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Postharvest Problems of Vegetables and Fruits in the Tropics and Subtropics

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Postharvest losses are a problem for many food crops but are particularly severe for highly perishable vegetables and fruits (1,14). In the tropics, transportation delays can cause vegetable crop damage ranging from 22 to 78% (28). Included are losses associated with overripening, mechanical injury, weight reduction, trimming, sprouting, and discoloration (Table 1).

A 1976 survey of fruit and vegetable losses at the transport, wholesale, and retail levels in Taiwan (Table 2) (16) indicated that losses were most severe for Chinese cabbage, common cabbage, papaya, turnip, muskmelon, carambola, watermelon, cauliflower, and celery. Moderate losses were recorded for banana, citrus, tomato, eggplant, cucumber, and green peppers.

High temperature and humidity accelerate loss rates. Molds, insects, and rats multiply more rapidly under warm, moist conditions, and the rate of chemical and physiological damage in vegetables and fruits increases as temperatures rise (1).

Many losses can be substantially reduced by following recommended practices for handling, transport, and storage. In developed countries, improved packaging, refrigerated transport, and an awareness of the role of refrigeration in quality maintenance have made it possible to move farm produce to distant cities in field-fresh condition and provide consumers with a relatively constant year-round supply (13).

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Table 1. Postharvest losses in selected vegetables (28).

Vegetable	Days held	Other conditions	% loss due to Decay	Trimming	Mech. damage	Wt loss	Other	Total
Beans (snap)	2	in sacks	-	-	15	5-8	5 a	25-28
Cabbage	4	exposed	15-20	15-20	10	-	-	40-50
Cauliflower	7	exposed	10	2-4	2-4	5	15 b	34-38
Corn (sweet)	2	at 10°C	-	-	-	5	50 c	55
Onions (white)	150	d	15-25	5	2-3	10	15-35 c	47-78
(red)	240	d	10-15	5	2-3	5	5-20 c	27-48
Potato (Irish)	300	at 4°C	5-15	-	2-3	5	10 c	22-33
Tomato	4	degreened	1-12	-	4-6	2-4	15-12 f	22-32
Total range								22-78%

[a] Loss of turgor.
[b] Change of color of curd.
[c] Decrease in soluble solids (sweetness).
[d] For white: stored at 4.5 months at 1°C, 2 weeks at 27°C.
For red: stored for 7.5 months at 0°C, 2 weeks at 27°C.
[e] Sprouting in storage.
[f] Over-ripening and culls (very small, misshapen, etc.).

Table 2. Postharvest losses in selected fruits and vegetables at the transport, wholesale, and retail levels in Taiwan (16).

Commodity	% loss at each level Transport	Wholesale	Retail	Total
Chinese cabbage	4.4	22.8	4.9	29.7
Cabbage	4.3	20.9	4.9	28.0
Turnip	2.4	9.5	4.1	15.3
Eggplant	3.0	3.2	1.9	7.9
Cucumber	3.1	3.1	1.5	7.5
Green bean	3.4	0.6	0.2	4.2
Green pepper	2.9	2.8	1.4	6.9
Cauliflower	3.5	5.4	3.1	11.6
Celery	2.5	5.6	2.6	10.4
Tomato	0.6	5.1	2.0	7.6
Ponkan	2.6	1.7	5.0	9.0
Liu-cheng	1.7	3.0	4.3	8.7
Watermelon	10.9	1.2	0.1	12.1
Muskmelon	2.1	5.1	9.3	15.7
Papaya	2.1	7.3	14.3	21.3
Carambola	2.4	6.5	7.2	15.2
Apple	1.6	0.9	3.2	5.7
Banana	-	2.7	6.6	9.0

On the basis of land area, production volume, and value, the ten most commercially important vegetables grown in the tropics are common cabbage, sweet potato, eggplant, potato, tomato, onion, garlic, radish, beans, peas, and leafy greens. The export trade from tropical countries is increasing, but overall volume is small. While the export potential for tropical vegetables is high, two serious limitations are evident: The failure to maintain produce quality and inappropriate handling techniques that cause postharvest injury (28).

The most pressing requirement of the Taiwan vegetable industry, for example, is improvement of the system used for handling and transporting perishable produce from growing areas to terminal markets (16). Successful marketing of horticultural produce requires an efficient system capable of providing the consumer with safe, nutritious, quality products.

Handling

In general, the quality of vegetables and fruits cannot be improved after harvest (14), and deterioration usually starts after the crop is picked. The more carefully a product is handled, the slower its deterioration rate during subsequent postharvest operations. Rough handling causes bruises, cuts, scratches, and abrasions that break the natural protective covering of the skin (11). Such injuries not only spoil the appearance of the produce, but hasten ripening and deterioration. The most serious injuries lead to infection and greatly increase losses due to rotting. Only sound, clean, bruise-free produce can be successfully stored. Carrot losses in domestic cold stores are mainly attributed to bacterial infections that enter through harvesting cracks and broken tap-roots (6). A curing treatment that reduces losses has been suggested as an alternative. This technique, which is still considered experimental, consists of storing the roots at 24-26°C with 98% relative humidity for two days in a sealed container (9).

Protective Treatments

Pathogens can quickly spread from infected to non-infected crops during storage or transport. Incipient infections at harvest are a major cause of the decay that develops during marketing. Prevention often requires an integrated approach including protective treatments in the field or postharvest treatments in the packing house (14).

The use of fungicides and other chemicals to control diseases and physiological disorders are accepted postharvest practices (14, 29). The most serious postharvest diseases are those that cause rapid and extensive breakdown of crops that are high in moisture content and nutrients. In these types of crops, contamination can quickly spread throughout an entire produce shipment. This condition is exemplified by *Rhizopus* spp. attack on stone fruits and strawberries, *Penicillium* spp. on citrus and pome fruit (blue and green mold rots), and *Erwinia carotovora* (bacterial soft rots) on leafy vegetables and potatoes. It has been estimated that 30% of all fruit rots are caused by a species of *Penicillium*, and 36% of vegetable decay by soft rot bacteria (29).

In industrialized countries, citrus fruits, bananas, and many stone fruits are treated in the packing house with fungicides (11, 14). Benomyl, thiabendazole (benzimidazole), and o-phenylphenate are the most common fungicides used to protect citrus fruit against green and blue mold. Potassium sorbate added to the standard fungicide treatments for citrus can reduce losses due to post-harvest decay by as much as 35% beyond the level of protection provided by standard fungicides alone (23).

Under humid conditions, fresh chestnuts produced in the highlands of Taiwan become moldy in just a few days. However, when the nuts are mixed with thiabendazole-treated sawdust and packed in kraft paper, they can retain their freshness for at least two months (35).

The use of chemicals for the postharvest preservation of perishable produce has been the subject of extensive research and consequently poses little risk to the consumer (11,14,29). However, the development of postharvest chemical treatments in the vegetable sector lags behind the technology developed for fruit crops (9). Benzimidazole fungicides have shown promise but are not universally effective. There is also a need for the development of safe and acceptable bactericides, particularly for control of bacterial soft rots.

Hot water treatments (50°C) can eradicate established infections not controlled by chemical agents (14,29). Care should be taken, however, to ensure that the heat required for disease control does not exceed the injury threshold of the host. Green bean losses over a two week period can be reduced from 25 to 6% when pretreated with 45°C water for three minutes (36). However, high temperature (boiling water or microwave) and short-time treatment have no effect on the inhibition of rooting and sprouting of garlic and cloves, but, rather, cause rapid deterioration of the vegetables due to heat injury (21).

Some interest has developed in combining heat and fungicides. Under this system, the temperatures used are less than those required for complete disease control, but are also below the crop's injury threshold. To bridge the gap, fungicides are used at relatively low dosages. The lower heat and fungicide rates tend to complement one another (7,29,30).

To control rotting, browning, and weight loss in lychees stored at 20-30°C, a benomyl treatement (0.05% at 52°C for two minutes) is recommended (30). This is followed by packing the fruit in small baskets and wrapping with PVC film (0.01 mm thickness). The conventional packaging method for Taiwan lychees slated for export is to place 10 to 30 kg in bamboo baskets or in cartons lined with polyethylene sheets. The fruits (with stems and leaves) are cooled with ice water before packing. Brown mold often develops on the fruits during transport. If kept in a dry environment, severe moisture loss and browning can occur. A new packaging method has been developed that uses a small paper box and a PVC cover (3). Each box contains 20 fruits without stems. The lychees displayed in the box retain their freshness and color after two weeks of storage at 3°C. Deterioration after three weeks is about 10%. Even this rate of loss can be prevented, however, by pretreating the fruit with thiabendazole fungicide (500 ppm) or dicloran (500 ppm). Fruit dipped in hot water containing 500 ppm benomyl for 30 seconds at 55°C retains its quality even when stored at 10°C for three weeks. In this instance the percentage of decayed fruit is only 2%.

Temperature Control

Most decay-producing organisms grow slowly at low temperatures. Therefore, temperature control is probably more critical for vegetables than for other types of crops in reducing the development of storage pathogens (9,11,12,13,14). Low temperatures delay the development of postharvest diseases by inhibiting host ripening, by prolonging disease resistance associated with immaturity, and by directly inhibiting the pathogen with temperatures unfavorable to its development (12,29). Vegetables and fruits have optimum storage temperatures that maintain a desired quality level over a certain time span. Low temperature storage should therefore be used to maintain minimum temperatures without injuring the commodity.

In Taiwan, inexpensive farm storage methods have successfully extended the marketing season for some vegetables, but the length of storage and its effect on the quality of the produce are unpredictable. Although most consumers prefer freshly harvested produce, demand from processors and distributors has helped to increase the use of short- and long-term refrigerated storage (6). Processors of asparagus, mushrooms, tomatoes, and bamboo shoots use short term storage to carry them over the period of peak supply. Similarly distributors store their produce to extend the marketing season, avoid price declines, take advantage of scarce supplies, and to expand their export markets.

A survey of cold storage facilities in Taiwan indicated that there were about 340 commercial refrigerated stores on the island in 1976 (6). Of these, 200 (total capacity of 180,000 tons) were primarily involved in the storage of vegetables and fruits. To date, considerable capital investment has been made in providing refrigerated storage facilities to grower cooperatives and processing factories. However, cold stores are rarely found on small-scale farms, and many farmers still depend on daily sales.

The total amount of vegetables and fruits stored in commercial refrigeration units in Taiwan from 1973 to 1975 has been estimated at 274,000 tons (6). Of this amount, 78% were vegetables. The nine major commodities stored were carrot (33.2%), potato (22.7%), onion (6.2%), asparagus (3.6%), green bean (3.1%), vegetable soybean (2.8%), pea pod (2.5%), mushroom (2.1%), and cabbage (1.7%). Carrot, potato, and onion can be stored for more than three months. Other commodities can be kept for only a few days or for several weeks prior to marketing or processing. A new industry for processing frozen vegetables for export (broccoli, pea pods, peas, sweet corn, mushrooms, green asparagus and vegetable soybean) has further increased the use of cold stores.

There is seasonal variation in the storage of vegetables in Taiwan. From April until the end of August, the use of cold stores reaches a peak period. This is due to the shortage of vegetable supplies in the summer when production is normally low. Research on the bulk storage of cabbage at low temperature indicated that cold storage of common cabbage is feasible in Taiwan only if the crop is harvested in May and stored no later than August (4). The storage of Chinese cabbage at low temperatures was found to be economically feasible only if the vegetables were harvested in May and stored no later than June. Prolonged storage significantly decreased profit margins.

Chilling Injury

Although many fresh vegetables and fruits are best kept at temperatures slightly above 0°C, e.g. carrots, cabbages, apples, and oranges, others are sensitive to chilling and suffer physiological disorders if not stored at moderate temperatures (8,11, 24,26,27,29). Many tropical fruits, e.g. bananas and mangoes, will be damaged if stored below 7.5°C (8). Green beans, cucumbers, eggplants, certain melons and squash, sweet peppers, and tomatoes are also sensitive to cold and generally must be stored above 7.5°C (29). If kept too long under low temperatures, beans develop a streaky brown stain and/or discolored sunken spots. Cucumbers develop sunken, water-soaked spots and slimy patches. With time, the flesh deteriorates and the fruit rots. Tomatoes become soft, develop rot spots, and lose flavor (11).

All "warm season" vegetables, except sweet corn, are subject to chilling injury. In contrast, cool season vegetables can be stored near 0°C (24). Asparagus and potatoes are exceptions.

Chilling injury is a major problem in postharvest handling of susceptible plant materials because it precludes the storage of many commodities at low temperatures. The problem is particularly acute when produce with different optimum storage temperatures are combined in one shipment. Moreover, because normal refrigeration cannot be used for many tropical fruits and vegetables, most are not traded internationally unless their volume justifies special transport and storage facilities, as in the case of bananas (27).

The problem of chilling injury is best resolved by avoiding exposure to harmful temperatures. Treatments that have shown promise include conditioning with cool temperatures before chilling, intermittent warming, hypobaric conditioning, increased atmospheric CO_2 during chilling, and pretreatments with calcium or ethylene (24).

Rapid Cooling

After harvest, perishable vegetables should be removed from the field and refrigerated as rapidly as possible or else graded and packaged for marketing. Since aging and deterioration is a continuing process after harvest, the marketable life of a crop depends on precise temperature maintenance and the care taken in handling.

On-farm rapid precooling, especially forced-air cooling, is gaining widespread acceptance in the United States and many other industrialized countries (13,22,31). In California, precooling is the first step, and one of the most important, in handling tomatoes for the fresh market (17). Prompt cooling helps maintain the produce at a reasonable temperature during shipment. The more quickly field heat is removed from the crop, the longer it can be maintained in good marketable condition. In a tropical environment, a delay of two hours between harvesting and cooling can reduce shelf life by a whole day (12). Mushrooms held at 10°C have only 25 to 50% the shelf life of those held at 1°C (10). In Taiwan, canners are able to produce 14% more finished product with bamboo shoots stored at 5°C for two days after harvesting than with those held at room temperature before processing (5).

Precooling slows aging and ripening, retards the growth of decay organisms, and, more importantly, reduces water loss due to reduced vapor pressure in the plant tissue. Various precooling methods include hydrocooling, vacuum cooling, air cooling, and cooling with contact ice and top ice (13). The choice of a suitable cooling method usually depends upon such factors as available sources of refrigeration, cost, product volume, and product limitations. Forced-air refrigeration is generally best for perishable foods that require rapid cooling, and is particularly effective if the air is saturated with water vapor. This system prevents wilting during the cooling of produce with a high surface/volume ratio that lose moisture rapidly, e.g. broccoli, lettuce, green beans, and strawberries (12,22).

After cooling, produce should be continuously refrigerated at recommended storage temperatures. If warming occurs, the benefit of prompt precooling may be lost. Cool storage rooms are an essential part of any cooling facility, allowing precooled produce to be held at optimum temperatures before marketing. Moisture condensation that accumulates on the surface of cold produce when moved from a cool store or transport vehicle to a warm, humid environment is difficult to remove. Its presence provides ideal conditions for the development of decay organisms when the produce is no longer cooled (12). Therefore, precooled produce should be kept cool unless warming is necessary for ripening. For short journeys, covered stowage may provide sufficient thermal protection, while intermediate journeys may require closed stowage in an insulated vehicle. Longer journeys usually require a vehicle that is both insulated and refrigerated.

The facilities for maintaining proper temperatures during all segments of marketing are sometimes referred to as the cold chain (14). In the United States and other technologically advanced countries, the cold chain is well developed, although not always used to maximum advantage. In many countries few of the links in the cold chain exist, and it is the lack of refrigeration that is largely responsible for the enormous postharvest losses that these countries incur.

Atmospheric Control

The rate of deterioration of fresh produce can often be reduced by the use of controlled atmospheres (14,31,33). Controlled atmospheres can be used either in conjunction with cold storage to increase storage life or as an alternative to refrigeration where biological or economic factors intervene. It is useful, for example, to store cold-sensitive produce at higher than normal temperatures in a controlled atmosphere. Wang (32) found that Chinese cabbage stored in 1% O_2 at 0°C was still salable after five months of storage, whereas the same commodity, stored in normal air at 0°C, was salable only with extensive trimming after three months of storage. The response of common cabbage, Chinese cabbage, and other commodities to modified atmospheres has been investigated (19,20). Few commodities are commercially stored or transported with the aid of atmospheric controls in developing countries. Suitable refrigerated vehicles with controlled atmosphere facilities are not readily available, and the costs of compressed or liquified gasses used to regulate in-transit atmospheres are prohibitive. Modified atmospheres created by special packaging such as the enclosure of produce in plastic bags or liners is one option open to growers (31).

In California, strawberries shipped at 3°C on plastic-covered pallets with average CO_2 levels above 10% have about one-half the decay rate of berries shipped in normal containers (15).

Despite advances in the knowledge and application of controlled atmospheres, temperature regulation is still the most effective means of maintaining quality after harvest. It is by far the simplest and most direct way of retarding respiration, ripening, and other aging processes (12).

Packaging and Transport

The use of proper containers and their correct loading prior to transport are important factors in the distribution of fresh vegetables (13,14,25,34). Heavy losses of commodities destined for local markets occur nevertheless through careless packing, loading, unloading, and rough handling. Transport to the market in many countries is frequently carried out in overloaded vehicles on poor roads.

Vegetables and fruits vary widely in their susceptibility to mechanical injury. The most prevalent types of damage are caused by cuts, compression, impact, and vibration. The choice of suitable packaging and packing methods must take into account the type of produce to be transported and the type of damage likely to occur. Three principles should be generally observed when packaging perishable products: Individual specimens should not move against each other or against the walls of the package, the package should be full but not overflowing, and it should not be tightly packed. In addition, the package must retain its strength throughout the marketing chain. The most suitable package for a given type of produce will depend on such varying factors as distance to be travelled, nature of the market, method of handling and transport, environment, availability and cost of packaging materials, and the need for refrigeration (34).

A wide range of packaging materials are used in the handling, storage and marketing of produce in Taiwan (Table 3)(6). The seven major types are bamboo baskets (65.7%, mainly for 11 commodities including bananas, citrus, turnips, carrots, potatoes, cabbages, vegetable soybeans, and green beans), cardboard cartons (15.7%, mainly for 12 commodities including pineapples, pears, apples, pea pods, and some mushrooms), wooden boxes (3.4%, for potatoes, onions, and pears), plastic bags (0.1%, for asparagus and green beans), plastic baskets (0.1%, for asparagus and potatoes), and plastic boxes (0.5%, for asparagus). In many tropical and subtropical countries, the cheapest package will continue to be the traditional bamboo basket. The cardboard cartons used in industrial countries rapidly lose strength as they absorb moisture and are therefore unsatisfactory under tropical conditions or when used in cool, high humidity storage facilities (34).

Conventional Storage and Processing

Conventional storage and processing methods such as drying, pickling, salting, and sugaring have been practiced in the tropics for many years and are still potentially useful in many locales. The utility of these techniques is due to a number of factors including a reduction in the storage life of perishables due to high heat and humidity and the susceptibility of warm season crops to chilling injury when placed in cold storage. In addition, farm holdings in the tropics are generally small and farmers most often distribute their produce through small village markets. These factors, alone or in combination, make small-scale conventional processing attractive in rural areas, especially where access to central markets is limited.

Salting, for example, is one of the best low-cost methods for preserving fresh vegetables. The addition of 2 to 2.5% salt (fresh weight basis) can promote aerobic lactic acid fermentation which promotes the development of a microbial flora that converts cucumbers to pickles and cabbage to sauerkraut. The improvement of packaging methods such as canning or bottling further enhances the storage life of these products, and small-scale, on-farm processing plants of this kind have helped to stabilize the production volume and price of cucumber in Taiwan.

Sun drying is another common practice used to preserve vegetables and fruits in the tropics and subtropics. Popular dehydrated vegetable products in Taiwan include radish, bamboo shoot, cabbage, and pepper. Relatively advanced dehydration techniques have also been adapted from small-scale processes in Taiwan, including simple tunnel drying, pan frying, and oven drying.

Table 3. Vegetables and fruits kept in commercial cold-storage in Taiwan: Storage temperature and packaging material and type (6).

Commodities	Storage temperatures (°C)	Packaging materials and types (%)								
		Bamboo baskets	Cardboard cartons	Wooden boxes	Nets	Plastic boxes	Plastic baskets	Plastic bags	In bulk	Total
Bananas	1-17	91.2	0.2						8.7	100
Pineapples	1-4		100.0							100
Citrus	1-6	96.3	3.7							100
Pears	0-5		99.7	0.3						100
Apples	0-6	12.5	87.5							100
Turnip	2-5	100.0								100
Carrots	(-5)	92.4	7.0						0.6	100
Potatoes	1-4	82.7	0.4	13.5			2.7	0.7		100
Onions	1-4	1.5		0.6	97.8				0.1	100
Asparagus	(-20)									
	1-4		15.2			34.3	22.5	28.1		100
Cabbage	2	100.0								100
Vegetable soybean	(-20)	89.5	10.5							100
Green bean	(-20)-(-18)	68.1	11.1		0.3			20.4		100
Pea pods	(-2)	100.0								100
Mushroom	(-3)-(-0)									
	6-7	1.8	29.1		69.1					100
Total		65.7	15.7	3.4	12.0	0.5	0.1	0.1	0.9	100

In general, the application of conventional methods are limited by the following constraints: Limited storage life and non-uniformity of fresh produce, loss of nutritional value, poor sanitation, and low efficiency. The combination of modern techniques and conventional processing can help resolve these constraints, however, and increase profits (18).

Conclusions

It is difficult to assess the amount of food lost each year to rough handling and transport, inappropriate storage methods, and other types of preventable postharvest damage. It is clear, however, that such losses represent a significant portion of the total amount of food produced in the tropics. This, of course, applies to all food crops, but is particularly true for nutrient-rich vegetables and fruits. These types of crops, although a small part of the consumer's overall diet, provide significant amounts of vitamins A and C, iron, calcium, protein and many of the other nutrients usually lacking in tropical diets.

In recent years, important progress has been made at the Asian Vegetable Research and Development Center in developing "tropicalized" vegetable varieties that can increase both the quantity and quality of vegetables available to consumers in developing countries (2). Maximum benefits will only be realized from the new varieties, however, if concrete steps are taken to limit postharvest losses. Fortunately, a great many methods already exist that can reduce these losses, and researchers are actively seeking new ones for the future. Most of these techniques will require modification, however, to meet local requirements. In the case of Taiwan, indigenous and foreign technologies were successfully modified to meet the demands of its large-volume domestic market and the exacting standards of its export markets. In other countries, local requirements will be different, and the adaptation of new technology and conventional practices must be carefully considered to meet local needs.

Reducing postharvest losses should not be viewed strictly from the viewpoint of technology, however. Experience has shown that education plays a key role in reducing losses at virtually every stage of the food chain. Education programs must therefore be aimed at the farmer, the wholesaler, retailer, and even the consumer. Each of these groups has a role to play and each must be considered in any effort to reduce postharvest losses.

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