food preferences. For instance, potatoes traditionally boiled with the skin on are normally stored in the attic where the dryness and air circulation cause them to shrivel rapidly; they are considered preferable to fresh tubers because of their sweetness (*Papa dulce*). On the other hand, modern varieties, peeled before preparation, are often kept with the seed potatoes on the ground, where moisture helps to keep them firm and makes them easier to peel.

Seed potatoes are often stored on the ground on a thin bed of straw or eucalyptus leaves, in piles against the walls of the house up to about one-and-a-half meters high, or in outbuilding stores. Sometimes small bins (*trojas*) are also constructed of adobe bricks to give the piles more stability and keep the potatoes more level.

Where animals are found in the house, the potatoes may be stored on low shelves; ware potatoes may also be stored on a platform of eucalyptus branches (*Chaclanka*) in the rafters of the house and covered with a thin straw layer.

Field storage is more common at higher elevations. Selected potatoes are placed in a straw-lined hole or clamp, covered with straw and sealed with soil. The cool, moist conditions reduce dehydration; however, there is the risk of rotting if the clamp is flooded.

Storage losses are primarily due to disease, dry rot, gangrene and bacterial soft rot, dehydration, and sprouting. Losses can be greatly reduced by selecting only good-quality potatoes to be stored in order to prevent spread of infection in the stored crop.

Clamp- or pile-stored potatoes often display preferential sprouting of the lower layers where light does not reach them to inhibit the process. Refrigerated storage inhibits sprouting, but may be difficult and expensive to arrange in some locations. Chemical sprout inhibitors are available and used commercially; however, they generally inhibit suberization, so that loss reduction due to prevention of sprouting may be offset by losses due to inhibited curing. Further, the problem of chemical residues in the tubers may arise from tetrachloronitrobenzene ("Tecnazene," "Fusarex"), which is reported not to inhibit curing and to have fungicidal properties, although its sprout-inhibiting properties are less than some other chemicals.

Research during 1975 at CIP into small, above-ground earth storage systems at Huancayo (3,200 m) showed that where natural air was conducted under the pile of tubers, they stored acceptably, but where no air was provided all the tubers were lost. In Ecuador, partial underground storage constructed with local materials and provided with air ducts under the tubers to utilize night temperature cooling produced less than 10 percent loss of potatoes stored for 5 months.

Improved storage with provision for high humidity/low temperature ventilation is the most likely means of reducing storage losses. The value of the harvested crop and current market prices will determine the degree to which providing these conditions will be economically justifiable. Booth and Harmsworth (1977) provide an analysis of the factors affecting choices among traditional, improved, and refrigerated storage in terms of their cost effectiveness.

Curing. As we have seen in the discussion of yam storage, curing is the wound-healing process that occurs through suberization of the cells adjacent to damaged surfaces, followed by formation of wound periderm, cork, and skin. The general thickening and hardening of the skin provides greater protection against infection.

Curing should be undertaken as soon as the potatoes have been placed in storage, before wound pathogens have an opportunity to become established. Successful curing may be achieved over a wide range of temperatures between 8°C and 20°C and with high relative humidity, at least 85 percent, without causing condensation on the tubers. These conditions can be readily provided; the high respiration rate of the freshly harvested potatoes causes a rapid increase in temperature as soon as ventilation is restricted, and water evaporation from the fresh wounds and adhering soil increases the humidity. Little research has been carried out on the effect of temperatures above 20°C on the curing process. Below 20°C it is completed in 10-14 days, although different varieties and types of wounds heal at different rates (Booth and Harmsworth, 1977).

Freeze-drying. Chuño, a naturally freeze-dried potato product, has been a staple food for Andean altiplano inhabitants since pre-Columbian times. The potatoes are spread out on rock ledges to freeze at night and to thaw under the high radiation of the sun during the day. The water released by freezing is trampled out to evaporate, producing a dry product called black chuño, which is reported to store almost indefinitely.

A more sophisticated product is made by soaking the tubers, after the freezing and thawing, in cold running water for 2-3 weeks. The skins slough off, and the dried product is white chuño.

Cooked potatoes sun dried by this technique give an even better product.

Sweet Potatoes (*Ipomoea batatas*)

Sweet potato production in developing countries totaled 17 million tonnes in 1976, approximately 2 percent of total developing country food crop production, mainly in Southeast Asia, Brazil, and Central and East Africa (FAO, 1977a).

The postharvest loss situation appears similar to that of Irish potatoes, except for the sensitivity of sweet potatoes to cold temperatures, with damage occurring when the temperature falls below about 12°C. There is little quantitative information on postharvest losses in developing countries, but it is generally believed that under tropical conditions they are very high (Coursey, 1971).

Most studies on sweet potato storage have been made under the sophisticated conditions of the southern United States and Japan, where sweet potatoes are grown as a summer crop and storage is through a cool or cold winter. Under these conditions, roots cured at 35°C and a relative humidity of 85-90 percent give the best results (Kushman and Wright, 1969).

Taro (*Colocasia esculenta*) and Tannia (*Xanthosoma sagittifolium*)

Taro is an ancient vegetable grown throughout the tropics for its edible corms. It is a major subsistence crop of a number of Melanesian and Polynesian Islands, but the bulk of it is from Africa, where the name "cocoyam" is applied to both taro and tannia. Production figures are no longer reported separately by FAO; in 1974, the last year of separate reporting, taro production in developing countries was approximately 4 million tonnes. Production of both crops together was reported as 4.3 million tonnes during the same period.

There is very little published information about taro storage. Gollifer and Booth (1973) report storage rots of taro corms in the Solomon Islands, which prevented storage for longer than 1-2 weeks. The rots are reported as being of three types: dry rot caused by *Fusarium solani*; spongy black rot caused by *Botryodiplodia theobromae*; and a *Sclerotium* rot due to *S. rolfsii*. Under humid conditions all three fungi could penetrate and rot undamaged corms, although most natural infection is thought to occur through wounds. No rot occurred at low humidity. In the Cameroons, Praquin and Miche (1971) recorded weight losses of between 12-15 percent in sound corms after 4-6 months' storage. However, when sprouting occurs (soon after harvest), over 50 percent loss was observed after 2 months and 95 percent after 5 months. *Fusarium* rots are also found in *Xanthosoma* cocoyam in Nigeria.

In view of the role of mechanical damage in permitting access to fungal infection, great care should be taken to minimize damage during handling. Curing may reduce infection, and with suitable environmental conditions it is possible that storage life may be considerably extended. Pit or clamp storage, in which high humidity is maintained, is traditionally used in some parts of the world.

Other Nongrain Staples

Banana (*Musa* AAA cvs.), plantains (*Musa* AAB and ABB cvs.), ensete (*Musa ensete*), coconut (*Cocos nucifera*), breadfruit (*Altocarpus altilis*), and dates (*Phoenix dactylifera*) are the main nongrain staple food crops other than root crops.

The cooking bananas and plantains are by far the most important of these crops. They grow readily throughout the tropics and are a familiar feature of rural villages where there is sufficient moisture and good rich soil to support their growth. In West Africa, the Caribbean, and northern parts of South America they are very widely used. Under suitable conditions they grow continuously and are typically available throughout the year in the humid tropics. In drier regions they show some seasonal tendency, and at higher elevations they are very susceptible to damage from frost (Burden and Coursey, 1977). Postharvest food losses of these crops as staples in the rural diet are less important where there is ample supply and difficult to assess where there is scarcity. The available published figures of 20-80 percent loss apply to the movement of bananas and plantains from the rural area to the urban markets. Inadequate transport and marketing arrangements are the chief problems. A major investigation of the postharvest problems of plantains has recently been initiated by the Tropical Products Institute.

Ensete (the Abyssinian banana) does not have edible fruit; the starchy pulp of the stalk of the plant is either used directly for cooking or is fermented in a pit for several days. The plant is locally important as a staple in parts of Uganda and southwestern Ethiopia, but is not used elsewhere.

Coconut production is mainly for the oil in the dried flesh of the nut, and comparatively little is eaten, except as a confection, in most parts of the world. Creams prepared from the flesh are important as additives to various dishes.

Breadfruit is a staple of local importance in some places. Losses in the crop have never been quantified, but are certainly very high. The fruit is only fit for human consumption for a very short period: it cannot be eaten until mature, and becomes inedible again once the ripening process commences.

Dates are a staple for a large number of people, particularly in the Near East, 2.4 million tonnes having been produced in 1976. There is no information on postharvest losses.

Vegetables and Fruits

Vegetables and fruits play an important role in the diet of many peoples in the tropics, providing essential minerals and vitamins and adding flavor, color, and variety to what would otherwise be a monotonous diet. They also contribute protein and calories. Developing-country production of fruit and vegetables in 1976 represented nearly 20 percent of total food crop production (FAO, 1977a).

In this section, as in the one on cereal grains, we are discussing only the fruits and vegetables used indigenously as food and are not concerned with the considerable losses associated with food processing (such as canning), either for the urban supermarket or for export.

Comparatively little information is available on postharvest losses in fruits and vegetables. This lack may result from a number of causes which, taken together, exemplify the complexity associated with both estimation and reduction of losses of all perishable produce. They include the facts that:

- Deterioration and loss of fruits and vegetables occur more rapidly than with durable staples, even with good handling and costly storage facilities, and some storage methods (refrigeration, for example) have costs in direct proportion to time of storage.
- The relative unit value, compared with necessary handling and storing costs, is normally low.
- Fruits and vegetables are comparatively large and vary in shape and size, complicating unit specification.
- It is difficult to express weight loss of these and other perishables on a constant-moisture basis.

• The relative food value and importance of fruits and vegetables and other perishables to the diet (or to survival) is normally less than that of the durables.

• Production, commonly spread throughout the year in tropical latitudes, can often be organized to provide a relatively continuous supply of different fruits and vegetables without storage.

The major perishables (as defined in part by the magnitude of their production) are listed in Table 5:2 along with reported production estimates and loss estimates in developing countries. General information on the post-harvest physiology, handling, and utilization of tropical and subtropical fruits and vegetables is provided by Pantastico (1975), Ryall and Lipton (1972), Ryall and Pentzer (1974), and Lutz and Hartenburg (1968).

Loss Estimates

From the few figures available, losses of fruits and vegetables are clearly excessive, save in a few cases where the unit food value is relatively high and efficient handling and distribution systems operate. The average minimum

Tomatoes, onions, and garden eggs, Akosombo market, Ghana. Note the straw hats providing shade for people, and the absence of shade for vegetables (FAO photo by Peyton Johnson) loss reported for fruits and vegetables is 21 percent; many more "qualitative" references not included here indicate estimates of 40-50 percent and above. The figures are hard to interpret. One can only conclude that losses are severe, that more critical work is required to obtain better estimates, and that as living standards slowly rise in developing countries, both government and private organizations will endeavor to improve the marketing process and the supply of higher quality fruits and vegetables (and other perishables) to the consumer.

Storage

With fruits and vegetables, low-temperature and modified-atmosphere storage will often provide adequate conservation for those commodities of sufficient value to justify capital and running costs; however, in many situations these technologies are not yet economic, particularly in those that are the principal focus of this study. Simple, inexpensive alternatives are available for minor storage improvements, but extensive improvements will depend as much on administrative and managerial factors as on technology. These factors include:

- Improved packaging, marketing, and transport arrangements to move the fruits and vegetables rapidly and without damage between production and consumption (which can be as simple as protection from the sun, or as complicated as refrigeration);
- Stronger extension systems to provide better information and inputs (seed, fungicides, etc.) to farmers;
- Better processing facilities and quality control for local canning, drying, bottling, and pickling, where there is sufficient market for these products;
- Choice of planting varieties with good postharvest quality and storage life, along with breeding programs aimed at developing these qualities; and
- Low-cost cooling systems, which offer by far the greatest possibility for extending the life of perishables and radically changing traditional handling limitations. (Even relatively low reductions in temperature could have an enormous impact, making this a priority area for research.)

Physiological Conditioning

One aspect of food loss reduction in developing countries that has so far received little attention is manipulation of the physiological condition of the produce. Some types of physiological change can be effected that result in reduced storage losses.

Delayed ripening of fruit by removal of endogenously produced ethylene has been used to enable bananas and plantains to be transported at ambient temperatures instead of under refrigeration. The fruit is sealed in polyethylene bags containing a potassium permanganate-impregnated absorbent, which eliminates the ethylene as it is produced.

Drying, Pickling, and Fermentation

A number of fruits and vegetables—particularly pimentos, peppers, and the subtropical fruits (such as grapes, apricots, and plums)—are amenable to drying, traditionally by the sun. In many countries, large quantities of red bell peppers are processed in this way as a condiment, and in the Far East, large quantities of cabbage are dried. These items undoubtedly add nutrients to the diet, although the contribution is probably minor. Data on the magnitude of production or associated losses are scarce.

In drier regions, large amounts of grapes, apricots, apples, and plums are preserved by drying. There is little information on the losses of these commodities in developing countries.

In a number of developing countries, particularly China, Thailand, and Korea, a variety of vegetables are pickled. Great quantities of cabbage are preserved for use during the winter as sauerkraut or kimchi, and lesser amounts of cucumbers and carrots, more for use as condiments than as

Drying vegetables under roof eaves, Nepal (Courtesy E. S. Ayensu) vegetables. In Africa, okra, mushrooms, and cucurbits are commonly dried. In the Indian subcontinent, many fruits and vegetables are preserved as chutney. There is no information on losses associated with this process. The application of pickling and fermentation methods to preservation of tropical vegetables is a potentially important area for research.

Diseases

The control of postharvest diseases of fruit and vegetables has improved substantially in the last 10 to 15 years with the introduction of new chemicals, a development which has been compared to the impact of antibiotics in medicine. These chemicals, including thiabendazol, benomyl, 2-aminobutane, and a few others, are capable of dramatically reducing fungal infection in plant material. They may be applied in very low concentration, as aqueous solutions or suspensions of only a few parts per million, by spraying or dipping methods. Little or no toxicity to higher life forms is reported, although resistance problems have arisen. Much research needs to be done, and clearly the utmost caution should be exercised in introducing chemicals into developing countries for use in connection with foods, even for experimental purposes. Nevertheless, the possibility now exists for their reducing losses of perishables under certain circumstances, in settings where other organizational and handling improvements have been made and where the economics of storage and marketing warrant it.

Much research has been conducted on the use of radiation to extend the life of horticultural produce. To date, however, this technology has not been licensed by the U.S. Food and Drug Administration for produce sold for human consumption. It is also reported to be more expensive than refrigeration and not as effective (Maxie *et al.*, 1971).

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Chapter 6

Postharvest Losses of Fish

In terms of postharvest loss, fish* is unique among the staples examined in this study. For no other class of food is there both so much evidence of serious loss at every stage from harvest to consumption and so little precise knowledge of the overall proportion of losses to the potential harvest or to the fish finally consumed.

In this discussion of postharvest fish losses, attention is focused particularly on artisanal fisheries, which are small scale, poor, dispersed, and unorganized. The following aspects of fishing and fish consumption are not considered in this report:

- Commercial fisheries carried out by large vessels on the high seas;
- Fish meal and fish oil industries; and
- Fish caught but not consumed as a result of religious or ethnic preferences or taboos.

These excluded areas, although of great importance in terms of losses, are not central to the focus of this study. Previously, we have said that nonutilization or underutilization of commodities not recognized as acceptable food is not loss. However, for fish we need an expanded definition of postharvest food loss that includes, among other things, nonuse of edible species.

Specifically, postharvest losses of fish should include fish discarded at sea as by-catch in the harvest of other species, such as shrimp; this seems justified not only because the by-catch frequently represents a multiple in the weight of the principal—and economically more valuable—harvest, but also because the discarded harvest often contains a large proportion of locally acceptable food fish, because the loss could be identified, and because research and development could be applied to reduce this loss.

By extension, the loss definition should include food fish that is locally unutilized or underutilized for any reason except on religious or ritual grounds. This inclusion is made not only because this potential food is

*In this study "fish" is used for all aquatic animal produce.

quantitatively identifiable, but also because an effort should be made to determine by research special handling and preservation requirements that might exist for these species and that may be contributing to their neglect.

Because fish harvesting obviously differs in many ways from the land harvests of the other food commodities in this study, an overview of fishing and fish consumption will be helpful as a prelude to further discussion of postharvest fish losses.

General Aspects of Fish Harvest and Consumption

Fisheries

Fisheries (as opposed to fish farming) involve the greater proportion of worldwide fishing activities, and those on the high seas represent probably the most dangerous and demanding of food-providing occupations.

Although there are significant regional differences, preference on shore and in the marketplace in most developing countries is for whole fish. Under the primitive conditions of preservation and distribution that usually prevail, only small harvests can be rapidly disposed of. As a result, most ocean fishing in developing countries is carried out by fleets of many small fishing boats skippered by individualistic, competitive captains, each acting according to his own lights and laws, trying to make the best living he can.

The fishing trade is doubly hazardous: once because of the dangers inherent in harvesting, and again because of the perishability of a commodity whose consumers demand that it be fresh. It requires a great deal of perseverance and capital to weather the vicissitudes of fish supply and demand. The fishermen who sell their catch to tradespeople—who in turn operate in the open market—have since time immemorial had to use all the tricks of the trade to avoid being left with large amounts of unsold and inedible catch. The special vulnerability that has forced many fishermen and fish-traders to resort to sharp practice in selling their goods has led fish trading to be placed, in many countries, at the very bottom of the hierarchy of desirable professions.

Consumption

Of the 20,000-25,000 species of fish known to exist in salt and fresh waters, only a few dozen species are utilized at present on any sizable scale, though many others are used on a small scale in specific locations.

Experience with toxic species or those traditionally believed to be poisonous has compelled consumers, especially in warm climates, to demand that fish remain whole to permit identification of species and inspection for freshness. It has also generated local traditions that only particular fish species are acceptable for human consumption; species that are desirable in one place may, for a number of reasons, be quite unacceptable in others.

In 1976, of the worldwide catch of about 70 million tonnes of fish–in the general sense of food of aquatic origin–about 35 percent was used for the manufacture of feed material for animals (almost all used in industrialized countries); about 40 percent was consumed "in the round" fresh or frozen; 10-15 percent was dried and cured (although in some developing countries consumption of cured fish is disproportionately higher); and 8-10 percent was canned, with the rest being used in miscellaneous ways. Here again, regional variations in the forms in which the fish is consumed cannot be overemphasized. Fermented fish products, such as those common in Southeast Asia, for instance, are locally consumed in very large quantities and should be studied much more intensively to determine their nutritional contribution to consumers' diets. If unutilized or underutilized species such as capelin, krill, squid, and other major groups of aquatic animals could economically be harvested, processed, distributed, and marketed, the total aquatic food resource would be increased by as much as tenfold.

James (1977) summarizes the information regarding the costs of expanding existing fisheries to meet the demand, particularly in developing countries. He points out that the investment in equipment, manpower, and technical development required simply to double production from the present level would be of the order of $30 billion, or about $500 per additional tonne.

Importance as Food

All available evidence indicates that fish has been used as human food since long before recorded history. At present, fish provides about 17 percent of the world's animal protein intake (Table 6:1).

Fish is unique insofar as it is the only universal staple that inhabits a medium potentially hostile and dangerous to man. This seems to have endowed it with attributes and powers more varied, colorful, and deeply engrained than those associated with any other food. The need to select nontoxic species from the harvest and to devise methods to avoid spoilage has provoked strict preference and avoidance patterns, with the development of severe criteria for safety and precise eating habits and taboos.

About 60 percent of the world's edible fish catch goes to consumers directly in the round, reflecting the purchaser's desire to inspect the raw fish carefully for freshness. In countries where Japanese and other Far Eastern fish sausages and sauces are unknown, the only fish products in which the original identity is not preserved are products similar to fish sticks and gefilte fish, but these represent only a very small proportion of fish consumed.

TABLE 6:1 Estimated World Vegetable and Animal Protein Production, 1975*

Protein Source	Amount of Protein (Million Tonnes Per Year) Available to Man	Fed to Livestock	Total
Cereals	57	38	95
Legumes	24	6	30
Other Vegetables	5	1	6
Livestock	30	3	33
Fish**	6	3	9

*From Pimentel *et al.* (1975).

**Fish includes all seafoods harvested from the ocean and for 1975 is estimated at 66 million tonnes (based on FAO figures) that contain an estimated 14 percent protein. This includes a reduction from 17.5 to 14 percent in total fish protein that occurs in cleaning the fish consumed by man. An estimated 33 percent of the fish harvest is fed to livestock.

Fish thus represent close to 17 percent of man's direct animal protein intake; in certain regions they make up the bulk of a nation's animal protein fare.

It is noteworthy that in spite of the wide availability of fish resources, the recognized nutritional value of fish, and the important economic contribution that fisheries have made everywhere, fish is still largely consumed as it was in ancient times; with the exception of canning and mechanical refrigerated freezing, no basic technological advances have been made in its preservation. This observation is significant here because it does not apply to the consumption or preservation of any other staple food and reflects the age-old stubbornness of the consumer in dealing with fish. This pervasive attitude continues to influence the nature of the fishing, fish-processing, and fish-marketing industries. It also affects the possibility of estimating postharvest losses in developing countries.

As fishery resources available to the subsistence fisherman are very limited because of these attitudes, and are in many cases exploited at or above their maximum potential, it is essential to make better use of what is landed and to preserve its economic value.

Postharvest Losses

FAO estimates for fisheries in some countries place fish losses among the highest for all commodities. There are very few documented studies to support this; one carried out on Lake Chad indicates that fish losses there may be as high as 50 percent.

James (1977) roughly estimated losses of dried fish due to insect infestation at 3 million tonnes per year (25 percent of 12 million tonnes produced); due to discarded edible by-catch from shrimping alone at 5 million tonnes (5 times the total shrimp catch); and due to spoilage at 2 million tonnes (i.e., 10 percent estimated spoilage loss of the 46 million tonnes used for direct human consumption, of which 20 million tonnes is estimated to be consumed fresh). These rough conservative approximations give a loss figure of 10 million tonnes a year–20 percent of the total catch now going to direct human consumption.

These figures are highly speculative, since there are no reliable data for any developing country on either postharvest losses or the unregistered harvests caught by unchartered and uncontrolled individual fishermen. In general, however, it seems clear and can easily be documented that:

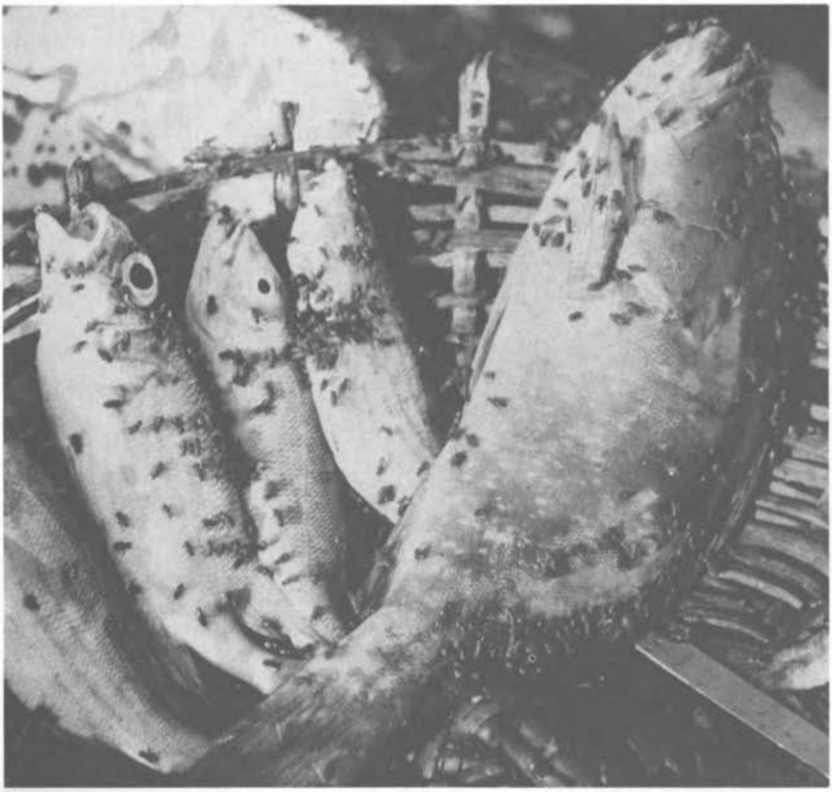
- Serious postharvest food losses begin immediately after harvest on board ship because of the lack of means to preserve the catch until landed;
- Important losses are caused by enzymatic spoilage and insect infestation as the catch is landed, is processed on the beach, and awaits transportation to market; and
- Further heavy losses are caused by primitive methods of handling, preservation, transportation, and exposure at market.

Moreover, the entire marine fisheries industry in developing countries is so fractionated by local customs and cultures, and is controlled by so many individual entrepreneurs from harvest to the consumer, that losses occur simply as a consequence of frequent handling and transfer of the variously processed food from one middleman to another. It seems, therefore, fair to say that no reliable figures for overall postharvest losses are available at present for any one region.

The committee recommends that, in view of the present situation and since loss assessment must be an integral part of loss reduction intervention, efforts should be concentrated on initiating a number of specific projects, particularly in Southeast Asia, a) to assess losses in relation to local socioeconomic conditions; b) to understand the technological and social organization of artisanal fisheries in different regions; and c) to improve the handling and processing techniques in those stages where the most important losses occur and where the greatest loss reductions can be achieved–on board boat and during drying, transportation, and marketing.

Despite the difficulty in establishing global or even regional loss figures, there is probably merit in developing methods for loss measurement, or at least for informed estimates in specific fisheries or geographic areas. Some concrete figures, even if used only as examples, would help persuade governments to commit funds for prevention. Selected studies in Southeast Asia and Africa might well strengthen the case for intervention.

Food losses in the artisanal fisheries industry are related to the various steps, discussed below, of the postharvest system as it leads from the initial catch to the consumer's table.



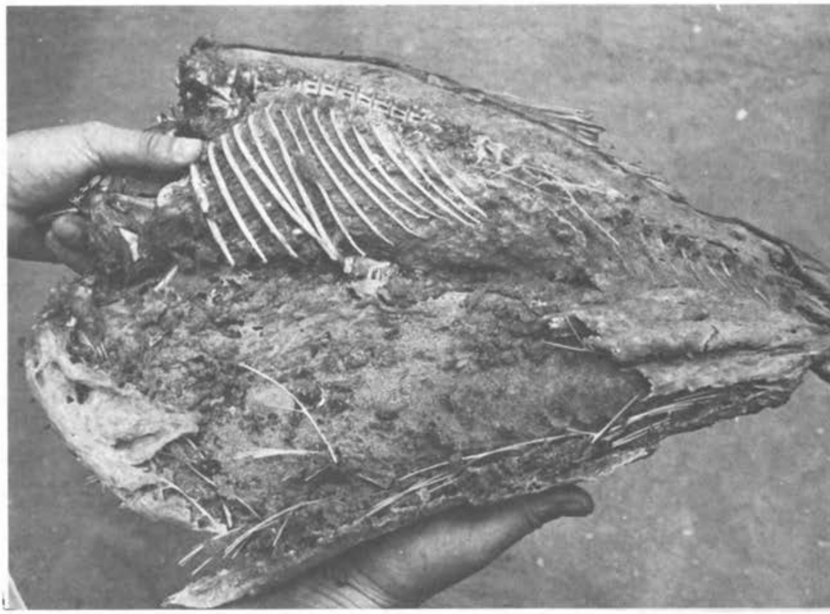
Flies on market fish, Haiti (FAO photo by Martin Routh)

Fresh Fish

The extent of postharvest losses on board the fishing vessel is unknown, but it is likely to be considerable because of spoilage due to lack of refrigeration; actual losses are camouflaged, however, because even stale or spoiling raw fish is processed. This results in economic loss, since the price for the fresh and poor-quality dried product is often the same per unit weight and the fresh fish is five times the weight of its dried equivalent.

Traditionally Processed Fish

Major losses occur with traditionally processed products, particularly with sun-dried, smoke-dried, or salted-and-dried fish. Although these are very different products that are often specific to a region, all of them can be referred to as dried products.



Insect-eaten dried fish, Mopti, Mali (FAO photo by J. Chevalier)

Drying

The simplest and most widely used technique for preserving fish is sun drying, in which the landed fish are spread on the beach or on a mat and allowed to dry in the sun.

The wet fish are subject to attack by blowflies, mainly *Chrysomyia* spp., whose larvae burrow into the fish and cause damage and spoilage. Apart from physical damage to the fish and the enhanced spoilage, the blowflies are a dangerous carrier of pathogenic organisms, particularly since the beaches they infest are widely contaminated with human feces as a result of limited public sanitation facilities.

Dried fish are subject to attack by *Dermestes* beetles, which consume the fish if this infestation is allowed to proceed.

A wide range of other insect pests and mites also attack drying and dried fish.

Salting

Preliminary salting is often used to enhance the quality and acceptability of naturally dried fish. Salting either by stacking the split fish with dry salt between the layers or, preferably, by immersing the fish in brine, speeds up the removal of water from the flesh and reduces the time necessary for air or sun drying. In the case of oily fish such as sardines, where prolonged drying leads to discoloration and rancidity, a 15-minute immersion in saturated brine may reduce drying time by half. Waterman (1976) reports that presalted dried fish was kept in fair condition for 6 months, while unsalted controls were rotten or moldy.

Salting is also a chemical method of bacterial and insect control. Flies will not attack fish that has been brined before drying, and the rate of attack by beetles is inversely proportional to salt concentration (James, 1977). One of the most difficult problems with salted dried fish is to control reabsorption of moisture from humid atmospheres after processing. For this purpose, proper packaging is required.

Smoking and Smoke Drying

Smoke drying is widely used in Africa for a variety of foodstuffs, many of which are suspended for a period over cooking fires as a means of deterring insect infestation. In the Lake Chad area, fish may be partially dried in the sun and then covered with grass or papyrus, which is set on fire and the fish scorched and charred to form a hard, protective outer surface. Some fish may be smoked over a grid or fire, or simple kilns may be employed.

Fish-smoking, Abidjan, Ivory Coast (FAO photo)

These methods, however, offer little protection against insects and may result in additional loss from charring and burning. The insect pests lay their eggs in the flesh before and during drying. In thick-bodied fish they are deterred during smoking, but the larvae already present penetrate the deeper parts of the fish where the heat and smoke cannot reach. Products attacked by insects range from those with high water content and a storage life of 1-2 days to hard-dried products with shelf lives of several months.

A certain amount of spoilage results from storage of improperly processed products, which causes direct losses. Improved quality-control procedures and market incentives will alleviate these losses. Traditional processing may be responsible for a loss of nutritional value as high as 15 percent (Hoffman *et al.*, 1977).

Storage and Distribution

After losses to insects, the most important physical and economic losses of fish result from crumbling during storage and distribution. Poorly dried fish is a fragile product that, if roughly handled or vibrated on overloaded trucks on poor roads, will crumble to a powder. Prior insect attack weakens the structure and can result in a mixture of pieces and a powder of fish and insect frass. With poor packaging there can also be direct physical losses and, although fish powder has a market, there are always economic losses. Inadequate protection of fish during storage and transport is recognized as an area in need of study.

Strategies for Loss Reduction

With an industry as fractionated, little-organized, independent, and subsistence-oriented as capture fisheries in a developing country, the obstacles that must be overcome to bring about change are enormous. To effect social change, there are basic requirements of cultural and economic appropriateness, political compatibility, and sound promise of economic or other benefits that must be met. Cooperation with members of the food-fishing industry—the men and women who harvest, process, sell, buy, preserve, store, package, transport, and purchase fish for marketing—involves the same basic considerations as cooperation with those who deal with and consume the farm commodities discussed in this study. Requirements for successful intervention in a traditional postharvest system, adapted here to the fishing industry, include:

- A communication link between the fishing people and the rest of the community;

- Incentives for loss-reduction efforts;
- Government support;
- Knowledge of locality-specific social and cultural patterns; and
- Knowledge of locality-specific preference for, and avoidance of, certain fish species.

In the case of fish, locality-specific patterns and preferences are especially important. All suggested postharvest conservation strategies must be appropriate—that is, must fit into the system technologically, culturally, and socially. For example, the idea of comminuting fresh fish with cereals or tubers in simple meat-grinding machines to manufacture inexpensive "intermediate moisture products" (which are stable because of the low moisture content of the product) should only be proposed if such fish-cereal mixtures are known and accepted by the community in question.

There are also, of course, unique characteristics of the fishing industry itself that must be considered in planning for reduction of postharvest loss. For example, in an industry that consists typically of one-man operations with very small boats, it is essential that appropriate scale not be overlooked in the design of conservation technology. Other problems that must be considered include the small space available on a fishing boat, the large number of boats, and the small batch sizes of fish that must be processed and protected after they are landed at widely dispersed coastal locations.

The rest of this chapter deals with specific characteristics of the fishing industry as they relate to postharvest food losses: the locations at which intervention may be most effective in reducing loss; new technologies; and training and organization. As with grain and perishable losses, the initial step in planning loss reduction is to pinpoint stages at which intervention appears to be needed and promises to yield substantial benefits.

Aboard Ship

The most effective intervention at the immediate postharvest stage is improvement of storage conditions to reduce deterioration of fish prior to landing. However, each local situation must be looked at separately for cost effectiveness, and many potential improvements may be beyond the resources of the artisanal fisherman. There is need for research and development in this area. Low-cost cooling devices would be particularly helpful and, though ice would be better, even seawater cooled by several degrees can greatly retard spoilage of certain species.

On Shore

Insect infestation of wet fish with *Chrysomyia* (blowflies), followed in dried fish by *Dermestes* (beetles), cause losses that are measurable (though with difficulty), but these vary so much from one area to another or from season to season that accurate measurement is difficult and expensive. As an example, in the rainy season in Malawi losses due to blowfly larvae varied from 2 percent to 40 percent (Meynell, 1978). These losses can be significantly reduced by dipping boxes of small fish in an inexpensive insect-repellent solution.

A variety of technologies, old and new, have been developed to improve on simple sun drying to reduce blowfly and beetle infestation. These methods are discussed in an FAO publication "The Production of Dried Fish" (Waterman, 1976); see Note 6-1.

It should be stressed that the following techniques should be considered in the context of local circumstances and that introduction of these technologies to new or different areas is likely to require adaptive research and development. Waterman's treatment of the principles of drying is highly recommended to anyone interested in acquiring a detailed basic knowledge of the subject.

Preparation of the Fish

In preparing simple, naturally dried fish products, with or without supplementary salting or smoking, the basic preparation and the degree of hygiene with which the fish is handled are crucial to the quality of the final dried product.

Although drying is often seen as an alternative for unsold fresh fish, and although the characteristic flavor of dried fish may to some degree mask the flavor of stale raw fish, poor quality fresh fish makes poor quality dried fish. To the extent that the fish can be cleaned thoroughly and, if possible, chilled before drying, the better the product and the less likely the occurrence of losses.

Drying, Salting, and Smoking

Once drying has been decided upon, the first step is to keep insects away from the fish and reduce the drying time by raising the fish off the ground. Simple racks constructed from local materials work very well. It is also desirable to be prepared to cover the drying fish in case of rain (as an alternative to moving them under cover from the racks), and plastic sheeting is cheap, effective, and generally available. In Zambia and in West Africa, this method of drying freshwater sardines is combined with a period of drying in a smoking oven. Salting is also used to speed up the drying and preserving process. The availability at reasonable cost of plentiful, good quality salt is an important aspect both of technology and of government policy on salt, which is frequently a monopoly.

Traditional method of fish drying on a hut roof, Tanga, Zambia (FAO photo by J. Haile)

New smoking oven designs have been developed by a number of workers and are slowly being introduced (see, for example, Clucas, 1977). The strong-tasting smoke-dried product is in popular demand and will probably continue to be competitive with fresh and frozen fish products. A disadvantage in many countries is the increasing scarcity and cost of wood and charcoal, although the new oven designs are much more efficient in fuel use than the traditional ones.

Solar Heating

Heat treatment of fish to kill insects and their larvae and eggs is well established. In Bangladesh, Doe *et al.* (1977), using a simple solar dryer constructed in the form of a tent from polyethylene plastic sheet and sticks, killed all stages of blowfly in 20 hours at 45°C. The temperature was achieved with clear plastic facing the sun and black plastic behind; vents were provided at top and bottom.

Chemical Control of Tropical Insect Infestations

The literature contains a number of suggested chemical treatments for both short- and long-term infestation. However, it stresses at the same time the inherent limitations of the technology imposed by the potential hazard to

Sun drying salted catfish, Lake Tonle Sab, Cambodia (FAO photo by S. Bunnag)

the consumer. There is as yet no chemical means to control insects that may be recommended and applied on a commercial scale without this health hazard. Caution in the use of chemical control is vital in developing countries where different insecticides are produced, transported, distributed, and used by many people who have little knowledge of their hazards. Moreover, there is a lack of coordination between scientists working on experimental control and health authorities, so that work to improve the safety of certain compounds may be academic because of a ban on their use.

The use of contact insecticides should be considered only as a last resort, where:

- No other means of coping with the pest infestation is as practical or economic;
- The techniques employed are simple and foolproof; and
- The treatment uses insecticides of low mammalian toxicity at dosage rates that leave residues within FAO/WHO tolerance limits.

Some examples are given in Note 6-2.

Systems that include insecticides generally call for a combination of physical methods (such as drying racks) with chemical, using insecticides to control insects by treating fish containers or places where fish is handled rather than the fish itself. These techniques, used in a way that minimizes potential contact of the fish with residues, should be used with physical methods wherever possible before resorting to direct contact methods.

More research is needed, and new products of low toxicity must be developed, before direct treatment with insecticides can play a more important role in insect control in fish. The focus should be on the extension of effective and safe methods to the producers. This may require patience; dried fish production is generally carried out by small, widely scattered, and conservative groups who would be reluctant to adopt new methods even if trained extension agents were available to convey them. On the other hand, aggregation of production through centralized collection and processing by large-scale mechanical dryers requires high capital investment, and the standardized product may not have market appeal.

Refrigeration and Ice

Because of the ingrained preference for whole, fresh fish, there is major interest in using refrigeration and ice to extend storage life. With ice, tropical species (i.e., those actually living in warmer water, rather than in cold water in tropical regions) generally keep longer, on average, than cold water species. Shelf lives up to 45 days have been recorded for some species, and 20-30 days is common. This probably results from a deterrent effect of the greater temperature difference between ice and warm-water fish on spoilage microorganisms and tissue enzymes.

There appears to be little if any advantage in deheading and gutting tropical species for cold or chill handling. The further handling creates additional hazards, and the intact fish is commonly preferred in the local market.

With a number of exceptions (apart from a small percentage of modern urban markets), the use of refrigeration is still limited, although it is expected to increase (Jones and Krone, 1976). Where refrigeration does exist, postharvest losses associated with refrigerated storage and transportation are likely to be so minor compared with other postharvest losses that they can be overlooked here. An excellent account of the use of refrigeration technology for fish preservation can be found in the FAO report *Ice in Fisheries* (1974).

Solar- and wind-powered cooling and ice-making equipment is still relatively young. Research in this, as in other aspects of renewable energy source utilization, should be encouraged. Application of renewable energy to the particular needs of developing countries should also be encouraged, perhaps through cooperative research and development projects at a regional level between universities and governmental organizations in developed and developing countries.

New Technologies

Recent developments for preserving fish as fish silage, fish cheese, and low-salt fermented fish (using added cereal "ragi" in Southeast Asia) are discussed in the proceedings of a conference organized by the Tropical Products Institute in London in 1976 (Tropical Products Institute, 1977).

Traditionally, fermented fish has been widely used in Southeast Asia as *nuoc-mâm*, but its high salt content has limited its use, particularly by young children, as a source of protein in the diet. The development of low-salt fermented fish offers the possibility of extending the protein supply wherever this variety of marine product—one in which the source species is unidentified—is acceptable.

New Methods of Drying

Introduction of drying racks, improved smoke-drying ovens, and design and introduction of better solar driers can each contribute to loss prevention.

Training and Organization

Extension links are weak throughout the third world, although extension services exist on paper in many countries. It is vital to demonstrate to young, developing-country men and women that technical extension can be a rewarding career. Many of the solutions to postharvest loss can come from extension work, particularly that resulting from socially oriented research projects with women. In some areas, particularly in Africa, women are the economic power in the fish business and extension work is unlikely to succeed unless this is recognized and women extension officers trained. Osuji (1976) makes the following points about the need for extension in the dried-fish industry, for instance:

> Extension services are necessary in order to increase the awareness on the part of fishmongers as well as consumers of the considerable economic and nutritional losses incurred through insect damage. Such campaigns would attempt to destroy the traditional belief in most places that the beetles are part and parcel of the dried fish, or that "dried fish must have beetles." Attention should be drawn to the fact that beetle infestation is not spontaneously generated within the fish. Infestation can, on the contrary, be prevented or reduced to a minimum by the application of simple measures including better sanitation and the inexpensive modification of existing techniques.

The principle loss of value to the fisherman for his fresh fish results from his inability to hold fish in the expectation of better markets. Containerized chill stores, supplied with ice from central locations, can be established reasonably cheaply. These can be used to test the economic feasibility and acceptance by the fishermen before permanent (e.g., ferrocement) stores are built. Community storage can also be organized for dried fish, making adequate disinfestation and protection possible.

Marketing and Infrastructure

Fishermen, because of the nature of their trade, are particularly vulnerable to pressures exerted by the middlemen who often exploit the situation. However, experience has shown that it is dangerous for external assistance to be directed at supplanting the middleman, for the improvement of social and economic conditions of the community as a whole is important to creating larger and more prosperous markets for fish and fish products.

However, the adoption of new technologies through extension programs is bound to be unsatisfactory unless there is also provision for improvement of the infrastructure. Economically feasible projects, successfully implemented on a small or local scale, need to be multiplied by substantial investments. These investments are also required to improve the general quality of rural village life. They include provision of port and landing facilities, improvement of fish marketing and storage, and a water supply with improved sanitation and sewage disposal. Upgrading road or water transport can also substantially reduce postharvest losses.

Each of these areas–technology, extension, and infrastructure–has a critical maintenance component to which both governments and technical assistance agencies should be particularly sensitive, as this is generally the weakest part of improved technology as a component of economic development.

Notes

6-1

As Waterman points out:

> There are hundreds of different dried fish products in the world, and a great number of ways of making them. Some of the products are highly prized, some are tolerably pleasant, while others are barely acceptable except as an alternative to starvation. The intention here is not to persuade producers of dried fish to make standard products; the raw material, the climatic conditions and the markets are all so different in different regions that uniformity is neither possible nor desirable.

He also points out that:

> Of the many accounts of regional methods on record, it is unfortunate that all too often the essential details are missing that make all the difference between haphazard procedure dependent largely on luck, and a controlled reproducible method. This is rarely the fault of the recorder; in all probability the process times and temperature, brine strength, water content and other factors have never been measured, let alone set down on paper.

6-2

For wet fish, short immersion in pyrethrum solution (0.125 percent w/v) with 1.25 percent w/v piperonyl butoxide has been recommended for short-term fly control prior to drying (McLellan, 1963). This was not effective against dermestids, which require a further immersion of the dried fish in a water emulsion containing 0.018 percent w/v pyrethrins and 0.036 percent w/v piperonyl butoxide. Provided the fish was properly dried before treatment and well-drained after, it did not become too moist for storage or unacceptable to consumers (Proctor, 1972, 1977). This method of control is reported to be effective for 8-12 weeks. Recent work in Malawi (Meynell, 1978) has shown that dipping or spraying boxes of fish with a solution of pyrethrum (0.02 percent) synergized by piperonyl butoxide (0.04 percent) reduced losses from blowfly by 10 percent at a cost of 0.1¢ per pound.

Recommended Reading

It is difficult to suggest background reading material solely related to postharvest fish conservation. The interested reader is advised to peruse publications in the wider field of handling, processing, and distribution of fish. From these it is possible to identify problem areas where losses are apparent and, in many cases, where means of prevention are defined. A recent FAO bibliography extracts the major monographs and journal articles in the postharvest area.

A number of the FAO technical papers and reports listed below are readily available and should be consulted.

However, the most concise and recent materials are the Proceedings of the Conference on Handling, Processing, and Marketing of Tropical Fish (Tropical Products Institute, 1977), and the forthcoming Proceedings of the Symposium on Fish Utilization, Technology, and Marketing in the IPFC Region, Manila, Philippines, 8-11 March 1978.

Food and Agriculture Organization of the United Nations. 1974. *Ice in Fisheries*. FAO Fisheries Report No. 59, Revision 1. Food and Agriculture Organization of the United Nations, Rome. 75 pp.

______. 1977. *Freezing in Fisheries*. FAO Fisheries Technical Paper No. 167. Food and Agriculture Organization of the United Nations, Rome.

______. 1977. *Selected Publications on the Technology of Fish Utilization and Marketing*. (In English, French, and Spanish). FAO Fisheries Circular No. 136, Revision 1. Food and Agriculture Organization of the United Nations, Rome. 57 pp.

Tropical Products Institute. 1977. *Proceedings of the Conference on the Handling, Processing, and Marketing of Tropical Fish, London, July 5-9, 1976*. Tropical Products Institute, Ministry of Overseas Development, London, 511 pp.

Waterman, J. J. 1976. *The Production of Dried Fish*. FAO Fisheries Technical Paper No. 160. Food and Agriculture Organization of the United Nations, Rome. 52 pp.

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Doe, P. E.; M. Ahmed; E. Muslemuddin; and K. Sachithananthan. 1977. A polythene tent drier for improved sun drying of fish. *Journal of Food Technology* (Australia) 29(11):437-441.

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Hoffman, A.; A. Barranco; B. J. Francis; and J. G. Disney. 1977. The effect of processing and storage upon the nutritive value of smoked fish from Africa. *Tropical Science* 19(1):41-53.

James, D. 1977. Postharvest losses of marine foods–Problems and responses. Paper presented to the Institute of Food Technologists 37th Annual Meeting, Philadelphia, Pennsylvania, 5-8 June 1977.

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McLellan, R. H. 1963. The use of pyrethrum dip as protection for drying fish in Uganda. *Pyrethrum Post* 7(1):8-10.

Meynell, P. J. 1978. Reducing blowfly spoilage of sundried fish in Malawi using pyrethrum. In: *Proceedings of the Symposium on Fish Utilization, Technology, and Marketing in the IPFC Region, Manila, Philippines, March 8-12, 1978*. (in preparation)

Osuji, F. N. C. 1976. The dried fish commerce in Nigeria: Methods of processing, storage and marketing in relation to pest damage. *The Nigerian Field* 41:3-18.

Pimentel, D.; W. Dritschilo; J. Krimunel; and J. Kutzaian. 1975. Energy and land constraints in food protein production. *Science* 190:754-761.

Proctor, D. L. 1972. The protection of smoke-dried freshwater fish from insect damage during storage in Zambia. *Journal of Stored Products Research* 8:139-49.

______. 1977. The control of insect infestation of fish during processing and storage in the tropics. In: *Proceedings of the Conference on the Handling, Processing, and Marketing of Tropical Fish, London, 5-9 July 1976*, pp. 307-312. Tropical Products Institute, Ministry of Overseas Development, London.

Tropical Products Institute. 1977. *Proceedings of the Conference on the Handling, Processing, and Marketing of Tropical Fish, London, 5-9 July 1976*. Tropical Products Institute, Ministry of Overseas Development, London. 511 pp.

Waterman, J. J. 1976. *The Production of Dried Fish*. FAO Fisheries Technical Paper No. 160. Food and Agriculture Organization of the United Nations, Rome. 52 pp.

Chapter 7

Education, Training, and Extension

Postharvest food loss, for all its importance, involves problems and issues still little known or understood in either industrialized or developing countries. The members of the study committee are convinced, as a result of their practical experience with food loss problems in many countries, that better education and training about food loss and its alleviation are essential if significant worldwide improvement is to occur. This conviction has been reinforced by a request for suggestions distributed by the committee throughout the developing countries; the returns clearly identified education and training, particularly of extension workers, as a priority need among loss-reduction activities.

In assessing the need for education, training, and extension with regard to postharvest food losses, the committee has had neither the resources nor the special competence to make a scholarly investigation. These topics demand attention, however, and this chapter summarizes certain important aspects of them.

Education and Training

Comprehensive instruction on ways to minimize postharvest food loss is needed at every level, from public officials who make policy to administrators, technicians, extension generalists, extension specialists, and the producer at the farm or fish-catch level. Education and training programs must be locally designed and conducted and, most important, adapted to local needs.

There are many elements to be considered in the development of national systems of education and training in conjunction with postharvest food loss reduction. They include:

- Extension services, with training of extension specialists;
- Graduate-level training and research;
- Training of students from developing countries in industrialized-country institutions;

- Nonformal training for rural communities; and
- Preparation of teaching materials at basic and advanced levels.

The balance between these needs and available resources should be determined by the national postharvest food conservation policy body. However, the national policy body will require an implementing agency with trained professional staff. One model of such an agency has been developed on the basis of extensive experience by the British Tropical Products Institute, and is described in an extract from a recent paper (Prevett, 1977) which relates the kind of training required to the type of implementing agency. (See Note 7-1.)

The model represents only one of many possible approaches to the planning and implementation of postharvest food loss activities; smaller and less-expensive structures could be used and different institutional linkages established. It illustrates the variety of special skills that bear on postharvest loss problems, the need for relevant specialists to be trained about postharvest losses, and the importance of extension agents in carrying out effective loss reduction. But it should be noted that the model leaves a number of important issues for governments and technical assistance agencies to resolve. For example, what kind of structures can facilitate improved consultation between national policy bodies and leaders at the village level? In the process from assessment to decision making, how can planning best be informed by a sound understanding of the sociocultural conditions that underlie food losses and affect preventive measures? How can local initiative be encouraged?

Extension Services

Although extension services constitute one of the basic mechanisms for education and training at both the producer and consumer levels, extension as currently practiced has a number of weaknesses in terms of postharvest food loss education. Usually, extension service workers are not trained in recognizing and dealing with the broad range of postharvest food loss problems. There are also mismatches between trainers and the people being trained. In some countries this is particularly evident where women—who are producers and marketers of basic foods as well as the family members responsible for food preparation—are bypassed for male extension workers. Women may regard many of these activities as ones of which men can have no useful knowledge. Unless women can be trained and employed as extension agents and given full backing (including the same career opportunities as men), many of these producers and marketers will not be reached. Equally important may be education in the government itself, since there is often no practical awareness of the seriousness of food losses and the fact that simple intervention could reduce them significantly.

In most countries, the key person to give farm-level training should be the extension agent. Rarely does this agent now have a background in techniques for food-loss prevention. This situation should be remedied so that the agent can become the person who helps the food producer recognize the economic consequences of postharvest losses, motivates him to reduce losses, and trains him in practical techniques. At the same time, the general extension agent must be supplemented by specialists who have more comprehensive experience in reducing losses in grains, fruits, vegetables, meats, and fish.

The initial selection of extension agents is crucial because they must be sensitive to the culture of the people whom they serve. They must recognize that the people with whom they work are intelligent and must be prepared to accept guidance about local conditions and practices. However, studies of extension work have clearly shown that merely intensifying extension programs can be a wasted effort unless a number of other developments take place simultaneously. These include giving farmers incentives to adopt new approaches; removing local constraints that may inhibit acceptance of new methods; getting support of the local community for various demonstration activities; and, not least, giving extension workers incentives to do their work properly, including decent working environments and mechanisms for promotion and professional advancement.

In addition to classic extension services, there are certain other techniques, along with a variety of media, for reaching food producers through training and education programs. Nonformal education techniques are especially effective. For example, natural leaders within the community who practice good food conservation techniques can be used as a resource for extending education begun by the extension agents. Radio, TV, and visual materials produced for the local area are of particular importance.

An understanding of postharvest food conservation should also be fostered at the primary and secondary school levels. It is here that techniques of sanitation, hygiene, and prevention of insect infestation can be taught at an early age as a part of the basic curriculum.

The committee strongly recommends a basic multilevel program of training and education to reduce postharvest food losses, as follows:

1. *Farm and agriculture training.* Training programs in postharvest technology should be directed toward extension services, agricultural colleges, and farmers' training institutes. There is also a need for ongoing, in-service training and career development for workers at all levels in the food storage, processing, distribution, and marketing system.

2. *Managerial training*. Managers of both government and private marketing, storage, and processing organizations should be given enough technical

knowledge to increase their awareness of the problems involved in the decisions they make.

3. *Support staff training.* The training need requiring the greatest input, both of national commitment and expert assistance, is in-country training aimed at the lower staff levels of government and quasi-government marketing agencies; that is, at personnel involved in produce-inspection and pest-control services, extension services, etc.

4. *Food handler and producer training.* Courses should be designed to meet the special needs of personnel responsible for procurement, quality control, pest control, warehouse management, drying, handling, and processing of foods. Graduate-level training in these technical areas is necessary to establish a professional staff cadre.

5. *Aid programs for local training of graduate and senior staff in technical institutions.* Traditionally, such programs have largely concentrated on men, despite the fact that women may control, or be involved in, important stages of the marketing and processing of certain commodities. It is essential that proposed changes lead not to the replacement of women by trained men, but rather to the recruitment and retraining of women for the new occupations the changes will create in procurement, quality control, pest control, warehouse management, etc. Otherwise, they will be excluded from their present occupation with no alternatives, to the detriment of their own status and economic position.

6. *Development of learning models.* Effective learning models for village people—who are often illiterate—should be determined, including the kinds of teaching aids needed and the people who can best prepare teaching materials for the various levels of learning. These broader questions must be tackled by authorities or bodies at the national level.

7. *Manpower development.* Cooperation between aid agencies and recipient governments is urgently needed for enlarging the personnel required to initiate postharvest food loss reduction programs.

At the 1975 meeting of the FAO Committee on Agriculture, FAO was requested to carry out in its regular program a survey of available technical expertise for agricultural development, both in developed and developing countries, and to establish and periodically update this inventory. As the second part of such a study, an evaluation should be made, at both the national and international level, of long-term requirements for skilled manpower. Training capacities of both developed and developing countries should be adapted to meet these demands.

8. *Constructive use of local customs.* Knowledge about local customs and institutions needs to be integrated into educational activities. It may be advisable to pool past experience and to encourage the development of models for this purpose.

Notes

7-1

Components of a National Program and Its Personnel Requirements (from Prevett, 1977).

The objective is to initiate, develop and sustain national postharvest food loss reduction programs, encompassing the whole postharvest system.

All postharvest planning and activity within the framework of a national program should be closely integrated and coordinated, and authority for this should be invested in the appropriate Ministry (normally, the Ministry of Agriculture). In our view, the most effective way to achieve the necessary action, in the long term, is through the establishment of a national "Postharvest Research, Training and Advisory Unit" with the following objectives:

1. To ensure efficient postharvest operations through the application of known technology and continuous evaluation and follow-up.
2. To establish programs of adaptive research to determine the extent to which available technology may be applied to local conditions and, where appropriate, to undertake research and investigations on local problems for which solutions are not evident.
3. To assist in the establishment of continuous in-service training for staff of storage, marketing, and processing organizations and others active in the postharvest field.
4. To assist in the development and maintenance of an effective extension service to farmers, farmers' cooperatives, traders and local marketing agencies.
5. To assist government departments and organizations concerned with the planning of agricultural policies and programs, and coordinate activities with external technical assistance agencies.

In order to establish a unit of this type with responsibility for grains, professional staff experienced in the following fields will be required:

Head	– Senior technologist with wide experience in food grain technology and storage
Biologist	– Experienced storage entomologist/biologist
Processing Engineer	– Cereal technologist with milling experience
Storage Engineer	– Agricultural engineer experienced in grain drying, handling and storage and storage structure design
Training Officer	– Agricultural educator trained in storage technology

Extension Officer – Agricultural extension worker trained in storage technology

In many cases the first step will be to conduct an initial survey to identify the component parts of the system (i.e., harvesting, threshing, drying, handling, storage, marketing, and processing), to determine their interrelationships and relative importance, and to identify areas in which immediate remedial action is justified and those in which loss assessment or other studies are needed in order to determine the appropriate course of action. For such a survey a team of three specialists will be required: a grain marketing economist, a grain storage specialist with broad experience in analyzing causes of grain losses and controlling them, and a grain storage and processing engineer. Projects involving loss assessment need to be serviced by personnel having suitable technical expertise in relation to the part of the system under study, coupled with experience in loss assessment methodology. They will need to be supported by suitably trained survey teams in order to ensure the proper collection of data. Extension of these activities to include non-grain staples will require additional personnel with experience appropriate to the crops under consideration.

The availability of financing is clearly of the utmost importance to the successful implementation of such a program, but the availability of adequately trained and experienced manpower will be one of the major constraints. The problem is two-fold. The long-term objective, through training, must be to upgrade the capability of local staff involved at all levels of operation from the subsistence farmer through to the consumer, in all sectors of the postharvest system. However, technical assistance agencies that are planning activities designed to meet this objective are already aware of the global shortage of expertise in tropical postharvest technology and there is an urgent need for action to increase the availability of this "expert" manpower.

For an effective program of postharvest loss reduction, implemented by a technical training and advisory unit operating under a national policy body, two main types of trained personnel are required–extension agents and subject matter specialists–"expert" personnel, in the FAO terminology, both supplied by technical assistance agencies and trained through national programs.

Recommended Reading

There is very little published information specifically directed at extension and training aspects of postharvest loss reduction. In addition to the three publications in this list, the general literature on extension in agricultural production and rural development should be consulted.

Abdel-Hamid, F., and Abdel-Aziz. 1975. *Storage of Food Grains: A Guide for Extension Workers*. Food and Agriculture Organization of the United Nations, Rome. 33 pp.
Community Development Trust Fund of Tanzania. 1977. *Appropriate Technology for Grain Storage*. Report of a Pilot Project, in cooperation with the Institute of Adult Education, Economic Development Bureau, 234 Colony Road, New Haven, Connecticut, USA 06511.
Lindblad, C., and L. Druben. 1976. *Small Farm Grain Storage*. United States Action/ Peace Corps Program and Training Journal, Manual Series No. 2. VITA Publications, Manual Series No. 35E. Volunteers in Technical Assistance, Mt. Rainier, Maryland.

Reference

Prevett, P. F. 1977. Personnel needs and training for postharvest food loss reduction activities. Paper presented at the International Working Group Meeting on Postharvest Food Losses in Developing Countries, October 31-November 3, 1977, National Academy of Sciences, Washington, D.C.

Chapter 8

Conclusions and Recommendations

The committee's basic conclusions about postharvest food losses and their reduction are summarized below. The chapter begins with a general discussion of these conclusions and ends with a section of specific recommendations.

General Conclusions

Loss Estimation Problems

From published information of actual measurements of food loss and estimates by experienced observers, it is clear that postharvest losses of food in developing countries are enormous. When the consequences of such losses are measured in terms of human suffering and economic cost, they represent an international challenge that richly merits priority attention.

The variability of these losses—from season to season, among different crops, from location to location, and under different kinds of postharvest treatment—makes accurate measurement of their extent extremely difficult, and hence expensive. In certain cases, it may never be possible or economically feasible to estimate losses, whether of weight, quality, or nutritive value, with any statistically significant degree of accuracy.

Until recently, loss estimation methodology has been given little critical attention (with a few notable exceptions), and the value of published information has been reduced by the absence of standard methods and definitions. Fortunately, this has been rectified for the cereal grains with the preparation of the manual of Postharvest Grain Loss Assessment Methods (Harris and Lindblad, 1978). No comparable methodologies exist for perishables, which constitute an area requiring priority attention.

Current and Projected Losses

Although the methods of loss estimation are frequently suspect and the supporting data rough, there are, as we have noted, sufficient data to show that substantial amounts of food are being lost annually in the postharvest system. Since estimates of loss and production in developing countries are subject both to differing interpretations and degrees of accuracy, projections of the amounts of food that might become available through loss reduction are doubly difficult. Within these limitations, however, it is necessary to make rough approximations to illustrate for decision makers the possible magnitude of the losses involved.

Conservative expert opinion resists generalizations of loss estimates because they cannot be substantiated by statistically sound data. For planning purposes experts cite minimum overall losses of 10 percent for durable crops and 20 percent for nongrain staples, perishables, and fish. Table 8:1 gives an extrapolation in monetary terms of these minimum loss estimates for 1976.

The figures in Table 8:1 indicate that in the developing countries a conservatively estimated minimum of 42 million tonnes of cereal grains and legumes were lost in 1976; this amount is equivalent to 60 percent of the annual total cereal production of Africa, 95 percent of Canada's annual cereal grain output, and slightly more than the production of Indonesia and Thailand combined. At 250 kg per year, this tonnage would provide more than the annual minimum calorie requirements of 168 million people–twice the population of Pakistan, or a quarter of the population of India.

Table 8:2 presents analogous calculations based on projections of food crop production in 1985 and continued losses and prices at present levels.

TABLE 8:1 1976 Estimates of Minimum Postharvest Food Losses in Developing Countries*

	Durables	Perishables	Fish
1976 food production (million tonnes)	420**	255**	
Estimated minimum loss percentage	10	20	
Estimated minimum loss (million tonnes)	42	51	10***
Estimated price/tonne (US $)	165****	25	225***
Estimated loss value (US $ billions)	6.9	1.3	2.3

*"Developing Market Economies" according to FAO (1977) definition.

**Production estimates from FAO (1977) assuming 79 percent of durables and 75 percent of perishables are actually used for food (based on NRC, 1977).

***James (1977).

****Figure used by the International Food Policy Research Institute (IFPRI, 1977).

TABLE 8:2 1985 Projections of Minimum Postharvest Food Losses in Developing Countries

	Durables	Perishables	Fish
Projected 1985 food production* (million tonnes)	472	302	
Estimated minimum overall loss percentage	10	20	
Projected minimum losses (million tonnes)	47	60	10
Estimated price/tonne (1976 US $)	165	25	225
Estimated loss value (US $ billions)	7.8	1.5	2.3

*Based on approximately 2 percent annual increase from 1976 FAO production reports and figures in the World Food and Nutrition Study (NAS, 1977, Appendix A, Table 1) of approximately 75 percent of total durable crop production used for food in 1985. Also assumes the proportion of durables to perishables produced in 1976 (61:39) will hold for 1985, and that there are no improvements in food conservation.

In total, these figures represent a conservative minimum estimate of 107 million tonnes of postharvest food losses, which, together with 10 million tonnes of fish losses, is valued at approximately US$11.5 billion. Successful implementation of the United Nations General Assembly VIIth Special Session Resolution calling for a 50-percent reduction in postharvest food losses by 1985 would, therefore, save an estimated US$5.75 billion worth of food annually.

A 2-percent annual increase in production of food crops over 1976 figures would result in a production of durables very close to the projected demand figures for grain in 1985–474.5 million tonnes (NRC, 1977). If this level of production were achieved, however, a shortfall of food grain would result from the projected postharvest loss–a minimum of approximately 47 million tonnes. Production sufficient to meet both the projected demand and the estimated 10 percent postharvest loss would require an increase of 2.85 percent annually. If the United Nations Resolution's 50-percent loss-reduction target were to be achieved over this period, the annual production increase required could be reduced to 2.32 percent.

It must be stressed again that these figures and computations are only illustrative and that they are included to show the magnitude of the problem and the potential benefits of its alleviation. Moreover, we do not yet know what proportion of the postharvest losses it is technically or economically feasible to reduce. Nor will we be in a position to assess this until systematic, coordinated efforts to estimate and reduce losses are implemented at national, regional, and local levels over a wide area. For this reason, it is important for loss estimation and loss reduction efforts—both technical and socioeconomic aspects—to be integrated within the framework of a national policy. This will enable identification of targets where food loss reduction will have particular social benefit, a major need.

Food Conservation Programs

Implementation of the United Nations Resolution on food loss reduction will require substantial resources including, in particular, trained men and women. The committee believes that available information justifies worldwide expansion of current efforts, directed particularly toward helping developing countries to establish their own postharvest loss-reduction policies and programs.

The current level of international effort expended for estimating and reducing losses is hard to quantify, since few organizations and programs are limited to, or clearly identified by a concern for, postharvest loss activities. It is also difficult to disaggregate expenditures on storage, for example, from national agriculture budgets or large agricultural development loans.

Furthermore, few developing countries have research and extension activities specifically directed to postharvest losses. There is general agreement among knowledgeable observers that, with a few notable exceptions, the overall level of effort directed to postharvest losses is inadequate compared with both agricultural production activities and the potential savings of food.

There are many reasons for this insufficient attention to the postharvest system, differing from country to country. Among the more important reasons for this neglect is the lack of professional identity and opportunity for career employment, which in turn reflects the limited attention and money allocated to the problem. In part, this is because the high costs and environmental consequences of continued expansion of production have only recently made postharvest conservation of food an obvious alternative. Further, the cost effectiveness of postharvest loss reduction on a broad scale has not been demonstrated. Nevertheless, loss reduction through "sound conservation practice," involving actions that use relatively small investments of time and money, is a reasonable way to protect the investments of labor, capital, and other inputs already made to produce the food.

Food Conservation Practices and Technologies

Sound conservation practices range from a variety of common-sense measures (such as better hygiene, simple technologies for storage or drying like those described in the Lindblad-Druben manual, or shade and ventilation for marketed perishables) to the use of small, sophisticated equipment (such as moisture meters). Each situation will present a different range of possibilities to be identified and evaluated; governments can assist this process by providing incentives to conserve food and helping farmers assess their own conservation possibilities.

Among new technologies for conserving food, solar-powered devices have received particular attention because of their presumed low running costs. The devices most needed are those for drying crops or for cooling, particularly to extend the market life of perishables. There is no significant commercial manufacture of solar crop dryers, although a number have been designed. Their basic limitation is that they do not operate when they are needed most–in wet, humid weather. According to a recent National Academy of Sciences report, solar cooling and refrigeration require considerable research and development "because of the lack of a practical solar refrigerator at any price and of any understanding of the cost of systems that could be developed. An objective and critical analysis of the need for, and the prospect of, practical solar refrigeration should be the first step in any development effort" (NRC, 1976). Low-cost cooling, solar powered or not, is of such potential importance in developing countries that it may justify, at least in part, the need for this research and development.

Technical Assistance Agencies

A number of national and international agencies are engaged in postharvest food loss reduction in developing countries, and an FAO-prepared list is included at the end of this chapter. Many of these agencies work closely together, with coordination of effort where possible. Information about efforts to conserve cereal grains and grain legumes is coordinated by the Group for Assistance on Systems relating to Grain Afterharvest (GASGA). GASGA includes in its membership the Tropical Products Institute (TPI), supported by the British Overseas Development Ministry; Kansas State University, supported by the U.S. Agency for International Development; the Canadian International Development Research Centre (IDRC); the Institut de Recherche Agronomique Tropical et Cultures Vivrières (IRAT) of France; the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO); and the Food and Agriculture Organization of the United Nations (FAO). The secretariat functions are provided by TPI and IRAT. No central organization yet exists for the perishables, nor is there machinery for coordinating the general postharvest interest of the donor agencies (like that existing for production in the Consultative Group for International Agricultural Research).

Personnel and Training

The loss reduction activities described above, along with other national projects and programs not specifically identified, do much useful work in postharvest technology. However, all are affected by a common problem: the critical shortage of trained technical personnel.

Personnel training concerns must be complemented by organizations that facilitate the integration of activities at the village level; that improve communication between farmers and representatives of governments, educational agencies, and planning organizations; and that help disseminate information and learning materials.

Socioeconomic Considerations

Governments need information that will enable a careful weighing of alternatives for food conservation and that will place cost-benefit analyses in a comprehensive socioeconomic context.

Particular attention must be paid to conditions that provide incentives at various levels of food-conservation activity, including:

- Incentives for farm men and women to change established practices;
- Incentives for young people to assume careers in postharvest food conservation; and
- Encouragement for the general process of development at the farm and village level.

The traditional, nonmarket, largely subsistence level of food production—where only small amounts of food enter the market economy and where the bulk of agricultural production takes place and is consumed—offers particularly important opportunities for food conservation. Efforts to reduce loss at this level will affect large numbers of needy people. The analysis of social cost-benefits in Chapter 2 indicates that attention to the traditional sector can alleviate problems for families while creating secondary benefits for other sectors of society. Some of these benefits may be quite direct, such as generating cash to create demand for new services on the village level or creating incentives for entering the market economy. Others may be less tangible; for example, greater security and more opportunities for individual choice by farm men and women.

The effects of food conservation may also benefit the urban poor, whose numbers are increasing rapidly and who often have more limited means than rural people to adapt to shortages of food.

Publications and Information

There is a very large body of published material that deals with many aspects of postharvest food technology, and the bibliography compiled for this study has proved to be much more extensive than anticipated. Although much remains to be done to update and improve this compilation and to make the information more widely available, it represents progress in collecting the material in a comprehensive way.

A number of problems complicate this effort, however; an important one is access to the information. It is difficult to identify entries relevant to postharvest losses from the titles of papers and other publications because of the lack of recognition, until recently, that postharvest food loss involves a discrete set of problems. As a result, the information is widely scattered throughout the technical literature on agriculture, applied biology, food technology, or engineering, much of it in relatively obscure journals with limited circulation. Far greater use could be made of this knowledge if it were easier to identify and obtain.

A second impediment to a comprehensive bibliography is that information directly and obviously related to losses in developing countries is predominantly on grain storage, with very little on losses of perishables and fish or on the economic and sociocultural aspects of food loss. FAO has now created a separate postharvest section in the AGRIS bibliography, where relevant publications will be clearly identified. There is the further need, however, for a mechanism to select and update this bibliography on a continuing basis; to refine the present bibliographic entries in the system, since there are relevant publications not listed (both current and back to, say, 1945); and to establish a retrieval system for the information in the bibliography in reprint, microfiche, or photocopy form, available particularly to workers in developing countries. Currently, FAO has a service in all member countries that enables anyone to obtain copies of FAO publications from local booksellers or publications offices using local currency. However, this does not include publications of other organizations or copies of technical papers, although these may be listed in the AGRIS bibliography. There are plans for a technical information retrieval service in FAO that would make available selected non-FAO publications listed in AGRIS, but this is several years hence; at the moment there are no plans to include postharvest technology as a category in the system, and funds are not yet available for this purpose.

One of the most active sources of information about postharvest storage losses in developing countries is that provided by the TPI Storage Department through the bimonthly periodical *Tropical Storage Abstracts*, free copies of which are sent to some 3,000 organizations and specialists.

Thus, in response to growing awareness, there already exists an abstracting service, operating from a specialist organization that has built up an important network of contacts, and backed up with document supply services. The potential for closer collaboration between TPI and the Commonwealth Agricultural Bureau (CAB) is being explored with special reference to gaps that may exist in their combined coverage of the literature on tropical food storage and postharvest losses and to the possibility of joint publishing of abstracts in this field. Account will be taken, of course, of the work of FAO/AGRIS and other organizations in this subject area.

Since this study was completed, Kansas State University has made arrangements to provide, at cost, microfiche or xerox copies of publications in their possession on postharvest food losses. In addition to numerous publications on postharvest grain losses, this service will cover all of the publications assembled during the compilation of the bibliography for this study, amounting to perhaps a third of the entries listed and including publications on roots and tubers, and fruits and vegetables. Inquiries should be addressed to:

Postharvest Documentation Service
Kansas State University Library
Manhattan, Kansas 66502

A third problem, in addition to the inadequacy and inaccessibility of postharvest food loss information, is the quality of the published information. In many cases, reports describe and quantify food losses but the information is not sufficiently specific about what is meant by "loss"; there is often no distinction between damage and loss, or, in quantification, between percent unit loss or percent weight loss. There is usually no attempt to clarify the relationship between what the observer is measuring and the definition or perception of loss by the consumer; social and economic data that would greatly increase the validity and usefulness of reports is seldom included. The weakness of the published data results not only from the absence of standard methodology, but also from the fact that food loss observations are often secondary to the objective of the study.

Recommendations

The conclusions above lead to the committee's specific recommendations for implementing food conservation programs throughout developing countries.

Institutional Arrangements, Policies, and Mechanisms

The Committee recommends that the following institutional arrangements and mechanisms be established in developing countries to deal with postharvest food losses:

- A national policy body;
- A national implementing agency or postharvest food conservation unit; and
- A mechanism to facilitate communication among planning agencies, decision makers, and villagers.

We further recommend that technical assistance agencies direct their efforts toward helping governments strengthen the capabilities of these postharvest food conservation bodies where they exist and to support their creation where they do not.

The national policy body will provide an overview of the postharvest food loss situation; will determine priorities and allocate resources in the context of national development objectives and in harmony with social, cultural, and economic realities; and will coordinate activities among the various ministries and agencies involved and initiate requests for technical assistance.

To be effective, this body should have high-level representation from the agencies and ministries, since it must influence policies and regulations. It might typically report to the office of the prime minister or president and be chaired by the minister of agriculture.

The postharvest food conservation unit, or implementing agency, composed of senior technical professional men and women, will administer the national food conservation program. Ideally, it should be a multidisciplinary group of experienced food technologists, storage-structure engineers, agricultural economists, entomologists, chemists, and social anthropologists, among others, according to the nature of the specific problems in the country. Part of the unit's responsibility will be to strengthen local capabilities to identify points of serious loss in the postharvest system, aided by mechanisms to facilitate communication between villagers and officials.

Collectively, the policy and operating bodies would be responsible for assessing the national food loss situation and developing a national plan of action; undertaking rapid assessment of potential points of severe loss; examining national policies with respect to pricing and the role of marketing boards and other financial agencies; providing effective quality control in government commodity purchasing; supporting research in both technical and socioeconomic areas; and, ultimately, recommending policy options on food conservation to the decision makers.

The committee recognizes that in some countries these bodies already exist and that technical assistance agencies have successfully supported them. But many other countries lack such structures, and the committee believes that their role is crucial to the success of national commitment to loss reduction. Without these bodies of able people at the appropriate level of influence and expertise, directing the initial steps toward public information extension programs, research, and development of incentives—in short, assuring the legitimacy and status of postharvest food conservation and of those who work in it—there is little likelihood that significant reductions in loss can be achieved. Postharvest technology should become an integral part of the research and extension program of all agriculture and fisheries organizations in developing countries.

Creation or support of such bodies does not necessarily imply large capital investment. The implementing agency can be relatively small, and much of its work can be directed to assisting other agencies, such as the national agricultural extension service, in their efforts to bring food conservation improvements to farming and fishing families and rural villages.

Postharvest Loss Estimation

The committee recommends more systematic approaches to loss estimation in developing countries by:

- Adoption of standard loss estimation methodology;
- Development of guidelines for loss estimation of perishables;
- Consideration of socioeconomic aspects of food loss; and
- Integration of loss estimation conservation activities.

Adoption of Standard Methodology

Agreement is needed on both the kinds of methodology appropriate for given situations and the ways in which estimated losses are reported. These are discussed in detail in the Harris-Lindblad manual, which should be used as the basis of a standard grain loss estimation procedure. Rapid assessment methods should be clearly distinguished from scientific measurement of weight loss, and methods and results should be explicitly reported to avoid ambiguity. It would be particularly helpful if losses of major durable crops in a particular country or region could be reported at a standard moisture content equal to that at which most of the crop is normally stored.

Development of Guidelines for Loss Estimation of Perishables

In the case of perishable crops and fish, time from harvest and precision about temperature and humidity are of the utmost importance in describing the loss situation. The condition of the food—whether the fish is whole or gutted, the vegetable whole or peeled, etc.—must be explicitly reported.

Consideration of Socioeconomic Aspects of Food Loss

Knowledge about the cultural perception of loss in a particular society is vital, both with respect to the definition of loss (what is or is not regarded as loss) and to an understanding of the local importance of loss and, hence, inherent incentives for loss reduction. Similarly, information about the cost effectiveness of loss reduction measures is woefully inadequate, and increased understanding of economic and social benefits is central to gaining support of the sustained efforts needed to reduce loss on a meaningful scale. Multidisciplinary assessment of loss should also be stressed.

Integration of Loss Estimation and Loss Reduction

Given the formidable difficulties for estimating losses of many foods–fish, for example–it may only be possible to measure losses by the relative effects of conservation activities. Moreover, since it is also desirable to institute loss reduction measures as quickly and extensively as possible, it is hard to justify using the limited supply of trained observers for estimation alone. Wherever feasible, estimation and conservation efforts should be planned and carried out as coordinated activities.

International Cooperation Mechanisms

The committee recommends that an organization be created to give international focus to the neglected area of loss in perishable staples.

The committee, which includes several members of organizations that belong to GASGA, believes that this organization has made an excellent beginning in international cooperation and coordination of efforts to reduce postharvest grain losses. Similar efforts are necessary in areas not covered by GASGA, particularly for the perishable staples. An organization created to deal with problems of perishable staples should receive support additional to that currently provided to GASGA and grain loss reduction generally, and perishable staples should not come under the authority of an expanded GASGA.

The establishment of such a group will be a step towards strengthening mechanisms for international cooperation, which in turn will help to legitimize the postharvest area on a professional, worldwide basis. Strengthening the multilateral FAO assistance programs for regional collaboration in fish technology research should also be encouraged. These programs, which have been started in Asia, Africa, and Latin America, attempt to link institutes within the region to work on common problems and to seek assistance from institutes in developed countries. The National Marine Fisheries Service (NMFS) and university departments in the United States could well be included in the further development of these fisheries activities; exchange visits and supplemental equipment are the main costs involved.

Information on Postharvest Food Losses

The committee recommends that, in view of the importance of improving the quality and availability of published information on postharvest food losses, the international technical assistance agencies should cooperate in efforts to strengthen and expand postharvest food loss documentation services.

Specifically, the following steps should be taken:

• FAO should be supported with funds to ensure that the AGRIS bibliographic reference service section on postharvest technology is strengthened and continually updated. This will entail provision of technical expertise to identify appropriate postharvest technology publications for entry to the system on a regular basis.

• Support should be provided for a microfiche service of the AGRIS publications (through FAO or another agency) to national or regional institutions engaged in postharvest food conservation research, education, or extension. This will make reprints of the information generally available from a source either within a developing country or from a regional institution in a neighboring country.

• Industrialized-country institutions should be supported in cooperating with FAO to provide assistance in selecting postharvest entries for the reference service (GASGA members, their equivalents for the perishable staples when these are established, and national agricultural library systems).

Authors, editors, and reviewers should make every effort to ensure that publications dealing with postharvest food losses are clearly identifiable by title, and that loss estimation or measurement methodology is adequately described and, where possible, conforms to generally agreed-upon standards.

The bibliography prepared in connection with this study should be sent to one or two institutions actively engaged in postharvest loss research in each developing country and to institutions elsewhere working on developing country food losses. Compilation of national bibliographies of research findings would be very useful.

Education, Training, and Extension

The committee recommends establishment of new training programs and strengthening of existing programs to remedy acute personnel shortages at all levels of the postharvest food system.

Specifically, training efforts are recommended at the following levels:

1. Training programs in postharvest technology for agricultural colleges and similar institutions for extension workers, farm men and women, and others working in agriculture and fisheries. This, the single most important training need, should be accomplished within the framework of a system of career development and professional opportunity.

2. Courses and in-country training programs for other personnel in the postharvest food system, including:

• Lower cadres of marketing agencies involved in procurement, quality control and pest control, warehouse management, and drying, handling, and processing of foods;

• Managers of both government and quasi-government marketing, storage, and processing organizations who should be given sufficient technical knowledge to increase their awareness of the problems involved in their decisions; and

• Country representatives of technical assistance agencies who should be familiar with postharvest loss problems.

3. Teaching skills and materials developed at universities, colleges, and research institutions for instructing fishermen and farmers. There is also need for graduate-level training in technical areas to increase the professional staff for teaching and research programs; technical assistance agencies and governments should assist this training both in-country and by providing scholarships to overseas institutions.

We further recommend, as an educational priority co-equal with manpower training, the establishment of programs to deliver postharvest conservation information to rural people. Two major channels exist for disseminating this information:

1. Formal educational resources such as schools, literacy programs, and adult education programs at the rural level should be used to spread postharvest conservation information. This information should also be integrated with other village improvement services, including health and sanitation and community development activities of all kinds.

2. Informal education mechanisms such as radio, television, and newspapers should be used to maximum advantage for emphasizing the importance of postharvest loss reduction, as should agencies outside the formal educational system—for instance, religious and youth organizations and commercial enterprises.

Research and Development

The committee recommends, as basic to formulation of national food loss reduction policies, intensive research on socioeconomic factors, general postharvest technologies, and crop-specific technologies. The bulk of this research should be developed by the national postharvest loss reduction unit, in collaboration with appropriate research arms of the universities, the research institutes of ministries, and the private sector. These research needs, which should be concentrated at the rural level, are discussed below.

Socioeconomic Research

Substantial refinement of knowledge about economic cost-benefit factors in postharvest food loss reduction is needed. Plans for food conservation should be supported, meanwhile, by knowledge of the effects of social and cultural factors on the introduction of technological change.

General Research and Development Needs

The most important research and development needs include:

• Development of low-cost cooling systems for food preservation in developing countries.

Current drying and processing technologies and storage structures are at least adequate under most conditions for preserving durable crops in developing countries, for useful lengths of time and at reasonable cost. This is not yet true for perishables; the two modern developments that enable large quantities of perishables to be stored and transported over long distances—canning and cooling—are not yet economic in many developing countries. The development of cooling technology with low capital and running costs could extend the life of perishables in rural areas and have a dramatic impact on the health, income, and welfare of rural people.

• Research on insecticides, fungicides, and rodenticides, with particular reference to their safety for use in foodstuffs, their environmental consequences, and their use in integrated systems of pest management.

With present chemicals, there are increasing concerns about cost, safety, and effectiveness (as a result of development of resistance by pests), and the development of alternatives should be a matter of high priority.

• Fundamental research on tropical food crop deterioration and its relationship to environmental conditions.

Comparatively little work has been carried out on the biochemical and physiological aspects of postharvest deterioration of perishables in the tropics, including the precise effects of various conditions of temperature and humidity and pathogenic organisms. This research is closely linked with, and complementary to, research on low-cost cooling systems.

• Research on storage characteristics or other qualities of crops that affect their postharvest fate, as one aspect of breeding and selection programs.

Too often the increased production characteristics of an "improved" variety are utterly negated by increased postharvest losses. Resistance of crops to storage loss should be part of this research.

• Socioeconomic studies of the problems of introducing centralized storage in rural areas, with implications for technology design, costs, handling system, and management essential to facilitate this process.

Since wider introduction of centralized storage is probably inevitable, one consideration of the studies should be ways of reducing losses by reducing the number of hands through which commodities pass.

• Adaptive research on small-scale storage technologies, including development of cheap rodent- and insect-resistant containers that are properly ventilated or sealed as well as resistant to moisture and rainfall.

• Rodent surveys and greater emphasis on rodent control in both agricultural and health extension services.

Commodity-Specific Research Priorities

The following research areas are listed to illustrate the kind of work that needs to be done with individual commodities and are not meant to be a full list of priorities.

Rice

More economic drying of wet-season rice, including, particularly, natural ventilation methods and use of preservatives for short-term preservation

Improved design for threshing, parboiling, and milling equipment

Maize

Improved low-cost drying and storage cribs

Improved village-level processing equipment

Millets and Sorghums

Improved traditional storage and fumigation methods

Improved village-level processing equipment

Legumes

Improved milling equipment

Ways to avoid loss of cooking quality during storage

Roots and Tubers

Determination of optimum storage temperature, humidity, and ventilation for different varieties

Better box and clamp design

Storage of cassava chips, flour, and pellets

Use of sprouting and rot inhibitors

Fruits and Vegetables

Low-cost, controlled-environment storage, including waxing, storage under plastic sheeting, gas absorbents, rot retardants, etc.

Better low-cost packaging

Damage control during storage and movement, and in the market

Fish

Better drying, smoking, and salting methods

Improved on-board storage and use of by-catch.

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Organizations Actively Involved in Postharvest Food Conservation*

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Commonwealth Scientific and Industrial Research Organization, Mechanical Engineering Division, Melbourne, Australia
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Food Research Institute, Campinas, São Paulo, Brazil
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*Food and Agricultural Organization of the United Nations (1975), Reducing Postharvest Food Losses in Developing Countries. (AGPP: MISC/21). FAO, Rome. 15 pp. and annexes. N. B. Since the preparation of this list a number of additional organizations have become engaged in postharvest loss reduction; they may be identified from the list of contributors to this study.

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Resume

La croissance démographique mondiale rend l'accroissement des ressources alimentaires prioritaire et urgent. Une étape capitale, mais négligée jusqu'à présent, dans ce but, est la réduction du gaspillage subi par les produits alimentaires entre la récolte et la consommation. De sérieuses études révèlent que, dans les pays en voie de developpement, de très importantes pertes ont lieu après la récolte. Ces dernières peuvent être de l'ordre de plusieurs millions de tonnes et s'élever à des milliards de dollars. Les programmes visant à réduire ces pertes seront d'autant plus efficaces qu'ils seront fondés sur la juste mesure de leur ampleur. Il est certainement très difficile d'évaluer avec précision l'ampleur de ce gaspillage à cause, en partie, du caractère de variabilité qui lui est propre, mais aussi à cause de plusieurs facteurs économiques et culturels perturbant le mouvement des denrées alimentaires de la production à la consommation.

Il est cependant possible d'évaluer ce gaspillage et par conséquent d'y remédier. L'étude suivante a pour but de déterminer les chances et les limites d'une action tendant à combattre ce gaspillage de denrées alimentaires. Elle résume certains travaux et sources d'information sur les pertes affectant la pêche et certaines des plus importantes cultures; elle commente aussi certains aspects économiques et sociaux mis en jeu, identifie les principaux besoins et suggère plusieurs doctrines et programmes pour les pays en voie de développement et les instituts d'aide technique.

Evaluation des Pertes Alimentaires

Pour réduire ce gaspillage alimentaire il faut d'abord analyser le problème quantitativement. Le calcul des pertes, contrairement à celui de production fait à partir du potentiel génétique mesurable des récoltes, est lié à des conditions locales et saisonnières telles, qu'un concept de moyenne appliqué à cette notion de perte devient presqu'insignifiant.

L'inexactitude des techniques de calcul des pertes d'un côté, et le manque d'extrapolation, même à partir de données spécifiques et bien caractéristiques, de l'autre, rendent difficile le calcul des pertes économiques. Il n'y a pas de doute cependant que ces pertes puissent être mieux calculées et mieux comprises et que de meilleures méthodes doivent être développées et normalisées.

L'amélioration des méthodes d'évaluation du gaspillage subi par les produits alimentaires est essentiel pour remédier à ce problème. Les experts s'opposent au calcul de pourcentages nationaux ou globaux qui n'ont pas de valeur statistique, sauf dans le cas où celui-ci s'effectuerait à une échelle expérimentale limitée. Les chiffres avancés par les experts, pour des besoins de plannification, indiquent des pertes de 10% au moins pour les récoltes durables (grain et légumineuses) et de 20% ou plus pour les autres cultures de base (igname, manioc) et différentes denrées périssables, poissu inclu. Même si ces chiffres ne sont que des estimations prudentes à l'appui d'une politique d'aide, il n'en demeure pas moins que le gaspillage alimentaire mondial est effrayant et qu'il justifie une mobilisation substantielle de moyens intellectuels et financiers pour mieux l'analyser et y remédier. La Résolution de la VIIème Session Spéciale de l'Assemblée Générale des Nations Unies en 1975, engageant les états membres à réduire les pertes alimentaires de 50% vers 1985, reflète bien ce problème.

Comment Reduire un Tel Gaspillage

L'importance d'une telle tentative dépendra surtout des exigences économiques. La technologie moderne et des moyens suffisants permettent théoriquement de conserver la plupart des denrées alimentaires, presqu'indéfiniement et sans pertes. Les fonds engagés dans une entreprise de conservation des produits alimentaires doivent être fonction des circonstances et besoins particuliers. Avant d'entreprendre des programmes à grande échelle, il faut être mieux informé sur la probabilité des coûts, la main-d'oeuvre et les besoins de l'organisation. Tout d'abord, les différents pays doivent s'engager politiquement à réaliser des entreprises d'intérêt national.

La coordination d'une telle entreprise étant tellement complexe, chaque pays nécessite un organisme directeur national, spécialiste de cette question, et composé d'experts à plein temps. Cet organisme serait chargé d'analyser et de contrôler les pertes globales, d'établir un ordre de priorités et de conduire des recherches. Cet organisme devrait avoir un accès aux plus hauts échelons du gouvernement vu que le gaspillage en question peut résulter aussi bien d'un désintéressement envers la conservation, causé par la politique des prix, du système de taxation et autres régulations gouvernementales, que des conditions naturelles.

Malheureusement, peu de pays ont des organismes destinés à encourager les différents ministères concernés à adopter et coordonner une politique d'action commune. La création de tels organes est devenue urgente et les organisations d'assistance technique devraient aider dans ce sens les pays en voie de développement. Les efforts nationaux conduits à l'heure actuelle pour réduire les pertes subies après la récolte sont non seulement insuffisants, mais aussi trop tournés vers le problème du stockage du grain. Cela est très compréhensible vu le charactère saisonnier de la production du grain et la place qu'il occupe dans l'alimentation de beaucoup de sociétés. Cependant, les autres cultures fondamentales, constituant la principale source de calories dans le régime alimentaire de nombreuses sociétés, devraient attirer une attention toute proportionnelle à leur importance nutritive, comme par exemple les fruits et les légumes. Cela ne devrait cependant pas détourner tous les efforts concentrés actuellement sur le grain.

Dans la plupart des sociétés, une si grande importance est attachée à la consommation de poisson frais de variétés connues (à cause du danger qu'il y a à manger du poisson abimé ou vénéneux) que l'offre de variétés moins connues ou celle de produits de transformation du poisson (écailles ou protéines concentrées par exemple) est peu probablement encline à pallier le problème des pertes alimentaires. Les efforts devraient plutôt tendre à: 1) améliorer le stockage; 2) aider les pêcheurs à créer des coopératives qui pourraient, à leur tour, faciliter l'accostage et les procédés de transformation du poisson, grâce à des installations plus perfectionnées; 3) améliorer la commercialisation et la transformation des espèces courantes. Les variétés moins connues devraient servir, si possible, d'engrais et de nourriture pour les bestiaux.

Aspects Sociaux, Culturels et Economiques

Le gaspillage des denrées alimentaires et dû aussi bien à des phénomènes sociaux et culturels que des conditions naturelles. Les coutumes locales forment une inévitable toile de fond sur laquelle se jouent les activités d'après la récolte. La notion même de ce qui constitue la cause de ce gaspillage varie d'une culture à une autre. Les techniques de conservation des ressources sont plus fréquemment dictées par les coutumes que par leur efficacité. Les rôles joués par l'homme et la femme, les rapports entre individus et familles marquent inévitablement la façon dont les produits alimentaires sont manipulés et emmagasinés après la récolte.

La technologie et les analyses empiriques ne sont donc pas les seuls éléments d'une lutte contre le gaspillage. Pour devenir efficaces, les techniques doivent s'adapter au milieu culturel et social. Il faudrait, en plus, souligner les avantages liés a l'adoption d'une technique judicieuse de conservation des produits alimentaires. La motivation est un élément important dans la tentative de réductíon du gaspillage alimentaire. Aucun producteur n'est prêt à investir des fonds ou des forces dans cette lutte à moins qu'il ne soit compensé par un meilleur revenu, par un certain état de sécurité ou par un statut quelconque.

Le manque de données concernant le gaspillage subi après la récolte est particulièrement grave en ce qui concerne les aspects économiques et sociaux de ce problème. Cela signifie que la rentabilité d'une telle opération n'est pas encore bien prouvée. Néanmoins, certaines améliorations dans les opérations de conservation n'engagent pas de grands investissements et peuvent réduire le risque de gaspillage au niveau de la ferme. L'investissement dans des opérations de lutte contre les pertes alimentaires offre aussi des avantages. Ceci est surtout vrai pour le secteur fermier traditionnel des pays pauvres où le gros de la population produit et consomme la plupart de la récolte, dont une petite partie seulement est commercialisée. La réduction du gaspillage apporterait dans ce cas plus de sécurité face aux années de pénurie. Elle permettrait aussi la création de nouveaux emplois et d'excédents dirigés vers les marchés. Cela entrainerait, par conséquent, un plus grand mouvement de marchandises et de services vers les zones rurales. L'action du gouvernement dans la lutte contre ce gaspillage a probablement plus d'importance au niveau du secteur fermier traditionnel; dans les autres secteurs de l'économie, les produits alimentaires sont dans les mains d'entrepreneurs qui, normalement, répondent aux exigences du marché et prennent des mesures de conservation appropriées.

Education et Formation Professionnelle

Le manque de reseignements sérieux sur la nature, l'étendue, et une éventuelle baisse des pertes alimentaires et le fait que ce secteur ne soit pas considéré comme branche technique bien distincte comportant des chances d'avenir professionnel, entrainent une pénurie critique de personnel qualifié et expérimenté. La réponse à cela se trouve dans des efforts de formation professionnelle à tous les niveaux. Un enseignement périscolaire pourrait éveiller la conscience publique sur les règles d'hygiène à respecter dans la manipulation et le stockage des denrées alimentaires. Cet enseignement devrait inclure la formation d'ouvriers agricoles (dont le rôle est particulièrement important au niveau de la ferme) et de personnel administratif ainsi qu'un enseignement secondaire et supérieur dans des disciplines telles que la biologie et le génie civil. Une attention toute particulière devrait être prêtée à la formation professionnelle des femmes qui, dans de nombreuses sociétés, jouent un rôle vital pendant et après la récolte. L'aide actuelle en faveur des programmes de formation professionnelle devrait être renforcée et complétée par des possibilités de recherche et de formation dans les pays en voie de développement.

Information Technique et Recherche

Rares sont les sources d'information relatives au problème du gaspillage alimentaire dans les pays en voie de développement. Celles dont nous disposons traitent principalement de l'engrangement du grain. Il faudrait plus d'information sur les denrées périssables et sur les facteurs socio-économiques affectant la conservation des aliments. La littérature actuelle sur ce sujet et dont les titres ne révèlent pas toujours son contenu, est dispersée dans différentes revues techniques. Une documentation internationale, mise à jour et comprenant un système de microfiches et de copies d'exposés techniques est indispensable.

Bien que les données exactes et spécifiques manquent, nombreuses sont les sources d'information techniques et scientifiques qui pourraient être exploitées. Cependant, des recherches doivent être menées pour vérifier leur valeur dans les domaines technique, économique et social. Le secteur privé dans les pays en voie de développement est très important car il est informé et expérimenté sur les pratiques de conservation des cultures commerciales d'exportation après la récolte.

Les efforts de recherche devraient aussi porter sur l'amélioration des installations de transformation des produits vivriers pour qu'elles fonctionnent efficacement sous un climat tropical. Cela concerne surtout l'équipement de séchage, de battage et de mouture, qui, souvent trop vieux, mal opéré et à mauvais escient, est la cause de pertes évitables. Un matériel de réfrigération simple et bon marché faciliterait considérablement le stockage et la commercialisation des denrées périssables.

Enfin, une recherche de base menée principalement en coopération avec les pays en voie de développement, est nécessaire. Les sujets d'études devraient inclure l'amélioration des pesticides biodégradables (insecticides, rodenticides and fongicides). Ces derniers doivent être utilisés dans un système total de traitement anti-parasitaire et remplacer les produits chimiques toxiques auxquels beaucoup de parasites s'habituent et qui sont dangereux pour les hommes, le cheptel et la faune. Les centres de recherche agricole internationaux et les programmes de sélection des cultures devraient examiner les caractéristiques d'après-récolte de chaque nouvelle variété lorsqu'ils font la sélection de cultures à introduire dans les pays en voie de développement.

Notre étude confirme qu'il n'y a aucune technologie simple, bon marché et ayant à elle seule un effet profond sur les pertes subies après la récolte. Au contraire, la conservation des denrées alimentaires ne peut être réalisée qu'en combinant des efforts d'organisation locale, d'identification des problèmes, de formation professionnelle, de documentation, et de technologie adaptée. De bonnes méthodes de conservation doivent être appliquées de façon continue et être constamment perfectionnées au fur et à mesure des nouvelles données informatives. Une baisse significative des pertes alimentaires mondiales résultera seulement de l'ensemble de ces tentatives nationales qui devraient être soutenues le plus possible par les organisations bilatérales et internationales d'assistance technique.

Resumen

Con el crecimiento de la población mundial, el aumento de la oferta de alimentos pasa a ser una prioridad aún más urgente. Una medida vital, aunque descuidada, para lograr este fin consiste en reducir las pérdidas de alimentos que se producen entre la cosecha y el consumo. Estudios fidedignos ponen de manifiesto que las pérdidas poscosecha de los principales alimentos en los países en desarrollo son de enorme magnitud, según cifras prudenciales del orden de las decenas de miles de toneladas* y de miles de millones de dólares. Los programas para reducir estas pérdidas han de fundarse en estimaciones razonables de su magnitud, lo mismo que la evaluación de la eficiencia de tales programas. Con todo, resulta muy difícil estimar las pérdidas poscosecha con precisión. Esto se debe en parte a su inherente variabilidad. Sin embargo, también se debe a muchos factores económicos y culturales que obstaculizan una corriente eficiente y fluida de alimentos por el sistema poscosecha del productor al consumidor.

No obstante, pueden realizarse útiles estimaciones de las pérdidas de alimentos, así como mejorar su conservación. Este estudio tiene por objeto evaluar el potencial de las medidas para reducir las pérdidas y sus limitaciones. Se resumen trabajos ya publicados e información acerca de las pérdidas de los principales cultivos y la pesca; se examinan algunos de los factores determinantes económicos y sociales; se identifican los principales sectores de necesidad, y se sugieren varias opciones de política y programas para los países en desarrollo y los organismos de asistencia técnica.

Estimación de las pérdidas

Toda medida para reducir las pérdidas de alimentos ha de iniciarse con una evaluación cuantitativa del problema. Sin embargo, las estimaciones de las pérdidas, en contraste con las estimaciones de producción, que se basan en el potencial genético de los cultivos, conmensurable, están tan relacionadas con la localización y las estaciones que el concepto de niveles medios pierde casi todo sentido. La poca exactitud de las técnicas de encuesta de las pérdidas,

*En este informe se usa la tonelada (tonelada métrica) como unidad de media.

por una parte, y las limitaciones que afectan a la extrapolación de incluso pérdidas concretas y bien caracterizadas, por otra, hacen muy difícil obtener estimaciónes fiables de las pérdidas económicas. Indudablemente, es posible entender y evaluar mejor las pérdidas, pero es menester concebir y normalizar mejores métodos.

Las mejores estimaciones de las pérdidas son esenciales para tomar decisiones de política acerca de la asignación de recursos a fin de reducir las pérdidas. Los expertos se resisten a estimar las pérdidas nacionales o globales de los principales productos alimenticios, ya que es imposible documentar estadísticamente las cifras, con excepción de experimentos controlados limitados. Al presentar cifras "indicativas" con fines de planificación, los expertos suelen referirse a pérdidas mínimas globales del 10 por ciento para los cultivos duraderos (granos cereales y granos leguminosos) y del 20 por ciento o más para los cultivos distintos de los cereales (por ejemplo, ñame o mandioca) y otros alimentos perecederos y el pescado. Incluso si se aceptan estas estimaciones (con las reservas del caso) como cifras prudenciales, valores mínimos en apoyo de la asignación de fondos para reducir las pérdidas de alimentos, es evidente que las pérdidas mundiales son aterradoras y justifican sustanciales inversiones de recursos intelectuales y financieros para entenderlas mejor y reducirlas. Esto queda patente en la Resolución de 1975 del séptimo período extraordinario de sesiones de la Asamblea General de las Naciones Unidas que obliga a los países miembros a reducir las pérdidas de alimentos poscosecha en un 50 por ciento antes de 1985.

Reducción de las pérdidas

El grado de reducción de las pérdidas depende en última instancia de circunstancias económicas. Dados la tecnología moderna y recursos suficientes es posible en teoría conservar la mayoría de los productos alimenticios sin pérdida casi indefinidamente. Con todo, los gastos en conservación de alimentos tienen que justificarse por necesidades y circunstancias particulares. Antes de que puedan iniciarse programas a escala nacional para reducir las pérdidas, se necesitan más datos sobre los costos probables y las necesidades de personal y de organización. Las medidas efectivas para reducir las pérdidas tienen que empezar con el compromiso político de los países para poner en práctica la acción necesaria a nivel nacional.

En vista de la compleja coordinación que se requiere para lograr una reducción, todos los países necesitan un organismo nacional de política poscosecha, con un cuadro profesional a jornada completa dedicado a evaluar y vigialr las pérdidas generales, identificar casos graves de prioridades y llevar a cabo investigaciones. Este organismo también debe proporcionar a las autoridades opciones de política realistas, de modo que la inversión para reducir las pérdidas sea conmensurable con los costos y los beneficios económicos y sociales que suponga. El grupo encargado de la política poscosecha debe tener acceso a los más altos niveles del gobierno, ya que las pérdidas pueden ser consecuencia tanto de desincentivos para la conservación debidos a la fijación de precios, los impuestos y otras políticas gubernamentales reguladoras, como de causas biológicas o físicas.

Es de lamentar que sean pocos los países que cuentan con grupos poscosecha responsables de desarrollar y coordinar la política entre los ministerios. Se recomienda encarecidamente el establecimiento de estos organismos, y las instituciones de asistencia técnica deberían estar dispuestas a ayudar a los países en desarrollo.

Las actuales medidas nacionales para estimar y reducir las pérdidas de alimentos, además de insuficientes, prestan excesiva atención a evitar las pérdidas de almacenamiento de cereales. Esto es comprensible dado el carácter estacional de la producción de cereales y su importancia para la supervivencia en muchas sociedades. Sin embargo, los productos más corrientes distintos de los cereales, que son la principal fuente de calorías, al menos en la dieta de muchas regiones, deberían ser objeto de una atención proporcionada con su importancia en la dieta, lo mismo que las legumbres y las frutas. Con todo, esto no debería reducir los esfuerzos dedicados a los cereales.

En casi todas las sociedades se concede tanta importancia a la comida fresca y a las variedades más conocidas de pescado (en vista del peligro de ingerir variedades estropeadas o tóxicas), que el aumento del consumo de variedades menos conocidas o productos de pescado elaborados (por ejemplo, escamas de pescado o concentrados proteínicos) no contrubuiría a reducir las pérdidas actuales. En cambio, los esfuerzos deberían orientarse a: 1) mejorar el almacenamiento; 2) ayudar a los pescadores a crear cooperativas, que colectivamente podrían justificar la mejora de los muelles y de las instalaciones de tratamiento del pesdaco, y 3) mejorar la comercialización y la elaboración (secada, salado y ahumado) de las capturas de las especies más conocidas. Las variedades menos conocidas deberían usarse en lo posible para alimentar animales y como fertilizante.

Aspectos sociales, culturales y económicos

Las pérdidas de alimentos están tan relacionadas a fénomenos sociales como a factores físicos y biológicos. Las actitudes y prácticas culturales constituyen en forma inevitable obstáculos críticos en las operaciones poscosecha y en la reducción de las pérdidas. La propia comprensión del carácter de las pérdidas de alimentos suele variar notablemente entre las distintas culturas. Es frecuente que las técnicas de conservación de alimentos estén determinadas por creencias tradicionales, más que por su utilidad inmediata. Las funciones del hombre y la mujer, o las relaciones entre las personas y las familias, pueden influir en las formas particulares en que se elaboran o almacenan los alimentos.

Así, las medidas nacionales para reducir las pérdidas de alimentos no pueden fundarse exclusivamente en datos tecnológicos o empíricos. Las técnicas y la información han de ser cultural y socialmente aceptables para ser útiles. Es más, debería insistirse en los incentivos para adoptar prácticas adecuadas de conservación de alimentos. Es improbable que los productores dediquen dinero o esfuerzos a actividades de reducción, a menos que prevean un buen rendimiento, ya sea en ingreso, seguridad o posición social.

En este contexto se plantea el problema de la falta de datos acerca de las pérdidas de alimentos poscosecha, especialmente grave por lo que hace a los aspectos económicos y sociales de las pérdidas, en el sentido de que todavía no puede demostrarse debidamente la eficacia de la reducción de las pérdidas de alimentos desde el punto de vista de los costos. No obstante, hay sencillas mejoras de las prácticas de conservación que sólo requieren una pequeña inversión monetaria y podrían reducir mucho el riesgo de graves pérdidas a nivel de las explotaciones agrícolas. Hay también beneficios indirectos que pueden derivarse de la inversión para reducir las pérdidas poscosecha. Esto es válido ante todo para el sector agrícola tradicional de los países pobres, donde la mayoría de la población produce y consume la mayor parte de los cultivos alimentarios, que sólo pasan al mercado en pequeñas cantidades. En este caso, la reducción de las pérdidas de alimentos suponen una mayor seguridad en los años malos. También supone la posibilidad de generar empleo y excedentes de alimentos para ser comercializados, que pueden cubrir los gastos de una mayor corriente de bienes y servicios para las zonas rurales. Es probable que la acción del gobierno para reducir las pérdidas tenga más trascendencia en el sector agrícola tradicional que en otros sectores de la economía, donde los productos alimentarios están en manos de empresas que hacen frente a las fuerzas del mercado mediante medidas adecuadas de conservación.

Educación y formación

La falta de información general fiable sobre la magnitud, naturaleza y posibilidades de reducir las pérdidas poscosecha, junto con la circunstancia de que no se suele admitir que se trata de una esfera técnica importante con posibilidades de carrera profesional, han resultado en una escasez crítica de personal cualificado con experiencia. Esto podría evitarse gracias a medidas de educación a muchos niveles. Estos esfuerzos deberían incluir programas populares, a fin de ampliar el grado en que el público se hace cargo de la necesidad de higiene en la manipulación y almacenamiento de alimentos. También deberían comprender cursos de formación para trabajadores de extensión agrícola (que tienen una función de particular importancia en el sector rural agrícola) y de personal administrativo, así como formación universitaria completa en disciplinas de biología e ingeniería. Debe prestarse particular atención a aumentar las oportunidades de formación para las mujeres, que en muchas sociedades tienen un papel vital en los trabajos de cosecha y poscosecha. El actual apoyo de asistencia técnica para los programas nacionales de formación poscosecha deben consolidarse y complementarse mediante oportunidades de investigación y formación en los países industrializados.

Información e investigación técnicas

No hay mucha información publicada acerca de las pérdidas y su reducción en los países en desarrollo. La que hay se refiere fundamentalmente al almacenamiento de cereales, y se necesita más información sobre los productos perecederos y los factores socioeconómicos que afectan a la conservación de alimentos. La literatura está muy dispersa en revistas técnicas y con frecuencia no puede identificarse por el título con las pérdidas poscosecha. Se necesita un servicio internacional de documentación sobre pérdidas poscosecha, constantemente actualizado con servicios de microficha y separatas de documentación técnica a escala mundial.

Si bien no hay datos exactos concretos, se dispone de un gran volumen de información técnica y científica general sobre las pérdidas de alimentos en los países industrializados, que podría aprovecharse. Es menester realizar investigaciones de adaptación, a fin de que estos datos resulten técnicamente válidos, e investigaciones socioeconómicas que aseguren su aceptación social y justificación económica para aplicarlos a los países en desarrollo. El sector privado de los países en desarrollo puede ser muy importante, dadas su información y experiencia en cuanto a la conservación poscosecha de los cultivos comerciales y de exportación.

Se necesita más investigación aplicada para mejorar el equipo de elaboración de alimentos con miras a su buen funcionamiento en los trópicos. Esto es especialmente aplicable al equipo de secado, trillado y molienda, que suele estar constituido por maquinaria vieja, mal manejada y concebida para otros fines, causa de pérdidas inevitables. Además, se requiere de modo especial equipo de refrigeración barato y sencillo que puede aumentar en forma espectacular el almacenamiento y comercialización de productos perecederos.

Por último, se necesita investigación básica, gran parte de ella en cooperación con países industrializados. Entre los temas de estudio deberían incluirse los pesticidas biodegradables (insecticidas, raticidas y fungicidas), como parte de sistemas integrados de control de las pestes, en sustitución de los productos químicos tóxicos, frente a los cuales muchas pestes han conseguido inmunidad, que pueden ser una amenaza para las personas, el ganado, la flora y la fauna. Los centros internacionales de investigación de cultivos y los programas nacionales de cultivos forrajeros deberían estudiar también las características poscosecha de nuevas variedades, al seleccionar los cultivos que deberían iniciar los países en desarrollo.

Este estudio viene a confirmar que no hay una tecnología sencilla y barata que, por sí sola, pueda reducir mucho las pérdidas poscosecha. Antes bien, la conservación poscosecha de los alimentos sólo puede lograrse gracias a una combinación de organización centrada en la localización, la indentificación de problemas, la formación, la información y la adecuada tecnología. Deben aplicarse en forma continua prácticas idóneas de conservación, con mejoras permanentes a la luz de la nueva información. Estas medidas nacionales de carácter continuo tendrán por resultado grandes reducciones de las pérdidas mundiales de alimentos, y deberían contar con todas las posibilidades de apoyo por parte de los organismos bilaterales e internacionales de asistencia técnica.

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Single copies of published reports listed below are available free while the supplies last upon request, on your organization's letterhead, to the Board. Other interested readers may procure the reports listed here for the applicable fee from the National Technical Information Service (NTIS) whose address appears below.

5. **The Role of U.S. Engineering Schools in Development Assistance.** 1976. 30 pp. Examines opportunities and constraints facing U.S. engineering schools in mobilizing their resources to aid developing countries. NTIS Accession No. PB 262-055. $4.50.

7. **U.S. International Firms and R, D & E in Developing Countries.** 1973. 92 pp. Discusses aims and interests of international firms and developing-country hosts and suggests that differences could be mitigated by sustained efforts by the firms to strengthen local R, D & E capabilities. NTIS Accession No. PB 227-787. $6.00.

8. **Ferrocement: Applications in Developing Countries.** 1973. 89 pp. Assesses state of the art and cites applications of particular interest to developing countries–boat-building, construction, food and water storage facilities, etc. NTIS Accession No. PB 220-825. $6.50.

11. **Aquatic Weed Management: Some Perspectives for Guyana.** 1973. 44 pp. Report of workshop with the National Science Research Council of Guyana describes new methods of aquatic weed control suitable for tropical developing countries. NTIS Accession No. PB 228-660. $5.25.

14. **More Water for Arid Lands: Promising Technologies and Research Opportunities.** 1974. 153 pp. Outlines little-known but promising technologies to supply and conserve water in arid areas. NTIS Accession No. PB 239-472. $8.00. (French-language edition is available from the Office of Science and Technology, Development Support Bureau, Agency for International Development, Washington, D.C. 20523 or through NTIS, Accession No. PB 274-612. $8.00.)

16. **Underexploited Tropical Plants with Promising Economic Value.** 1975. 187 pp. Describes 36 little-known tropical plants that, with research, could become important cash and food crops in the future. Includes cereals, roots and tubers, vegetables, fruits, oilseeds, forage plants, and others. NTIS Accession No. PB 251-656. $9.00.

17. **The Winged Bean: A High Protein Crop for the Tropics.** 1975. 43 pp. Describes a neglected tropical legume from Southeast Asia and Papua New Guinea that appears to have promise for combating malnutrition worldwide. NTIS Accession No. PB 243-442. $4.50.

18. **Energy for Rural Development: Renewable Resources and Alternative Technologies for Developing Countries.** 1976. 305 pp. Examines energy technologies with power capabilities of 10-100 kilowatts at village or rural level in terms of short- and intermediate-term availability. Identifies specific research and development efforts needed to make intermediate-term applications feasible in areas offering realistic promise. NTIS Accession No. PB 260-606. $11.75. (French-language edition is available from Office of Energy, Development Support Bureau, Agency for International Development, Washington, D.C. 20523.)

19. **Methane Generation from Human, Agricultural, and Animal Wastes.** 1977. 131 pp. Discusses means by which natural process of anaerobic fermentation can be controlled by man for his benefit, and how the methane generated can be used as a fuel. NTIS Accession No. PB 276-469. $7.25.

20. **Systems Analysis and Operations Research: A Tool for Policy and Program Planning for Developing Countries.** 1976. 98 pp. Examines utility and limitations of SA/OR methodology for developing country application and means for acquiring indigenous capabilities. NTIS Accession No. PB 251-639. $6.50.

21. **Making Aquatic Weeds Useful: Some Perspectives for Developing Countries.** 1976. 175 pp. Describes ways to exploit aquatic weeds for grazing, and by harvesting and processing for

use as compost, animal feed, pulp, paper, and fuel. Also describes utilization for sewage and industrial wastewater treatment. Examines certain plants with potential for aquaculture. NTIS Accession No. PB 265-161. $9.00.

22. Guayule: An Alternative Source of Natural Rubber. 1977. 80 pp. Describes a little-known bush that grows wild in deserts of North America and produces a rubber virtually identical with that from the rubber tree. Recommends funding for guayule development. NTIS Accession No. PB 264-170. $6.00.

23. Resource Sensing from Space: Prospects for Developing Countries. 1977. 203 pp. An examination of current and prospective applications of interest to the LDCs, certain implications for long-term governance of a remote sensing system, and desirable technical cooperation initiatives to diffuse user capabilities. NTIS Accession No. PB 264-171. $9.25.

24. Appropriate Technologies for Developing Countries. 1977. 140 pp. Examines fundamental issues and inter-relationships among economic, political and social factors relating to choice of technologies in developing countries. Discusses criteria of appropriateness and suggests policies for improving technical decisions. (Non-LDC readers must order from Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Ave., N.W., Washington, D.C. 20418 USA, enclosing payment of $6.25.)

26. Leucaena: Promising Forage and Tree Crop for the Tropics. 1977. 118 pp. Describes *Leucaena leucocephala*, a little-known Mexican plant with vigorously growing, bushy types that produce nutritious forage and organic fertilizer as well as tree types that produce timber, firewood, and pulp and paper. The plant is also useful for revegetating hillslopes and providing firebreaks, shade, and city beautification. NTIS Accession No. PB 268-124. $7.25.

29. Postharvest Food Losses in Developing Countries. 1978. 197 pp.

30. U.S. Science and Technology for Development: Contributions to the UN Conference. 1978. 226 pp. Serves the U.S. Department of State as a major background document for the U.S. national paper, 1979 United Nations Conference on Science and Technology for Development. Includes an overview section plus five substantive sections as follows: 1) industrialization; 2) health, nutrition and population; 3) food, climate, soil and water; 4) energy, natural resources and environment; and 5) urbanization, transportation, and communication.

Related Publications

Other reports (prepared in cooperation with BOSTID) available from the above address are:

An International Centre for Manatee Research. 1975. 34 pp. Describes the use of the manatee, a large, almost extinct, marine mammal, to clear aquatic weeds from canals. Proposes a research laboratory to develop manatee reproduction and husbandry. Published by the National Science Research Council of Guyana. NTIS Accession No. PB 240-244. $4.50.

Ferrocement, a Versatile Construction Material: Its Increasing Use in Asia. 1976. 106 pp. Report of a 1974 workshop with the Asian Institute of Technology, Bangkok, Thailand. Surveys applications of ferrocement technology in Asia and the Pacific Islands. Includes construction of grain silos, water tanks, roofs, and boats. Published by Asian Institute of Technology. NTIS Accession No. PB 261-818. $6.50.

Workshop on Solar Energy for the Villages of Tanzania. 1978. 167 pp. Report of a 1977 workshop with the Tanzania National Scientific Research Council, Dar es Salaam, Tanzania. Reviews state-of-the-art of small-scale solar energy devices, and suggests short- and long-range projects using them in villages. Published by Tanzania National Scientific Research Council. NTIS Accession No. PB 282-941. $9.00.

International Consultation on Ipil-Ipil Research. 1978. 172 pp. Report of a 1976 conference sponsored with the Philippine Council for Agriculture and Resources Research, Los Baños, Laguna, Philippines. Contains background papers and workshop summary session reports on ipil-ipil (*Leucaena* spp.). (Companion volume to report no. 26 above.) NTIS Accession No. PB 280-161. $8.00.

Out of Print Publications

The following out-of-print BOSTID reports are available *only* from the National Technical Information Service. To order, send report title, NTIS Accession Number, and amount indicated. (Note: Prices are current for April 1978 and are subject to change without notice.) Pay by NTIS Deposit Account, check, money order, or American Express Card. U.S. orders without prepayment are billed within 15 days; a $5.00 charge is added. Prices for foreign buyers are double the prices indicated below, and payment in full must be enclosed. Send order to:

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1. **East Pakistan Land and Water Development as Related to Agriculture.** January 1971. 67 pp. Reviews World Bank proposed action program in land and water management. NTIS Accession No. PB 203-328. $5.25.

2. **The International Development Institute.** July 1971. 57 pp. Endorses concept of new science-based technical assistance agency as successor to AID; examines its character, purposes, and functions. NTIS Accession No. PB 203-331. $5.25.

3. **Solar Energy in Developing Countries: Perspectives and Prospects.** March 1972. 49 pp. Assesses state of art, identifies promising areas for R & D, and proposes multipurpose regional energy research institute for developing world. NTIS Accession No. PB 208-550. $5.25.

4. **Scientific and Technical Information for Developing Countries.** April 1972. 80 pp. Examines problem of developing world's access to scientific and technical information sources, provides rationale for assistance in this field, and suggests programs for strengthening information infrastructure and promoting information transfer. NTIS Accession No. PB 210-107. $6.00.

6. **Research Management and Technical Entrepreneurship: A U.S. Role in Improving Skills in Developing Countries.** 1973. 40 pp. Recommends initiation of a systematic program and indicates priority elements. NTIS Accession No. PB 225-129. $4.50.

9. **Mosquito Control: Some perspectives for Developing Countries.** 1973. 63 pp. Examines biological control alternatives to conventional pesticides; evaluates state of knowledge and research potential of several approaches. NTIS Accession No. PB 224-749. $6.00.

10. **Food Science in Developing Countries: A Selection of Unsolved Problems.** 1974. 81 pp. Describes 42 unsolved technical problems with background information, possible approaches to a solution, and information sources. NTIS Accession No. PB 235-410. $6.00.

12. **Roofing in Developing Countries: Research for New Technologies.** 1974. 74 pp. Emphasizes the need for research on low-cost roofs, particularly using materials available in developing countries. NTIS Accession No. PB 234-503. $6.00.

13. **Meeting the Challenge of Industrialization: A Feasibility Study for an International Industrialization Institute.** 1973. 133 pp. Advances concepts of an independent, interdisciplinary research institute to illuminate new policy options confronting all nations. NTIS Accession No. PB 228-348. $7.25.

15. **International Development Programs of the Office of the Foreign Secretary**, by Harrison Brown and Theresa Tellez. 1973. 68 pp. History and analysis, 1963-1972; lists staff/participants and publications. NTIS Accession No. PB 230-543. $5.25.

Other out-of-print reports (prepared in cooperation with BOSTID) available from the National Technical Information Service are:

Products from Jojoba: A Promising New Crop for Arid Lands. 1975. 30 pp. Describes the chemistry of the oil obtained from the North American desert shrub *Simmondsia chinensis*. NTIS Accession No. PB 253-126. $4.50.

Aquatic Weed Management: Some Prospects for the Sudan and the Nile Basin. 1975. 57 pp. Report of a 1975 workshop with the Sudanese National Council for Research. Suggests modern and innovative methods for managing the water hyacinth. Published by National Council for Research–Agricultural Research Council of Sudan. NTIS Accession No. PB 259-990. $5.25.

Natural Products for Sri Lanka's Future. 1975. 53 pp. Report of a workshop with the National Science Council of Sri Lanka. Identifies neglected and unconventional plant products that can significantly contribute to Sri Lanka's economic development. Published by National Science Council of Sri Lanka. NTIS Accession No. PB 251-520. $5.25.

Reports in Preparation (working titles)

BOSTID will fill requests for single copies of reports in preparation upon publication as outlined at the beginning of this section.

25. Tropical Legumes: Resources for the Future.
27. Firewood Crops: Bush and Tree Species for Energy Production.
28. Underexploited Microbial Processes of Potential Economic Value.

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