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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

UNITED NATIONS
ENVIRONMENT PROGRAMME

FOOD LOSS PREVENTION IN PERISHABLE CROPS

based on an expert consultation
jointly organized by the

Food and Agriculture Organization of the United Nations

and the

United Nations Environment Programme

AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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FOREWORD

This study deals with the post-harvest losses occurring in perishable crops and how they can be reduced or prevented. It is the combined result of study tours, literature search, and discussions during an Expert Consultation jointly organized by the Food and Agriculture Organization and the United Nations Environment Programme in May 1980. More than 30 specialists from the different disciplines of the post-harvest system and representing a wide geographical area were at one stage or another involved in this study.

This publication is primarily intended for policy-makers, planners, development corporations and potential investors in the developing countries, although it could conveniently be used as background material for training courses in post-harvest technology. With its mixture of technical background information and recommendations for curative action it is hoped that the document will create sufficient awareness for initiating steps to recover a food availability which is now lost.

The publication is divided into two main parts, preceded by a Summary in which the Recommendations for post-harvest loss prevention measures in perishable crops are incorporated.

In Part I the concept of post-harvest loss prevention and its increasing importance to provide more food is introduced followed by the Conclusions reached by the Expert Consultation. Part II describes the technical aspects of post-harvest losses and the factors that influence their magnitude and opportunities for their reduction.

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SUMMARY

Forecasts as to the extent to which the increasing demand for food in the world can be fulfilled over the next decades range from very cautious to optimistic. More concrete is the expectation that the necessary food supplies will have to be derived increasingly from the intensification of agricultural production rather than from additional land use. This will require a more judicious use of limited production inputs and may have repercussions on costs.

The reduction of post-harvest food losses is a complementary means for increasing food production. This draws its importance not only from a moral obligation to avoid waste, but also because the cost of preventing food losses in general is less than producing a similar additional amount of food of the same quality. Therefore, the concept of food loss prevention, to which attention was drawn by the World Food Conference in 1974, will afford mankind increasingly significant opportunities to meet its food requirements. The programmes that have been initiated so far at the international level, amongst which is FAO's Food Loss Prevention Programme, have focused mainly on the durable food grains because of their prominence in the daily diet. The perishable crops, because of their high moisture content, are inherently more liable to deteriorate, especially under tropical conditions. Fruits and vegetables provide basic food and nutritionally essential vitamins and trace elements and, moreover, have an important role in improving food flavour and acceptability.

This study, therefore, is concentrated on the perishables of plant origin and endeavours have been made to review the magnitude of losses, the places where they occur and the measures that can be taken to reduce them in the developing countries.

The findings and course of action to improve the situation are reflected in the Recommendations proposed by the Expert Consultation on Food Loss Prevention in Perishable Crops, held at FAO, Rome, in May 1980, and are listed below:

RECOMMENDATIONS

1. An international action programme of post-harvest food loss prevention in perishables of plant origin should be initiated. A proper balance should be maintained between post-harvest scientists and economists, engineers and food technologists in project formulation and implementation.

2. All projects designed to increase food production or improve food marketing should give consideration to the post-harvest implications of the project including both project development and project monitoring phases.

3. All post-harvest food loss reduction activities should consider the environmental impact of that activity. Environmental and health issues should be part of the documentation of project proposals and the planning process.

4. Each country should attempt to identify the principal problem areas affecting losses in perishables of plant origin occurring in its own post-harvest system with a view to establishing appropriate priority areas for action. Since the value of the product may be doubled in the post-harvest period, these value changes need to be assessed for specific crops. The scale of priorities should be compiled on the basis of the magnitude of the losses, their economic and nutritional importance and the feasibility of applying effective remedial action that is operationally and economically reasonable. A systems approach should be used in this process taking into account biological, physical, economic and social factors with reference to the various economic groups including the rural poor. There should be full participation of the expected beneficiaries in the planning of food loss reduction activities. Traditional technologies should not be ignored.

5. The use of proper temperature management procedures should be promoted. This includes simple cooling systems such as shading from direct sunlight and use of evaporative cooling. Where appropriate, more cool stores and better utilization of existing cool stores should be promoted. The International Institute of Refrigeration should co-operate with national and international organizations to organize training in refrigeration management, design, operation and maintenance suitable for conditions experienced in developing countries.

6. The search for low cost cooling systems should be intensified. This should include the application of solar energy and other renewable sources of energy to power cooling systems. Practical research programmes should be drawn up by national and international agencies and institutes to adapt refrigeration techniques to the needs of developing countries.

7. There should be development and promotion of gentle handling of horticultural produce at all steps in the harvesting and marketing system when it is technically feasible and economically viable. This includes the development and use of improved market and field containers that are used to harvest, transport and store horticultural produce. All training manuals should emphasize that mechanical damage is the major factor in providing pathways for infection of produce by microorganisms. The avoidance of mechanical injury should be an essential criterion in the design of harvesting and handling machinery. The importance of efficient marketing systems as a factor in the prevention of post-harvest losses particularly the less durable fruits and vegetables has also to be recognized and such systems adapted to suit the requirements of efficient perishables' marketing.

8. There should be active encouragement of rigid sanitation and public health procedures of all produce handling and operation areas, sanitary operation of equipment, containers and stores, and sorting out and proper disposal of diseased and damaged units from the produce.

9. The relevant International Agricultural Research centres of the Consultative Group for International Agricultural Research in collaboration with national and other international institutes should be encouraged to initiate or expand a co-ordinated programme of research to resolve outstanding problems related to post-harvest factors and storage behaviour of horticultural crops, e.g., root crops. Plant breeders in these institutions should consider long inherent storage life as an important criterion of selection in the breeding of fruits, vegetables, roots and tubers.

10. Research to develop small scale drying technology or other suitable appropriate technologies for transforming horticultural crops should be promoted. The use of these technologies should be promoted where their benefits have been clearly demonstrated.

11. Every country should be cautioned against the use of hazardous protective agricultural chemicals until the following actions have been accomplished:

a) analytical laboratories and inspection services have been established to monitor the proper use of pre- and post-harvest agricultural chemicals;

b) guidelines have been developed and are being applied to educate farmers and food handlers in the proper and safe use of hazardous compounds and safe disposal of empty containers;

Information should be available in each country as to which national and regional laboratories have the facilities to identify decay organisms.

12. A variety of types of training programmes in prevention of losses in horticultural crops should be initiated. These should be designed to suit the differing needs of the people in different parts of the harvesting and marketing chain. While most training should be provided within their own country exchanges with other countries may be beneficial in some cases. The transfer of existing good storage technology from national and international institutes to potential users should receive priority in the programmes of these institutions.

13. The following publications should be prepared:

a) technical loss prevention manuals for commodities or groups of commodities;

b) a world-wide directory of institutions and training programmes involved with prevention of losses in perishable crops;

c) guidelines for loss assessment.

14. An international information network on food losses in horticultural crops should be established making as much use as possible of existing national and international programmes to facilitate technical co-operation between similarly oriented institutions. The information to be collated in a World Directory (13 b) should form the basis for establishing International and Regional co-operation in improvement of training at all levels.

I. Rationale and Directions for Reducing Food Losses in Perishable Crops

Securing an adequate food supply has been the fundamental concern of mankind over the millenia, and even in today's modern world of great scientific and technological achievements, diets are inadequate for about five hundred million people. In the community of nations concern is increasingly focused on fulfilling the basic needs of all people, and the need for food is a dominant one. Without ensuring satisfactory diets, people cannot lead healthy and productive lives.

Agriculture, including fisheries, is the main if not the sole provider of food and the crucial question can be raised if and how far agriculture can respond to the rising demand for food in the coming decennia.

A recent study (FAO) referring to 90 developing countries representing 98% of the population in the developing world (excluding China) reveals that the most striking share of increases in food demand will be caused by expanding world population. By the year 2000 fifty per cent more food will have to be available to meet present intake levels; yet additional food supplies will be needed by the end of the century to conquer famine and malnutrition. With respect to the material production inputs, which include land, water, minerals, organic substances, and energy, to meet these production targets, the availability of land will be the most limiting factor. Consequently, between 1980 and 2000 only twenty-eight per cent of the required additional crop production will be derived from area expansion and seventy-two will have to come from yield increases and more intensive cropping. This, in turn, will put more than proportional demands on water, fertilizer, pesticides, energy and managerial skills.

These figures and trends may illustrate that the case to reduce post-harvest losses, or preserving what has been produced with increasing efforts and costs, has become much stronger and will become more so in the future.

Attention to the concept of post-harvest food loss reduction as a significant means to increase food availability was drawn by the World Food Conference held in Rome in 1974. The 7th Special Session of the U.N. General Assembly in 1975 passed a Resolution calling for a 50 per cent reduction of post-harvest losses by 1985. This recognition of the potential value of post-harvest loss reduction has found practical expression in the continuing debate among a number of International Organizations and Institutions. As a result several initiatives at the international level have been taken with the special aim of making a concerted effort to reduce unnecessary losses at all the post-harvest stages of the food production process. In FAO, after consultation with its Governing bodies, food loss prevention became a priority area and an Action Programme became operational in early 1978. The United Nations Environment Programme supports and promotes ecologically sound and sustainable development. Food loss reduction is an important activity in which UNEP has an interest, because this will increase the resource base as well as enhance the environment.

The FAO Action Programme so far has focused only on staple foods with particular emphasis on food grains, in order to make the greatest possible impact with limited resources. This should, however, not detract from other important foods where losses are known to exist in the post-harvest system. It was felt that a stage had been reached where a second large group of commodities, the perishable crops, which for reasons of their importance to human nutrition, their magnitude of production and their vulnerability to spoilage, have common characteristics and problems, should be investigated further.

To this end the United Nations Environment Programme and FAO organized an Expert Consultation on the subject. Preceding this meeting three Consultants with different background and geographical expertise visited major Centres of activities in this field and prepared three working documents.

For the Consultation itself another 15 Specialists from the various post-harvest disciplines and with a broad geographical coverage were invited. The 4-day meeting took place in May 1980 at FAO Headquarters in Rome. The complete list of people attending, or having assisted in the preparation of this Consultation, is given on Pages xvii-xix. The major task of the Meeting was to discuss and complement the information prepared by the Consultants on the present status of the post-harvest food losses occurring in perishable crops and the opportunities and means to reduce these losses.

The conclusions reached by the meeting were:

1. Post-harvest loss in perishable crops constitutes an important issue that needs increased and continuing attention at national, regional and international levels by FAO, Governments and other concerned organizations because it requires fewer resources and applies less pressure to the environment in maintaining the quantity and quality of food than through increased production to offset post-harvest losses.

2. Traditional effective methods for preventing and reducing post-harvest losses need to be identified and exploited; this includes maintenance of continuous supply, storage for restricted periods, and transformation to durable products.

Some valuable traditional technologies for food preservation are in danger of becoming lost because they are being superseded by more sophisticated methods of doubtful long-term value. Modern and technology-intensive methods should be applied appropriately according to prevailing conditions including cultural factors. Efficient and proper management of such technologies is as important as the types of equipment and facilities selected.

3. The entire food production and supply system needs to be addressed as a whole, because of the interrelationship between and amongst the different components of the system. A substantial amount of post-harvest losses have their origin in the pre-harvest stage, for example, genetic factors, infections, pest infestations, environmental factors and cultural practices during the production stage.

4. Most post-harvest losses in horticultural produce result from infection by fungi and bacteria (pre- or post-harvest), and from inherent physiological activity although insects, rodents, nematodes, and occasionally birds may cause significant losses under certain conditions. Insects can disseminate some plant pathogens and also provide wounds as points of entry for microorganisms. In general, pre-harvest application of fungicides is more important in the control of post-harvest problems of fruit and vegetable crops than in root crops. Infections established prior to harvest are extremely difficult to control after harvest. Sanitation in all post-harvest operations is a key factor in eliminating sources of infection and reducing levels of contamination.

5. A distinction needs to be made between post-harvest losses incurred as a result of inadequate production planning (surpluses), speculation or excessive quality grading (mostly occurring in developed countries) and losses incurred due to lack of know-how, technology, or infrastructure (mostly occurring in developing countries) because the reduction of the different types of losses requires different approaches.

6. All food losses occur within a particular socio-cultural and economic environment. Techniques to reduce food losses require cultural and economic adaptations. While physical aspects are clearly most important, the subject must be considered within the wider framework of an approach whereby human as well as physical factors are taken into account.

7. Since losses are commodity and location specific, there is a need for specific activities, e.g., workshops, pilot projects, training courses, marketing studies, etc., in each country or region to address the priority problems of that area. Particular attention needs to be given to locally important commodities in each area. International assistance to developing countries in the field of post-harvest loss prevention needs to be geared to improve capability of the developing country to handle these programmes.

8. There is a need for an international information network to promote exchange of information on prevention of losses in perishable crops. Links between existing national and international institutions need to be strengthened. There is a need for a periodically annotated bibliography covering studies on post-harvest food losses in perishable commodities and for a world-wide directory of post-harvest technology centres and personnel.

9. There is a need to establish exchange programmes (technical co-operation between developing countries) between countries of similar needs and interests but which have an apparent difference in advancement in post-harvest handling systems.

10. Proper management of temperature and humidity of root crops and certain other perishables in the initial post-harvest period is essential to good curing which improves wound healing and minimizes infection by microorganisms.

11. Refrigeration is an important tool in the temperature management of perishables. It is desirable to remove field heat as soon as possible after harvest and to store at that temperature which will give the longest shelf-life. However, refrigeration technology should not be adopted as a panacea for all problems connected with deterioration associated with high temperature. Its introduction needs careful study, due consideration of its appropriateness and of the supporting infrasctructure available within the post-harvest system, as well as the relation of refrigerated storage capacity to the collection, pre-cooling, transportation, marketing and distribution system. Special care may be needed when a complete "cold chain" cannot be maintained within this system, and where refrigerated storage would form an additional operation in post-harvest handling.

12. A key factor influencing the magnitude of post-harvest losses is the severity of mechanical damage to the crop during harvest and subsequent handling because it provides pathways for invasion by fungi and bacteria.

13. Intervention activities need to be particularly directed to those individuals involved in handling the commodity throughout the post-harvest system and consideration needs to be given to their level of understanding.

Any innovation to reduce post-harvest losses introduced to the private sector should be accompanied by a clear financial incentive.

In exploring new technologies, due attention needs to be paid to ensuring their acceptance by producers and market operatives, particularly if the adoption of a new technology would mean the displacement of labour or a particular class of labour (e.g., women).

14. In view of the very short post-harvest storage life of cassava, research work on fresh cassava should continue but priority should be placed on research related to its transformation into stable products. Gari and cassava flour are examples of such transformed products.

In the case of yam, parallel work is necessary on the fresh product as well as on the transformed forms but with major emphasis on storage of the fresh product.

Processing or transformation of perishable crops could form a rural agro-industrial operation and assist in retaining the added value of processing in rural areas.

15. Additional research effort is needed in some areas where basic knowledge is inadequate, for example, chilling damage to tropical fruits and vegetables, the causes of deterioration of cassava, dormancy of yams, post-harvest physiology and pathology of roots and tubers, genetic improvement techniques, biological pest control, the effect on storability of chemicals and cultural practices used during the growing period. This will require the training and employment of specialized post-harvest technologists concerned with perishable crops.

16. Based on presently available information, the use of post-harvest chemicals has not shown toxicological problems. But when they are used there is need to ensure that the dosages and residues conform with internationally recommended maximum levels, e.g., of the FAO/WHO Codex Alimentarius Commission.

17. The preparation of outlines on when, where and why losses occur in selected perishable food crops is desirable but it is recognized that preparing a full methodology for loss assessment on perishables of plant origin is a complicated and time-consuming task. Diagnostic studies using an interdisciplinary approach are needed to properly identify the area where losses occur within the post-harvest system of perishable food crops.

18. There are some important issues that lie outside the immediate scope of this Expert Consultation that warrant further attention, for example, preventing the possible carry-over of excessive field pesticides into the post-harvest system, agricultural chemicals that have been banned in the country of origin but nevertheless still exported, grades and quality standards for horticultural products, reduction of losses in household food preparation, and increased consideration of environmental aspects in post-harvest intervention activities related to cereals and other foods.

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FAO Headquarters, Rome
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II. Post-Harvest Losses in Perishable Crops

1. INTRODUCTION

1.1 The Problem

"There is a war going on that began millions of years ago. Although the many generations of soldiers have not changed a great deal in appearance during this time, the tactics and weapons have grown more sophisticated. Each army has won a share of the battles, but the consummate victory has eluded both. Neither side can afford to give up, for nothing less than the sustenance of life is at stake. The war I refer to is, of course, the war between humankind and certain species of insects, weeds, pathogens, nematodes, rodents, and other pests that daily compete for our crops, gnaw at our dwellings, infest our domestic animals, or destroy our health" (Kuhr, 1979).

The above statement vividly describes the problem mankind has always had to preserve his food supply after he has produced it. The loss of foods in the post-harvest system is not new; it has always been a problem for mankind. In these days of rapidly enlarging populations in the poorest countries where food is already short, there is an increasing urgency to do a better job of conserving mankind's food supply in order to alleviate hunger and malnutrition. Some far-sighted individuals have been drawing attention to the problem of post-harvest losses for many years.

The United Nations General Assembly resolution of September 1975 focused world-wide attention on the problem of post-harvest food losses and called for concerted action to reduce these losses in the following words: "The further reduction of post-harvest food losses in developing countries should be undertaken as a matter of priority, with a view to reaching at least a 50% reduction by 1985. All countries and competent international organizations should co-operate financially and technically in the effort to achieve this objective".

As a result of this resolution a number of national and international donor agencies expanded existing programmes and initiated new programmes that were directed to the problem of reducing post-harvest losses. Most of these activities have been directed toward reducing losses in cereal grains, oilseeds and grain legumes.

A report prepared by the United States National Academy of Sciences in 1978 on the problem of post-harvest food losses in developing countries pointed out the need for giving consideration to losses in food products other than the cereals, particularly roots and tubers, fruits and vegetables. Largely as a result of this report, the donor organizations are beginning to consider intervention programmes that can reduce losses in horticultural crops.

Post-harvest losses of fruits and vegetables are more serious in developing countries than those in well developed countries. An additional constraint to improving this situation is that in most developing countries the number of scientists concerned with post-harvest food losses is significantly lower than those involved in production research. In the early days of horticulture in well developed countries, heavy losses occurred in much the same manner as they do today in developing countries. Increasing industrialization in technologically advanced nations gradually brought about improvements in crop handling. Elaborate harvesting equipment replaced the crude harvesting tools. Collection centres were strategically established in major producing areas. Containers were remodelled to add more protection to the produce. Commercial storage plants were installed and grade standards adopted. Engineers and economists became more and more aware of raw material behaviour. Concomitant advances in Refrigeration Technology in the developed countries have made possible establishment of cold chains for the entire post-harvest and handling operations. At the institutional level post-harvest research was initiated. Pilot packing houses were installed, coupled with the development of intensive training programmes. The improvement of product quality and reduction in post-harvest losses became the main concern of producers, middlemen, marketing specialists and consumers. Today, enormous volumes of quality horticultural crops produced in technologically advanced countries are made available to millions of people through improved post-harvest handling. Thus, historically and by necessity, post-harvest technology is part of the normal development processes in agriculture.

These handling procedures are not fully recognized in less developed countries. Here agriculture may be characterized as disjointed. Production is not linked with marketing. With perishable crops like fruits and vegetables, storage, packaging, transport and handling technologies are practically non-existent. Hence, considerable amounts of produce are lost. Thus, as more fresh fruits and vegetables are needed to supply the growing population in less developed countries, as more produce is transported to non-producing areas, and as more commodities are stored longer to obtain a year-round supply, post-harvest loss prevention technology measures become paramount. It is distressing to note that so much time is being devoted to the culture of the plant, so much money spent on irrigation, fertilization and crop protection measures only to be wasted about a week after harvest. It is, therefore, important that post-harvest procedures be given as much attention as production practices. The stages from planting until the products reach the consuming public must be a mutual undertaking between the growers and those who will handle the products after harvest.

Fruits and vegetables, roots and tubers (horticultural crops) are quite different in nature from cereal grains and oilseeds: the differences are summarized in Table 1. The causes of spoilage, the rate at which spoilage occurs, the degree of spoilage, and the actions needed to reduce spoilage are substantially different than for the cereals. Because of these differences it is necessary to design a different set of intervention programmes to reduce post-harvest losses in horticultural products.

Table 1

Comparison of Horticultural Crops vs Cereals

Cereals and Oilseeds	Horticultural Crops
Low moisture content, typically 10% to 20%	High moisture content, typically 70% to 95%
Small unit size, typically less than 1 gram	Large unit size, typically 5 g to 5 kg
Very low respiration rate with very small generation of heat. Heat production is typically 0.05 megajoule/ton/day for dry grain	High to very high respiration rate. Heat production is typically 0.5 to 10 megajoules/ton/day at $0^{\circ}C$ to 5 to 70 megajoules/ton/day at $20^{\circ}C$
Hard texture	Soft texture, easily bruised
Stable, natural shelf life is one to several years	Perishable, natural shelf life is a few days to several months
Losses usually caused by molds, insects and rodents	Losses usually caused by rotting (bacteria, fungi), senescence, sprouting, and bruising
Losses in LDCs* usually 10% to 20%	Losses in LDCs usually 15% to 50%

* Least Developed Countries

In the warm humid tropics, fresh fruits and vegetables have an extremely low level of natural protection against the climate, pests and bio-chemical and physiological deterioration. It is also in the warm humid tropics that human diseases are most numerous and widespread and consequently where the need for the nutritional value of fresh fruits and vegetables is most essential. On the other hand, dried grains and legumes, and to a certain extent, root crops (yams), have a fair degree of natural protection against the various deteriorative elements, even though considerable post-harvest losses do occur.

1.2 Importance of Perishable Crops

Production data for the root crops are given in Table 2 (Appendix 1 - Page 1). In terms of importance as assessed by volume of production within the tropics these are cassava, potatoes, yams, sweet potatoes, taro and others. It is estimated that some 174 million tons of roots and tubers are produced annually, of which cassava constitutes about 60%. Cassava is almost entirely produced and consumed in developing countries although in recent years there has developed a substantial trade in dehydrated cassava chips which are exported from developing countries to European countries as a low-cost animal feed ingredient. The European Economic Community imported 2.3 million tons of dried cassava chips in 1975. Next in volume of production are potatoes, yams and sweet potatoes. These make contributions respectively about 14, 11 and 10%. At the end of the scale taro contributes a lowly 2.2% while miscellaneous tubers account for 2.5%.

Table 3 (Appendix 1 - Page 2) lists the major vegetables and Table 4 (Appendix 1 - Page 3) lists the major fruits that were produced in developed countries, developing countries, and centrally planned economies in 1978. The total world production of roots, tubers, vegetables and fruits is enormous and approaches that of the total production of the staple cereal grains as can be seen from the following figures:

Commodity	Production 1978 (million tons)		% of Cereal Production	
	World	Developing Countries	World	Developing Countries
Cereals	1,580.8	730.6	100%	100%
Roots & Tubers	522.9	290.1	33.1	39.7
Vegetables & Melons	327.2	189.2	20.7	25.9
Fruits	261.9	141.6	16.6	19.4
Total horticultural production	1,112.0	620.9	70.4	85.0

(Data from FAO Production Yearbook 1978)

The total annual production of horticultural crops in developing countries is 620 million tons which is 85% of the cereal production in these countries. This surpasses the relative world average where horticultural crop production is only 70% of the cereal production. These high production figures indicate the important role that horticultural crops play in the economy of developing countries, although it must be remembered that these crops are far higher in water content than are the cereals.

The ten leading horticultural crops in developing countries in terms of total production are the following:

Commodity	1978 Production (million tons)
Cassava	110.5
Banana	35.1
Potato	29.5
Citrus fruits	23.9
Plantain	20.4
Yam	20
Sweet potato	16.9
Tomato	14.5
Mango	13.5
Grapes	11.3

Horticultural crops are essential for a nutritionally balanced diet. Fruits and vegetables are the major source of vitamins A and C, a good source of calcium and iron, and they supply part of the requirements for a number of other minor nutrients. Roots, tubers, bananas and plantains are important sources of calories and also supply a number of minor nutrients, and some protein.

In addition, horticultural crops add variety, enjoyment and a sence of satisfaction with the diet because of their appealing colours, flavours and textures. For example, it has been said that although onions and garlic are not rich in nutrients, they make a vegetarian diet acceptable because of the savoury flavour they impart to the monotonous starchy diet in a developing country. It is no accident that onions rank third, and garlic ranks tenth in volume of vegetable production in developing countries. (Table 3)

On all of these counts - economics, nutrition, acceptability - horticultural crops play a major role in developing countries, amply justifying the contention that something should be done to reduce the high losses that presently occur in these commodities.

1.3 Definition of Terms

Since the ramifications of food and the food supply spread right through society it is necessary to define exactly what is meant by the term "post-harvest food loss" if we are going to have a manageable problem with known boundaries. The working definition given below is based on that developed by Bourne (1977) and modified by the U.S. National Academy of Sciences (1978) and Harris and Lindblad (1978). For the sake of convenience the definition is divided into three parts.

"POST-HARVEST" begins at the moment of separation of the edible commodity from the plant that produced it by a deliberate human act with the intention of starting it on its way to the table. The post-harvest period ends when the food comes into the possession of the final consumer.

"FOOD" means weight of wholesome edible material that would normally be consumed by humans, measured on a moisture-free basis. Inedible portions such as skins, stalks, leaves, and seeds are not food. Potential foods (e.g., leaf protein) are not foods; they do not become food until they are accepted and consumed by large populations. Feed (intended for consumption by animals) is not food.

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

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

1.4 Causes of Losses

There are so many causes for losses in the post-harvest food chain that it helps to classify them into 2 groups and a number of sub-groups.

A. PRIMARY CAUSES OF LOSS are those causes that directly affect the food. They may be classified into the following groups:

a) Biological. Consumption of food by rodents, birds, monkeys and other large animals causes direct disappearance of food. Sometimes the level of contamination of food by the excreta, hair and feathers of animals and birds is so high that the food is condemned for human consumption. Insects cause both weight losses through consumption of the food and quality losses because of their frass, webbing, excreta, heating, and unpleasant odours that they can impart to food.

b) Microbiological. Damage to stored foods by fungi and bacteria. Micro-organisms usually directly consume small amounts of the food but they damage the food to the point that it becomes unacceptable because of rotting or other defects. Toxic substances elaborated by molds (known as mycotoxins), cause some food to be condemned and hence lost. The best known of the mycotoxins is aflatoxin (a liver carcinogen), which is produced by the mold Aspergillus flavus. Another mycotoxin which is found in some processed apple and pear products is patulin, which is formed in the apple by rotting organisms such as Penicillium expansum which infect fresh apples before they are processed.

c) Chemical. Many of the chemical constituents naturally present in stored foods spontaneously react causing loss of colour, flavour, texture and nutritional value. An example is the Maillard reaction, that causes browning and discolouration in dried fruits and other products. There can also be accidental or deliberate contamination of food with harmful chemicals such as pesticides or obnoxious chemicals such as lubricating oil.

d) Biochemical reactions. A number of enzyme-activated reactions can occur in foods in storage giving rise to off-flavours, discolouration and softening. One example of this problem is the unpleasant flavours that develop in frozen vegetables that have not been blanched to inactivate these enzymes before freezing.

e) Mechanical. Bruising, cutting, excessive peeling or trimming of horticultural products are causes of loss.

f) Physical. Excessive or insufficient heat or cold can spoil foods. Improper atmosphere in closely confined storage at times causes losses.

g) Physiological. Natural respiratory losses which occur in all living organisms account for a significant level of weight loss and, moreover, the process generates heat. Changes which occur during ripening, senescence, including wilting, and termination of dormancy (e.g., sprouting) may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. A reduction in nutritional level and consumer acceptance may also arise with these changes. Production of ethylene results in premature ripening of certain crops.

h) Psychological. Human aversion, such as "I don't fancy eating that today". In some cases food will not be eaten because of religious taboos.

Microbiological, mechanical and physiological factors cause most of the losses in perishable crops.

B. SECONDARY CAUSES OF LOSS are those that lead to conditions that encourage a primary cause of loss. They are usually the result of inadequate or non-existent capital expenditures, technology and quality control. Some examples are:

a) Inadequate harvesting, packaging and handling skills.

b) Lack of adequate containers for the transport and handling of perishables.

c) Storage facilities inadequate to protect the food.

d) Transportation inadequate to move the food to market before it spoils.

e) Inadequate refrigerated storage.

f) Inadequate drying equipment or poor drying season.

g) Traditional processing and marketing systems can be responsible for high losses.

h) Legal standards can affect the retention or rejection of food for human use by being too lax or unduly strict.

i) Conscientious, knowledgeable management is essential for maintaining food in good condition during marketing and storage.

j) Bumper crops can overload the post-harvest handling system or exceed the consumption need and cause excessive wastage.

1.5 Sites of Losses

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

a) Harvest. The separation of the commodity from the plant that produced it. In the case of roots, tubers and bulbs the commodity is lifted out of the soil.

b) Preparation. The preliminary separation or extraction of the edible from the non-edible portion, e.g., the peeling of fruits and vegetables.

c) Preservation is the prevention of loss and spoilage of foods. For example, the sun-drying of fruit, the use of refrigeration and the use of fungicides to inhibit mold growth in fruits.

d) Processing is the conversion of edible food into another form more acceptable or more convenient to the consumer, for example, the manufacture of fruit juice and the canning of fruits and vegetables.

e) Storage is the holding of foods until consumption. Most storage is common storage (ambient temperature) but there are extensive storage capacities that can hold food under refrigerated or controlled atmosphere conditions.

f) Transportation. All forms of transportation are used to convey foods from the point of production to the ultimate point of consumption.

Post-harvest losses in fresh root/tuber crops have their origin in mechanical damage, physiological processes, infection by decay organisms and, occasionally, pest infestation. The losses caused by these processes may occur during all stages of the food supply system from crop maturity, through harvesting, transportation and storage. The degree of loss associated with these factors is determined by the plant material involved, the prevailing environmental conditions and management of the food supply system. The major causes of loss in roots and tubers and the sites where they occur are summarized below:

Factor	Mechanism	Stage affected	Resulting loss
Mechanical	Rupture	Harvest	Moisture loss
	Bruising	Harvest, transport storage	Access to pests and disease
	Crushing	Transport storage	
Physiological	Transpiration		Water loss
	Respiration	All stages before transformation	Dry matter loss
	Sun scorch	Infield after lifting	Tissue degradation
	Greening	In field after lifting	Toxins
	Chilling	Storage	Loss of palatibility
	Inversion of starch	Storage	Change in taste
	Sprouting	End of dormancy Storage	Heightened transpiration, respiration
Pathogenic bacteria & fungi	Necrosis and tissue degradation	Pre-harvest Storage	Partial to complete loss Downgrading
Insect infestation	Boring and chewing	Preharvest Storage	Partial loss Access for decay organisms
Rodent & bird damage	Chewing Pecking	Preharvest Storage	Partial loss Access for decay organisms

1.6 <u>Magnitude of Losses</u>

Reliable statistics on losses are few. It is possible to find individual cases with losses ranging from 0% to 100%. The extent of losses is highly variable depending on a number of conditions. Stable foods such as cereal grains can be stored in good condition for several years, whereas perishable foods such as fruits and vegetables, spoil quickly unless given special treatment such as canning and freezing. The longer the time the food is stored the more opportunity there is for losses of all kinds to occur. Perishable crops generally suffer from higher losses than the cereals.

A number of figures for the extent of loss is quoted in scientific literature and by the communications media, but much of this information is unreliable because the amount of loss has been estimated and has not been obtained by actual measurements. There is often the temptation to cite "worst case" figures to dramatize the problem.

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

Another precaution that needs to be taken in assessing overall losses is to ensure that the arithmetic of calculating loss figures is correct. The extent of losses can be unwittingly exaggerated unless the arithmetical calculations are correctly performed. Some examples of misleading arithmetical calculations are discussed by Bourne (1977).

The pattern of losses varies widely from country to country. There is a marked contrast between the site of major losses in developed countries and developing countries. In a typical developed country losses may be fairly high during harvesting because the agricultural machinery that is used to harvest the crops leaves some of the commodity in the field and mechanically damages some of it. Considerable quantities of foods may be discarded at the point of harvest because they are of the wrong size, shape or colour. These are planned losses. In developing countries harvest losses are usually lower because most of the crop is hand picked. The amount of material rejected in developing countries is less because the expectation of quality and uniformity is generally lower than for developed countries.

In developed countries losses are generally small during processing, storage and handling because of the efficiency of the equipment, good quality storage facilities, and close control of critical variables by a highly knowledgeable cadre of managers. In contrast, in developing countries losses in processing, storage and handling tend to be rather high because of poor facilities and frequently inadequate knowledge of methods to care for the food properly.

Table 5 (Appendix 1, Page 4) lists some estimates of losses of selected commodities in developing countries. The tragedy of these enormous losses in developing countries is not only that this is a severe economic loss in regions that are struggling to escape from poverty but also a major loss of important nutrients to populations who are malnourished.

Pantastico (1977) pointed out that post-harvest losses in developing countries often exceed production losses and cites as an example the following figures for losses in the Philippines:

Crop	Production (m. tons)	Production Value ($)	Percentage Loss	Loss Value ($)
Fruits	2,763,443	403,909,220	28.1	113,498,490
Vegetables	1,640,541	248,564,310	42.2	104,894,130
Total	4,403,984	652,473,530	-	218,392,620

1.7 Loss Assessment

There appears to be no established generally accepted methodology for determining post-production loss in root/tuber crops. The National Academy of Sciences (USA) publication (1978) on post-harvest losses makes the following differentiation between assessment, measurement and estimation of losses:

Assessment is a rough quantitative approximation of food loss or the characterization of the relative points of loss in a particular food supply system. This approach implies a measure of subjectivity resulting from a lack of sufficient information.

Measurement on the other hand is a more precise quantitative observation with less subjectivity. With measurements there is a high expectation of reproducibility without observer bias.

Estimation is the interpretation of a number of scientific measurements. Here the process of interpretation depends on the experience and judgement of the observer.

At whatever level of precision post-harvest loss is determined the value will be specific in time and for location. This is due to the fact that loss is a function of the condition of the material, the prevailing environment, the nature and intensity of bio-degenerating organisms and the crop material management. None of these are constant. They are all dynamic factors liable to continuous change. As a consequence, crop loss, however determined will always be variable. This is illustrated by yam storage. Some cultivars of the rotundata/cayenensis/discorea species remain dormant for about 3 months, during which period storage loss is low. When placed in the traditional yam barn the keeping characteristics of these yams are good. It is generally believed that little improvement can be achieved without radical change in storage technology. However where the tubers are infected by nematodes the storage potential is much reduced and high losses occur.

It would be useful to have a standard method for assessing losses for each type of commodity but this is a difficult task due to crop diversity, inherent perishability and the complexity of the marketing and distribution channels.

1.8 Effects of the Environment on Food Losses

The environmental conditions under which foods are stored and processed can have a major effect on the keeping quality of the foods and the amount that is lost. The major environmental influences on the keeping quality of foods are the following:

Temperature. In general, the higher the temperature the shorter the storage life of horticultural products and the greater the amount of loss within a given time, as most factors that destroy the produce or lower its quality occur at a faster rate as the temperature increases. This statement applies to the rate of growth of spoilage micro-organisms, the rate of indigenous physiological change and physical processes such as water loss and wilting. Figure 1 shows changes in the quality of lettuce and asparagus during storage at different temperatures. Lettuce stored at 25°C becomes unsaleable within 7 days, while lettuce stored at 10°C will reach the unsaleable condition in approximately 18 days and lettuce stored at 0°C requires 35 days to reach the point of being unsaleable. For asparagus the loss of quality occurs at a more rapid rate than lettuce, reaching the point of being unsaleable in 3 days when stored at 25°C. Figure 1 is a clear demonstration of the rationale for the extensive cold storage facilities that are used for storing horticultural produce.

Humidity. There is movement of water vapour between a food and its surrounding atmosphere in the direction towards equilibrium water activity in the food and the atmosphere. A moist food will give up moisture to the air while a dry food will absorb moisture from the air. Fresh horticultural products have a high moisture content and need to be stored under conditions of high relative humidity in order to prevent moisture loss and wilting, exceptions to this being onions and garlic. Dried or dehydrated products need to be stored under conditions of low relative humidity in order to avoid absorbing moisture to the point where mold growth occurs.

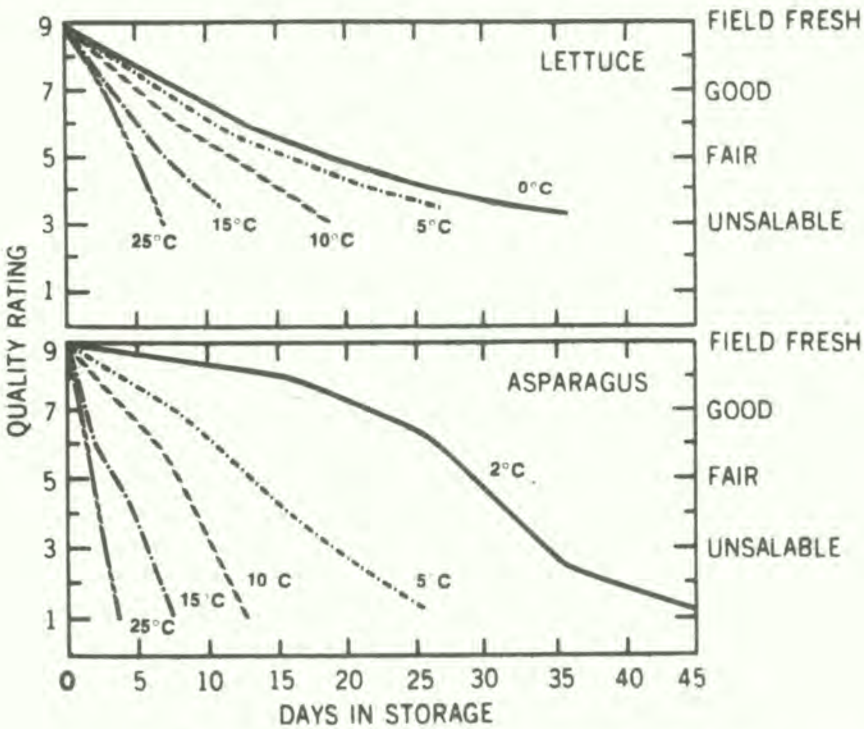

Figure 1. Loss of quality in fresh lettuce and asparagus stored at various temperatures (from Lutz and Hardenburg 1968)

Solar Radiation. The solar radiation that falls upon foods held in direct sunlight increases the temperature above the ambient temperature. The amount of increase in temperature depends on the intensity of the radiation, the size and shape of the food, and the duration of exposure to the direct rays of the sun. The intensity of solar radiation depends upon latitude, altitude, season of the year, time of day, and degree of cloud cover. Under clear skies it is most intense when the sun is most directly overhead. Hence the intensity of radiation is greater in tropical zones than in temperate zones. As discussed above, a high temperature is deleterious to food quality and increases wastage. It is ironic to note that, in the temperate climates where the intensity of solar radiation is moderate, almost all food is kept inside under cover whereas in tropical climates, where solar radiation is much higher, considerable quantities of food can often be found in the direct rays of the sun deteriorating in quality at a rapid rate.

Altitude. Within a given latitude the prevailing temperature is dependent upon the elevation when other factors are equal. There is on the average a drop in temperature of 6.5°C for each Km increase in elevation above sea level. Storing food at high altitudes will therefore tend to increase the storage life and decrease the losses in food provided it is kept out of the direct rays of the sun.

Atmosphere. The normal atmosphere contains by volume, approximately 78% nitrogen, 21% oxygen, 1% argon, 0.03% carbon dioxide, various amounts of water vapour and traces of inert gases. Modifying the atmosphere can improve the shelf life and reduce wastage of certain foods.

One type of controlled atmosphere storage (CA) is refrigerated storage in which the level of oxygen is reduced to about 3% with the carbon dioxide content being raised to 1 to 5%,depending on the commodity. This CA storage may double the storage life over that of regular cold storage for certain varieties of apples and pears by slowing down the natural rate of respiration.

Many fruits, the "climacteric fruits", generate ethylene gas during ripening and the presence of this gas accelerates the rate of ripening. If the ethylene is removed from the atmosphere surrounding these fruits as it is generated, their storage life may be extended. Experiments have shown that placing such fruits in a fairly gas-tight container with potassium permanganate, which absorbs ethylene gas, can substantially extend the storage life even at ambient temperature.

"Modified atmosphere storage" is another type of controlled atmosphere storage. This term denotes storage of horticultural products in a beneficial atmosphere other than air that is not under as close regulation as in CA storage. Modified atmosphere storage can be obtained in boxes of pears, apples, and cherries that are lined with polyethylene film which acts as a barrier to the escape of carbon dioxide and the ingress of oxygen. Another method of obtaining a modified atmosphere storage is by the addition of dry ice which increases the carbon dioxide in the atmosphere to some extent.

Time. The longer the time the food is stored the greater is the deterioration in quality and the greater is the chance of damage and loss. Hence storage time is a critical factor in loss of foods, especially those that have a short natural shelf life. The time involved from harvest to consumption of perishable commodities is much shorter than that from planting to harvest. While production time could take about several years for fruit trees, and generally about three to four months for vegetables, the duration of post-harvest handling could be as short as one day to a few weeks. Any improvement in post-harvest handling treatments would therefore involve less risk and would be more economical than improvements in production.

Biological pressures. Bacteria and fungi are always present in the atmosphere to contaminate food and cause spoilage should conditions favour their growth. However, it should be emphasized that the contamination or inoculation process with bacteria and fungi occurs to an equal extent during the harvesting process. Soil organisms as well as foliage pathogens can be introduced. Bacteria that cause disease in plants are not usually introduced from the air per se except in aerosols. Micro-organisms can multiply very rapidly whenever conditions are favourable for growth. The only foods that are free from micro-organisms are those that have been thermally processed, such as canned goods.

A similar situation occurs with insects. Insects are in the field and can accompany foods as they are brought from the field into storage. Most of the stored products' insects can increase in number by a factor of 10 to 50 times per month under favourable conditions. Stored food insects are ubiquitous, hiding in storage facilities and moving with stored foods when they are moved. Consequently we can assume that foods can become infested with insect pests at any time unless special precautions are taken.

Rodents and sometimes birds can exert biological pressures similar to those of insects and micro-organisms. The great capacity of living organisms for multiplication by geometric increase generates heavy biological pressures upon stored foods.

1.9 Environmental Considerations

A number of people who have accepted the idea of the need for better conservation of food wonder why the United Nations Environment Programme (UNEP) is interested in food losses and control of food losses. There are substantial reasons for UNEP's interest in this area and these will now be discussed.

UNEP is interested in promoting the health and well-being of both people and the environment, as well as sustainable development. Reducing food losses should improve nutritional status and human health, especially in those countries where a large proportion of the population is inadequately fed. Decreasing food losses offers an opportunity to reduce the pressure on the land and still deliver the same quantity of food to the table, thus reducing to some extent environmental damage caused by agricultural practices. Hence, UNEP encourages the conservation of food because of its positive environmental effects.

UNEP is interested in efficient and non-wasteful utilization of resources. Although it is difficult to obtain firm figures, it is generally conceded that considerably less energy and other inputs are required to conserve food than to produce an equal quantity of food. For example, it has been estimated that the total energy cost of good grain storage practice is about one percent of the energy cost of producing that grain. Hence, UNEP encourages good conservation practice because of its more efficient use of energy and other inputs.

UNEP's activities include reviewing proposed new initiatives to determine the environmental impact of these initiatives before they are put into effect and to help select from among competing initiatives those that are most desirable from the environment standpoint, to encourage their use, and to do this in the early planning stages of the project. Hence, UNEP is interested in what methods are proposed to be used to reduce post-harvest food losses.

The next section of this report lists thirteen methods that are used to reduce losses in horticultural products. The first twelve methods have little adverse effect on health, safety or the environment and are recommended for use on environmental grounds. Of course, it is recognized that additional criteria will be used to make the final selection of methods to be actively promoted.

The thirteenth method of control is by use of post-harvest chemicals which is of great interest to UNEP because of the justifiable concern about the consequences of man-made chemicals that are used and discharged into the environment. The question of post-harvest chemicals is reviewed and the conclusion drawn that they probably cause little harm to human health and little damage to the environment when they are correctly used, but there may be grave risks to both if they are misused. This leads to the conclusion that post-harvest chemicals should only be used in those locations where there is adequate training in their proper use backed up by adequate machinery to enforce proper use. The environmental approach in this case is not to oppose the use of chemicals but to point out the need for using them properly and carefully.

The finding that most of the thirteen methods for reducing losses do not aggravate the environment or harm human health is encouraging. It means that intervention programmes can be planned with the knowledge that they cause much positive good and little harm. It is worth the effort of this exercise to establish this finding.

2. FACTORS RELATED TO THE POST-HARVEST SYSTEM

2.1 Technologies

The major technologies for reducing losses in horticultural products are listed below followed by a statement of probable environmental effects from the named procedure.

2.1.1 Gentle handling

Because of their soft texture all horticultural products should be handled gently to minimize bruising and breaking of the skin. Bruising renders the product unsaleable to most people although it usually has minor effect upon the nutritional value. The skin of horticultural products is an effective barrier to most of the opportunistic bacteria and fungi that cause rotting of the tissues. Breaking of the skin also stimulates physiological deterioration and dehydration. Careful digging and movement of roots and tubers significantly reduces post-harvest losses. Careful handling of fruits and vegetables to minimize bruising and breaking of the skin likewise is a well-known method of reducing post-harvest losses as is the provision of adequate shipping containers to protect the produce from bruising, and puncturing of the skin. Reducing the number of times the commodity is handled reduces the extent of mechanical damage.

Environmental effects. There are no adverse environmental effects to this technology. Thus careful digging, harvesting and handling, and appropriate packaging and transportation are environmentally sound methods for reducing losses. Also, since damaged skin is the major entry point for fungal infections, some of which produce mycotoxins, gentle handling can improve the safety of the produce.

2.1.2 Temperature control

It is well known that cooling horticultural produce extends storage life by reducing the rate of physiological change and retarding the growth of spoilage fungi and bacteria. Cooling is the foundation of quality protection (see Figure 1 - Page 12). There are several ways of reducing the storage temperature of horticultural crops:

Cooling technique	Environmental effect
a) Keep out of direct rays of sun.	This is an easy low-cost method with minimal effect on the environment. Almost all societies can provide shade at low economic or environmental cost.
b) Use natural cooling, e.g., harvest during the cool early morning hours, open stores for ventilation during the cool of the night, utilize the cool temperature of high altitude or a natural source of cold water when available.	Minimal environmental costs.
c) Evaporative cooling obtained by drawing dry air over a moist surface.	Minimal environmental and economic costs. Restricted to areas of low humidity and low-cost water.
d) Mechanical refrigeration.	Energy costs and economic costs are relatively high but give most positive control of temperature. Generated heat is dumped into the environment.
e) Cool promptly after harvest.	High energy cost.

Since every degree reduction from ambient temperature increases storage life, every form of cooling is beneficial even if it is not optimum cooling, i.e., simple low-cost cooling or refreshing the product is better than no cooling at all.

The optimum storage temperature for most temperate horticultural crops is close to $0^{\circ}C$. If they are cooled slightly below this temperature they freeze and suffer from "freezing injury" and spoil quickly. Most tropical horticultural crops however can be injured even at temperatures above freezing point. This is called "chilling injury" and causes rapid deterioration in quality. The optimum storage temperature for most tropical horticultural crops is between 7° to $10^{\circ}C$; for yams and bananas it is about $15^{\circ}C$.

Although refrigerated storage is not often appropriate for some commodities such as yams, it should be considered an important element in the temperature management of a wide range of perishable crops because it gives the most positive and direct control of temperature. The popularity of refrigerated storage in some countries has suffered setbacks due to occasional poor design of units and bad management. This has sometimes resulted in the impression that refrigerated storage is costly and unsuited for use in developing countries, which is not necessarily the case. Good design and proper management are essential ingredients in considering the introduction of refrigeration techniques as are the supporting infrastructures available within the post-harvest system. When studied on a case-by-case basis it seems likely that refrigerated storage will continue to find many successful applications to the needs of developing countries.

There are four basic principles which must be correctly applied for successful refrigeration of perishable crops:

(i) Select only healthy products. Refrigeration does not destroy pathogens responsible for product deterioration but only slows their activity; it does not improve product quality but only maintains it. A damaged product will deteriorate more quickly than a healthy one even in refrigerated storage, hence it is pointless to submit poor quality produce to refrigeration. In addition storage under refrigeration increases the cost to the product. The storage therefore of low grade diseased produce frequently cannot achieve an adequate economic return.

(ii) Timely cooling: Since refrigeration slows the development of micro-organisms and physiological changes responsible for deterioration of perishable crops, it is obvious that cooling should be applied as soon as possible after harvest. The technique of pre-cooling was developed to fill this need by cooling produce soon after harvesting down to a temperature appropriate to that product.

(iii) Adhere closely to optimal conditions for temperature and relative humidity. It is well known that refrigeration provides maximum storage life if these two parameters are correctly adhered to. This fact is especially important for tropical fruits and vegetables because their optimum storage temperatures vary considerably between varieties and even between producing areas. One of the main roles of research centres in tropical countries should be to define optimum storage conditions for commodities grown under tropical conditions. There is a need to evaluate the limitations of storage of these commodities under a range of temperature conditions and to consider the implications and problems of product compatability under conditions of mixed commodity storage.

(iv) Uninterrupted cooling: Refrigeration should be applied from the point of harvest through to the point of consumption where maximum post-harvest life with high product quality is justified. This is the well known concept of the "cold chain".

2.1.3 High humidity

High humidity retards wilting and maintains the product in better condition. Most horticultural products store best in an atmosphere that has a relative humidity of 90% (Lutz and Hardenburg, 1968). Providing humidity has little environmental cost.

2.1.4 Waxing of the surface

Waxing the surface of horticultural products is a treatment used on a number of commodities including citrus fruits, apples, rutabagas and cucumbers. It retards the rate of moisture loss, and maintains turgor and plumpness and may modify the internal atmosphere of the commodity, and is performed primarily for its cosmetic effect; the wax imparts a gloss to the skin and gives the produce a more shiny appearance than the unwaxed commodity. Sometimes anti-fungal agents are incorporated into the wax to inhibit growth of fungi. Simple waxing is a technique that could probably be used more widely in developing countries with advantage. In some countries indigenous waxes may be suitable for this purpose. For example, experiments in Colombia have shown that waxing of cassava can extend the storage life from 2 to 3 days up to about 30 days by preventing discolouration in the vascular tissue. (Buckle et al 1973) Work in India has also demonstrated the efficacy of indigenously produced wax emulsion formulations in extending the storage life of different fruits and vegetables. (Dalal et al 1970)

Environmental effects. The waxes and wax formulations that are used in the U.S. are approved by the Food and Drug Administration and are kept under continuous review. Most of the ingredients in the wax mixtures are classified "Generally Recognized As Safe" (GRAS). In most cases the skin is removed and discarded before consumption in which case the wax is not ingested and should cause no special problems. However, problems might arise if unregistered formulations are used, or if the skin is eaten by humans or fed to animals.

2.1.5 Controlled atmosphere storage

Controlled atmosphere storage consists of placing a commodity in a gas-tight refrigerated chamber and allowing the natural respiration of the fruit to decrease the oxygen and increase the carbon dioxide content of the atmosphere in the chamber. Typically, for storage of apples the oxygen content is lowered to about 3% and carbon dioxide is allowed to increase to 1 to 5%. This atmosphere can extend the storage life of apples by several months and allows fresh apples to be marketed every month of the year. This technology requires expensive storage chambers and close supervision of the composition of the atmosphere and is unsuited for widespread use in less developed countries.

Some roots and tubers are stored in pits in the ground, known as "clamp storage". Well designed clamps tend to change the atmosphere to some extent by reducing oxygen and increasing the carbon dioxide content. Modified atmosphere storage would probably be effective for a limited number of commodities in developing countries especially if coupled with low temperature storage. Wills and Wimalasiri (Hort. Science, 14 528 1979) have recently shown that short pre-storage exposure to high carbon dioxide and low oxygen atmosphere of vegetables can extend the storage life of commodities even at ambient temperature.

Environmental effects. Since this technology only manipulates the proportions of gases that are naturally present in the air there should be no adverse environmental effect.

The new technology of hypobaric storage is emerging which maintains reduced pressure in the refrigerated storage chamber by means of vacuum pumps. In this system the commodity is placed in a flowing stream of highly humidified air which is maintained at a reduced pressure and controlled temperature. Under these conditions, gases released by the commodity that limits its storage life, are flushed away. Reports indicate that the storage life of certain fruits and vegetables is extended substantially by this procedure. The economic feasibility of this type of controlled atmosphere storage is presently being tested. This is an energy-intensive and capital-intensive technology and is perhaps unsuited for less developed countries. The major environmental effect is the high energy cost.

2.1.6 Field factors

Maturity at time of harvest is an important factor in the keeping quality of horticultural products. Commodities that are harvested in an immature state not only have poor eating quality but may tend to shrivel in storage and be more susceptible to storage disorders. When picked too mature the commodity is soft or fibrous, the flesh breaks down more quickly and it has a shorter storage life. There is an optimum time of harvest to give maximum storage life for fruits, vegetables and tubers.

The rootstocks used for establishing fruit orchards may affect losses. For example, McDonald and Wutscher (1974) reported decay in grapefruit ranging from 3.3% to 27.7% depending on the rootstock. It is reported that the storage life of fresh cassava can be greatly extended by leaving part of the stalk attached to the tubers at harvest time. There are a number of other field factors that affect losses and these should be utilized as much as possible.

Environmental effects. Generally there are no adverse environmental effects in these operations.

2.1.7 Suberization and curing

Potatoes, sweet potatoes, yams and several other roots and vegetables have the ability to heal skin wounds when held at moderately warm conditions and high humidity for several days after harvest. The self-healing of wounds, cuts and bruises is known as curing. There are two steps in the curing process. First is suberization - the production of suberin and its deposition in cell walls. The second is the formation of a cork cambium and production of cork tissue in the bruised area. The new cork tissue seals the cut or bruised areas and helps prevent the entrance of decay organisms. The healing of injuries received in harvesting and handling prolongs the storage time and reduces the incidence and spread of decay in storage.

The storage life of onions and garlic is extended by exposure to warm dry conditions for several days to dry the outside skin and prevent the ingress of spoilage organisms. This process if also known as curing although physiologically it is rather different and causes about 5% weight loss. Curing is carried out in the field when weather conditions are suitable; otherwise the product is subjected to forced circulation of warm dry air when first put into storage.

This is sound environmental practice. There is little effect on the environment from curing.

2.1.8 Genetic control of shelf life

Each variety of a horticultural crop has a limited storage life even under optimum storage conditions. The potential storage life is partly under genetic control and can be manipulated by breeding. Table 6 (Appendix 1 - Page 5) shows the normal storage life of some North American varieties of potatoes and onions under good storage conditions. This very wide range of storage life is typical of horticultural products; each variety has its own particular life span.

Plant breeders should be encouraged to include potential storage life as one criterion in their programme for breeding improved varieties of roots, tubers, fruits and vegetables. This is particularly needed with the breeding programmes in tropical climates where refrigerated storage capacity is in short supply. This should be a high priority method for reducing losses in horticultural products.

Farmers should be encouraged to grow varieties that have long storage life. For example, Martin and Degras (1978) point out that different yam varieties differ in storability from a week to several months. Extension agents and experiment stations should be encouraged to include inherent storage life as one of the considerations to be taken into account when deciding which types of crops and which varieties of those crops should be recommended to farmers.

There are no known adverse environmental effects from the efforts of plant breeders to extend the inherent storage life of horticultural crops. However, the results of plant breeders' work may need to be monitored. The U.S. Food and Drug Administration established regulations for release of new varieties of edible plants when it was discovered that a new potato variety that was released in 1969 had an unusually high content of the toxic glycoalkaloids that are naturally present in potatoes. The FDA regulations apply to any plant material that provides more than 2% of the U.S. diet. The regulations require that plant breeders must establish two points before releasing a new variety:

(i) that the content of the major nutrients is no lower than the average found in existing varieties of that commodity and (ii) that toxic substances naturally present in the commodity are no higher than normal for existing varieties.

2.1.9 Shorten the time between harvest and consumption

In developing countries a considerable amount of produce is wasted because of poor transportation systems and poor marketing procedures. Much produce is spoiled because it is stored beyond its inherent shelf life before marketing is completed.

Improving transportation and marketing facilities, spreading the harvest season by growing varieties that mature at different times, and staggering the planting dates of annuals and reducing the number of steps between producer and consumer are methods that can be used to shorten the time between harvest and consumption.

2.1.10 Processing

Considerable quantities of fruits and vegetables are processed by dehydration, canning and freezing in developed countries. In developing countries small amounts of these commodities are processed for local consumption although large volumes of some commodities are processed for export (e.g., canned pineapple).

Canning and freezing require a high capital cost, high energy costs and expensive packaging and are unsuited for widespread use in less developed countries. Dehydration or sun drying is the simplest and lowest cost method of preservation and should be more widely used in developing countries because it converts a perishable commodity into a stable item with long storage life. Some excellent quality dehydrated products can be made from roots and tubers; this kind of processing should be encouraged.

Environmental effects. Occupational hazards in the fruit and vegetable processing industry are the normal hazards associated with machinery, for which adequate safety measures are well developed. The National Institute for Occupational Safety and Health in the U.S. (NIOSH) have no complaints on safety hazards in processing plants that handle horticultural products. The U.S. Occupational Safety and Health Administration (OSHA) have no regulations specific to the fruit and vegetable processing industry other than the broad guidelines that apply to industry in general. The fruit and vegetable processing industry is not on the list of occupational groups in which excess cancer incidence is reported by the U.S. National Cancer Institute.

There are occupational risks to some workers with specific horticultural products. For example, Barber and Husting (1977) report isolated cases of contact dermatitis among workers handling raw fruits and vegetables, including carrots, asparagus, mangoes, cashew fruits and nuts, and some citrus fruits. Fruit and vegetable handlers may also suffer contact dermatitis due to sensitivity to specific insecticides and fungicides. Indirect effects of handling fruits and vegetables include chapping and moniliasis from exposure to moisture, photosensitisation dermatitis from sunlight, and parasitism from mites. Products that cause photosensitization include fig, rue, lime, bergamot, parsnips, parsley, carrots, fennel, dill and pink rot celery. Raw pineapple fruits contain the proteolytic enzyme bromelain which causes skin irritations to workers in pineapple processing plants. This problem is overcome by supplying workers who handle cut fruit with rubber gloves.

2.1.11 Heat treatment

Some of the organisms that cause rotting are inhibited or killed at elevated temperatures that are below the injury threshold of the product. For example, hot water dipping of mangoes at about 50°C for a few minutes kills many pathogens without adversely affecting the quality of mango. Heat treatment is however not a desirable procedure for most fruits and vegetables. When applicable, very rigid temperature controls are needed.

There is little adverse environmental effect from heat treatment. Small amounts of heat are dumped into the environment.

2.1.12 Sanitation

All handling, storage, cleaning and washing equipment for horticultural products should be kept in a sanitary condition in order to minimize the risk of spreading infection. Diseased or damaged units should be sorted out and properly disposed of because their presence promotes the growth of fungi and bacteria. Insects infesting cull piles may fly to good produce and introduce pathogenic organisms and increase losses. Wash water should be changed at regular intervals before it becomes heavily contaminated with fungi and bacteria and spreads infection. In some cases the wash water is treated with chlorine or some other chemical in order to reduce the count of viable organisms. The sanitation programme in the People's Republic of China is considered an exceptionally important element of pest control.

The environmental effects of good sanitation practice are minimal.

2.1.13 Use of chemicals

A number of chemicals may be applied to horticultural products in order to obtain a desirable post-harvest effect. Most of these are applied after harvest, but a few are applied in the field in order to obtain a specific post-harvest response. For example, the sprouting of onions in storage can be delayed by spraying the onions with maleic hydrazide (MH) in the field while the tops are still green. Chemicals used pre harvest whose sole purpose is to achieve a post-harvest effect should be included in the list of post-harvest chemical treatments.

Post-harvest chemicals are classified into groups below (Pantastico 1975). Many of these are not used commercially and are of research interest only:

a) Fungicides which prevent or delay the appearance of rots and molds in the product. Examples are, sodium orthophenylphenate (SOPP), benomyl, thiabendazole (TBZ), sodium hypochlorite, and sulphur dioxide (SO_2). Methyl formate (Erinol), ethyl formate and (in some countries) ethylene oxide are frequently applied to dried fruits to kill infestations of insects and molds. Sulphur dioxide and benzoic acid are frequently, and propionic acid, ascorbic acid or sorbic acid sometimes, added to processed fruit products, especially juices, to inhibit the growth of yeasts and molds.

b) Chemicals that delay ripening or senescence. Examples are: the kinins and kinetins that delay chlorophyll degradation and senescence in leafy vegetables, gibberellins that retard the ripening of tomatoes and hold citrus fruits on the tree beyond normal maturity, and auxins that delay physiochemical deterioration of oranges and green beans.

c) Growth retardants that inhibit sprouting and growth. Examples are maleic hydrazide which is applied pre-harvest and inhibits sprouting in a number of stored commodities, e.g., onions and potatoes. A number of chemicals are applied post-harvest to potatoes to control sprouting, for example, CIPC, TCNB and MENA. Daminozide (Alar) gives increased fruit firmness, better colour and early maturation in apples.

d) Chemicals that hasten ripening and senescence. Examples are ethylene and compounds such as Ephephon that release ethylene, abscisin, ascorbic acid, β -hydroxyethyl hydrazine (BOH), acetylene and substances that release acetylene such as calcium carbide, and certain alcohols and fatty acids.

e) Chemicals that may hasten or delay ripening and senescence depending on the dose and the commodity on which they are used. Examples are 2,4-D; 2,4,5-T; indoleacetic acid (IAA) and naphthalene acetic acid (NAA).

f) Metabolic inhibitors that block certain biochemical reactions that normally occur. Examples are cycloheximide, actinomycin D, vitamin K, maleic acid, ethylene oxide, and carbon monoxide.

g) Ethylene absorbants. These delay ripening and senescence because they remove the ethylene produced by the fruit. They are usually placed in close proximity to the commodity and leave no residue on it. An example is potassium permanganate-impregnated alumina or vermiculite (Purafil).

h) Fumigants to control insects or sometimes molds. Ethylene dibromide and methyl bromide are the most commonly used fumigants.

i) Colouring. The use of artificial colours is sometimes permitted in order to improve the appearance of a fruit. For example, fresh oranges from Florida may have artificial colour added to the skin for cosmetic purposes. Since most people do not eat orange skins other than for marmalade it is considered to be a harmless addition.

In warm climates ethylene is used to degreen lemons, oranges and tangerines imparting a brighter colour to the skin. Ethylene is a naturally occurring metabolite of ripening fruits.

j) Food additives. A number of compounds are permitted to be added to processed horticultural products for preservative or functional effect. The major preservatives are sulphur dioxide, benzoic acid or benzoates, and sorbic acid or sorbates. Functional additives include antioxidants, colouring, flavouring, thickeners, emulsifiers, etc. The use of food additives in the U.S.A. is regulated by the Food and Drug Administration (FDA). Other countries have an equivalent government agency to regulate the use of additives. At the international level the Joint FAO/WHO Expert Committee on Food Additives (JECFA) formulates general principles governing the use of food additives and makes recommendations regarding their examination and control. Food additives will not be discussed further because they are only used in processing and formulating horticultural products and are not applied to raw horticultural products. One exception is sulphur dioxide which is used to fumigate fresh grapes in cold storage in order to control growth of yeasts and molds.

There are two important differences between the use of chemicals in the field and the use of post-harvest chemicals:

(i) Smaller quantities of post-harvest chemicals are used. For example, the normal dose of CIPC for controlling sprouting of potatoes is about 30 grams per ton and the normal dose of ethylene dibromide for fumigation of fruits and vegetables is about 30 grams per ton. These levels contrast with the use of field chemicals where doses of one to several kg. per hectare are commonly used.

(ii) The chemicals are not broadcast over the field but are applied in the confined space of the storage chamber.

It is impossible to obtain figures for the quantities of post-harvest chemicals that are used because this is considered proprietary information by the companies that manufacture and formulate them. However, all post-harvest chemicals are classed as "minor use" by the U.S. Environmental Protection Agency because the quantities used are relatively small.

In the U.S. a company must produce experimental evidence of the toxicity, safety, and usefulness of a new agricultural chemical before it can be registered for use as an agricultural chemical. Each use must be cleared through registration for every commodity to which it is applied. The Environmental Protection Agency has the responsibility for registering pesticides and setting tolerances. Table 7 (Appendix 1 - Pages 6-10, incl.) lists the post-harvest chemicals that are cleared for use in or on raw agricultural commodities by the U.S. Environmental Protection Agency and the tolerance for each commodity for which they are registered. This list is kept under continuous review. Any changes that are made in the list are published in the U.S. Federal Register. The FAO/WHO Codex Alimentarius Commission recently published "Guide to Codex Maximum Limits for Pesticide Residues" and plans to update this list at regular intervals.

In addition to the chemicals listed in Table 7 a large number of materials are exempted from the tolerance in post-harvest pesticide formulations. Most of these are inert ingredients that do not affect the pest but do improve the functional properties of the pesticide formulation. Examples of these chemicals are: surfactants, solvents, diluents, synergists, preservatives, stabilizers, antioxidants, thickeners, emulsifiers, and antifoam agents. Most of these substances are Generally Recognized As Safe (GRAS) by the U.S. Food and Drug Administration.

The use of post-harvest chemicals in the U.S. is strictly controlled and monitored. The chemical suppliers usually describe in detail on the label and/or in supplementary literature exactly how, when, and how much of the chemical is to be used. This is backed up by the agricultural extension service of each state which keeps in close contact with the farmer. Most states have a cadre of inspectors who regularly draw samples of horticultural products and submit them to a central analytical laboratory to assay for chemical residues. Few violations of the regulations are detected, and most samples tested are found to be well below the tolerance. Most other developed countries maintain close supervision and control of the use of post-harvest chemicals on horticultural products.

The situation may be quite different in the less developed countries where governments usually do not have the expertise or back-up analytical laboratories to monitor adequately the use of post-harvest chemicals on perishable crops. It is difficult to obtain information on this topic, but from a general knowledge of how governments in LDCs operate, it appears to be a matter that deserves investigation. Presumably, the pesticide tolerances for the major export crops (e.g., fresh bananas) are effectively monitored by the large corporations who operate this trade and by the developed countries that import these commodities. One cannot be so sanguine about the horticultural crops that are indigenously produced and consumed in the less developed countries.

The U.S. Cancer Institute has prepared a list of 26 chemicals or industrial processes associated with cancer induction in man. (Table 8 - Appendix 1 - Page 11) None of the items found in this list are found in Table 7.

The International Labour Office in Geneva, Switzerland, has compiled a list of 69 compounds that are listed as carcinogens by one or more of the following countries: Australia, Belgium, Finland, Federal Republic of Germany, Italy, Japan, Sweden, Switzerland, United Kingdom, Union of Soviet Socialist Republics, United States of America. (Table 9 - Appendix 1 - Page 12) None of these 69 compounds appear in Table 7.

The fact that none of the chemicals listed in Table 7 appear in either of the above two carcinogen lists does not guarantee that they are not carcinogenic because the question of what causes cancer is not completely resolved. Apart from carcinogenicity there is also the question of other ways in which chemicals may be harmful to human health, e.g., teratogenicity and mutagenicity. The question of the safety of the chemicals that are added to foods is changing rapidly because much research and regulatory attention is being devoted to this issue in a number of countries.

The whole issue of harmful chemicals in the environment is complex and not very clear at the present time. However, we can make two reasonable assumptions about chemicals added to horticultural products:

1. The developed countries have the expertise to engage in the debate on the harmfulness of chemicals, to evaluate the risks and benefits of their use, to enact new legislation controlling their use as new knowledge becomes available and to establish the inspection-analysis-prosecution machinery to ensure that the legislative intent is carried out. It is reasonable to assume that any proven grave risk from the use of chemicals will soon be brought under control in the developed countries.

2. Most of the less developed countries have little of the kind of expertise listed above. There is a real risk that chemicals will be improperly used and their improper use will not be brought under control, with the potential to cause harm to human health and the environment. Therefore, the use of post-harvest chemicals in a given country should be discouraged until adequate inspection services and analytical laboratories have been established to ensure that these chemicals are used safely.

Environmental effects. Misuse of certain post-harvest chemicals may lead to serious environmental harm. As far as can be determined little is known about the ultimate effects of post-harvest chemicals on the environment when they are correctly used. It seems to be generally assumed that since the compounds are used in small quantities in confined areas, and since most of them decompose into non-active substances there are no adverse environmental effects. Although this is a reasonable assumption there is little concrete evidence either for or against this widely held opinion.

2.2 Pests

The major causes of loss in perishable produce after harvest are certain pathogenic fungi and bacteria. Viruses and nematodes play a minor role in post-harvest losses; rodents and insects are also generally of lesser importance in contrast to the significant damage they cause in food grains.

In addition to the direct loss in quantity of food resulting from microbial infections, a partial loss results because of effect on appearance and/or quality resulting from disfiguring surface infections of fruit, root, and tuber crops. Other secondary adverse effects may include a decline in shelf life, possible contamination with mycotoxins, acceleration of ripening because of release of ethylene in pathogenesis by certain fungi, and in some instances deterioration of canned fruit crops because of the presence of heat-resistant hydrolytic enzymes formed by decay fungi in fruit tissues prior to the canning process.

The loss in the post-harvest period may originate from infections that were initiated by fungi during the growing season well in advance of harvest. Much of this pre-harvest infection involves a group of fungi that are capable of infecting healthy developing fruits either by direct penetration, e.g., anthracnose diseases caused by species of colletotrichum or by invasion via natural openings such as lenticels or stomates or through breaks in the tissue at the points of attachment of fruits to the plant. In many cases the infection process may be incomplete. Thus, sub-cuticular mycelium may be formed which remains in a latent stage until the post-harvest period when changes in susceptibility may occur and the pathogen mycelium may ramify through the tissue.

Many of the fungi (e.g., species of Penicillium, Rhizopus, and Geotrichum) and bacteria (e.g., species of Erwinia, Bacillus and sometimes Clostridium) involved in decay problems associated with the post-harvest period may be considered as opportunistic pathogens. They are usually incapable of penetrating uninjured tissue or aggressively attacking vigorous healthy plants during their active growth period. However, they do have the ability to parasitise fleshy plant organs when tissues are bruised, injured by insects, or otherwise placed under environmental stress. In many cases tissues are invaded by a succession of organisms which may interact in a synergistic manner.

Each species of root, tuber or fruit is affected by specific groups of fungal or bacterial pathogens. It is important that broad non-specific designations of these organisms be avoided (i.e., molds or rot organisms). The species of fungi or bacteria associated with specific decay problems should be properly identified. For example, it has been clearly shown that species of Rhizopus differ markedly in their susceptibility to specific fungicides.

The main factors affecting disease development are:

1. host susceptibility
2. maturity
3. wounds and wound healing
4. temperature of the commodity
5. relative humidity (especially in storage)
6. packaging
7. handling, in general
8. concentration of inoculum

The basic methods of control involve three different approaches 1) prevention of infection 2) elimination of incipient or latent infections, and 3) prevention of spread of the pathogen in the host tissue.

Losses due to micro-organisms may be reduced by:

1. refrigeration
2. improved handling procedures
3. pre- and post-harvest chemical control

   Although every effort needs to be made to minimize or reduce dependence on chemicals, in many cases no viable alternatives exist. A wide range of fungicides are now available that are effective and safe to use. Incipient infections can be eliminated or reduced by application of certain fungicides such as benomyl which have the capacity of diffusing into host tissue and killing the pathogen in situ. Certain fungal pathogens initiate infections of fruits and vegetables during the growing season and these can be controlled best by timely application of fungicides prior to harvest. It is essential to ensure that chemical controls are used properly.

4. preventing contamination during the washing process

   In the case of tomatoes and possibly other fleshy vegetables when warm product is washed in cold water infection is augmented. Because of the temperature differential air in the tissue contracts and this draws water, often containing soft rot bacteria, into the tomato via wounds and fresh stem scars. If soft rot bacteria are present, water deeper than about 0.3 m increases the risk of infection because of the pressure differentials inside and outside the fruit. If washing is needed, proper, prompt drying is essential in order to prevent rapid growth of spoilage organisms in superficial wounds and lenticels. Sweet potatoes and yams have a longer shelf life when stored unwashed.

Unresolved problems

The actual physiological processes involved in the rapid deterioration of cassava after harvest are not yet fully understood, although much research is in hand. For many other commodities also, knowledge is lacking about changes in physiological processes in the post-harvest period. In particular there is a need to determine the relationships of these changes to the increased susceptibility of perishable products in the post-harvest period.

Data is lacking with respect to the effect of chemicals, singly or in combination, as used in the growing period on the storability of commodities. Fertilizer, weed control chemicals and vine killers for potatoes are examples of the chemicals used which may affect storage characteristics or disease susceptibility.

The physiological basis for resistance of perishables to pest attack needs to be known. Mechanisms of resistance of micro-organisms to different fungicides and bactericides are also little understood.

Biological control systems should be further explored. For example, it is known that, by dipping root stocks into suspensions of an avirulent strain of the crown gall bacterium that produces a very specific antibiotic (bacteriocin) later infection by the crown gall (bacterium) of stone fruits can be prevented. Other similar antagonistic relationships are known to exist: they may offer possibilities for more techniques for biological control of insects. Biological controls are an important feature in the plant protection programmes of the People's Republic of China.

2.3 Marketing and Distribution

The approach of the market specialist to the problem of food losses in perishables is to identify the place in the market chain where losses of unusual magnitude occur. The physical place where such losses are registered is less important than the position in the chain where losses occur and the relation of the specific loss situation to the total market chain. In relating losses incurred at a specific situation to the total chain, the objective is to find out whether the loss can be explained by defects further up or down the chain or by the system as a whole.

Losses in perishable produce occur everywhere from the field to the ultimate consumer and depend on the degree of perishability of the produce; they are inherent in the very nature of the product. Since the market chain or system refers to specific operations, handling, transportation and trade practices, there is a close correlation between the type and magnitude of loss incurred by a specific product and the chain or system wherein it moves. This implies that for a given commodity moving in a particular chain, there is something like a standard level of loss inherent in the chain, the reduction of which could not be obtained by improving isolated operations taking place within the chain. It would require a change in the total market system itself. To avoid losses or even significantly reduce them at isolated stations in the chain may not be a realistic proposition. However, any obvious isolated practice that leads to heavy losses, such as faulty packaging, must be corrected.

Marketing methods and conditions vary widely from country to country and any attempt to attribute losses to a particular point in marketing chains or to any specific system or marketing runs into difficulty because it is not possible to generalize on a wide basis. For this reason, a systems approach should be adopted for dealing with food losses whereby all the factors applicable to a given situation and in an individual country have to be considered before any meaningful diagnosis can be made. Any success achieved in reducing losses at the "grass roots" level particularly where applied to traditional marketing systems should receive wide publicity as such successes are not often known beyond their immediate area of application.

Management of losses is essentially action-oriented. It is effected within a given market system for which "norms" of loss levels can be established. Managing the losses with reference to acceptable levels would be quite similar to management by objectives. Each marketing system has its own rationale and is affected by policy decisions with regard to production, marketing and consumption. The latter will have a direct incidence on the effect of any measures that might be implemented for the reduction of losses. An examination of the type of production and marketing system would be helpful in revealing how susceptible a given market system or sub-system may be for the introduction and application of measures aimed at bringing losses down to a desirable level.

Traditional subsistence systems are widespread throughout the developing world and are characterized by local exchange or barter trade, sharply limited geographical movements of produce and typical small units of sale or barter. Losses do occur but they tend to be overestimated and may be difficult to reduce. The subsistence economy sets its own limits: the chain from field to consumer is usually short, both in time and distance. Practically everything is consumed because every quality finds a ready consumer. Improvement of the system in terms of reduction of losses may be limited to the provision of shade. Recommendations might not go beyond encouraging the producer to collect his fruits and vegetables under a tree or build a make-shift shed or tent.

The situation is quite different when one looks at the emerging marketing systems where a surplus production economy is rapidly replacing the previous subsistence or semi-subsistence economy and the marketing system is not well adapted for the task of collecting, moving and distributing massive surplus production. Losses of unusual magnitude do regularly occur in the system and here there is good scope for the introduction and application of specific measures to reduce losses depending on the readiness of the system to transfer the improvement down or up the chain. Most measures that focus on gentler handling, better conditioning, faster transportation and proper storage would seem to be effectively applicable only within an improved market infrastructure including suitable roads. Quality consciousness and the introduction and acceptance of some forms of quality separation by the trade and the consumer must precede the demand by the farmer for better, and therefore higher cost, boxes or containers. This again can hardly be expected if the higher prices paid for better quality cannot be transferred down the chain to the producer. Much closer communication relating producer capacity to retailer/consumer demand is a prerequisite to such developments, and the more efficient management of marketing enterprises.

In some regions particularly high levels of loss have been observed when governmental and quasi governmental agencies participate directly in horticultural crop marketing. This to a great extent is due to faulty management, inexperience in the commissioning and operation of cold stores, lack of technical knowledge in despatch and transportation techniques, the absence of a sales operation to match the buying programme and generally unrealistic pricing policy. The scope for remedial action in these incompletely integrated sub-marketing systems is great. This may deserve priority in any action programme for the reduction of losses. The crops which have typically been the object of intervention programmes by Governments are potatoes and onions, but other crops such as oranges have in some areas been included.

2.4 Socio-economic Aspects

A complete analysis of the post-harvest system would include not only the "physical" but the "human" aspects; that is, a study of those social, psychological and economic factors which influence the behaviour of the people involved in post-harvest activities. It is these people, the subsistence farming families or those individuals who produce, process or market on a commercial basis, who are required to change their behaviour when schemes are launched to reduce post-harvest losses. Any technological change required of a producer is likely to produce social and/or economic changes. Additionally, the nutritional status, e.g., of children or mothers, may suffer. Introduction of even simple machinery can displace women's paid labour; production of a marketable surplus may provide the family's first cash income. Preliminary diagnostic studies make it possible to ascertain the possible effects of such technological changes and to identify the socio-economic constraints influencing the producers and their acceptance of proposed changes. The prime task of such studies would be to locate where losses occur, who is responsible and who bears the loss. A range of social and economic relationships also needs to be explored with respect to any proposed remedies. For example, who will be the primary beneficiaries of the proposed interventions (landlord, middleman, owners of capital, urban consumer or —— the producer?); what changes in responsibilities or functions are required; what additional obligations or risks may be incurred and by whom? In brief, who loses, who gains (as perceived by the people concerned) in monetary, time, social and psychological terms?

To make studies of this type it is clearly necessary to involve applied social scientists, economists and nutritionists at an early stage of planning any activities related to reduction of post-harvest losses. Despite the fact that the producers' attitudes to loss and understanding of its implications may be limiting factors in motivating the adoption of change, their skills and knowledge ought not to be ignored or underrated. All concerned with post-harvest operations should be involved in the planning of improvements.

It is of particular importance to identify which members of the producer's, handler's or processor's family are responsible for the various post-harvest activities. Efforts can then be made to ensure that the right people are included in training programmes, credit schemes and other services which may be planned.

In order to make a systematic approach to the reduction of post-harvest losses it may be seen that co-ordination is necessary with activities developed to alleviate related problems. A post-harvest system cannot be viewed in isolation from other aspects of rural development. In this connection the Programme of Action adopted at the 1979 World Conference on Agrarian Reform and Rural Development provides guidance regarding priorities for action.

2.5 Future Developments for Horticultural Products

Brand new concepts that eventually lead to extensive new technologies usually burst upon us without warning. It is impossible to forecast when, or in what form such major breakthroughs will appear. Hence, such dramatic advances in post-harvest handling of horticultural products cannot be discussed in this report. But we can discuss probable future trends by extrapolating presently known trends into the future.

Processing

Rising standards of living can be expected to increase demand for canned and frozen horticultural crops as well as the demand for convenience foods that contain one or more horticultural crops as a major component. Losses after processing are usually very low. On the other hand, they are energy-intensive and the disposal of the discarded packaging materials as solid waste creates some environmental problems.

Large scale factory processing of horticultural crops concentrates large quantities of waste materials such as skins, cores, and seeds in one place in contrast to the highly dispersed distribution of waste from commodities that are consumed fresh at home. Traditionally, little attention has been given to disposal of this waste material and it has caused environmental problems. In recent years, attention has been drawn to this problem, e.g., the joint UNEP/FAO sponsored seminar on agricultural residues held in Rome in January 1977. Many governments now require food processing plants to upgrade the handling of their waste materials.

New Chemicals

The large chemical corporations continue to search for new chemicals to control the pests and diseases that attack crops and products. The cost of testing and registering a new agricultural chemical is now so high that only the larger corporations can afford to take the risk, and even they are mainly interested in pesticides for major crops such as maize, wheat, soybeans and cotton because they cannot expect to recover the costs of developing a new chemical unless potential sales are high. After a chemical has been registered for use with a major crop, it can also be registered for a minor crop at much less cost if it is shown to be effective.

New chemicals for post-harvest treatment of horticultural crops will continue to appear but mainly as spin-offs from use on major crops. It is unlikely that many new chemicals will be developed especially for post-harvest application because of the relatively low volume of sales anticipated for such application, which is insufficient to justify the high cost of obtaining the initial registration.

Irradiation

Irradiation of horticultural products kills infesting insects thus permitting products to be shipped into areas that have a quarantine against certain insects. It also delays sprouting of bulbs and tubers, permitting long-term storage of commodities such as onions, potatoes and yams without sprouting.

Although several decades of research have been devoted to this peaceful use of atomic energy there is almost no commercial use of irradiation technology even though it continues to be energetically advocated by the International Atomic Energy Commission and a total of 26 commodities have received restricted or unrestricted clearance in one or more of 19 countries having legislation on irradiated food (Vas, 1977). Maxie et al (1971) concluded after a lengthy study that irradiation was, in general, not as effective as good commercial refrigerated storage for fruits and vegetables. A 1976 report pointed out that after a quarter of a century of world-wide work on this promising technology there is today only one truly commercial application, namely, the inhibition of potato sprouting in Japan.

Radiation technology has not been widely adapted in commercial practice for the following reasons:

a) It costs more than chemical treatments. Chemical treatments usually cost about 10 cents to $1.00 per ton of product. Irradiation probably costs several times as much although exact figures are difficult to obtain. The twelfth session of the Joint FAO/WHO Codex Alimentarius Commission in 1978 noted that the economic feasibility of the irradiation process still required practical demonstration.

b) The food must be passed through the irradiator thus creating an additional handling stage which adds to the cost, and may increase bruising and wounding of the commodity.

c) Irradiated vegetables may be more susceptible to storage rots and fungi because the natural wound healing processes are impaired. Irradiated potatoes sometimes darken when cooked. Irradiated onions contain a small piece of unsightly black tissue in the centre of the onion where the growing tip is killed by the radiation.

d) Much more elaborate safety precautions are required for an irradiator than for chemical treatments.

e) The softening of vegetable tissue caused by irradiation makes the commodity more liable to bruising during subsequent handling and transportation.

To sum up, it appears that irradiation technology for horticultural products is unlikely to be widely used under present circumstances. Although the International Atomic Energy Commission continues to maintain a vigorous programme to introduce irradiation as a food preservation technique it seems unlikely that irradiation will be widely used unless all chemical treatments are banned or some new major breakthrough in irradiation technology is developed.

Drying Technology

Since drying is the lowest cost preservation technology it should develop as a major method of preservation of horticultural products especially in LDCs. Much drying can be accomplished by means of solar energy. Simple drying systems can be established as small-scale localized units for single families or villages. The fact that the quality of dried products is not necessarily as high as the canned or frozen product need not be a liability in developing countries where low price is so important and the expectation of quality and convenience is not as high as in the developed countries.

Wider Use of Chemicals

The advantages of chemical treatments (effective, low cost, easy to apply) will surely lead to their greater use in LDCs. This could result in danger to human health and the environment if the chemicals are misused or abused.

3. ROOTS AND TUBER CROPS

3.1 The Root/Tuber Crop Resource

Useful insights into the post-harvest loss complex of root crops are provided by a study of their characteristics. The principal roots and tubers are derived from nine species. They are all of high moisture content, and their parenchyma cells are packed with starch grains. These materials show variable degrees of inherent keeping life, from some species of yam, like Dioscorea alata which remains dormant for 3-4 months to cassava in which there is no natural dormancy. When such material is stored in the fresh state, respiration and transpiration continue with inevitable losses of water and dry matter. Prolonged high levels of transpiration result in a change of texture affecting quality and weight loss. The dry matter loss, caused by superation constitutes a real food value as distinct from the moisture loss which only has an economic value. Sprouting at the end of dormancy can result in dramatic loss as the physiological state is altered. At this stage the stored starch is transformed to sugars and utilized by the elongating shoots with appreciable loss of both food value and moisture.

The main root/tuber crops are cassava (Manihot esculenta Crantz), the yam (Dioscorea spp.), the potato (Solanum spp.), the sweet potato (Ipomoea batatas L. (Lam) and the edible aroids (Colocasia spp. and Xanthosama sagittifolium). With the yam, the potato, and the aroids many different species are used in the cultivated complex. Differences between these are usually sufficient to merit separate treatment. A list of the more frequently used root/tuber species is given in Appendix 2.

Taro (Colocasia esculenta var esculenta) illustrates the system of maintenance of continuous food supply well. This species which has no seasonal growth constraint is planted in moist situations conducive to year-round growth. By systematic replanting whenever material is harvested, continuous supplies are assured. A similar absence of seasonality in cassava (Manihot esculenta) together with its ability to produce mature roots at various time intervals after planting permits year-round harvesting in most ecological systems. By opting for continuous food supply the opportunity for post-production losses is restricted to the food preparation phase. The same benefits accrue from the use of crop scheduling.

Maintenance of food supplies over restricted periods through storage is an essential feature of yam-based food supply systems. The success with yam storage lies in recognition of the limits to the potential for storage and in producing an environment conducive to keeping the material in sound condition. Perceptive farmers like those in Nigeria and the Ivory Coast often construct different stores to meet the separate requirements of D. alata and the different cultivars in the D. rotundata/cavenensis complex. These sytems work well within the normal period of yam tuber dormancy. They are so successful in West Africa that improvements in the best indigenous practice could hardly be expected without recourse to the technologies of reduced temperature storage, the use of controlled gas environments or ionising radiation. These latter technologies are however not commonly applicable in developing countries because of cost and lack of know-how.

Considerable quantities of roots and tubers are transformed into more durable products by drying, fermentation and comminution in different combinations and sequences producing a variety of materials each with distinctive characteristics. Other benefits that often accrue from transformation include the removal of toxic substances naturally present and the convenient-to-use nature of the transformed product. Although the ultimate keeping potential is constrained by environmental conditions, transformations have good prospects for long-term maintenance of root/tuber crop supply because they convert a perishable commodity into a form with stability similar to that of the cereal grains.

A feature of much of the indigenous processing technology is its high labour requirement. Because of this, food supply strategies based on transformation tend to be restricted to economic environments where labour is available. As a result root crop transformation is widely practised among subsistence economies where labour inputs have zero or low cash value. Attempts are being made to establish root/tuber crop transformation commercially, but success has been variable. Radical changes in the entire system of production may be required, as has been suggested with yam (D. rotundata/cavenensis) in Nigeria for manufacture of instant pounded yam.

3.2 The Major Root/Tuber Crops

3.2.1 Cassava (Manihot esculenta Crantz)

Known variously as manioc, yuca, tapioca and mandioca, the edible portion of cassava is a starchy root which matures in harvestable state in 8-24 months according to cultivar and climate. In addition to the roots, the leaves also have potential for use as food as for instance in parts of Central and West Africa. Cassava cultivars are often grouped into "sweet" with relatively low contents of cyanogenic glucosides and "bitter" with high cyanogenic glucoside content although many intermediate forms exist. The "sweet" types may be eaten raw or lightly boiled without harm while the "bitter" forms require processing to remove cyanogenic glucosides.

The cassava roots have no natural dormancy and are highly susceptible to deterioration. The nature of this deterioration is as yet not fully understood, although two factors, one an indigenous physiological one and the other associated with microbiological infection, have been identified. The physiological deterioration, of which the symptoms are tissue discolouration, can commence as soon as 24 hours after harvest. Acting independently of, but usually following, the physiological changes, microorganisms, both fungi and bacteria develop in the flesh of the roots causing additional damage and loss: this microbial deterioration usually develops only 5-7 days after harvest. (Booth, 1974; Lozano, Cock and Castano, 1978).

This rapid post-harvest deterioration of cassava roots places serious constraints on their use with fresh produce trade and on the holding of buffer stocks for large-scale processing.

The short storage life of fresh cassava imposes constraints on its distribution and use. As a result, the choice of market for which production is intended becomes influenced by location. The range over which production for the fresh market extends is therefore a function of the distance from their markets and the efficiency of transport. The time of delivery rather than distance per se is the important limiting factor. In the vicinity of Bogota, Colombia, up to an 8-hour interval from harvest to delivery is acceptable. With the current status of roads and vehicles this permits production within a 300 km radius. With more effective preservation or a faster delivery system, this range could be extended. It is claimed that the market for fresh cassava in Colombia is so structured that as quality deteriorates, the price is lowered, thereby enabling roots of decreasing quality to be bought by successively poorer income groups.

Techniques to extend the fresh life of cassava roots have been independently developed in several countries. At the Instituto de Investigaciones Tecnologicas in Colombia deterioration has been delayed by coating tubers with a film of paraffin wax (IIT 1973). At CIAT fresh tubers were shown to have improved keeping characteristics when plant stems are cut and removed but tubers are left unharvested for up to 14 days. Tubers so treated remained sound for as long as 30 days. This technique has much to commend it, but has not yet been tested on a large scale. Other practices developed in joint CIAT/TPI projects include storage in earth silos, and storage of roots in plastic bags and in absorbent packs. These methods appear to have some utility in small and medium scale production but have not yet been proved in large-scale commercial operations. None of these techniques have as yet attained general application.

The transformation of cassava to more durable forms, frequently in forms more convenient to use than fresh roots, is partly associated with the detoxification process for the removal of hydrocyanic acid. From the crop loss point of view these products are important since they are frequently more able to avoid the rapid deterioration of the fresh tubers. Cassava products may be classified in a variety of ways, but for simplicity these may be regarded as food starch and whole root products. These latter may be fermented or unfermented and may either be "flour" or "gari" types.

Cassava starch is extracted from roots after peeling, washing, rasping, squeezing, settling and drying. Two types of starch are produced, sour or fermented and sweet or unfermented. Sweet starch is dried immediately following extraction while sour starch is stored for 3-4 weeks when some fermentation involving lactobacilli and yeasts occurs. Sour starch is favoured for baking and commands a better price than sweet starch at least in some countries. This latter has similar conformation to corn starch with which it competes disadvantageously.

Gari, the most commonly used form of cassava in West Africa, accounts for some 70% of the entire cassava production in Nigeria. It is estimated that between 4 and 5 million tons of roots are used each year for this purpose. Although there are close parallels between the production of gari and of Brazilian "farinha de mandioca", the West African variant has some distinctive features.

The effect of the longer fermentation affects the taste by the production of lactic acid, as well as well as reducing the content of free hydrocyanic acid. Production at levels of indigenous technology is highly labour-intensive, but this constraint is being progressively removed through a variety of innovations aimed at increasing labour productivity. The hygroscopic nature of gari is a major constraint to its keeping quality. In a humid atmosphere it can absorb sufficient moisture to make it vulnerable to the growth of fungal organisms. The recent practice of packaging gari dried to a safe moisture content of around 12% in sealed polyethylene bags enables the product to be kept in good condition for extended periods.

Farinha de mandioca is the Brazilian product from which gari derives. The stages of preparation are similar to those for gari, the roots being washed, peeled, grated, pressed, toasted and classified by size. Unlike gari, the mashed or grated mass is not permitted to ferment. The heating dries the product and allows some gelatinization and dextrinization of the starch as also occurs in gari making.

Other durable cassava products include cassava flour, dried chips and "cossettes" from which flour can subsequently be prepared by milling or grinding.

3.2.2 Yam (Dioscorea Spp.)

With yams, storage life is determined by dormancy since attempts to store yams after sprouting has commenced are impractical. During the period of dormancy the metabolic processes continue at reduced rate thereby keeping dry matter losses at relatively low levels. The various yam species have different periods of dormancy with 3-6 months for D. rotundata and D. alata and 1-2 months with D. cayenensis or D. trifida. Pathological factors are also of great importance in causing post-harvest losses in yams.

Traditionally, in West Africa, yams are stored in "yam barns" where good but uncontrolled conditions for storage exist by building the barns in the deepest available shade. This prevents heating by the sun and also helps to maintain high humidity. Several other indigenous yam storage systems are used but most of these are less satisfactory than the "barn" or "claie verticale".

It is generally believed that these systems are well adapted to the yam varieties and to the climatic conditions prevailing in West Africa and offer little scope for improvement at current levels of technology.

Of the methods used to extend storage only the use of ionising radiation has been an unreserved technical success. The practical application of this technique is not yet generally available. Reduced temperature storage is limited by possibility of chilling damage around 10-12°C and by the growth of fungal organisms at temperatures around 14°C. Treatment with chemicals used to suppress sprouting in other crops has had little success but active research is being pursued by TPI. Controlled gas storage has not thoroughly been investigated.

Transformation of yams to more durable forms is possible but these methods have not yet met with much commercial success. Traditional products such as "amala" are variable. This may be related to the intrusion of undesirable dark colours into the final product from the use of a mixture of varieties and the failure to deactivate the polyphenol oxidases during processing rather than to any inherent basic defect of the process. The attempts of commercial organizations to produce an instant pounded yam failed more as a result of non-technical problems such as the logistics of raw material supply than to technical defects in the process. New processes recently developed at the University of Ife, Nigeria, may provide the required answer. A yam flake product developed to pilot project level in the West Indies has not continued long in production at a commercial level.

3.2.3 The Potato (Solanum Spp.)

The potato, Solanum tuberosum, originally of highland tropical origin, but developed mainly as a temperate crop, is now being developed as a lowland tropical crop. Selections tolerant to high temperature and short days are being made in several parts of the tropics. At higher elevations in the tropics it is already established as a crop of some importance.

The extension of potato growing to these areas is a major concern of International Potato Centre (Centro Internacional de Papa - CIP). This Centre works together with existing bodies selecting areas for activity on the basis of comparative advantages. This approach forms a rational basis for co-operation and avoids the sometimes unintended, but nonetheless real, tendency towards replacement of national effort with that of an international organization.

The work on post-harvest loss in this Centre is integrated with that of the social science unit permitting a broader view of the problem. This approach, taking account of social, economic and ecological factors, could provide useful guidelines in the development of other work on post-production losses. An account of the studies in the Mantaro Valley is given by way of an illustration of the CIP approach.

The Mantaro Valley lying some 300 km to the South-East of Lima has been described by Mayer (1979). It is a riverine valley some 60 km in length and from 2 to 22 km in breadth. Three broad ecological zones are recognized. The valley floor is some 3,200 - 3,450 m above sea level. The eastern slopes between 3,400 and 3,950 m and the western slopes of similar elevation.

Finally a high zone above 3,900 m. The flat riverine soils of the valley floor have a high productivity with a capacity to support a diversified agriculture and a high population density. In this zone a contrast between large and small farms is noticed. In the zone of sloping land above 3,450 m soil productivity declines as does the number of crop species. The practices on the East and West slopes differ. On eastern slopes potatoes maintain their place in cropping systems but play a diminished role on western slopes. Under the more severe conditions of the High Zone potatoes become the most important component of the cropping system occupying some 57% of the arable land. These zones are constrained by three main environmental factors: precipitation, temperature and water balance. These are all subject to changes relative to elevation. Generally precipitation and exposure to frost increases with increasing elevation.

Several products are made from potatoes including chuno, papa seca, tungush and potato starch. Ecological zone and economic circumstances result in different comparative advantages between choice of product. The most common product at low elevation is papa seca, a parboiled dried product which requires fuel for boiling but which utilized what would otherwise be a waste product. This restricts production to the lower zones where fuel supplies are more assured. Hybrid or native varieties are used for papa seca since this process would not be sufficient to remove the glycoalkaloids present in the bitter varieties. Processing into chuno or tongosh which eliminates the bitter principle requires no cooking. The process however requires heavy night frosts and open areas on which to expose the potatoes to natural freeze drying. These conditions are all readily met in the high hills. Locally produced potato starch competes with commercially produced corn starch. It is clear from this example that changes due to the technological superiority of one process over another is unlikely since a different technique is adapted to meet different complexes of factors.

Potato Storage

Potatoes are stored for use as seed or for food or sale. Different methods of storage have been described by CIP (Werge, 1977) from which the following summary has been taken. He recognizes three main systems: house, out-building and field. Peruvian rural houses according to Stein (1961) appear to have been designed with storage of agricultural produce in view. The convenience and security of storage in the house is evident. The actual technique of storage adopted appears related to the intended use for the potatoes. Potatoes to be boiled in their skins are kept in the attic where the conditions permit drying and some shrivelling, causing the potatoes to become sugary and thus more favoured. Potatoes which are to be peeled before cooking may be stored on the ground where they lose less moisture and so remain firm.

Seed potatoes may be left on the ground on a thin layer of straw or eucalyptus leaves, in piles against the walls of houses or in shallow bins or "trojas". Where animals may have access to them if they are left on the ground, the potatoes may be placed on a platform or chaclanka of eucalyptus branches in the rafters and covered lightly with straw.

Field storage is more frequently adopted at higher elevations. Here straw-lined clamps, covered in turn with straw and soil, may be used. The cool moist conditions reduce dehydration but the system is vulnerable to flooding which may result in dramatic crop losses. At elevations of about 3,000 m ventilation with air at ambient temperature assists the storage process.

An interesting series of low-cost potato stores have been developed by the storage unit at CIP. These are developed and adapted to take advantage of prevailing conditions to facilitate storing. Control over the storage environment is attempted by using natural ventilation systems coupled with adequate insulation and shading. Where appropriate humidity modification using simple measures is also being researched. In the case of seed tubers, these are stored in simple low-cost stores exposed to natural diffused light which, to some extent, replaces the need for controlled low temperature storage.

3.2.4 Sweet Potato (Ipomoea batatas (L.)

Sweet potato is a crop of considerable unrealized potential. The roots are widely used as a carbohydrate food and recently attention has also been drawn to the nutritional value of its leaves as food. The ability of the roots to become suberized at high temperature and humidity in the classical curing process, gives the crop potential for extended storage. Storage is particularly successful when kept at relatively cool temperatures, although, if held below 12°C, chilling damage can occur. The most successful storage occurs in the southern states of America and in Japan, and successful storage for extended periods has still to be achieved in the Tropics.

There is interest in transforming the roots to more durable forms. In Trinidad, at the University of the West Indies, a sweet-potato-based flour was shown to have utility in wheat flour substitution in bakery products. There is interest there and elsewhere in the preparation of breakfast foods from sweet potato tubers. The manufacture of dried sweet potato flakes is already an established industry in the United States.

3.2.5 Taro (Colocasia esculenta) and Other Edible Aroids

The edible corms of these crops are normally eaten fresh after boiling or baking. Estimates in Fiji showed high peeling and trimming losses during preparation as food. The fresh corms do not normally remain sound for long periods, and signs of deterioration become apparent a few days after harvest. Observations in Fiji indicated that packaging in plastic bags enhances keeping quality. In the South Pacific it is traditional to keep taro by transforming it into a fermented product of which "Poi" is the Hawaiian variant. It is of interest to note that the presence of oxalic acid raphides in the corms acts as a deterrent to rats.

4. FRUITS AND VEGETABLES

4.1 General Considerations

Many post-harvest losses are direct results of factors before harvest. Fruits and vegetables that are infected with pests and diseases, inappropriately irrigated and fertilized, or generally of poor quality before harvesting, can never be improved by post-harvest treatments. Very often the rate of commodity loss is faster if the quality at harvest is below standard. Thus, the processes in the attainment and maintenance of quality from production, harvesting, handling and marketing must be considered a unified system. The success of preserving the harvest-fresh quality of produce demands control of each step in the system, depends on the previous step and therefore is a chain of interdependent activities.

The small size and isolation of many vegetable farms make it logical to employ manual harvest labour which is often relatively cheap and non-organized. Traditional methods of harvesting are still employed using a minimum of mechanical aids. Many of the farmers may know their market but do not analyze it and plant without much concern for it. Price considerations are usually given more weight than the quality of the produce. Early harvesting of carrots, chayote, snap beans, squash and bottle gourd give better quality, but lower yield. On the other hand, vegetables may be harvested before reaching prime quality if the prevailing market price is high due to the scarcity of the product. Knowledge of maturity indices is often inadequate, in most instances visual indices being used. Therefore, more experienced farmers can deliver better quality products than those with less experience.

The deterioration of a product starts during the harvesting operation. The more carefully a product is handled, the slower the deterioration process during subsequent handling operations. However, the farmers may be unaware or indifferent to the condition of the product after harvest, and harvesting procedures may thus be rather careless. The only constraint is to avoid external injury. Until farmers are convinced that careful handling will increase profits, it will be difficult to persuade them otherwise.

In many countries contract buying is practised where the contractor takes charge of the harvesting and may exert strict supervision of the operation.

The general problems for each fruit and vegetable group are summarized in Table 10:

Table 10 - General problems for each fruit and vegetable group at each handling step

Types of Fruits/Veg.	Handling Steps* Harvesting	Packing	Transporting	Grading	Storage	Retail
Fruits	Right stage of maturity	Over-packing; improper container	Rough handling; poor road conditions	Uneven ripening	Chemical changes; shrivelling	Over-ripening; shrivelling; browning
Roots	Excessive moisture may lead to rotting	Mechanical injury in sacks	Bruising	Malformation	Sprouting; improper curing; shrivelling	Sprouting
Tubers & Corms	Mechanical injury	Mechanical injury in sacks	Bruising	Malformation	Improper curing; sprouting & greening	Sprouting; rotting; shrivelling & weight loss
Leaves	Excessive wilting; rotting under high moisture conditions	Unsuitable container size; mechanical injury	Rough handling; high transit temperature	Over-trimming; mixed sizes	Wilting at low relative humidity; shrivelling	Over-trimming; excessive wilting; bacterial soft rot
Flowers	Flower shedding	Improper packaging	High transit temperature	Loose curd; insufficient wrapper leaves	Yellowing of curds	Loosening of curd; fading of colour
Stems	Improper method of harvesting	Breakages of tissues	High transit temperature	Malformation	Elongation of existing structure	Shrivelling
Bulbs	Maturity	Bruising and other mechanical injuries	Improper conditions in sacks	Misshapen	Sprouting	Shrivelling and sprouting

* Attacks by micro organisms can occur in all steps of the post-harvest system either directly or resulting indirectly from actions or conditions occurring in each of the steps.

In most of the developing countries of the world, harvesting methods are very simple. Picking poles, to which a hook or cutting knife is attached, are generally used. Fruit blemishes and injury are usually unavoidable. Quite often the fruits fall to the ground becoming subject to field infestation. Planning, preparation and organization in the harvesting operations are necessary. Suitable harvesting tools, hand gloves, containers and supplies are needed by the harvesters. The grower should exert strict supervision on the harvesting operation.

Grading is a thing that most farmers are loath to do until they are convinced it will bring them added revenues or increase the acceptance of their products. A farmer may separate different varieties if they are distinguishable, but consumers in the tropical countries usually are more price conscious than quality conscious. That is not to say that they are unmindful of the quality, but if good quality products are too highly priced, they are often willing to settle for a poorer quality product. With the variety of vegetables offered for sale, there is usually no difficulty in getting cheaper substitutes. Thus, initially, for local markets, grading should be limited to only what is necessary. Deformed fruits and those with splits, punctures and incipient rotting should be removed. If the market is conditioned to accepting sound fruit with harmless surface blemishes (e.g., russet, windscarring, or mite injury), it is well not to attempt to change the situation for the time being. The following are likely to occur in the absence of proper sorting and grading procedures:

(i) Presence of rotten items which contaminate food products at later handling stages.

(ii) Customer deception wherein good produce on top of the containers conceals items of low quality at the bottom of the pack.

(iii) Growers do not maximize their income because best prices for their product are not obtained.

Containerization is probably the weakest aspect in the distribution chain of fruits and vegetables. In general, packaging materials of unsuitable quality, such as large sacks, rough wooden boxes, second-hand cartons, bamboo baskets, or rattan containers are liable to cause produce to suffer from bruising, crushing, and puncturing. The use of suitable containers alone will do much to maintain the quality of fruits and vegetables. Farmers often select the cheapest and most readily available containers. For example, the use of bamboo baskets has several disadvantages. The sides are sharp and easily bruise the produce. They are too deep and without sufficient side reinforcement, thus causing the produce to be jarred or compressed. Moreover, handlers tend to throw rather than lift the produce gently because of its weight. The use of wooden crates could solve many of the objections to the bamboo baskets. The main objection to a wooden crate is that it is expensive. Moreover, the use of wooden crates might displace the bamboo basket as a home industry. The solution is to redesign the bamboo basket to suit the local market. Containers from other cheap, locally available materials, like veneer slats, can also be alternatives. Jute sacks or mesh bags and wooden crates are also used. In India, Arthar (Cajanus cajan) stick baskets are popular.

Small farmers often bundle leafy vegetables for the market with local fibres such as bananas, abaca, or papyrus. Cabbage, muskmelons, watermelons, squashes and gourds are often transported in bulk by trucks, generally covered by tarpaulin. Grass, leaves, rice straw and newspapers are used as liners when needed or desired. Martin (1979) reported that bruising in plantain and bananas was reduced by using crates and wrapping the bunches with banana leaves to act as cushioning material.

Transportation of produce from the field to the market is frequently damaging due to the poor condition of the roads, especially in remote areas where only narrow and unpaved feeder roads exist. High transit temperature during the day aggravates this problem. This causes heat build-up within the pack, resulting in deterioration of farm produce. The motto, "Pile it high and sell it cheap" pervades the fruit and vegetable marketing system.

Long journeys in hot weather in unventilated trucks on bad roads and poor stacking patterns of unsuitable containers cause considerable loss of fruits and vegetables. Thus, the main problem in transporting products over land is not so much the distance, but the conditions of transportation between the field, the assembly area and finally the market. The majority of farms, however, are in areas far from the highway where road conditions are not always adapted to the usual means of transport. Increasing urbanisation has forced growers to look for areas even farther from centres of population. Thus, carts, sleds, horses or bullocks or even people are employed to carry the products either to areas where transportation can be obtained or to collection points. Many roads have been constructed and conditions have improved over the years, but in most developing countries there is still a need for a more adequate road system connecting the farms to the ultimate markets.

Where fields are near the coast, river banks or lakes, water transportation plays a big role. Barges are popular means of transporting fruits and vegetables in Bangkok. Inter-island transport requires ships. Uncertainties in schedules and weather and handling delays at loading and unloading points are detrimental to the quality of perishable produce.

To summarise, transport losses are due to the following:

a) Unsuitable transport containers;

b) Overloading of mixed fruits and vegetables (in some developing countries people and even animals ride on top of the load);

c) Irresponsible driving;

d) Lack of feeder roads leading to highways or collection centres;

e) Rough roads;

f) Heat accumulation or very poor ventilation within the transport vehicles;

g) Virtual absence of refrigerated and insulated trucks;

h) Delays in product procurement after harvesting or at collection centres.

In many developing countries wholesale markets, if any, are integrated with retail markets. Ideally, wholesale markets should be separated from the retail ones. However, this is influenced by the structure of the marketing chain and the scale of the industry. Frequently wholesale markets are overcrowded, unsanitary and lack suitable facilities for display, storage, ripening, loading and unloading. A main contributory factor to loss of leafy vegetables is trimming at wholesale markets prior to delivery at retail stands. Examination of trimmings showed that wholesalers and retailers trimmed their produce mainly because of the presence of decaying portions of leaves, due to bacterial soft rot. Thus, prevention of rotting during transport and storage would result in substantial reduction for post-harvest losses of leafy vegetables.

Storage of fresh fruits and vegetables prolongs their usefulness, checks market gluts, provides a wider selection of fruits and vegetables throughout the year, helps in orderly marketing, and may increase the financial gain to the producer. Adequate storage may reduce subsequent losses, but cannot overcome pre-storage losses. Adequate storage involves proper regulation of temperature, humidity, air circulation, proper stacking pattern, regular inspection, and prompt produce disposal as soon as maximum storage life has been attained. The feasibility of the construction of cold storage facilities and the interest among farmers and handlers to utilise the cold stores would again depend upon the economic parameters of the project. One of the greatest impediments to preserving quality through refrigerated storage is the consumers' strong preference for freshly harvested produce and resistance to stored produce.

Information on the storage temperature and humidity requirements of fruits and vegetables and the length of time they can be kept without decline in market value is either inadequate or unknown to those who need the information. If a farmer is persuaded to store his produce in cold storage and the market value decreases due to inadequate knowledge of the proper utilization of cold storage, it is not only he who will become disillusioned, but his friends also will be convinced of the non-profitability of cold storage.

Lack of capital may also force farmers to ignore the use of cold storage, even when available and effectively managed. Many growers depend on almost daily sales for their income and hence may be forced to accept a lower price immediately, rather than to store their produce in the anticipation of a higher price. There is also the storage rental price which the farmer may not be willing to pay unless he is thoroughly convinced that he will not only recover his investment, but will also profit.

The retailer usually disposes of produce which has been damaged by factors occurring further back in the marketing chain. At this stage, deterioration of perishables has already progressed to such an extent that street vendors have little opportunity to prevent further losses, either through storage or other preventive measures, except by estimating their potential sale for the day and buying only the amount that can be disposed of.

In Malaysia, although fruits and vegetables are sold in the open market, retailers improvise beach umbrellas arranged side by side to provide acceptable shade to the commodity during market days. After the market is over in the afternoon the umbrellas are folded and the market area is again an open space. This simple technique or similar ones could be adopted in other developing countries as a temporary measure to provide shade to the produce.

Miscellaneous losses are numerous. The most important ones are:

a) Over-purchase of cheap but highly perishable fruits and vegetables leading to wastage due to inadequate storage facilities.

b) Rates of pay among "cargadores" (product haulers) usually depend on the number of containers that they can carry from one point to another. Hence, they disregard proper handling in their hurried attempts to make more trips.

c) Deterioration during storage occurs because some old stocks are intentionally kept too long in anticipation of eventual price increases;

d) Maintenance of transport, storage and other handling facilities are generally poor in developing countries resulting in a continual source of losses.

e) There is no efficient communication link between producers and wholesalers. Losses will always occur in the absence of a dependable communication system.

4.2 Individual Fruits and Vegetables

The following notes highlight some of the major problems of the more important commodities in the fruit and vegetable group. They are, however, indicative rather than exhaustive.

Bananas and Plantains. Harvesting is generally a one-man operation which frequently results in bruising and abrasions of fruits causing accelerated ripening and consequent decay. Latex staining is prevalent during dehanding. Bunches or hands are often piles one on top of the other without proper protection and fingers are easily detached and oftentimes wasted during transport. This is particularly true of the very open, loose bunches of certain plantain cultivars. In container transport loosely packed hands suffer considerable damage, especially on rough roads. In transit ripening and decay are usually high, notably over long distances.

Mango. Fruits are usually harvested at the time of the day when maximum latex flow is favoured. Latex stain is allowed to dry on the peel, hence immediately reducing consumer acceptability during retail. The collapsibility of the non-rigid crates often used for transport further aggravates quality loss by compression and bruising. The inaccessibility of production area to roads causes serious delays in transport, in addition to a mixed-cargo type of transport. Stacking in vehicles often does not provide for adequate ventilation. Loading and unloading operations are rather rough. Cold storage is not usually practised. Ripening is mainly aimed at improvement of the appearance for sales purposes and not for maintaining quality.

Papaya. Picking poles injure the fruit and there is a relatively high percentage of fruit dropping on the ground, causing breakage and bruising of ripe fruits. Peduncles are not usually trimmed hence injuring other fruits within the pack. Rigid containers are not adequately lined, and within a single pack fruits of assorted sizes and maturity stages are often found. In bulk transport fruits are piled one on top of the other without any suitable padding materials. High percentage of decay, particularly anthracnose, is the main problem during ripening and in retail.

Citrus. Improper time of harvesting greatly enhances rind injury or oleocellosis. Leaving long stubs on fruits injures other fruits within the pack. Containers used are large and overpacked, generally without sufficient ventilation. Containers are piled high with the bottom crates bearing the full weight of crates on top. Delays in transport due to poor roads often cause over-ripening or yellowing of the commodity. Poor storage conditions favour decay and physiological disorders such as chilling injury can also occur if cold stores are not well managed.

Grapes are attacked by Botrytis, Cladosporium and Alternaria during storage. However, if the storage temperature is strictly maintained between 0° and $2^{\circ}C$, fungal attack can be reduced to a minimum. Other loss factors could be berry drop, bruises, injury, water loss, and cracking of berries. Selection of unsuitable container type for packaging of grapes may also lead to heavy transit losses. Transit delays, adverse weather conditions and improper type of carriages, e.g., steel wagons, particularly during hot months may further aggravate transit losses.

Tomato fruits are usually picked when fully ripe, and are therefore very susceptible to cracking, bruising, and consequently decay. Packaging containers often used are deep bamboo crates with insufficient side reinforcements allowing jarring and compression during transport. Loading and unloading operations are very crude. Handlers tend to throw the packs rather than lift them gently, on account of their weight. During retail, sellers tend to pour the contents of the pack into another container, rather than transferring the fruit gently, thereby increasing bruise damage. Fruits at the breaker stage are mixed with the fully ripe or three-quarters ripe fruits reducing the market value of the pack. Shrivelling percentage can be high since fruits are often exposed to the sun.

Onions. Insufficient grading is still existent. Sprouted, injured and partly decayed bulbs are usually mixed with sound bulbs in a pack. The use of slatted wooden crates is advantageous, especially during transport. Mesh bags of 40-50 kg. capacity are also used. Sacks are thrown rather than lifted, on account of their weight. Packs are piled one on top of the other with no provision for adequate ventilation. Pre-harvest spraying with sprout inhibitors is seldom practised resulting in serious sprouting during storage.

Cabbage/Lettuce. Improper harvesting tools contribute greatly to damage to the produce in the form of cuts and abrasions. Trimming of outer leaves is usually not practised. In container transport, large crates are used (50 kg. capacity). Bruising and tearing of the leaves is of common occurrence due to the sharp edges of the containers. Containers are piled one on top of the other with the bottom crates carrying the weight of the heads above. Bulk transport likewise results in higher losses.

Peas and Beans. Factors such as the method of packing, suitability of containers, mode of transport, distance covered, number of transshipments, handling, and storage facilities in the consuming centres, all contribute to the degree of loss reported.

4.3 Institutional Aspects

The solution to the problems of improper handling of perishable produce in the tropics is rather difficult, owing to the complexity of the problem. It requires the solving of technical problems as well as those of credit, land, transportation and marketing availability. It also requires a change of people's attitudes to proposed solutions and new innovations. Such an approach can only be accomplished over the years, tackling specific problems in a stepwise fashion. There must be concerted efforts by the private and government sectors.

Extension work is needed to show that post-harvest procedures are as important as production techniques. It is not enough to produce good quality commodities through variety improvement and proper regulation of soil and climatic factors. The whole process from planting until the harvested products reach the consuming public must be a mutual undertaking between the growers and those who will handle the product after harvest. Post-harvest handling up to the final marketing stage must be considered as a single system. The success of maintaining the harvest-fresh quality of produce demands control, each step depending upon the previous one. If the initial quality of the product is poor, no post-harvest treatment can improve it, although careful selection and grading may salvage some good quality produce from a mixed-quality sample. Thus handling procedures from harvesting until the product reaches the consumers are chains of interdependent activities.

The establishment of wholesale markets or cold storage facilities by Governments or other agencies must also meet the general approval of the persons who must use them. Of what use would a modern wholesale market be if the wholesalers would rather use an antiquated one that is more accessible to them? The establishment of a cold storage plant in an area accessible to the users must be accompanied by a sustained information and promotion campaign. Emphasis must be laid on the benefits of the farmer. Realistic rental rates and payments after the sale of products could attract the farmer to use this facility. Above all, an essential prerequisite to the taking of a decision to erect a new wholesale market is the need to carry out a sound feasibility study to provide suitable information for the decision-makers to use.

The establishment of co-operatives has done much in certain countries but only where the organizations are effectively run and the members are aware of their responsibilities as well as the benefits. The farmers involved in co-operatives have a greater bargaining power and control of the production planning and marketing which may spur them on to improve or maintain the quality of their produce. They may also be encouraged to obtain credit.

Technical knowledge of post-harvest handling has been increasing and there is a need to translate this body of knowledge into systems and techniques that the farmer can understand and use. Agricultural extension information must be reliable. The extension worker must have a good grasp of his job and must know where to turn when he cannot solve problems himself.

A continuing problem is the low educational level of farmers in developing countries and their skepticism towards new methods they have never tried or seen before. Farming, especially of fruits and vegetables, is not looked upon as an attractive occupation. Often farming is an occupation of last resort. Vagaries of weather make farming a risky business and knowledgeable and enterprising farmers are few.

In a way, acceptance of improvements and innovation are tied up with the economic progress of a nation. If the buying power of the people is increased, they are more willing to accept the increase in prices associated with the improvement in the post-harvest handling of fruits and vegetables.

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Table 2

Production of Root/Tuber Crops in Developing Countries

(thousands of tons)

Crops	Africa	Latin America	Near East	Far East	South Pacific	Total	% 1975
Cassava	42,884	32,201	1,128	27,643	221	104,037	59.7
Potatoes	2,039	8,951	4,206	8,445	-	23,641	13.6
Yam	19,279	291	260	30	200	20,060	11.5
Sweet Potatoes	5,539	3,379	94	8,764	560	18,336	10.5
Taro	3,569	-	59	90	262	3,980	2.2
Others	1,446	811	-	1,674	390	4,321	2.5
Total	74,716	45,633	5,747	46,646	1,633	174,375	

Source: FAO Production Yearbook

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Table 3

Production of Major Vegetables, 1978
(thousands of tons)

Vegetable	World	Developed Countries	Developing Countries	Centrally Planned
Tomatoes	47,087	19,301	14,475	13,310
Cabbage	32,098	10,593	3,631	17,874
Watermelon	23,635	4,946	11,044	7,645
Onions	18,243	6,158	6,788	5,297
Carrots	10,073	4,417	700	4,956
Cucumbers	9,819	3,480	1,384	4,955
Peppers, green	5,999	1,742	2,270	1,988
Melons	5,864	2,325	2,118	1,321
Pumpkins	4,885	1,116	2,382	1,387
Peas, green	4,551	3,116	584	851
Cauliflower	4,283	2,243	997	1,043
Eggplant	4,031	1,229	1,504	1,298
Beans, green	2,429	1,407	548	474
Garlic	2,111	449	1,074	588
Artichokes	1,254	1,084	170	-

Data from FAO Production Yearbook 1978

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Table 4

Production of Major Fruits 1978
(thousands of tons)

Fruit	World	Developed Countries	Developing Countries	Centrally Planned
Grapes	56,030	35,658	11,264	9,981
Bananas	36,892	582	35,163	1,047
Oranges	34,110	14,637	18,344	1,129
Apples	31,280	15,753	4,370	11,157
Plantains	20,391	-	20,391	-
Citrus, nor orange	16,804	10,778	5,558	469
Mangoes	13,782	14	13,501	266
Pears	7,651	4,555	876	2,221
Pineapple	6,836	980	4,896	961
Peaches	6,787	4,560	1,168	1,058
Plums	5,241	2,465	481	2,296
Dates	2,264	39	2,625	-
Apricots	1,584	667	511	406
Strawberries	1,564	1,052	140	371
Papayas	1,514	54	1,424	36
Avocados	1,284	157	1,127	-

Data from FAO Production Yearbook 1978

Table 5

Reported Production and Loss Figures in Less Developed Countries

Commodity	Production (1,000 tonnes)	Estimated Loss %
Roots/Tubers		
Carrots	557	44
Potatoes	26,909	5-40
Sweet Potatoes	17,630	35-95
Yams	20,000	10-60
Cassava	103,486	10-25
Vegetables		
Onions	6,474	16-35
Tomatoes	12,755	5-50
Plantain	18,301	35-100
Cabbage	3,036	37
Cauliflower	916	49
Lettuce		62
Fruits		
Banana	36,898	20-80
Papaya	931	40-100
Avocado	1,020	43
Peaches, apricots nectarines	1,831	28
Citrus	22,040	20-95
Grapes	12,720	27
Raisins	475	20-95
Apples	3,677	14

Data from National Academy of Sciences report, 1978

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Table 6

Storage Life of Potato and Onion Varieties

Variety	Normal Storage Life (months)
POTATOES	
Nooksack	11-12
Russet Burbank	10-11
Kennebec	6-7
Katahdin	6-7
Sebago (Northern USA)	5-6
Norland (late harvest)	4-6
Norchip	4-5
Superior	4
Norgold Russet	3
Norland (early harvest)	1
Sebago (Southern USA)	1
White Rose	1
ONIONS	
Spartan Sleeper	7-8
Downing Yellow Globe	7
Premier	5-6
Fiesta	5
Yellow Sweet Spanish	4-5
Excel	3-4
Golden Beauty	3
Italian Red	1-2
Walla Walla Sweet Spanish	1-2

Table 7

Post-Harvest Pesticide Tolerances on Raw Horticultural Commodities
U.S. Environmental Protection Agency, July 1, 1977

Captan (180.103)	100 ppm	beet greens, cherries, lettuce, spinach
	50 ppm	apricots, celery, grapes, leeks, mangoes, nectarines, onions (green), peaches, plums (fresh prunes), shallots
	25 ppm	apples, avocados, blackberries, blueberries (huckleberries), cantaloups, crabapples, cranberries, cucumbers, dewberries, eggplants, garlic, honeydew melons, muskmelons, onions (dry bulb), pears, peppers, pimentos, pumpkins, quinces, raspberries, summer squash, tomatoes, watermelons, winter squash
	2 ppm	beets (roots), broccoli, brussels sprouts, cabbage, carrots, cauliflower, collards, cottonseed, kale, mustard greens, peas (dry and succulent), rutabagas (roots), soybeans (dry and succulent), sweet corn (kernels plus cob with husk removed), turnip greens, turnips (roots)
	0.25 ppm	taro (corm)
Methoxychlor (180.120)	7 ppm	sweet potatoes and yams
Inorganic bromides (from fumigation with methyl bromide) (180.123)		
	100 ppm	pomegranates, asparagus, ginger root
	75 ppm	potatoes, sweet potatoes, avocados
	50 ppm	green beans, lima beans, garlic, sweet corn, cabbage
	30 ppm	beets (roots), carrots, citrus, citron, salem-artichokes, kumquats, lemons, limes, okra, oranges, parsnip (roots), peppers, pimentos, radishes, rutabagas, salsify roots, cucumbers, grapefruit, horseradish, summer squash, tangerines, turnips (roots), yams

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Table 7 (contd.)

	20 ppm	apricots, cantaloups, cherries eggplant, grapes, honeydew melons, mangoes, muskmelons, nectarines, peaches, onions, papayas, pineapples, plums, fresh prunes, pumpkins, tomatoes, watermelons, winter squash, zucchini
	5 ppm	apples, pears, quinces
Inorganic Bromides (from fumigation with ethylene dibromide) (180.146)	10 ppm	beans (string), bitter melons, cantaloups, Cavendish bananas, citrus fruits, cucumbers, guavas, litchi fruit, litchi nuts, longan fruit, mangoes, papayas, peppers (bell), pineapples, zucchini squash
	25 ppm	(total organic plus inorganic bromine) cherries, plums, fresh prunes
Calcium Cyanide (180.125)	5 ppm	cucumbers, lettuce, radishes, tomatoes
Piperonyl butoxide (180.127)	8 ppm	almonds, apples, beans, blackberries, blueberries (huckleberries), boysenberries, cherries, cocoa beans, copra, cottonseed, crabapples, currants, dewberries, figs, gooseberries, grapes, guavas, loganberries, mangoes, muskmelons, oranges, peaches, peanuts (determined on the nut with shell removed), pears, peas, pineapples, plums (fresh prunes), raspberries, tomatoes, walnuts
Sodium dehydroacetate (180-159)	65 ppm	strawberries
	30 ppm	bananas, of which residue not more than 10 parts per million shall be in the pulp after peel is removed.
Tetraiodoethylene (180.162)	15 ppm	cantaloups
Ethoxyquin (180.178)	3 ppm	apples and pears

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Table 7 (contd.)

CIPC (180.181)	50 ppm	potatoes
Dipherylamine (180.190)	10 ppm	apples
2,6-dichloro-4-nitroaniline (180.200)	10 ppm	carrots, grapes, lettuce, rhubarb, sweet potatoes
	20 ppm	sweet cherries, apricots, peaches, nectarines
	15 ppm	plums (fresh prunes), blackberries, boysenberries, celery
Chlorosulfamic acid (180.201)	8 ppm	asparagus, carrots, cauliflower, celery, potatoes, and radishes
1,2,4,5-Tetrachloro-3-nitrobenzene (180.203)	25 ppm	potatoes
Aluminum phosphide (180.225)	.1 ppm	almonds, cashews, dates, filberts, Brazil nuts, pistachios, peanuts, pecans, walnuts
2,2-Dichlorovinyl dimethyl phosphate (180.235)	1 ppm	lettuce
	0.5 ppm	cucumbers, mushrooms, tomatoes, radishes
Thiabendazole (180.242)	10 ppm	apples, citrus fruits, pears
	3 ppm	potatoes, bananas
	0.4 ppm	banana pulp
Boron (180.271)	8 ppm	citrus fruits, (total, includes boron naturally occurring in the fruit).
Benomyl (180.294)	35 ppm	pineapples
	15 ppm	apricots, cherries, nectarines, peaches, plums (including fresh prunes)

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Table 7 (contd.)

	10 ppm	grapes, mushrooms
	7 ppm	apples and pears
	1 ppm	bananas of which not more than 0.2 ppm shall be in the pulp after the peel is removed
sec-Butylamine (180.321)	30 ppm	citrus fruits
Thiophanate-methyl (180.371)	15 ppm	apricots, cherries, nectarines, peaches, plums, prunes
Pyrethrins (180.128)	1 ppm	almonds, apples, beans, blackberries, blueberries (huckleberries), boysenberries, cherries, crabapples, currants, dewberries, figs, gooseberries, grapes, guavas, loganberries, mangoes, muskmelons, oranges, peaches, pears, peas, pineapples, plums (fresh prunes), raspberries, tomatoes and walnuts.
	0.05 ppm	potatoes
o-Phenylphenol and its sodium salt (180.129)	125 ppm	cantaloups, of which not more than 10 ppm shall be in the edible portion
	25 ppm	apples, pears
	20 ppm	carrots, peaches, plums, fresh prunes
	15 ppm	sweet potatoes
	10 ppm	citrus, citron, cucumbers, grapefruit, kumquats, lemons, limes, oranges, peppers (bell), pineapples, tangerines, tomatoes
	5 ppm	cherries, nectarines

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Table 7. (contd.)

Hydrogen cyanide (180.130)	50 ppm	citrus fruits
	25 ppm	almonds, cashews, pecans, walnuts
Biphenyl (180.141)	110 ppm	citrus fruits (and hybrids thereof)
2,4-D (180.142)	5 ppm	citrus fruits, lemons
Thiram (180.132)	7 ppm	bananas of which not more than 1 ppm shall be in the pulp after the peel is removed
	0.5 ppm	onions (dry bulb)
Copper carbonate, basic (180.136)	3 ppm	pears
Ethylene oxide (180.151)	50 ppm	black walnut meats, whole spices
Maleic hydrazide (180.175)	50 ppm	potatoes
	15 ppm	onions

Note: Maleic hydrazine is applied pre-harvest solely for its ability to retard post-harvest sprouting

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Table 8

Chemicals or Industrial Processes Associated with Cancer Induction in Man

Chemical or Process	Main Type of Exposure
Aflatoxins	environmental, occupational
4-aminobiphenyl	occupational
Arsenic compounds	occupational, medicinal, environmental
Asbestos	occupational
Auramine manufacture	occupational
Benzene	occupational
Benzidine	occupational
Bis(chloromethyl) ether	occupational
Cadmium industries	occupational
Chloramphenicol	medicinal
Chlormethyl methyl ether	occupational
Chromium industries	occupational
Cyclophosphamide	medicinal
Diethylstilbestrol	medicinal
Haematite mining	occupational
Isopropyl oil	occupational
Melphalan	medicinal
Mustard gas	occupational
2-Naphthylamine	occupational
Nickel	occupational
Chlornaphazine	medicinal
Oxymethalone	medicinal
Phenacetin	medicinal
Phenytoin	medicinal
Soot, tars and oils	occupational, environmental
Vinyl chloride	occupational

(Data taken from U.S. National Cancer Institute report entitled "Estimates of the Fraction of Cancer in the United States Related to Occupational Factors" September 1978).

Table 9

List of Carcinogens

Acetylamino fluorane
Alkali
O-Aminoazotoluene
2-Aminobenzidine
4-Aminobiphenyl and its salts
Antimony trioxide production
Arsenic and arsenic compounds
Asbestos
Auramine
Benz(α)pyrene
Benzene
Benzidine and its salt
Beryllium
Bichromic acid and salts
Bis(chloromethyl)ether
Cadmium and cadmium oxide
Chloromethyl methyl ether
Chlorinated biphenyl
Chloroform
Chromates
Chromic acid and its salts
Chromium compounds in chromate production
Chromite ore processing
Coal tar
Cobalt and its salts
Crocidolite
N,N'-Diacethylbenzene
4,4-Diamino diphenylmethane
Dianisidine and its salts
Diazomethane
1,2-Dibromoethane
3,3'-Dichlorobenzidine and its salts
3,3'-Dichloro 4,4'-diamino-diphenylmethane
Diethyl sulfate
4-Dimethylaminoazobenzene
N,N'Dimethylbenzine
1,1-Dimethylhydrazine
N,N'-Dimethylnitrosoamine
Dimethyl sulfate
Dioxane
Epichlorohydrine
Ethyleneimine
Ethyl thyocarbamide
Gasoline or petrol
Hexamethylphosphorictriamide
Hydrazine
Kepone
Magenta
4,4'-Methylenebis(2-chloraniline)
Methyl chloromethyl ether
Methylene dianiline
Methyl nitrosocarbamide
Monomethyl hydrazine
1-Naphthylamine and its salts
2-Naphthylamine and its salts
Nickel and its compounds
4-Nitrobiphenyl and its salts
Nitrosamines
Particulate polycyclic aromatic hydrocarbons
p-Phenylendiamine
1,3-Propane sultone
2-Propiolactone
Propyleneimine
Thallium
o-Tolidine and its salts
Trichloroethylene
Vinyl chloride
Vinyl cycloexene dioxide
Yellow fatty dye

A tabular compilation of values from Australia, Belgium, Finland, Federal Republic of Germany, Italy, Japan, Sweden, Switzerland, United Kingdom, Union of Soviet Socialist Republics, United States of America.
Occupational Safety and Health Series, No. 37, 1977, compiled by the International Labour Office, Geneva

Appendix 2 .

The Nomenclature of Common Root and Tuber Crops

Cassava	Manihot esculenta Crantz	
Yam		
White Yam	Iioscorea rotundata Poir.)	separation is not strict these being usually treated as a complex
Yellow Yam	D. cayenensis Lam.)	
Water Yam	D. alata L.	
"Chinese Yam"	D. esculenta (Lour.) Burk.	
Aerial Yam	D. bulbifera L.	
Chuch Chush Yam	D. trifida L.	
Edible Aroids		
Taro, "old cocoyam"	Colocasia esculenta var esculenta	
Eddoe	C. esculenta var antiquorum	
Tannia, "new cocoyam"	Xanthosoma sagittifolium	

Potato

Cultivated species of potatoes include:

- Solanum tuberosum sp tuberosum
- Solanum tuberosum sub sp Andigena
- Solanum stenotomum
- Solanum juzepczukii
- Solanum chaucha

Sweet potato — Ipomoea batatas (L.) Lam

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