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GOOD PRACTICE IN THE DESIGN, MANAGEMENT AND OPERATION OF A FRESH PRODUCE PACKING-HOUSE

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Good practice in the design, management and operation of a fresh produce packing-house

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Foreword

Market oriented production trends across Asia and the Pacific region, spurred by growth in the food service, supermarket and export sectors, rising living standards and growing consumer awareness necessitate a shift toward improved handling practices in fresh produce supply chains. Within the post-harvest system, the packing-house serves as a control point where quality management can be applied to assure a reliable supply of produce of good quality. Packing-houses also serve as sites for the effective implementation of strategies designed to eliminate or minimize microbial, chemical and physical contamination.

Well designed packing house facilities that conform to the principles of Good Manufacturing Practice (GMP) and which are equipped with an appropriate level and scale of post-harvest technology are, therefore, a critical and important component of the infrastructural base to support value adding and quality and safety management in fresh produce supply chains.

This publication documents good practice in the design, management and operation of fresh produce packing-houses. The guide is intended to serve as a technical resource for extension specialists, planners, farmer organizations, clusters and cooperatives on upgrading their post-harvest operations. It is hoped that the guide will serve as a useful resource to these key players and other stakeholders in the region's fruit and vegetable supply chains.

Hiroyuki Konuma
Assistant Director-General and
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Contents

Contents *(continued)*

Page

List of photos

Contents *(continued)*

Page

Contents *(continued)*

Page

List of figures

Contents *(continued)*

Page

Contents *(continued)*

Page

Contents *(continued)*

Page

Contents *(continued)*

Page

Contents *(continued)*

Page

List of tables

Contents *(continued)*

List of units

°C	degrees Celsius
cm	centimetre
d	days
g	gram
gal	gallon
h	hour
in	inch
K	degrees Kelvin
kg	kilogram
kJ	kilojoule
kPa	kiloPascal
kW	kilowatt
L	litre
m	metre
m^3	cubic metre
min	minute
mL	millilitre
mm	millimetre
N	normal
ppm	parts per million
psi	pounds per square inch
RH	Relative humidity
sec	second
V	volt

Acronyms and abbreviations

AC	Air cooling
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
AWR	Air-to-water ratio
C_2H_2	acetylene
C_2H_4	ethylene
CAC	Codex Alimentarius Commission
CaC_2	calcium carbide
$Ca(OCl)_2$	calcium hypochlorite
CF	Correction factor
CFC	chlorofluorocarbon
CI	Chilling injury
CIE	Commission Internationale d'Eclairage
ClO_2	chlorine dioxide
CO_2	carbon dioxide
EHWD	Extended hot water dip
EU	European Union
FA	Forced air cooling
FAO	Food and Agriculture Organization of the United Nations
GAP	Good Agricultural Practice
GMP	Good Manufacturing Practice
GRAS	Generally Recognised as Safe
H_2O	water
HACCP	Hazard Analysis and Critical Control Point
HC	hydrocooling
HCFC	hydrochlorofluorocarbon
HCT	half-cooling time
Hg	mercury
HOCl	hypochlorous acid
HSB	Hue-saturation-brightness
HWT	Hot water treatment
ID	identification
IPPC	International Plant Protection Convention
ISO	International Standards Organisation
MA	Modified atmosphere
MAP	Modified atmosphere packaging

MIG	Metal inert gas
MSDS	Materials Safety Data Sheets
NaOCl	sodium hypochlorite
NaOH	sodium hydroxide
NH_3	ammonia
NIST	National Institute of Standards and Technology (USA)
O_2	oxygen
OCl^-	hypochlorite ion
ORP	oxidation-reduction potential
PAES	Philippine Agricultural Engineering Standards
PCPM	Pest Control Programme Manager
PHTRC	Postharvest Horticulture Training and Research Center
PI	Package icing
PM	Production manager
PSM	Plant sanitation manager
PSSD	Post-harvest and Seed Sciences Division
PVC	polyvinyl chloride
QA	Quality assurance
QC	Quality control
QCO	Quality Control Officer
RC	Room cooling
RFID	Radio frequency identification
RH	Relative humidity
RU	Refrigeration unit
SSC	Soluble solids content
SSOP	Sanitation Standard Operating Procedures
T	temperature
TA	Titratable acidity
TIG	Tungsten Inert Gas
TSS	Total soluble solids
UPLB	University of the Philippines, Los Baños
UN	United Nations
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USFDA	United States Food and Drug Administration
VC	Vacuum cooling
VHT	Vapour heat treatment
WHO	World Health Organization

Chapter 1
Overview

1.1 Introduction

Horticultural perishable crops include fruits, vegetables, flowers and ornamentals. Fruits and vegetables can be marketed in the fresh form or as minimally processed products. Vital to maintaining their quality and maximizing their shelf-life is careful and minimal handling and proper temperature management. In general, there is no post-harvest technology for improving the quality of a commodity once it is harvested. Harvested produce is often brought to a common facility for preparation and storage pending transport to market. In its various forms, this facility is referred to as a *packing-shed*, a *pack-house* or *a packing-house.*

A *packing-house* can be defined as a designated facility where fresh produce is pooled and prepared in order to meet the requirements of a target market (Photo 1.1). In this context *market preparation operations* or *packing-house operations* are needed. The packing-house is the site where post-harvest treatments are applied and quality standards are monitored.

Photo 1.1 Packing facilities in Australia (left) and the Philippines (right). There may be significant differences in design, degree of mechanization and capacity but common to both is the need for applying Good Manufacturing Practice (GMP)

All producers should be looking with a view towards moving to centralized and well-designed packing-houses for preparation of produce for local markets as well as for export, especially in production areas that are situated in close proximity of major urban areas. Changes in the marketing structure for fresh produce and the growing consumer demand for fresh produce that is safe and of good quality, means there is a need to focus on the implementation of good practice in fresh produce supply chains. Packing-house facilities that conform to Good Manufacturing Practice (GMP) play a pivotal role in providing a clean environment for the proper washing, sorting, grading, treatment and packaging of fresh produce. This technical guide therefore focuses on the design of packing-houses that conform to GMP.

The investment and effort needed to set up a packing-house facility must be recovered through (Murray and George 1993):

- Higher returns on investment through higher produce prices that can be justified by the improved quality of the commodity.
- Higher returns on investment by reduced costs of handling and packing.
- Increased demand for the produce.
- Reduced post-harvest losses.

Functions of a packing-house facility

The packing-house system integrates components (raw materials, utilities, technologies, equipment and personnel) that function together to prepare produce for the market. Each component, therefore, has a significant effect on the final quality of fresh produce. Within the larger system of the post-harvest handling chain, the packing-house also serves as a control point where quality management can be applied to assure a reliable supply of produce of good quality to consumers. With increasing consumer concerns and requirements for food safety and quality, it is important that the packing-house serve as a suitable site for the implementation of effective strategies to eliminate or minimize microbial, chemical and physical contamination.

A packing-house facility can also serve as:

1. *An accumulation or collection point* – the produce is grouped into homogenous quantities according to the demands of specific markets.
2. *A temporary holding area prior to distribution* – during holding, the produce is protected from contamination and maintained at an appropriate temperature to minimize deterioration.
3. *A dispatch point of produce to different destinations* – if the facility services several markets, produce is segregated into distinct groups prior to loading. If a single vehicle is to be used for distributing produce, loading should be sequenced in such a way that the lot nearest the door is designated for the first stop, and the innermost lot is assigned to the last stop. For larger operations that supply a number of clients, produce for each destination is accumulated in designated areas to avoid errors during delivery, and to facilitate the checking of produce prior to loading.

Users of packing-house facilities

Growers

Large producers will find it necessary to perform packing-house operations in a central facility prior to marketing their produce. Unsorted produce generally commands lower prices because it is of mixed quality and may have a shorter shelf-life. The cost of additional sorting and grading must, therefore, be covered by buyers. A packing-house becomes even more important when markets demand quality produce.

Cooperatives and clusters

The advantages of a cooperative are optimized when packing-house operations are implemented in a central location. Farmers organized into cooperatives are better able to accumulate sufficient volumes of produce than are individual growers. Cooperatives increase the bargaining power of farmers and facilitate negotiations with buyers because only one entity is involved.

Cluster farming involves a group of individual producers who share a common commitment for marketing a single produce item. Usually, a particular area known for producing a specific commodity (in terms of volume and/or quality) is designated as the main production site. In comparison to traditional farmer cooperatives where commitment of the individual farmer to duties and responsibilities has often been less than warranted, cluster farming brings together a small group of farmers with similar interests and orientation (Montiflor 2008). The pack-house facility is better managed since fewer people are involved and decisions can be rapidly taken.

Traders

In practice, fruit destined for local markets are often subjected to rough handling, are packed in inappropriate containers and are transported under unsuitable conditions. Commodities procured by traders are often of mixed sizes and grades, are mechanically damaged, diseased and/or prematurely ripened. Re-sorting and repacking of these items is often needed before they can be brought to market.

Exporters

Ideally, commodities procured by exporters should have been sorted based on quality and size requirements and will only undergo minimal preparation for the export market. However, in situations where sorting and grading at the farmer or trader level is unreliable, it becomes necessary for the exporter to repeat these operations to ensure that the desired quality of the commodity is met.

Processors

Commodities required as raw material inputs for processing require some preparation to ensure quality of the finished product. Mangoes destined for processing into purées must undergo hot water treatment in order to prevent or reduce disease incidence. Otherwise, if disease is present, additional labour is needed to remove affected portions of the fruit, prior to processing, in order to prevent contamination.

Benefits of using a packing facility

Increased productivity of workers – a well designed and equipped packing-house allows workers to perform more efficiently. Volumes of commodities handled are increased and errors in sorting and grading are reduced.

Extended produce shelf-life – packing-houses provide an appropriate venue where market preparations can be properly performed. Well-trained and motivated workers ensure proper post-harvest handling of commodities, hence minimizing disease development, reducing mechanical damage and decelerating the rate of ripening and deterioration.

Improved produce quality – culls and rejects are more efficiently separated and removed from good-quality produce in a packing-house. This prevents cross-contamination and premature deterioration. Commodities are also better classified into different grades and sizes that can command better prices than mixed lines of produce.

Requirements of a packing facility

- *Adequate protection from sun and rain* – direct sunlight increases commodity respiration hence increasing the rate of deterioration. Rain, on the other hand, can promote disease development especially under high temperature conditions.
- *Proper flooring* – a firm, smooth and level coated concrete or tiled floor allows the unhampered movement of materials and personnel.
- *Good ventilation* – adequate air movement removes heat, ethylene and moisture produced during respiration and transpiration of a commodity. It also improves the comfort of personnel working inside a packing-house.
- *Good lighting* – adequate lighting is required to ensure that each item of produce can be inspected closely to allow removal of produce with physical, physiological or pathological defects. It will also improve staff effectiveness.

Requirements for GMP

Apart from standard packing facility requirements related to shelter and working conditions, measures also need to be taken to ensure the safety of produce in order to conform to consumer and market requirements. Unlike processed foods, fresh produce is not subjected to sterilization treatments to preserve its original flavour and texture. The application of GMP is, therefore, critical in assuring that all facilities and equipment used in fresh produce handling remain sanitary and do not pose a risk of chemical, physical or microbiological contamination to the produce. All personnel who handle materials and supervise production must also implement good hygienic practice (GHP) when handling produce to avoid contamination. More information on GMP is provided in Chapter 3.

1.2 Design considerations

Packing-houses can be of any size and configuration, and can be constructed using a wide variety of building materials depending on the resources available and the intended use of the facility. Factors to be considered in packing-house design include functionality, quality and volume of produce that must be handled and processed, worker safety and comfort, level and scale of operations, and location and site of the facility.

Functionality

Each and every component of the packing-house, as well as its location, must have a function that contributes to the success of the venture. For example, receiving areas for freshly harvested commodities may be left open to allow air circulation and facilitate unloading, although they should be shaded to avoid direct exposure to the sun. However, certain areas within the packing-house must be enclosed to avoid contamination from the surrounding environment as well as for security reasons.

Quality and volume of produce

The design of the facility must not adversely impact on the quality and safety of fresh produce. As cited earlier, walls allow heat and ethylene to accumulate within the facility, thereby increasing the rate of ripening and deterioration of produce. The facility must be large enough to accommodate the volume of produce to be handled. Future increases in volume must also be integrated in design considerations, so that provisions for expansion can be put in place during construction.

Worker safety and comfort

For higher productivity, greater morale and reduced liabilities due to accidents, worker safety must be incorporated into the design of the facility and equipment. Working conditions inside the facility should minimize fatigue and physical stress. It is important to monitor temperature and relative humidity (within or close to recommended levels through air-conditioning or sufficient ventilation), light levels, equipment ergonomics and the location of needed materials, tools, and equipment (easy to find, and easily accessible).

Level and scale of operations

Factors affecting the scale of operations

The complexity of a packing-house facility depends on the volume and variety of produce to be handled, the number of market preparation activities to be performed and the target market. For small operations, especially those catering for neighbourhood markets, field sheds or mobile packing facilities may suffice. For large operations, a permanent facility in a strategic location is needed. This document focuses on the location and design of permanent packing-houses. The facility may be designed for a single commodity only, or may handle different types of produce. Some packing-houses are equipped with cool storage facilities, while others are used exclusively for sorting and packing.

In cases where cool storage facilities are limited, compatibility issues may need to be considered such as storage temperature, relative humidity, ethylene sensitivity and odour absorption. For example, lettuce that requires storage at 0°C is incompatible with mangoes that suffer chilling injury at temperatures below 10°C. For many tropical commodities, holding at 10-12°C is a reasonable compromise. Traders supplying a mix of tropical and temperate commodities may need several cold rooms to handle the different temperature requirements of each type of commodity.

Organic produce must be handled separately from non-organic commodities to prevent accidental mixing. Equipment and implements must also be separated, or must be properly sanitized if shared between organic and non-organic items. 'Wet' (or traditional) markets tend to be less discriminating and demanding of produce quality than are supermarkets and institutional buyers who demand and can pay for produce of higher quality. Export markets not only expect produce that is of good quality, but also require it to be free of pests, diseases and chemical residues in excess of acceptable Maximum Residue Limits (MRLs) that may potentially harm the importing country's horticulture industry. Increasing quality and safety requirements means a more complex facility to carry out the necessary operations.

The success of a packing facility depends on the volume of produce to be handled. The larger the volume, the greater the utilization of the facility and its equipment and personnel; this translates into reduced costs for the facility. As the growing season of many crops is limited to certain months of the year, efforts should be made to identify off-season suppliers or alternative commodities in order to extend operations. The peak season for Philippine 'Carabao' mango occurs during the period January to May, with most fruit coming from northern Philippine provinces. During the off-season (June to November), Manila-based exporters procure fruits from farms in southern provinces. Aside from optimizing the use of their facilities, this also ensures that they maintain a continuous presence in their export markets, even if transport costs are higher.

Strategies for determining capacity

Three strategies can be used to estimate the capacity requirements of a packing facility (Bozarth and Handfield 2008):

Lead capacity strategy – capacity is increased according to an expected level of demand. This strategy provides the facility with sufficient capacity to meet all levels of demand, even during peak periods. Overcapacity in anticipation of high demand may also cost less and be less disruptive of operations than continuous expansion of capacity. The main risk involved with this strategy is excessive investment in equipment, facilities or floor area that can be very costly initially.

Lag capacity strategy – capacity is increased after demand has appeared. This reduces the risk of over investment, produces higher utilization rates and allows large investments to be postponed to later dates. This strategy, however, can result in delayed availability of produce as the packing facility tries to cope with the increased demand.

Match capacity strategy – this strategy attempts to strike a balance between lead and lag capacity strategies to avoid extremes of under- or over utilization.

One of the steps in establishing a packing facility is to determine future market needs via careful market research. The different market preparation operations that produce must undergo to meet these needs must then be determined. In view of the fact that these operations occur in sequence with each operation having its own specific capacity, there is at least one process or operation that limits the capacity of the entire chain of operations. This constraining process should be identified and improved as follows (Bozarth and Handfield 2008):

1. *Identify the constraint* – find the process with the lowest capacity.
2. *Exploit the constraint* – there must be careful management of the constraint to ensure no interruptions in the flow of the produce.
3. *Prioritize the constraint* – effective performance of the constraining process is the primary issue, with all other considerations being secondary issues.
4. *Elevate the constraint* – increase the capacity of the process.
5. *Find the new constraint* – once the original constraint has been addressed, new constraints should be identified and addressed using the same procedure.

Types of packing-house facilities

- *Conventional packing-houses* – these are structures intended for the usual preparatory steps for fresh produce packaging, and are located in strategic areas. The structure should be within easy reach of markets, sea ports and/or airports. Several growers may use one packing-house as a common service facility, which should be easily accessible to all of them.
- *Specialized packing-houses* – these are packing-houses for produce destined for high-end or export. Philippine Carabao mango destined for the United States, Australia and Japan must, for example, be packed in a screened area to prevent re-infestation with fruit flies once it has undergone quarantine treatment. Such facilities may also have small laboratories that are equipped with basic instruments for evaluating the quality of produce coming in and leaving the packing-house. Cold rooms may also be provided for pre-cooling and temporary holding to minimize the impact of transport delays.

Location of the facility

'Location' refers to the geographical area where the packing-house is constructed. The facility should be constructed as close as possible to the production area or to destination markets in order to:

- *Provide optimum service* – if the facility serves a corporation or association, then it should be able to provide service for the greatest number of growers. For traders targeting urban markets, the location should offer convenient access to transport hubs and supermarkets.
- *Reduce travel time of workers* – this maximizes their work schedule. It also reduces damage to produce due to in-transit vibration and exposure to sunlight.
- *Facilitate drop off and pick up of containers and produce.*

Apart from access to markets, the facility should also be located in the vicinity of port facilities (sea and air) and transport terminals (railways or highways) to facilitate hauling of produce. In situations where production areas are scattered and road conditions are poor, several field stations can be established to prepare produce for transport. Well-packed and padded containers can then be used to haul the produce to a larger central facility for further processing.

Access to labour should also be considered when deciding on the location of the facility. Provision of dormitories or shuttle services may be required if the labour force comes from distant areas. The extra cost of these provisions must be balanced by benefits.

Site of the packing-house

The site of the packing-house is the specific area where the main structure is built. When selecting a site, careful consideration should be given to the previous and current use of the area. For example, if the area being evaluated had been used for animal husbandry, contamination from fecal matter by insects or by air-borne dust particles is possible. Neighbouring areas should also be evaluated for possible sources of contamination; for example, chemical plants, power plants, waste treatment plants, livestock and poultry farms, garbage dumps and landfills. Sites likely to be contaminated by ethylene should also be avoided. The surroundings of the building should be free of litter, waste, refuse or animal feces. The following areas should be avoided (CAC 1969):

- *Polluted areas* (for example, with chemical waste, or radioactive sites) or industrial zones which emit contaminants such as ethylene and other gaseous compounds.
- *Flood-prone areas.*
- *Areas with high levels of pest infestations* (insects, rodents) where solid or liquid waste generated by the packing facility cannot easily be removed (for example, crowded urban centres where large trucks cannot enter).

The site should have the following features (adapted from ASHRAE 1998):

- *Sufficient area available for parking and movement of trucks,* layout of the facility and future expansion.
- *Reasonable cost of land or lease rates.*
- *Main highways for trucks should be easily* accessible. Sites with small narrow streets should be avoided.
- *Smooth field roads leading to the packing-house* are necessary to minimize vibration damage during hauling. Roads in close proximity to the facility should be paved to minimize dust that can contaminate produce.
- *Adequate shade should be provided at the packing-house* either as trees around the edge of the working area, or as roof extensions from the packing-house. These shaded areas keep produce out of the direct sunlight during and after unloading from the field. It should be noted however, that trees can be a source of microbial contaminants (for example, dried leaves/twigs) and insect pests, especially if the tree is fruit-bearing. Vegetation surrounding the packing-house must be trimmed and maintained in a sanitary condition as it can serve as a breeding ground for rodents and insect pests.

- *A sufficient and dependable supply of water and electricity* is essential – stand-by electric generators and water tanks should be available if electric and water supplies are unreliable. Electrical supplies must be able to accommodate the power requirements of the packing-house (for example, single-phase or three-phase electrical supply).
- *Access to communications* – this is widely available through cellular phones; thus signal strength at the site of the facility must be adequate and reliable. Internet access is also possible through wireless transmission. Where signal strength is weak, consideration must be given to the installation of cables for phone and Internet services.
- *Reliable communication systems* are necessary for rapid and up-to-date communication with producers and buyers. Extreme price fluctuations, especially in developing countries, can cause significant economic losses for small farmers and traders. In traditional wet markets, for example, prices can change significantly on a daily basis. Hence, timely information can allow stakeholders to make informed decisions in marketing their produce.
- *Sufficient load-bearing capacity* of the soil is required so the area should be able to bear the weight of the constructed facility, as well as fully-loaded vehicles.
- *Adequate drainage* – the packing-house should either be elevated or a series of canals should be constructed along the drip line of the roof to carry rain and wash water away from the structure. A drainage system should also be constructed to prevent the accumulation of stagnant water in areas surrounding the facility.
- *Consideration for natural disasters* – the site should not be located in areas prone to flooding because floodwater can be a source of human and industrial waste that can contaminate the facility and the fresh produce. Occurrence of soil erosion and the risk of landslides should also be considered. Erosion can undercut the foundation of structures while landslides can bury an entire facility in extreme cases. The structure should also be sheltered from high winds; if unavoidable, provisions should be made to block or mitigate wind strength.
- *Local zoning guidelines* – should be followed in areas where noise of equipment and vehicles (especially on a 24-hour-operating schedule) can be a disturbance to neighbouring areas.
- Other considerations include an acceptable level of peace and order, minimal taxes and insurance needs and community acceptance of the facility.

Chapter 2
Packing-house operations

Packing-house operations are specific for each commodity to be handled and for the target market. Operations include any of a number of steps, including trimming, cleaning, removal of excess moisture, curing, waxing, sorting and grading, ripening, degreening, packaging and pre-cooling. If excess raw material cannot be treated and packaged immediately or transport is delayed, then temporary holding in the packing-house is also necessary.

2.1 Key packing-house operations

Receiving

On entry at the packing-house, produce must be inspected for damage, insect or rodent infestation, decay, foreign materials and visible chemical residues and assigned with a code that identifies the supplier, date harvested or delivered, and production site (origin, lot/block number and tree number). Depending on the type of produce gross harvested weight might be recorded at this time. If possible, produce should be tested for chemical residues using test kits that may be confirmed as required by accurate analyses such as gas chromatography or high performance liquid chromatography (Boonyakiat and Janchamchoi 2007).

Maturity assessment

Depending on the intended market or requirements of the target market, maturity must be checked. Carabao mango subjected to VHT is, for example, checked for its maturity through flotation in a 1 percent salt solution. Fruits that float are culled because they are considered to be too immature. Immature mangoes when subjected to a disinfestation treatment like VHT are prone to internal breakdown. This is a physiological disorder characterized by white and spongy air pockets in the flesh with no external manifestations of the disorder (Photo 2.1).

Photo 2.1 Internal breakdown in 'Carabao' mango

Soluble Solids Content (SSC) provides an indication of the level of sweetness of some fruit. A minimum SSC has been established for the following crops (Hewett *et al.* 2009): pineapple – 12 percent, papaya – 13-15 percent, litchi – 16-17 percent and watermelon – 10 percent. 'Solo' papaya fruits are considered to have reached optimum maturity for harvest when Total Soluble Solids (TSS) is 12 percent. SSC and TSS are often used interchangeably.

Trimming

Trimming is a general term that refers to the removal of unwanted plant parts or those likely to be rejected by consumers or those parts that can contribute to deterioration. Specific trimming procedures for some commodities are described in Table 2.1. The dried flower remnants at the tip of the fingers of bananas are removed because these parts can harbour decay-causing organisms that can be a potential source of inoculum besides making the bunch of bananas unsightly. Workers should wear clean gloves during removal of dried flower remnants.

Table 2.1 Specific trimming procedures for some commodities

Commodity	Procedure	Description
Banana	Dehanding	Separation of hands from the stalk
	Deflowering	Removal of dried floral parts from the individual fingers
Cabbage		Removal of wrapper leaves
Carrot	Topping	Trimming of tops and vegetative parts
Garlic	Topping	Trimming of tops and vegetative parts
Lettuce		Removal of wrapper leaves
Onion (bulbs)	Topping	Trimming of tops and vegetative parts
Radish	Topping	Trimming of tops and vegetative parts
Roses	Dethorning	Removal of thorns from stems
Sweet corn, baby corn	Dehusking	Removal of husks
	Desilking	Removal of silk
Pineapple	Detopping	Removal of crown

Adapted from Bautista and Esguerra (2007)

The dried vegetative parts (leaves or tops) of onions are trimmed up to 2-3 centimetres above the neck to prevent disease development because the tops are succulent.

A long pedicel in fruit is commonly retained together with the leaves as a gauge of freshness. In citrus fruit however, a long pedicel tends to injure oil cells located just beneath the peel of adjacent packed fruit, resulting in discoloration of the peel, referred to as *oleocellosis*. This is especially true if citrus is uncured as oil cells remain turgid. The presence of leaves can also contribute to more rapid water loss because leaves have a relatively high surface area-to-volume ratio for transpiration. The pedicel of mango fruit is cut close to the shoulder followed by washing in water containing dissolved alum (double salt of aluminium sulphate) to coagulate the latex.

Trimming should be done with the proper tools such as sharp stainless steel knives or pruning shears. Box cutters with razor blades should not be used as they can snap and leave metal shards in produce. Blades are also subject to corrosion.

Sorting and grading

Commodities must be sorted and graded in order to facilitate marketing. Those destined for high-end or export markets may be classified according to national and/or international standards of weight, size, colour or visual quality. Domestic markets may have less rigorous standards that vary according to location, with each market differing in its definition of, for example, small, medium and large fruit.

Field sorting can help to reduce the volume of produce to be handled at a packing facility. It also lessens the chances of introducing contaminants into the packing facility. Tents or mobile packing sheds can be used as working areas for preliminary sorting of freshly harvested produce. Sorting for mechanical damage, pest damage, presence of decay or misshapen produce can easily be done in the field.

For large-scale facilities, sorting operations may be semi- or fully mechanized for rapid handling of large volumes of produce. These facilities usually cater to export markets, with excess volumes or second-class produce diverted to local markets or processing plants. Sorting and grading can be done manually using conveyors that move produce in front of trained personnel situated along the sides. For fully automated operations, machines equipped with machine-vision capability can sort and grade produce on the basis of colour and size. Machines equipped with near-infrared systems can sort produce according to sweetness and can detect physical injury.

Grading is the process of classifying produce into groups according to set criteria of quality and size recognized or accepted by governments and the industry. Each group of produce bears an accepted name and size grouping, such as Extra Class, Class I or Class II in the case of the Codex Alimentarius Commission (CAC) standards for fresh produce. Although the criteria used in grading vary with the commodity, some common properties that are used include:

- *Appearance* – the external condition of the produce that includes uniformity of variety, cleanliness, wholeness (no missing parts), colour and shape.
- *Stage of maturity and/or ripeness* – stage of maturity can either refer to commercial maturity or physiological maturity in the case of fruit and fruit vegetables. Commercial maturity or horticultural maturity is the stage of development when the plant part possesses the necessary characteristics preferred by consumers. Physiological maturity on the other hand, is the end of development of the crop when it has developed the ability to ripen normally after harvest. In some cases, stage of maturity and stage of ripeness are combined into colour grades such as green mature, coloured, semi-ripe or ripe.
- *Texture* – a characteristic related to finger-feel and mouth-feel like firmness, smoothness, turgidity, crispness, solidity, juiciness, mealiness and toughness.
- *Presence of damage or defect* – refers to any imperfection, lack of completeness or other conditions that differ from what is described as acceptable. Defects could either be permanent quality defects or those that do not progress or change with time such as deformities, growth cracks in tomato and potato, wind scars in mango, avocado and citrus. The other type of defect is called condition defect, which is of a progressive nature such as disease, physiological disorders, sprouting and discoloration such as yellowing and browning.

- *Safety and wholesomeness* – the condition of being clean and free from harmful contaminants such as heavy metals, pesticide residues, additives, food spoilage micro-organisms and physical contaminants such as hairs, wood splinters and broken glass.

Tables 2.2a and b summarize the common quality factors for fresh fruit and vegetables in the Codex Standards that can be used as a basis for grading.

Table 2.2a Quality factors for fresh fruit in the Codex Standards

Commodity	Codex document	Quality factors
Avocado	Codex Stan 197-1995	Wholeness, maturity, cleanliness, shape, colour, length of stalk, freedom from skin defects (corkiness, healed lenticels), sunburn, rotting, pests and pest damage, low temperature damage, abnormal external moisture, bitterness and foreign smell or taste
Banana	Codex Stan 205-1997, Amd. 1-2005	Wholeness (taking the fingers as reference), soundness, cleanliness, freedom from pests and pest damage, abnormal external moisture, damage caused by low temperature, foreign smell and/or taste, bruising, malformation or curvature, firmness, with pistils removed, stalk intact without bending, fungal damage or desiccation, hands and clusters must include a cleanly cut crown of normal colouring and free of fungal contaminants
Grapefruit	Codex Stan 219-1999, Amd. 2-2005	Wholeness, soundness, cleanliness, freedom from pests and pest damage, freedom from abnormal external moisture, foreign smell and/or taste, firmness, freedom from damage caused by low and/or high temperature, freedom from bruising
Litchi	Codex Stan 196-1995	Wholeness, maturity, colour, shape, freedom from skin blemishes, abrasion, discoloration, rotting, pests and pest damage, abnormal external moisture, foreign smell and taste
Mango	Codex Stan 184-1993	Wholeness, maturity, firmness, soundness, freedom from rotting, cleanliness, length of pedicel, freedom from black necrotic stains, bruising, damage caused by insects and low temperature, freedom from abnormal external moisture, foreign smell and/or taste
Mangosteen	Codex Stan 204-1997, Amd. 1-2005	Wholeness, intact calyx and pedicel, freshness (shape, colour and taste), soundness, cleanliness, freedom from rotting, latex, pronounced blemishes, pests and pest damage, freedom from external moisture, foreign smell and/or taste, ease in cutting open, skin at least pink colour
Papaya	Codex Stan 183 (1993, revised Jan. 2001)	Wholeness, maturity, freshness, cleanliness, length of pedicel, shape, firmness, freedom from skin defects (mechanical bruising, sun spots and/or latex burns), rotting, low and/or high temperature damage, abnormal external moisture and foreign smell and/or taste
Pineapple	Codex Stan 182-1993, Rev. 1-1999, Amd. 1-2005	Wholeness, soundness, cleanliness, freedom from pests and damage caused by pests, freedom from abnormal external moisture, foreign smell and/or taste, fresh in appearance including the crown, freedom from damage caused by low and/or high temperature, freedom from internal browning, freedom from pronounced blemishes, maturity requirement – minimum TSS content of 12 percent
Pomelo	Codex Stan 214-1999	Wholeness, maturity, colour (2/3 of surface showing coloration), TSS not less than 8 percent, cleanliness, shape, firmness, freedom from healed skin defects, bruising, rotting, pests, low temperature damage, abnormal external moisture and foreign smell and/or taste

Table 2.2b Quality factors for fresh vegetables according to Codex Standards

Commodity	Codex document	Quality factors
Asparagus	Codex Stan 225-2001, Amd. 1-2005	Wholeness, freshness in appearance and smell, cleanliness, shape/ straightness, compactness of tips, colour, freedom from rotting, pests and pest damage, bruises, abnormal external moisture, foreign smell and/or taste and damage caused by unsuitable washing or soaking, condition of shoots (not hollow, split, peeled or broken, cut at base of shoot is clean)
Baby corn	Codex Stan 188-1993	Wholeness, freshness, soundness, cleanliness, freedom from rotting and damage caused by pests, freedom from external moisture and foreign smell and/or taste, absence of silk
Tomatoes	Codex Stan 293-2008	Wholeness, soundness, cleanliness, freedom from pests and pest damage, abnormal external moisture, foreign smell and/or taste, freshness in appearance

Grading aids (Photo 2.2) can be used as a reference source by the classifier. Such pictorial guides on quality defects can be posted in strategic locations in the packing-house.

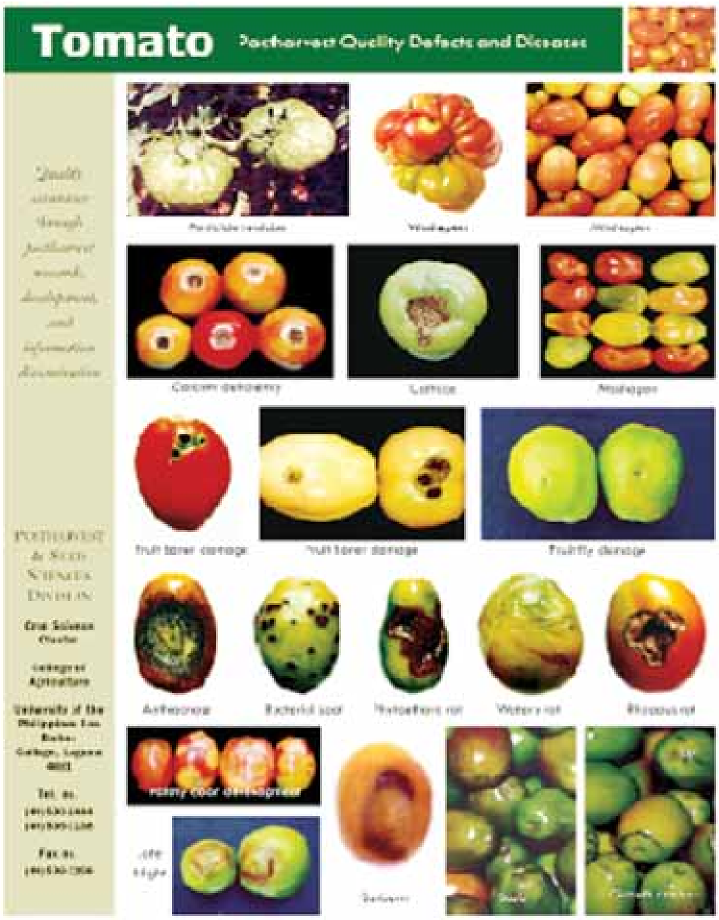


Photo 2.2 Different types of commodity defects that serve as a guide for packing-house personnel: tomato (top), 'Carabao' mango (on page 16)

Sizing

Sizing is the classification of produce into different categories based on size. Size classification can be based on weight (Table 2.3), diameter (Table 2.4) or length (Table 2.5). In the case of pineapple, size classification is based on weight with due consideration for the presence or absence of a crown as shown in Table 2.3. Sizing may be done manually or mechanically.

Table 2.3 Size classification of pineapples based on weight with due consideration for the presence or absence of a crown

Size code	Average weight ±12% (g)	
	With crown	Without crown
A	2 750	2 280
B	2 300	1 910
C	1 900	1 580
D	1 600	1 330
E	1 400	1 160
F	1 200	1 000
G	1 000	830
H	800	660

Source: Codex Standards for Pineapple: Codex Stan182-1993, Rev. 1-1999, Amd. 1-2005

Table 2.4 Size classification of grapefruit based on fruit diameter taken at the equatorial region

Size code	Diameter (mm)
0	>139
1	109-139
2	100-119
3	93-110
4	88-102
5	84-97
6	81-93
7	77-89
8	73-85
9	70-80

Source: Codex Standard 219-1999, Amd. 2-2005

Table 2.5 Size classification of baby corn based on length

Size code	Length (cm)
A	5.0 -7.0
B	7.0-9.0
C	9.0-12.0

Source: Codex Standard 188-1993

Delatexing/desapping

Latex stains and latex burns, also known as sapburn, are two of the most obvious post-harvest quality defects in mango, banana and papaya leading to inferior quality fruit if not properly managed. When the pedicel of a fruit is removed, latex exudes from the point of attachment. When latex enters the lenticels of fruit, burning will most likely occur several days after harvest and the effect is irreversible. Latex stain on the other hand, appears as shiny streaks or patches on the peel.

Photo 2.3 Delatexing of freshly-harvested and trimmed mangoes

In produce destined for export or coming from large plantations, prevention of latex staining is done immediately after, or within the day of harvest, or just after removing the pedicel of fruit. Latex stain in mangoes can be prevented during harvesting with the aid of wire-meshed trays positioned along the tree rows. As soon as the pedicel is cut, fruits are placed stem end down in wire-meshed trays for 30 minutes to allow the latex to drip (Photo 2.3). Fruits are then collected into plastic crates and brought to the packing-house for cleaning. Other methods of preventing or removing latex stains on fruit include dipping in anionic commercial detergent, 1 percent alum solution or washing in water.

Cleaning/washing

Cleaning removes latex, dirt, chemical residues, reduces the microbial load, insects such as mealybug and aphids, and other extraneous materials from the surface of the produce. Produce with a clean appearance is appealing to the consumer, and can be easily sold.

Soil adhering to produce can produce abrasion damage during transport, and serve as a source of contamination. Harvesters should, therefore, remove as much soil as possible prior to hauling produce to the packing facility. Physical damage must be minimized during the cleaning process (CAC 2003). The method of cleaning is determined by the nature of the commodity and the demand of the consumer. Leafy vegetables such as lettuce and muskmelons have rough surfaces that favour the attachment of microorganisms (Raiden *et al.* 2003), hence the need for washing. Bulb crops that will be stored such as onion and garlic, on the other hand, need not be washed. However, the dried outer scales need to be removed as they carry dirt. Fruits that are susceptible or suffer from latex staining need to be washed immediately after harvest to remove fresh latex adhering to the peel. Aside from improving appearance, this will also prevent latex burns.

The different methods of cleaning include:

- ***Washing*** – microbial contamination is usually found on the surfaces of fruit and vegetables, so washing is an important step in reducing the microbial load. The different methods of washing include:
    - o *Dump washing or immersion dipping* – dump tanks are used for removing dirt, hence water should be frequently changed and antimicrobial agents should be added (Photo 2.4). The water temperature in the dump tank should be slightly warmer than that of the produce because cooler water temperatures in the dump tank may lead to water absorption by the produce. This can cause microorganisms associated with the produce or in the water to be internalized making subsequent washing and sanitizing treatments ineffective. In most instances, it is not practical to expose produce to warm water. GMPs such as the use of antimicrobials in the wash water, spray washing and ensuring that both produce and water are clean, will reduce the number of microorganisms in the water and those that are associated with the produce.

Photo 2.4 Washing of mangoes by immersion dipping

Recycled water can be used without additional treatment as long as its use does not compromise produce safety. For example, water recovered from the final rinsing stage of leafy vegetables can be used for washing freshly harvested produce (CAC 2003).

- o *Spray washing* – this method makes use of a jet of fresh clean water. This method can also spread microorganisms by direct contact or when an aerosol is created, hence sanitizers must be added. When compared with immersion dipping, however, spray washing is less likely to spread microbial contamination.
- o *Brush spraying* – the commodity is brushed using soft sponges or brushes as they are sprayed with water. Brushing is usually done if the commodity is encrusted with dirt or sooty mould. Brushes should be clean and sanitized.

For some types of produce, a series of washes may be more effective than a single wash. Root and tuber crops for example may be washed initially to remove the bulk of field soil from the produce followed by second washing and/or sanitizing and a final rinse in fresh clean water.

- ***Wiping*** – some commodities are wiped with a wet or moist cloth (Photo 2.5). Alternatively fruits must be sprayed with water on a sorting table and then wiped with a clean piece of cloth.

Photo 2.5 Wiping tomatoes with a cloth moistened with a detergent solution

- ***Dry brushing*** – Dry brushing is applicable for water-sensitive commodities. Ginger is, for example, brushed without using water to remove clods of soil. Small brushes are used to remove adhering dirt and insects on durian fruit.
- ***Forced air*** – Forced air cleaning is applicable for water-sensitive commodities. Durian is subjected to pressurized air to remove dirt and insects. Silk in baby corn can also be removed using forced air. Periodic cleaning and sanitizing of equipment will reduce the potential for cross-contamination.

Quality of the wash water

Since water is in direct contact with the commodity, it should be of the highest quality. Water that is recirculated should also be of high quality. Water from the final rinsing stage is, for example, filtered and directed back or used directly in the initial dump tank or flume system for washing. Recycling improves water utilization but may introduce new microorganisms and cause the build up of organic matter in the water, thus increasing cross-contamination. Water re-use should be in counterflow to the production line, i.e., water used in the final rinse must be of the highest quality while water used to remove field soil from the produce need not be of high quality. World Health Organization (WHO) guidelines specify less than 1 000 coliforms per 100 mL of water as being acceptable for washing.

Wash water should be changed as frequently as necessary to maintain sanitary conditions. Water contact surfaces such as dump tanks, wash tanks, sprays and brushes should be cleaned and sanitized to ensure the safety of fresh produce.

Use of antimicrobials or sanitizers

Depending on its source, water can be contaminated; hence the ability to ensure water quality is essential. Antimicrobials or sanitizers are generally added to potable water to ensure that it is of the highest microbiological quality. Antimicrobials reduce the microbial population in water and on the surface of produce by 10- to a 100-fold. In some commodities, it may be necessary to follow surface treatment with antimicrobials by a clean-water rinse to remove treatment residues.

Commonly used antimicrobials include:

- *Chlorine* – this is a commonly used sanitizer in most packing-houses; it is added to water at 50-200 ppm total chlorine at pH 6.0-7.5 for a contact time of 1-2 minutes. Chlorine when dissolved in water generates hypochlorous acid (HOCl), the active compound that kills microorganisms.

  Common sources of chlorine are sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(OCl)_2$) and chlorine dioxide (ClO_2). NaOCl is also known as an ordinary bleaching agent or laundry bleach, while $Ca(OCl)_2$ is referred to as pool chlorine. NaOCl is generally marketed as a solution at a concentration of 5.25 percent; $Ca(OCl)_2$ is available in powder form but is not readily soluble in water. Undissolved particles can injure produce. To avoid this problem, the powder can be dissolved in a small volume of warm water prior to diluting to the appropriate concentration. Water circulation should be adequate and continuous during the sanitizing process to ensure the uniform distribution of chlorine.

  Ritenour *et al.* (2002) recommended a constant free chlorine concentration of 100-150 ppm maintained at a pH range of 6.5-7.5 for sanitizing purposes. At a minimum, chlorine levels should be monitored on an hourly basis. Time constraints during packing-house operations can, however, result in inadequate testing of water quality.

  Factors that influence the effectiveness of chlorine solutions include (Ritenour *et al.* 2002):

- *pH:* in solutions with a high pH, active HOCl breaks down and forms a hypochlorite ion (OCl^-) that is not as effective as HOCl. Solutions at pH 8 and above are not, therefore, very effective. At pHs less than 6, on the other hand, corrosion of equipment can occure. In order to ensure the adequacy of the sanitizing strength of a chlorine solution, the pH and free chlorine concentration must be known. The most widely used pH range for sanitizing is between pH 6.5 and 7.5.

  Adding NaOCl or $Ca(OCl)_2$ to a solution increases the pH. Hydrochloric acid (HCl) or citric acid can be added to lower the pH of a solution, while sodium hydroxide (NaOH, also known as lye) can be dissolved to increase pH. The pH can be measured using a pH meter that can be purchased from laboratory suppliers.

- *Chlorine concentration* – low levels of free chlorine (<40 ppm) are effective against many microorganisms. Higher concentrations are, however, required (100-150 ppm) during operations as losses of chlorine do occur.
- *Exposure time* – high levels of free chlorine can destroy microorganisms at exposure times of less than 1 minute. At lower concentrations, a longer exposure time is needed.
- *Organic matter* – this includes plant matter, dirt and other foreign material that can rapidly inactivate free chlorine. Inactive chlorine (combined with organic matter) can be detected with the use of test kits that measure total chlorine levels.
- *Water temperature* – free chlorine is more effective under conditions of high temperature. It is, however, also rapidly inactivated owing to more rapid reactions with organic matter.
- *Type and growth stage of bacteria* – germinating spores and mycelia are more easily deactivated than are spores. Microorganims growing inside injuries or as dormant infections are more resistant to free chlorine.

Free chlorine levels (rather than total chlorine) must be measured and the user must know the measurement limits of the test kit being used. Kits used for measuring the chlorine level in swimming pools can be used for the accurate measurement of 1-5 ppm free chlorine accurately. Water samples from the packing facility can be diluted with distilled water to reach this range. The use of water that contains minerals or organic matter for dilution, can lead to erroneous measurements. Chlorine concentrations must be regularly monitored and the water changed as required.

- *Hydrogen peroxide* – this is classified by the United States Food and Drug Administration (FDA) as a 'Generally Regarded as Safe' (GRAS) compound. The recommended level of usage is 0.27-0.54 percent (Biosafe Systems 2002). Hydrogen peroxide can be applied under ambient conditions or at high temperatures (40°C) without loss of effectiveness. It can, however, cause browning or bleaching in some vegetables.
- *Peroxyacetic acid* – this is a strong oxidant formed from hydrogen peroxide and acetic acid. It is highly soluble in water and leaves no known toxic breakdown residues or products. It is less affected by organic matter than chlorine and has broad-spectrum activity. Activity is greatly reduced at pH >7-8.

- *Ozone* – a water-soluble gas that is a very strong oxidizing agent and sanitizer and has the ability to diffuse through biological cell membranes. It is also a GRAS chemical and is currently legal for food contact applications. Concentrations of 0.5-2.0 ppm are effective against pathogens. Ozone readily decomposes in water with a half-life of 15-20 minutes (Sargent *et al.* 2000).
- *Electrolyzed (acidic or alkaline) water* – this is generated by electrolysis of a dilute solution of sodium chloride. Acidic electrolyzed water has a pH of 2.6-2.8 and also includes hypochlorous acid as a constituent, thereby providing strong antibacterial effects (Kim *et al.* 2001).

The effectiveness of any antimicrobial agent depends on its chemical and physical state, treatment conditions (such as water temperature, pH and contact time), resistance of pathogens and the nature of fruit and vegetable surface.

As the levels of organic materials and the microbial load increase in wash water, the efficacy of antimicrobial compounds decreases, rendering them inactive against microorganisms. The levels of antimicrobials should be routinely monitored on an hourly basis and recorded to ensure that they are maintained at appropriate concentrations. Simple test kits and colorant test strips/kits can be used for this purpose. Other parameters such as pH, temperature and oxidation-reduction potential that indicate levels of active agents or that affect effectiveness of the antimicrobial used, should also be monitored and recorded. Digital pH meters provide a direct and rapid reading of the pH.

Excessive concentrations of antimicrobials can damage equipment, reduce produce quality, be harmful to worker health and may pose a hazard to consumers. It is therefore important to follow the recommended level of antimicrobials in the wash water. Recommended levels as well as regulations and other relevant information such as toxicity are indicated on the container label, so they should be read carefully.

Table 2.6 shows the amount of commercially available NaOCl solution (5.25 percent concentration) needed to produce a range of sanitizing solutions for a total volume of 200 litres. A sample calculation is shown in Appendix A.6.

Table 2.6 Preparation of chlorine solutions from commercially available hypochlorite solution

Desired concentration of free chlorine (ppm)	Volume (mL) of 5.25% NaOCl solution per 200 L
50	190
75	286
100	381
125	476
150	571
175	667
200	762

Adapted from Ritenour *et al.* (2002)

Removal of excess moisture

After washing or dipping, water droplets that remain on the surface of the commodity must be removed prior to waxing, packaging, transport or storage. This is done to avoid decay, prevent wetting of fibreboard packaging and to improve the appearance of the package. Water elimination can be achieved through drip drying in racks or through pyramidal stacking of crates. Evaporation may be accelerated with several industrial-type fans or blowers to increase air movement.

For even faster removal of surface moisture, produce can be conveyed through a heated drying tunnel equipped with blowers and foam rollers. Produce can also be passed under an air knife (Figure 2.1) that blows off water droplets with a high-velocity air stream.

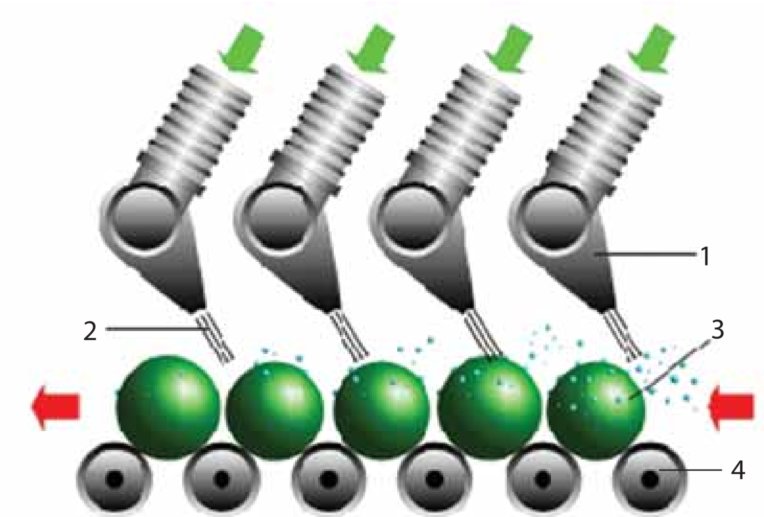


Figure 2.1. A series of air knives (1) direct thin streams of high-velocity air; (2) to blow water droplets off the surface of produce; (3) the commodity is moved and rotated on a bed of active rollers; (4) to expose the entire surface area to the air streams.

Curing

Bulb crops such as onions must undergo a curing process to prevent the entry of microorganisms. This process allows closing of the neck and drying of the outer scales. Freshly harvested citrus fruits must also be cured in order to prevent oleocellosis. In the case of Solo papaya, curing of newly harvested fruits for 24 hours in a well-ventilated area before washing and packing will reduce latex stains on the fruit.

Rapid curing may be accomplished by forcing heated air through produce placed in curing bins or on racks for several hours. Without forced air movement, curing is comparably slower and may require several days.

Waxing

This process is intended to replace natural waxes that may be lost during harvesting and handling, as well as to improve gloss, reduce moisture loss and decelerate ripening. Waxes impregnated with antifungal compounds may also be used for disease control. Appropriate coatings should impart gloss; be transparent, odourless and tasteless; biodegradable; impermeable to water, and semi-permeable to O_2 and CO_2.

Commodities that are generally waxed include citrus fruits such as mandarins, oranges, pomelos, apples and pineapples. For pineapples, waxing ameliorates chilling injury especially if pineapples are transported under refrigerated conditions. Methods of waxing include dipping, foaming, brushing and spraying (Photo 2.6). Some commodities may not be suited to a particular method of waxing owing to their morphology (Esguerra and Bautista 2007a).

Photo 2.6 Waxing of citrus by spraying

Hand waxing may also be used if mechanization is too expensive or machines are unavailable. However, care should be exercised to ensure that wax is uniformly applied. Wax layers that are too thin will have minimal effect on extension of shelf-life; layers that are too thick result in anaerobic respiration and poor flavour and aroma of the product. Hand waxing is also labour-intensive. An exporter of pomelo, shipping 500 000 pieces per year, once employed 70 workers for waxing. Using a mechanical waxer reduced labour requirement to 25 workers, decreased wax consumption by 50 percent and gave a more uniform application of wax (Murray and George 1993).

Ripening and degreening

In the context of market preparation operations, ripening is the process of artificially accelerating the transition of a fruit or fruit-type vegetable like tomato from its initial mature-green stage to a semi- or fully-ripe stage. At this stage, the commodity has fully developed all of the aesthetic and sensory characteristics desired by consumers. Many commodities are harvested at the green stage because they are more durable during transport, market life is longer (because of comparatively slower disease development, less time for moisture loss to occur), colour development is controlled and ripening provides flexibility for retailing. The hormone responsible for initiating ripening is ethylene (C_2H_4). A commonly used analogue to ethylene is acetylene (C_2H_2) that is used in artificial ripening.

The main drawback to early harvesting at the mature-green stage is that the produce will not have acquired maximum dry matter accumulation, and thus may not attain optimum taste and flavour when eaten ripe. Many citrus fruits do not develop the full orange or yellow peel expected by consumers when fruit are produced at temperatures above 12ºC. Degreening is a process used to destroy the green pigment that produces the desired peel colour of the fruit, such as yellow for banana and lemon, and orange for Valencia orange, ponkan and mandarin fruits.

Ripening and degreening are achieved by exposing mature and good quality produce to ethylene or its chemical analogue, acetylene, at an optimum ripening temperature with sufficient air circulation. Bananas, mangoes, papayas and tomatoes are commonly artificially ripened. Citrus fruit such as pomelos and mandarins undergo degreening.

Given the gaseous nature of ethylene and the fact that it is explosive at certain concentrations, special facilities and equipment are needed for its use as a ripening agent in large-scale operations. Table 2.7 summarises recommended ripening conditions using ethylene.

Table 2.7 Ripening or degreening conditions using ethylene for selected commodities

Commodity	Ethylene level (ppm)	Exposure time (h)	T (ºC)
Avocado	10-100	10-48	6-18
Banana	100-1 000	24	18-20
Durian	100	24	28
Honeydew melon	10-100	18-24	20
Mango	100	24	25
Pomelo	250-500	24	25
Satsuma mandarin	50-100	15	20-25
Tomato	100-1 000	24-48	20-25

Source: Rimando *et al.* (2007)

A common practice for ripening bananas in the Philippines is to dip the fruit in ethephon (2-chloroethyl phosphonic acid). Ethephon is commercially sold in the liquid form at concentrations of 480 g L^{-1}. Five mL of commercial solution diluted in 1 litre of water produces a stock solution with a concentration of 2 400 ppm. A 5-minute dip in a solution of 1 000 ppm ethephon is sufficient to initiate ripening of 'Cavendish' bananas. In practice, fruits packed in crates are dipped in tanks containing the ripening solution. These crates are then stacked separately from other commodities and are allowed to ripen.

In order to enhance yellow peel colour development and to minimize weight loss during ripening, commercial ripening of Cavendish banana makes use of ethylene gas (100-1 000 ppm) introduced into the ripening room when the pulp temperature has reached 18-20°C. Fruits are exposed to ethylene for 24 hours under high humidity (90-95 percent) conditions. The room is then ventilated and temperature and relative humidity (RH) are adjusted to 25°C and 85 percent, respectively.

Commodities can also be ripened with ethephon by combining it with caustic soda to liberate ethylene. About 200 mL of ethephon will produce 0.028 m^3 of ethylene (or 7.3 L ethephon to liberate 1 m^3 ethylene) (Reid 1992).

Mangoes can be ripened by exposure to calcium carbide (CaC_2). The optimum temperature for ripening is 20-25ºC. Calcium carbide is inexpensive and is simple to use. It is available as a grey crystalline material packed in air-tight containers to prevent absorption of moisture. As carbide may contain chemical contaminants and produces heat on absorption of water, it is commonly wrapped in newsprint to provide a porous liner separating it from the fruit. The carbide is inserted in the middle of a crate of fruit lined with clean newsprint to trap liberated acetylene within the crate. Fruit is held for 1-3 days before the crates are opened.

An example for calculating the space and airflow requirements for a ripening chamber is given in Appendix A.1.

Packaging

Packaging materials can be classified into two main groups: (1) Bulk packaging materials used for transport, hauling and wholesale marketing, and (2) retail packaging. Regardless of their classification, packaging materials should be convenient to handle, provide protection from mechanical damage and allow air circulation. Retail packaging should in addition contain information about the contents (such as volume, source, and country of origin), be attractive and provide convenience to the consumer (for example resealable, convenient to carry). Some markets may also specify that packaging materials be recyclable, reusable or biodegradable.

Bulk packaging materials include plastic or wooden crates and bins. Bins are usually larger than crates, facilitate the efficient handling of produce and require equipment such as forklifts or hoists for handling. The depth of these containers should not, however, induce compression damage. For manual handling, crates should not have a capacity exceeding 23 kilograms (50 pounds) (CAC 1995c). Overly large or overfilled crates are difficult to handle and can cause physical injury to workers, produce damage and the collapse of containers. On the other hand, underfilled containers can result in vibration damage as produce is free to move around during transit, particularly at the top layers in a package.

Cost is a prime consideration in selecting packaging for retail, but it should not be the sole criterion. Other considerations include availability, market requirements and ability to provide physical protection.

- *Baskets* – dried leaves and bamboo strips are woven into baskets that are widely used for hauling and wholesale marketing (Photo 2.7). These are readily available in many local markets, are light in weight and are inexpensive. They do not, however, offer physical protection against compression or impact and may damage the fruit through cuts and punctures due to sharp edges and points. It is a sensible practice to line the baskets with newspaper or polyethylene sheets in order to minimize physical damage.
- *Wooden/plastic crates and bins* offer greater protection against physical stress and can be stacked in several layers (Photo 2.8). Rough edges and splinters of wooden crates can, however, injure produce. Wooden crates and bins are also heavy and are difficult to clean and sanitize.

  Plastic crates approach the ideal for produce handling in that they are: lightweight, convenient to handle, easy to clean, reusable, stackable and nestable (Photo 2.9). When nested, the reduction in volume should be in the range of 2:1 or 3:1 to reduce the cost of returning empty crates. Disadvantages include theft, non-biodegradability and cost,

Photo 2.7 Bamboo baskets used as containers for transporting fruits and vegetables

Photo 2.8 Wooden crates used for tomatoes (left); plastic crates used for mangoes (right)

the latter making them unsuitable for export. The cost of returnable plastic crates can be recovered after eight to ten uses. They can, however be reused up to 100 times.

Users of plastic crates indicate that pilferage is approximately 5-25 percent if a security deposit is not required or if crates can be used for other purposes. A deposit should be at least as high as the cost of a new container to discourage theft and to replace lost containers (Fraser 1995).

- *Fibreboard cartons* – these are preferred for export (Photo 2.9). They can be manufactured in various shapes and sizes, are lightweight, clean and are printable. The cost of the carton is a disadvantage, especially if the material must be imported.

Photo 2.9 Fibreboard cartons containing bananas for sea shipment to domestic markets in the Philippines

Fibreboard cartons for produce that passes through hydrocooling, that is packed in a wet condition, or is packed with ice must be treated with wax or must have a water-resistant coating. Fibreboard material tends to absorb moisture, especially under high-humidity conditions, resulting in a loss of compression strength. At 90 percent RH, untreated fibreboard can lose 50 percent if its strength (CAC 1995c).

- *Plastic films and trays* are also used for retail packaging. Modified atmosphere packaging (MAP) has long been used to extend the shelf-life of many fresh and fresh-cut commodities (Photo 2.10). Under MAP, O_2 concentration is brought down to levels (typically 3-5 percent) that are sufficient to decelerate respiration. This extends the shelf-life, allowing produce to reach distant markets and increasing availability beyond the normal harvest season. A wide range of materials for MAP are available; the most commonly used are polyethylene and polypropylene films. Correct selection of film thickness and material is needed to avoid anaerobic conditions in MAP (O_2 <1%). Anaerobic levels of O_2 lead to fermentation, resulting in off-odours and off-flavours. Plastic trays are often used in combination with cartons to keep produce in place and to prevent shifting and abrasion damage.
- Bulk MAP storage involves enclosing pallet loads of produce in durable, reusable plastic shrouds with semi-permeable windows for gas exchange; the shroud material itself is thick enough that minimal gas exchange occurs through the shroud.

Many types of bulk packaging containers that are particularly suited for harvesting and hauling operations are available. Plastic crates that are used for different purposes should be colour-coded to prevent cross-contamination of produce. Plastic crates can also be used as export shipping containers. When used for this purpose, they are designed as single service containers. The size of

Photo 2.10 Polyethylene plastic bags used as MAP for calamondin fruit

the container may vary according to the degree of mechanization in the supply chain, produce characteristics and market preferences. The dimensions of the container must maximize the quantity of produce it can contain, without becoming too heavy or unwieldy. Containers that are manually handled should not be too heavy when filled, otherwise they can cause back injury to workers on lifting. For mechanized systems, larger containers can be used as long as this does not result in compression damage to the commodity.

If containers are to be used as retail displays, they should be shallow enough to display produce in single layers only, because retailers and consumers dislike 'hidden' produce.

Pre-cooling

Cold storage facilities, refrigerated trailers and refrigerated trucks are often only designed with enough cooling capacity to maintain their loads at a set temperature. This means that the commodity must already be at the desired temperature when loaded into the storage room or cargo truck. If the commodity is still maintained at field temperature, the refrigeration unit will be overworked and may not succeed in reducing produce temperature to the desired level (also known as the *setpoint temperature*). In some cases, cooling may not occur if the commodity is respiring too rapidly and the volume is large enough to overwhelm the refrigeration system. Produce must, therefore, be pre-cooled as soon as possible after harvest (Photo 2.11) and prior to refrigerated transport or storage.

A 12-metre (40-foot) refrigerated trailer with a cooling capacity of 42 000 kJ/hour can contain about 11 250 kilograms of mangoes when used for shipping these fruit in the Philippines.

The heat to be removed from a material (Q) can be estimated using Equation 2-1 where m = weight of the material (kg), C_p = specific heat (kJ/kg/K), and ΔT = change in temperature.

$$Q = mC_p\Delta T \qquad (2\text{-}1)$$

Photo 2.11 Forced air cooling of Brazilian mangoes packed in fibreboard cartons

For a fruit specific heat of 3.56 kJ/kg/K the fastest cooling time needed to bring fruit temperature from a field temperature of 30ºC down to its optimum level of 13ºC can be calculated as follows:

$$Q = (11\ 250\ \text{kg})(3.56\ \text{kJ/kg/K})(30\text{-}13)\text{K} = 680\ 850\ \text{kJ}$$

The fastest cooling time that could be achieved would now be 680 850 kJ divided by 42 000 kJ/hour or approximately 16 hours. This cooling time is too long and could give the fruit sufficient time to ripen, thereby reducing its shelf-life. Furthermore, the actual cooling time would probably be significantly longer because this rough estimate does not take into consideration actual conditions during cooling (for example, air circulation patterns, or packaging materials that also need to be cooled down).

If pre-cooling time is known, Equation 2-1 can also be used to determine the required cooling capacity. Using the previous example for a desired pre-cooling time of 5 hours:

$$Q = (11\ 250\ \text{kg})(3.56\ \text{kJ/kg/K}(30\text{-}13)\text{K}/(5\ \text{h}) = 136\ 170\ \text{kJ/h} = 3.78\ \text{kW}$$

The value of 3.78 kW represents the cooling capacity needed to cool the fruit down from 30ºC to 13ºC. A factor of 25 percent is added to the calculated value for cooling capacity to take into account heat coming from produce respiration, packaging materials, workers and air leakage from doorways. Therefore, the total refrigeration capacity required is 47.2 kW (Picha 2004).

Methods of pre-cooling include room cooling, forced air cooling, hydrocooling, vacuum cooling and package icing (Table 2.8). The method to be used will depend on the characteristics of the commodity and the resources of the operator. Table 2.9 gives some commodities and their recommended cooling methods. For more details on pre-cooling theory and methods, refer to Appendix A.3.

Table 2.8 Comparison of pre-cooling methods for perishables

Cooling method	Advantages	Disadvantages
Room cooling	Potentially lower capital and running costs compared to other cooling methods	Slow cooling rates especially for packaged produce; variable temperature distribution; limited to commodities with low respiration rates.
Forced air cooling	Existing cold storage facilities can be converted easily to forced air cooling; 4-10 times faster than room cooling; applicable to a wide range of produce	Requires greater fan horsepower and greater refrigerating capacity than room cooling; needs special stacking patterns and skilled operators.
Hydrocooling	Simple to perform; effective; reduces or reverses moisture loss; very rapid cooling method (2-23 times faster than forced air cooling)	Accumulation of decay causing micro-organisms in cooling water; needs water-resistant containers; high refrigeration requirement; produce must tolerate wetting and be resistant to water-beating; low energy efficiency.
Vacuum cooling	Quick and uniform cooling; very efficient	Expensive equipment, applicable only for produce with a high surface area-to-volume ratio and that which loses water readily from tissues; some weight loss occurs.
Package icing	Can be done manually for small volumes; direct contact with produce results in rapid cooling; surplus ice eliminates the need for refrigeration during transport over short distances; no moisture loss	Special equipment needed for large operations, packaging material must be water-resistant; commodity must be tolerant of wetting and near-freezing temperature; ice must be replaced for long-distance transport; ice occupies a significant amount of space in the package

Source: Brosnan and Sun (2001)

Water and ice used in cooling operations should be considered as potential sources of microbial contamination. Reuse of water to cool continuous loads of produce increases the risk of cross-contamination. For example, contaminated produce from a single container going through a cooling process, as in batch hydrocooling, may result in the buildup of microorganisms over time in the cooling water supply. GMPs during pre-cooling include the following:

1. *Proper temperature management* – the choice of pre-cooling method should consider that fruits and vegetables have varying temperature requirements for optimum quality, as shown in Tables 2.10 and 2.11. Many pathogenic and food spoilage organisms do not thrive at low temperature.
2. *Use clean and sanitary ice and water* – water and ice used in cooling operations are potential sources of contamination, especially water reused during hydrocooling. Ice used for package icing or for direct application to food should be produced from potable water. Water used in ice-making should be periodically tested. Operators should contact ice suppliers for information about the source and quality of their ice. Water in hydrocoolers should be changed as needed to maintain quality. Antimicrobials can be added in cooling water to reduce the potential for microbial contamination of produce.

Table 2.9 Pre-cooling methods for selected tropical commodities

Commodity	RC[b]	FA	HC	VC	PI
Fruits					
Banana	○	○			
Calamondin	○				
Durian	○	○			
Grapes		○			
Guava		○			
Jackfruit		○			
Lanzones		○			
Mango		○			
Mangosteen		○			
Papaya		○			
Pineapple		○			
Pomelo	○				
Rambutan		○			
Santol		○			
Sapota		○			
Soursop		○			
Strawberry		○			
Potted plants	○				

Commodity	RC	FA	HC	VC	PI
Vegetables					
Asparagus			○		
Beans, snap		○	○		
Bitter gourd	○	○			
Broccoli		○			○
Cabbage		○		○	
Cauliflower		○		○	
Celery			○	○	
Chinese cabbage		○		○	
Corn, sweet			○	○	○
Eggplant	○	○			
Garlic	○				
Ginger	○				
Jicama	○				
Lettuce		○		○	
Melon, honeydew		○	○		○
Okra	○	○			
Onion, green			○		○

Sources: Kasmire and Thompson (1992); Brosnan and Sun (2001)

RC = room cooling, FA = forced air cooling, HC = hydrocooling, VC = vacuum cooling, PI = package icing

3. *Proper maintenance of air-cooling equipment and cooling areas* – Air-cooling equipment and cooling areas should be periodically cleaned and inspected and maintained in clean and sanitary conditions. Potential sources of contamination should not be located near air intakes.

4. *Produce should be clean* – Produce that is clean and of good quality is resistant to microbial contamination. On the other hand, contaminated produce that goes through a cooling process as in hydrocooling may cause a buildup of microorganisms in the cooling water supply.

Cold storage

After pre-cooling, produce must be immediately loaded into refrigerated trucks for shipment to market. In situations when transport is delayed, or sufficient volume needs to be accumulated before shipment, then produce must be kept in storage at low temperature to avoid rewarming and to minimize deterioration. Tables 2.10 and 2.11 give recommended storage conditions for selected fruits and vegetables. In view of the fact that actual commodity response to storage conditions may vary in accordance with the site, the data given in these tables should be confirmed with storage trials using local produce.

Table 2.10 Recommended storage temperature and RH for selected fruit

Commodity	T (°C)	RH (%)	Storage life	Commodity	T (°C)	RH (%)	Storage life
Avocado ('Fuerte', 'Hass')	7	85-90	2-3 wk	Lychee	0-2	90-95	3-5 wk
Banana (green)	13-14	90-95	1-4 wk	Mango	13	85-90	2-3 wk
Breadfruit	13-15	85-90	2-6 wk	Mangosteen	13	85-90	2-4 wk
Cactus pear (dragon fruit)	2-4	90-95	3 wk	Oranges, mandarin	3-4	85-90	3-4 wk
Calamondin	9-10	90	2 wk	Papaya	10-13	85-90	2-3 wk
Canistel	13-15	85-90	3 wk	Passion fruit	7-10	85-90	3-4 wk
Carambola	5-10	85-90	4-7 wk	Pineapple	7-10	85-90	2-3 wk
Cashew apple	0-2	85-90	5 wk	Plantain	13-15	90-95	1-5 wk
Cherimoya	8-9	85-90	1-2 wk	Pomegranate	5	90-95	2 mo
Custard apple	5-7	85-90	4-6 wk	Pomelo	7-9	85-90	4-6 wk
Durian	10-13	85-90	2-3 wk	Rambutan	12	90-95	1-2 wk
Grapefruit	14-15	85-90	6-8 wk	Santol	7-9	85-90	3 wk
Grapes	-0.5-0	85-90	3-8 wk	Sapote	15-20	85-90	1-2 wk
Guava	10-13	90	2 wk	Soursop	13	85-90	1-2 wk
Jackfruit	13	85-90	2-6 wk	Starapple	3	90	3 wk
Lanzones	11-14	85-90	2 wk	Strawberry	-0.5-0	90-95	5-10 d
Lemon	7-10	85-90	2-3 mo	Sugar apple	7	90-95	4 wk
Lime	9-10	85-90	6-8 wk	Tamarind	7	90-95	3-4 wk
Longan	1.5	90-95	3-5 wk				

Sources: Yon and Jaafar (1993); McGregor (1987); Pantastico *et al.* (1975); PHTRC-UPLB Annual Project Reports

Given that production volumes may not be sufficient and that several types of commodities may be handled by a packing facility, it is often not feasible to provide a dedicated storage room to each commodity. The solution is to sort commodities into groups that are compatible with each other with respect to temperature (Table 2.12). Secondary compatibility issues include RH, ethylene production and sensitivity (Table 2.13) and odour emission and absorption (Table 2.14).

Cold rooms should be equipped with calibrated thermostats and calibrated thermometers to ensure proper temperature settings and to confirm that the actual temperature in the cold room is the same as the temperature setting. When possible, actual product temperatures should be monitored.

In situations where a packing facility requires several cold storage units, the cost of investment may be minimized by installing self-constructed insulated rooms. These rooms may be constructed using double-walled plywood panels with polystyrene sheets for insulation. In situations where commodities can be stored at temperatures above 10°C, residential air-conditioners are less expensive options than are packaged systems (Thompson 1992). Plywood panels should be painted white with a smooth finish.

Table 2.11 Recommended storage temperature and RH for selected vegetables

Commodity	T (°C)	RH (%)	Storage life	Commodity	T (°C)	RH (%)	Storage life
Amaranth	0-2	95-100	10-14 d	Jicama	13-18	65-70	1-2 mo
Asparagus	0-2	95-98	2-3 wk	Leek	0	95-100	3 mo
Bean, snap	4-7	95-98	7-10 d	Lettuce	0-1	95-100	2-3 wk
Bean, lima (in pod)	5-6	95	5 d	Melon, honeydew	7-10	90-95	2-3 wk
Beet, topped	0	98-100	4-6 mo	Okra	7-10	90-95	2-3 wk
Bittermelon	12-13	85-90	2 wk	Onion, green	0	95-100	4 wk
Broccoli	0	95-98	10-14 d	Onion, bulb	0	65-70	6-8 mo
Cabbage	0	98-100	3-6 wk	Parsley	0	95	2-3 wk
Carrot	0	95-100	4 wk	Peas	0-1	95	1-2 wk
Cauliflower	0	95-98	2-4 wk	Pepper, sweet	7-10	90-95	2 wk
Celery	0	95-98	2-4 wk	Potato	4	95	3-5 mo
Chayote	7	85-90	1-2 wk	Radish	0	95	3-4 wk
Chinese cabbage	0	95-100	2-3 mo	Squash	5-10	95	1-2 wk
Corn, sweet	0	95-98	4-8 d	Taro	7-10	85-90	3-5 mo
Cucumber	10-13	90-95	10-14 d	Tomato	10-13	85-90	7-10 d
Eggplant	12-15	90-95	7 d	Watermelon	10-15	90	2-3 wk
Garlic	0	60-70	6-7 mo	Winged bean	10	90	2-3 wk
Ginger	13	65-75	4-6 mo	Yam	16	70-80	3-6 mo

Sources: McGregor (1987); Pantastico (1975); PHTRC-UPLB Annual Project Reports

Factors to be considered during and after cold storage include:

- *Chilling injury (CI)* – low storage temperatures reduce respiration rates, ethylene production and moisture loss. However, holding produce below optimum storage temperatures for extended periods can result in CI. This is especially true for tropical produce that is sensitive to chilling conditions.

  CI is impacted by time and temperature and, therefore, the effect of temperature on CI is cumulative. Hence, holding produce at chilling temperatures for short periods of time may not induce CI. For example, Carabao mangoes can be held below 12°C for two weeks or less without any adverse effects. However, extending the storage period will induce CI, with symptoms usually expressed when fruits are brought out of storage and allowed to ripen. Jicama yambeans stored at 0°C and 5°C showed less weight loss and similar quality to those held at 15°C or 20°C for the first five days of storage. After two weeks, Jicama yambeans stored at 0°C or 5°C were inedible, while those at 15°C had fair to poor visual quality (Barile and Esguerra 1984). Eggplants kept for six days or more at 0°C or ten days or more at 5°C develop CI (Turnos 1993).

  Symptoms of CI include pitting of the peel, failure to ripen, wilting, loss of aroma and flavour, increased susceptibility to disease and browning of the pulp or peel (Photo 2.12). These are manifestations of the physical and biochemical changes in the commodity that include permeability of cell membranes, respiration rate and ethylene production. Specific CI symptoms are summarised in Table 2.15.

Table 2.12 Temperature compatibility groups for horticultural perishables

Temperature grouping	Fruit	Vegetables	Other crops
0ºC	Grapes, longan, lychee, orange, strawberry	Asparagus, bean sprouts, broccoli, cabbage, carrot, cauliflower, celery, corn (baby, sweet), garlic, leafy greens, leek, lettuce, mushroom, okra, onion (bulb, green), parsley, peas, spinach	–
7ºC	Mandarin, mangosteen, Valencia orange, pomelo	Beans (green), pepper (bell), potato	Young coconut
12ºC	Avocado, banana, durian, guava, jackfruit, lanzones, lemon, mango (Carabao, Katchamitha), papaya (Solo), pineapple (Queen, Smooth Cayenne), rambutan, santol	Beans (long, winged) bittergourd, cucumber, eggplant, ginger, tomato	–
RH grouping (%)	Fruits	Vegetables	Other crops
80-90	Avocado, calamondin, guava, jackfruit, lanzones, lemon, mango, mangosteen, papaya, pomelo, santol	Cucumber, eggplant, ginger, okra, melon (except muskmelon), peppers, potato, tomato	Young coconut
90-95	Banana, grapes, mandarin, lemon, longan, lychee, orange, rambutan, strawberry	Muskmelon, leek, mushrooms	–
95-100	–	Asparagus, bean sprouts, broccoli, cabbage, carrot, cauliflower, celery, corn (young, sweet), leafy greens, leek, lettuce, onion (green), parsley, peas	–

Sources: McGregor 1987; SPLFSA 2001

Table 2.13 Commodities that emit or are affected by ethylene

Fruits	Vegetables	Fruits	Vegetables
Apple, avocado (unripe), banana (ripe), durian (ripe), fresh-cut fruits, guava, jackfruit (ripe), kiwifruit, lychee, mango (ripe), papaya	Melon (cantaloupe, honeydew, muskmelon), tomato	Banana (unripe), grapefruit, guava, kiwifruit, lemon, mandarin, mango, mangosteen, papaya, persimmon, prune	Asparagus, broccoli, cabbage, carrot, cauliflower, celery, corn (sweet) cucumber, eggplant, green beans, leafy greens, lettuce, melon (muskmelon, honeydew, water), onion (green), okra, parsley, peas, pepper, shallots, sweet pea, sweet potato, tomato

Sources: McGregor 1987; SPLFSA 2001

Table 2.14 Commodities that produce or absorb odours

Odour-producing	
Fruits	**Vegetables**
Apple	Carrot
Avocado	Garlic
Citrus	Ginger
Grapes (if fumigated with SO_2, will damage other commodities)	Leek
Pear	Onion (bulb, green)
	Potato
	Pepper, green

Odour-absorbing	
Fruits	**Vegetables**
Apples (from onion and potato)	Cabbage (from apple, pear)
Avocado (from pepper)	Carrots (from apple, pear)
Citrus (from strongly-scented fruits and vegetables, onion)	Celery (from apple, carrot, onion, pear)
Grape (from garlic, leek, green onion)	(from green onion)
Pear (from onion, potato)	Eggplant (from ginger root)
Pineapple (from avocado, green pepper)	Mushroom (from green onion)
	Onion (from apple, pear)
	Potato (from apple and pear)
Other fruits and vegetables (from grapes if fumigated with SO_2)	

Sources: McGregor (1987); SPLFSA (2001); Thompson *et al.* (2000)

- *Condensation of moisture* – condensation occurs when warm air comes in contact with the cold surface of a commodity or container as it is brought out of storage. As the air cools, its capacity to hold moisture in vapour form decreases, causing moisture to form on the commodity in droplets. The temperature at which condensation occurs is referred to as the *dewpoint*. This is determined from a psychrometric chart as shown in Appendix A.4.

  Condensation enhances sprouting of bulb and tuber crops and favours disease development when condensate allowed to remain on the commodity. To minimize the effects of condensation, the following measures can be adopted:

  o Provide blowers to hasten evaporation of condensed moisture; leaving gaps between containers and pallets for better air circulation. Warm dry air is best for removing condensation.

  o Gradually bring the temperature of the commodity to ambient by setting the system at progressively higher temperatures. The temperature of the commodity must be higher than the dewpoint when it is removed from chilling conditions in order to prevent condensation.

  o If practical, produce can be brought out at night or early in the morning to take advantage of lower dewpoint temperatures of the air.

Table 2.15 Chilling injury symptoms in some commodities

Fruits	Symptoms
Avocado	Greyish-brown discoloration of the flesh and peel in severe cases, pitting, failure to soften
Banana	Dull colour after ripening (in severe cases, peel is dark grey), streaking due to darkening of vascular tissue, delayed ripening, pitting, black spots
Citrus	Brown-spotting, bitter off-flavour
Durian	Blackening of grooves between spines, development of red patches on the inner wall of the husk, failure of the pulp to ripen
Guava	Pitting, skin discoloration
Mango	Grey or brown discoloration and pitting of the peel, uneven ripening and peel colour development, poor flavour, water-soaked pulp, increased lenticel spotting
Mangosteen	Hardening of the rind, and turns pinkish-brown
Rambutan	Aril becomes leathery

Vegetables	Symptoms
Bittergourd	Large pits in the ribbed region, surface discoloration from green to dark brown, internal breakdown
Cucumber	Water-soaked areas, pitting, tissue collapse
Eggplant	Bronzing and pitting of the peel, browning of seeds and flesh
Jicama	Pitting, softening
Sweet potato	Surface pitting, susceptibility to decay, off-flavours, loss of table quality, loss of sprouting ability
Tomato	Blotchy peel colour during ripening, softening of the flesh
Yam	Marked softening in patches, slightly mottled grey discoloration of the flesh, brown discoloration under the skin, sponginess

Sources: Augustin and Azudin (1986); Siripanich (1993); Turnos (1993); Siripanich (1995); Ravi and Aked (1996); Mercadero and Esguerra (2000); Agillon (2003)

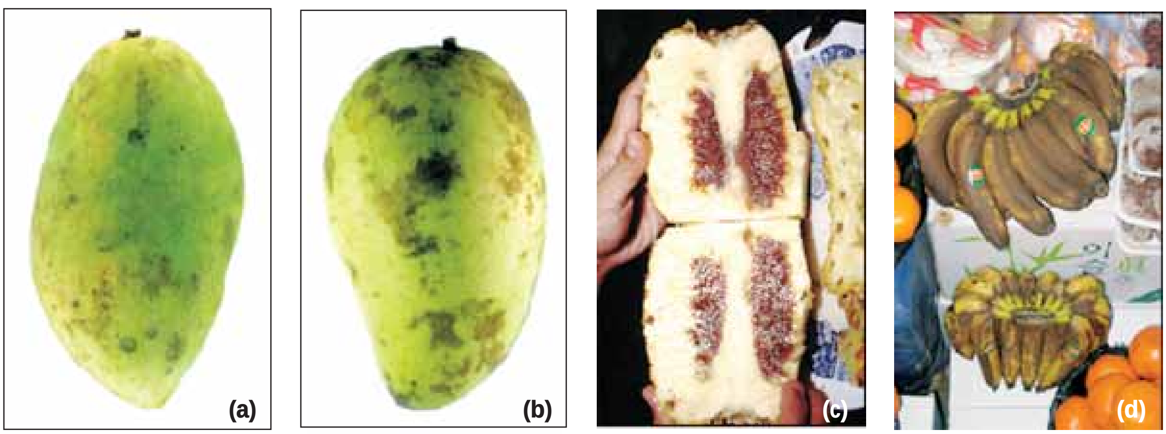


Photo 2.12 Chilling injury in (a and b) 'Carabao' mango (peel pitting and browning), (c) pineapple (pulp browning), and (d) banana (peel browning)

Treatments for disease control

Disease limits the storage life of perishables and can result in physical (such as discarded produce) and economic losses (for example reduced prices). Disease can be classified as being either pre- or post-harvest. Pre-harvest diseases infect produce during the early stages of development, with symptoms already visible while in the field; hence produce can be culled in the field. Examples of pre-harvest defects include scab in calamondin, avocado and mango and sooty mould in mango (Photo 2.13). Post-harvest diseases can be further classified as those resulting from latent infections in the field, and those in which infection occurred after harvest. Symptoms of post-harvest disease develop after several days of storage or as ripening progresses. Examples of latent infections include anthracnose and stem end rot in mango (Photo 2.14, and *Alternata* rot in tomato. Soft rot in lettuce and cabbage develops after harvest (Photo 2.14).

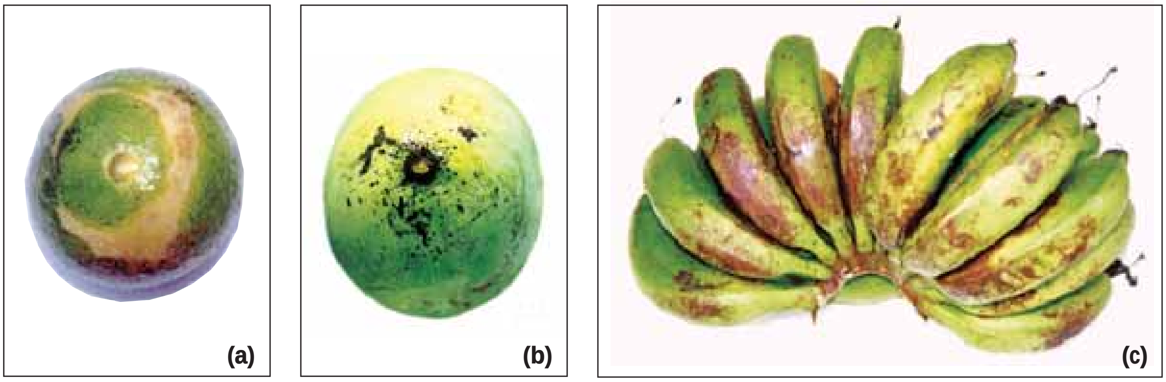


Photo 2.13 Pre-harvest defects: scab on calamondin (a), sooty mould on mango (b) scab on banana (c)

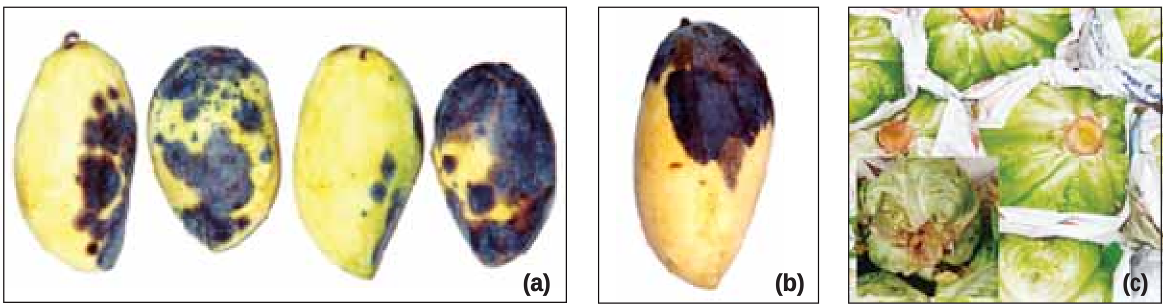


Photo 2.14 Post-harvest diseases: (a) anthracnose and (b) stem end rot in mango, (c) onset of soft rot in cabbage that eventually leads to severe decay (inset)

Diseases can be controlled before, during and after harvest. Pre-harvest control measures include the use of resistant cultivars, field sanitation and hygiene, bagging of fruits and in the case of latent infections in mangoes, timing and proper selection of fungicide sprays. Control of infection during and after harvest includes careful handling to reduce injuries that serve as avenues for microbial infection, sanitation of harvesting tools and aids, containers and cold rooms, and culling of infected fruit.

GRAS chemicals such as alum and lime can be used for the control of bacterial soft rot in cabbage, as can edible coatings such as chitosan (Asgar *et al.* 2004). The use of fungicides after harvest is increasingly being phased out because of health and environmental concerns. Physical treatments like hot water treatment (HWT) that do not leave chemical residues are becoming popular. Adequate control of anthracnose and stem end rot of mango and papaya is achieved by dipping fruit for five to ten minutes in water heated to 52-55°C and 49-51°C, respectively. Packing-houses for mango and papaya that cater to export and institutional markets are generally equipped with hot water tanks of varying capacities.

Quarantine treatments

Fruits and vegetables can host a wide range of insect pests of quarantine significance. Fruit flies are the most destructive of these insect pests and are a major barrier to export. Importing countries require quarantine treatments such as fumigation with methyl bromide and phosphine. Methyl bromide will, however, be phased out because of its high ozone-depleting potential.

Heat treatments such as VHT, an extended hot water dip (EHWD) and exposure to heated dry air are examples of physical methods of controlling insect pests that do not pose health risks from chemical residues and are more acceptable to consumers. Examples of approved heat treatment procedures for selected crops are shown in Table 2.16. EHWD is used for the treatment of Philippine Carabao mangoes exported to China. The treatment involves dipping the fruit in hot water at 47-48°C until the core pulp temperature reaches 46°C. A holding period for 15 minutes at 46°C is followed by ten-minute air cooling and 30 minutes of hydrocooling (Esguerra *et al.* 2006) as shown in Figure 2.2. For 'Tommy Atkins' mangoes, EHWD consists of dipping the fruits for 75 minutes in water heated to 46.1°C for fruit weighing less than 400 grams and 90 minutes for fruits weighing 400-650 grams.

Table 2.16 Commercial heat treatments for the export of fruit

Exporting country	Importing country	Commodity	Treatment and parameters
Chile	USA	Mountain papaya	Forced hot air or vapour heat treatment: fruit centre temperature = 47.2°C, approach period of 4 hr or more
Cook Islands	New Zealand	Aubergine, papaya, mango	Forced hot air treatment: fruit centre temperature = 47.2°C, 20 min holding period at 47.2°C
Belize	USA	Papaya	Forced hot air treatment: fruit centre temperature = 47.2°C, 20 min holding period at 47.2°C
Fiji	New Zealand, Australia	Papaya, aubergine, breadfruit, pepper, mango	Forced hot air treatment: fruit centre temperature = 47.2°C, 20 min holding period at 47.2°C
Mexico	USA	Clementine	Vapour heat treatment: fruit centre temperature = 43°C, 6 hr holding period at 43°C

Table 2.16 *(continued)*

Exporting country	Importing country	Commodity	Treatment and parameters
Mexico	USA	Mango	Forced hot air treatment: pulp temperature = 48°C
Mexico	USA	Citrus	Forced hot air treatment: fruit centre temperature = 44°C with approach period of 90 min or more, 44 min holding period at 44°C
New Caledonia	New Zealand	Peppers, aubergine, mango, litchi	Forced hot air treatment: fruit centre temperature = 47.2°C, 20 min holding period at 47.2°C
Philippines	Australia, USA, Japan, New Zealand, Republic of Korea	Mango	Vapour heat treatment: fruit pulp temperature = 46°C, 10 min holding period at 46°C
Samoa	New Zealand	Breadfruit, papaya	Forced hot air treatment: fruit centre temperature = 47.2°C, 20 min holding period at 47.2°C
Taiwan, Province of China	USA	Mango	Vapour heat treatment: fruit pulp temperature = 46.5°C, 30 min holding period at 46.5°C
Thailand	USA	Mango	Vapour heat treatment: fruit pulp temperature = 46°C, 20 min holding period at 46°C
Tonga	New Zealand	Breadfruit, papaya, peppers, aubergine, mango, tomato, avocado	Forced hot air treatment: fruit centre temperature = 47.2°C, 20 min holding period at 47.2°C
USA (Hawaii)	USA (mainland)	Litchi	Hot water treatment: 49°C for 20 min
USA (Hawaii)	USA (mainland)	Sweet pepper, pineapple (except 'Smooth Cayenne'), squash, tomato	Vapour heat treatment: pulp temperature = 45°C, holding period = 8.75 hr
USA (Hawaii)	USA (mainland)	Papaya, citrus	Forced hot air or vapour heat treatment: fruit centre temperature = 47.2°C for more than 4 hr
USA (Hawaii)	Japan	Papaya	Vapour heat treatment: fruit centre temperature = 47.2°C, RH >90% during the final 1 hr of treatment
USA (Hawaii)	New Zealand	Any fruit	Forced hot air: fruit centre temperature = 47.2°C for more than 4 hr

Source: Armstrong and Mangan (2007)

Cold treatments can also be used for quarantine disinfestation. Phytosanitary regulations in the United States and European Union require that no live *Thrips palmii* be present in selected Asian vegetables coming from the Dominican Republic. These vegetables, which include eggplant, long beans, bitter melon and long squash, must be treated by immersion in a water bath containing a crop oil/fatty acid-soap compound for 15 minutes at ambient temperature, followed by a 15-minute dip in water at 4°C (Picha 2004).

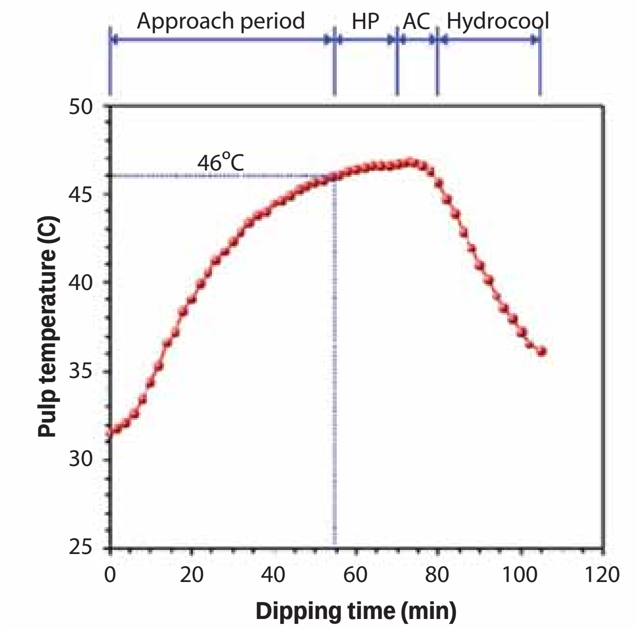


Figure 2.2 Time course of pulp temperature of large mango fruit during extended hot water treatment at 48°C for quarantine disinfestation. HP = holding period, AC = air cooling

Irradiation is another physical treatment being promoted as a phytosanitary measure. Irradiation is used to prevent the introduction and spread of regulated pests by achieving certain responses in the target pest such as mortality, aborted development, inability to reproduce (for example sterility) and inactivation. The United States Department of Agriculture (USDA) Federal Register has issued approved doses for the use of irradiation as a phytosanitary treatment for fruits and vegetables Table 2.17 although it has only received limited commercial use to date.

Table 2.17 Estimated minimum absorbed doses of irradiation for certain responses of selected pests

Pest group	Required response	Minimum dose (Gy)
Aphids and white flies	Sterilize actively reproducing adult	50-100
Seed weevils	Sterilize actively reproducing adult	70-300
Scab beetles	Sterilize actively reproducing adult	50-150
Fruit flies	Prevent adult emergence from 3rd instar larvae	50-250
Weevils	Sterilize actively reproducing adult	80-165
Borers	Prevent adult development	100-280
	Sterilize late pupa	200-350
Thrips	Sterilize actively reproducing adult	150-250
Spider mites	Sterilize actively reproducing adult	200-350
Beetles (stored products)	Sterilize actively reproducing adult	60-400
Moths (stored products)	Sterilize actively reproducing adult	100-1 000

Source: IPPC-FAO (2003)

Labelling

Labelling is necessary to promote brand recognition and to provide distinction to a product in order to differentiate it from competing products. Labels can either take the form of a stamp with ink directly transferred to the produce surface, applied as a sticker (Photo 2.15) or as a paper strap (especially for vegetables). Ink used for labelling should be resistant to moisture and must be approved for such use by the relevant government agency concerned with food safety.

Photo 2.15 Young coconuts and mangoes marketed with sticker labels

Temperature management prior to dispatch

Produce ready for distribution to market outlets or for hauling to port areas should be placed in an area that is separate from incoming raw material in order to prevent cross-contamination.

Exposure of cool produce to ambient temperatures should be minimized to prevent rewarming and to avoid condensation on the produce or the package which can encourage decay or weakening of fibreboard cartons. Ideally, the dispatch area should be enclosed and refrigerated for proper temperature management. Doorways of loading docks should be equipped with air curtains or plastic strip curtains to reduce the infiltration of warm air. As a less costly measure, insulated pallet wraps (Figure 2.3) can also be used to cover pallets and thereby delay rewarming.

As produce for dispatch may be packaged in containers of varying sizes (Photo 2.16), some difficulty may be encountered in making a stable stack. Small packs may be placed in stackable shallow plastic trays. Containers should be stacked according to their load-bearing capacity with the strongest containers (for example, plastic or wooden crates) placed at the bottom layers.

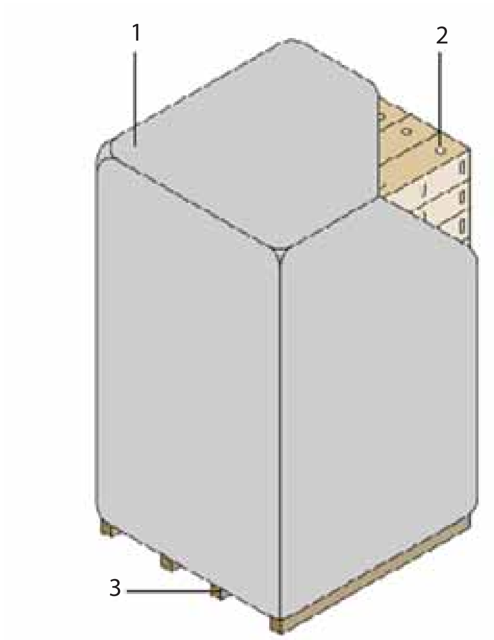


Figure 2.3 An insulated pallet wrap (1) to minimize rewarming of pre-cooled produce (2) on pallets (3)

Photo 2.16 Retail packs of fruit ready for dispatch to market outlets. Note the wet floor due to condensation forming on the cool packs

2.2 Basic information required to inform the level and scale of pack-house operations

Farm production

Pack-house activities must be scheduled on the basis of information on farm production, including the volume of peak harvests as well as daily, weekly and annual harvest volumes of the commodity to be handled. The volume of produce to be prepared each day impacts the size of the packing-house and equipment to be used. Consideration should also be given to future volumes to be handled and the location of new sources of produce – this will require market assessments of future sales. An area for expansion should be provided in case of increases in the volume and varieties of produce to be handled.

Basically, a floor area of 20 m^2 is required for the manual handling or receiving of one tonne of produce arriving at the pack-house at any one time (Bautista 1990). In packing-houses outfitted with equipment, additional floor area must be provided for each unit as well as for the working space needed (which is twice the area of the unit) and the space occupied by containers before and after each operation. Other data that may be needed include quality profiles, location and size of production areas and production seasons.

The quality profile of a commodity indicates the volume of good quality produce, the percentage of rejects, including the severity and incidence of defects, as well as the range and volume of sizes being produced.

Target markets and their quality and volume requirements

- *Domestic markets* – quality requirements for domestic markets, both wet and institutional markets such as supermarkets, hotels and restaurants are highly variable and are less stringent than are those of export markets. Standards for size, presence of defects and stages of maturity or ripeness may differ among local markets because of the highly fragmented nature of the industry in developing countries. However this situation is changing as multinational chains impose stringent production and post-harvest protocols to ensure that food safety and quality standards are met. As a more affluent middle class emerges in the urban centres of developing countries, produce standards for local/national sales will likely converge with those required for export.
- *Export markets* – quality requirements for export commodities are also variable, but are fully documented for each country and must be strictly followed. Quarantine and disease control measures may also be required for some commodities. Vapour Heat Treatment (VHT) of mangoes and papayas against fruit fly infestation is a requirement for many markets. A reliable supply of sufficient volumes is also important for exporters.
- *Processors* – external quality requirements for commodities destined for processing are the least stringent. The internal quality characteristics of such commodities are a main consideration.

Regardless of the type of market serviced by the packing facility, the total volume of produce to be delivered by farmers and that required by each client must be known for accurate estimation of the floor area, number of containers required, amount of labour needed, volume of storage facilities and capacity of equipment.

The sequence of steps required for specific pack-house operations can be clearly illustrated using flow charts (Figures 2.4 to 2.12). Flow charts should show the movement of all materials (commodities, containers, packaging material, waste material) within the packing-house, as well as those entering and leaving the facility.

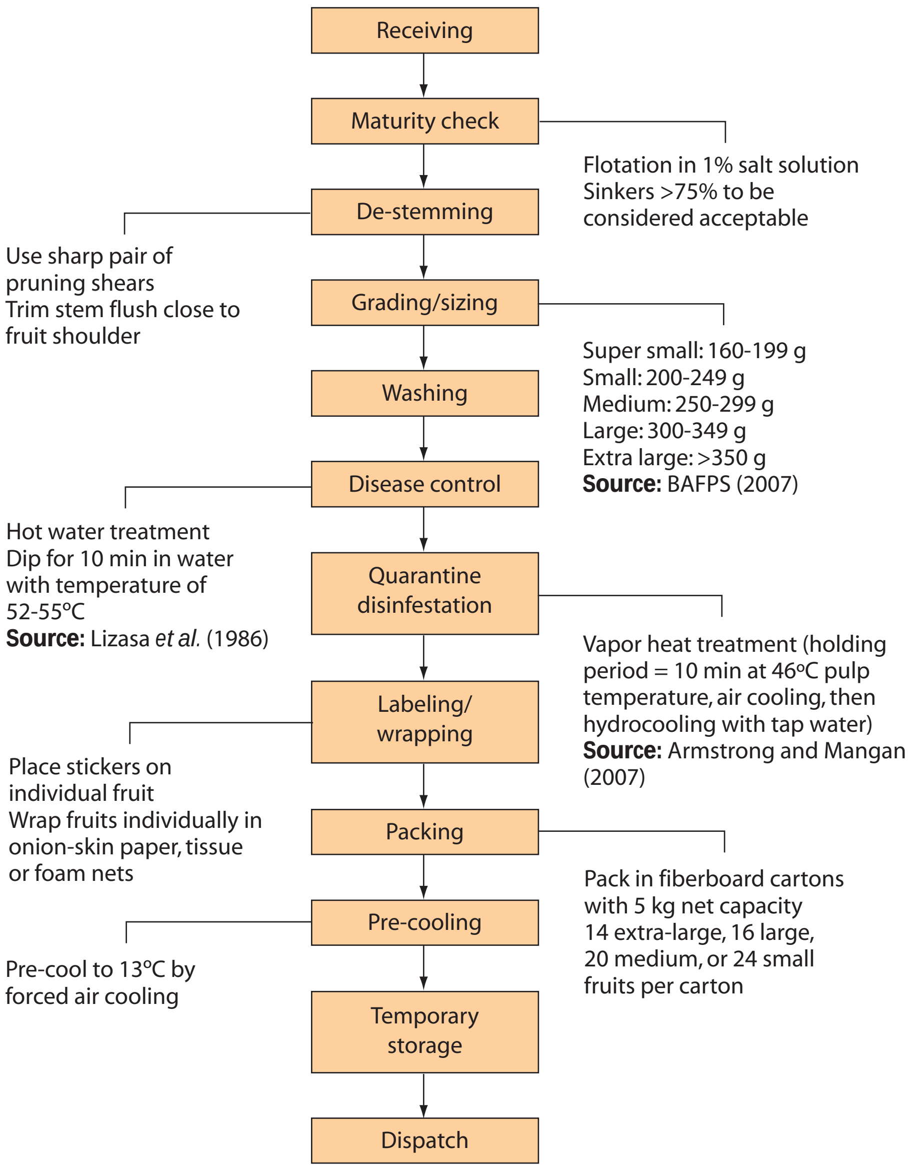


Figure 2.4 Process flow for 'Carabao' mangoes destined for export markets

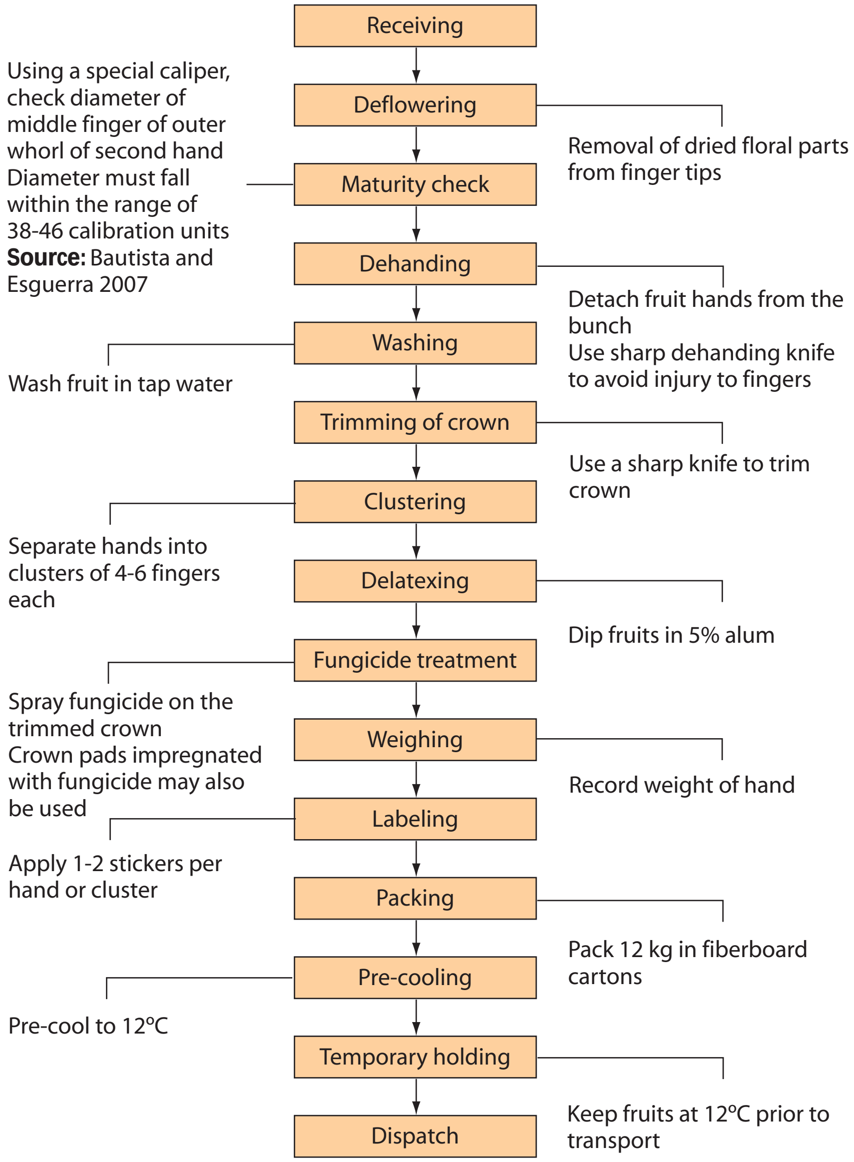


Figure 2.5 Process flow for bananas destined for export markets

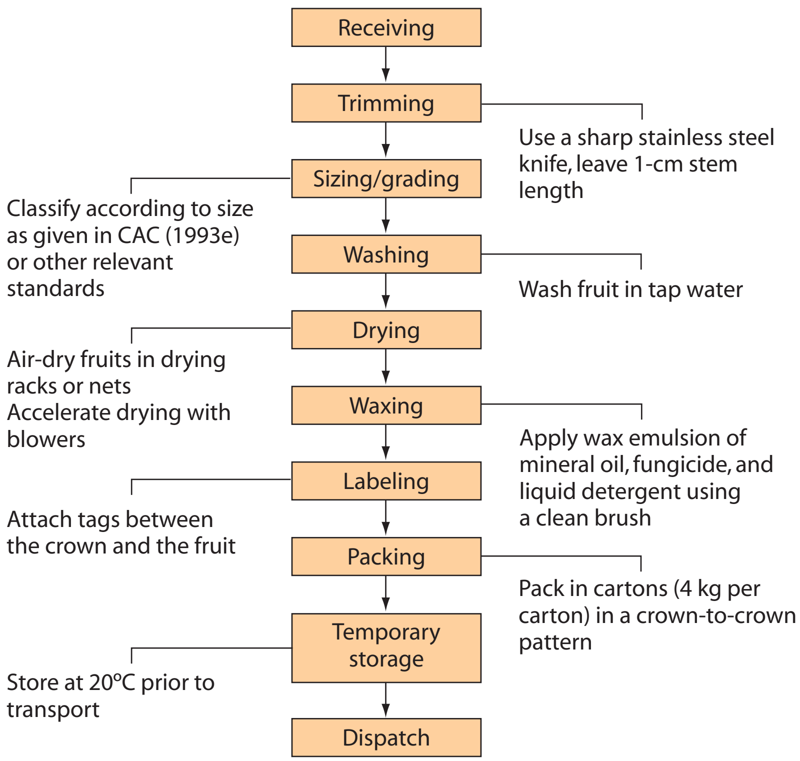


Figure 2.6 Process flow for pineapples destined for export markets

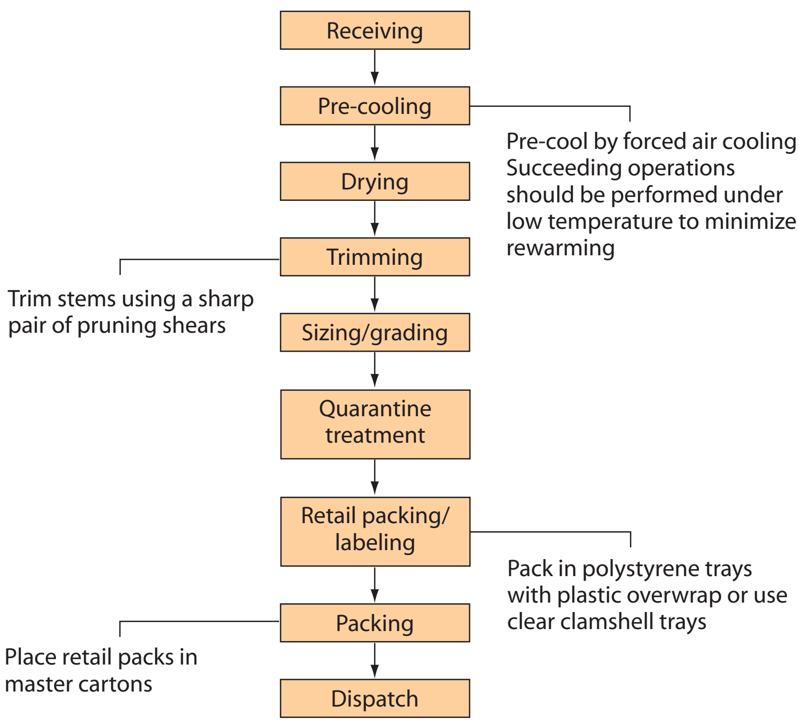


Figure 2.7 Process flow for okra destined for export markets

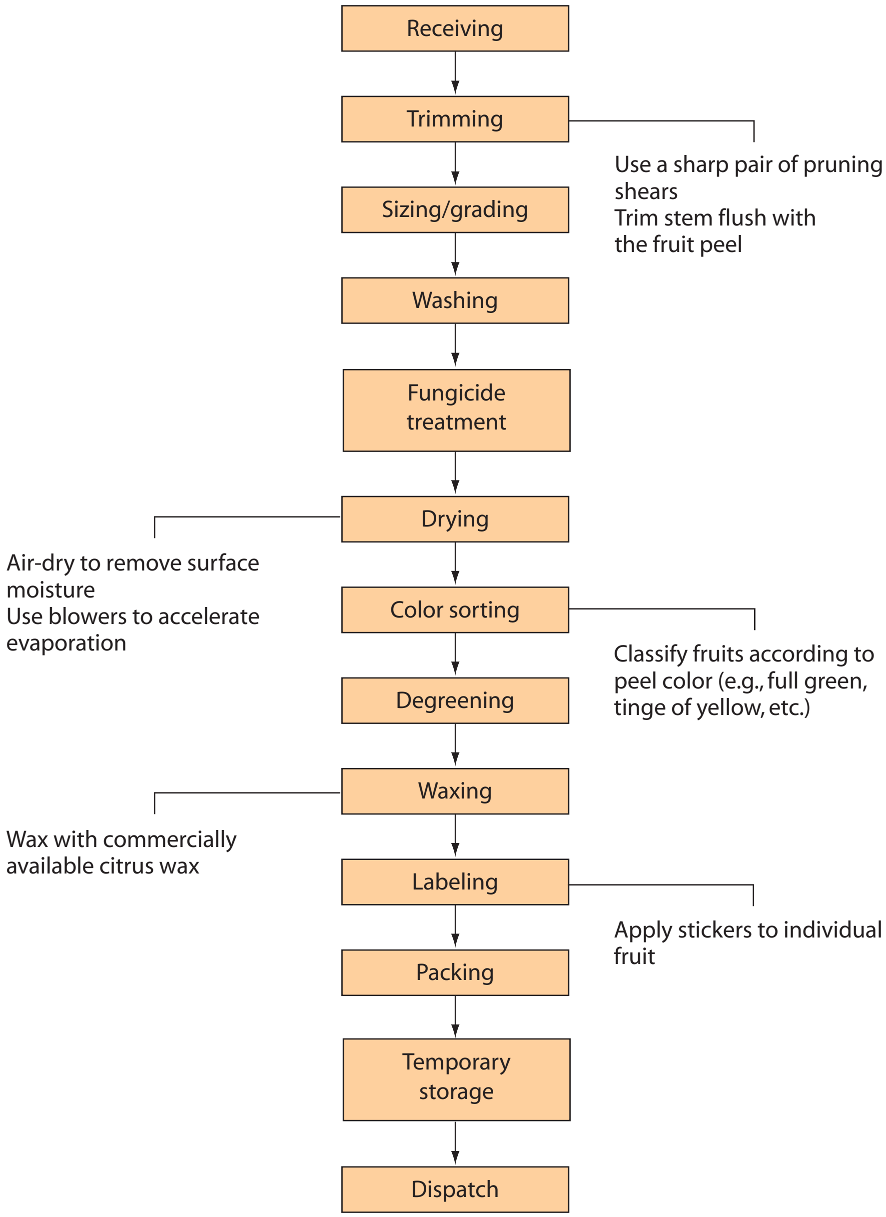


Figure 2.8 Process flow for mandarins destined for domestic markets

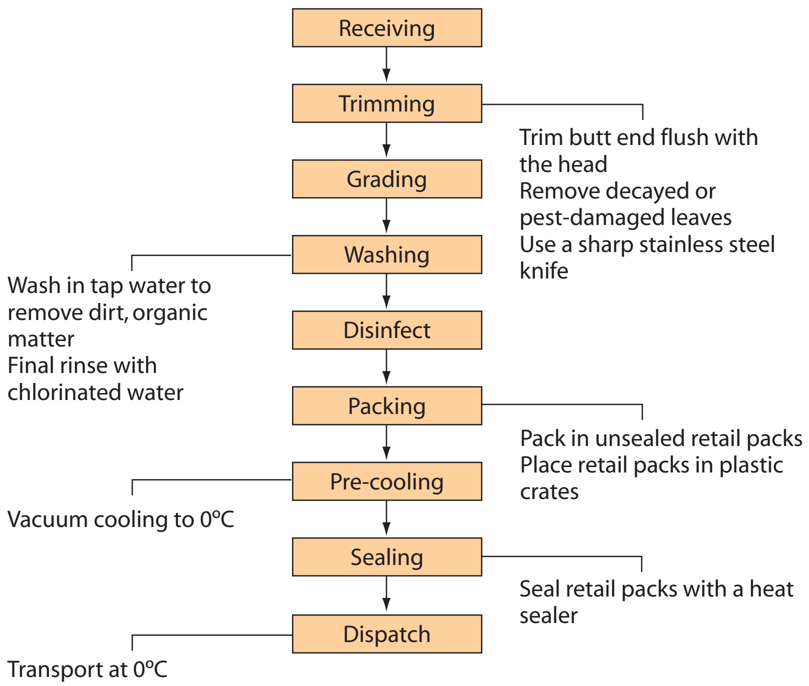


Figure 2.9 Process flow for 'Romaine' lettuce destined for institutional buyers

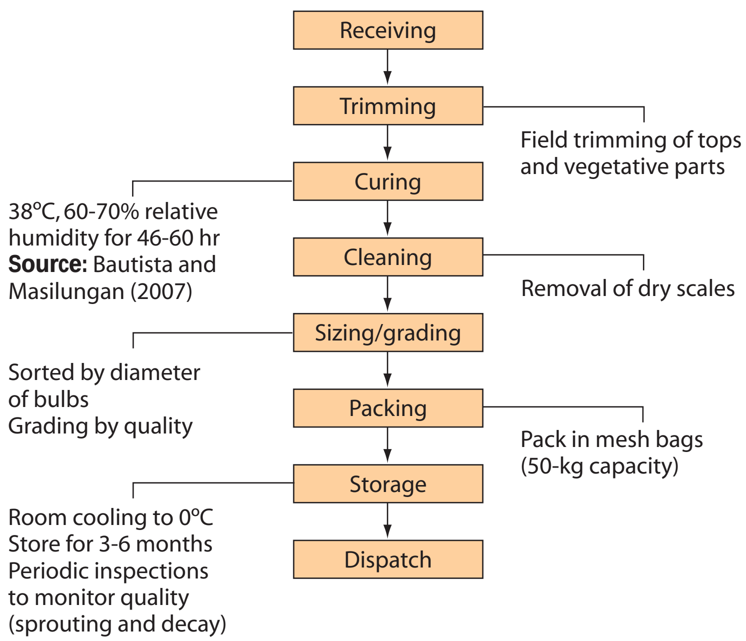


Figure 2.10 Process flow for bulb crops destined for institutional and domestic markets

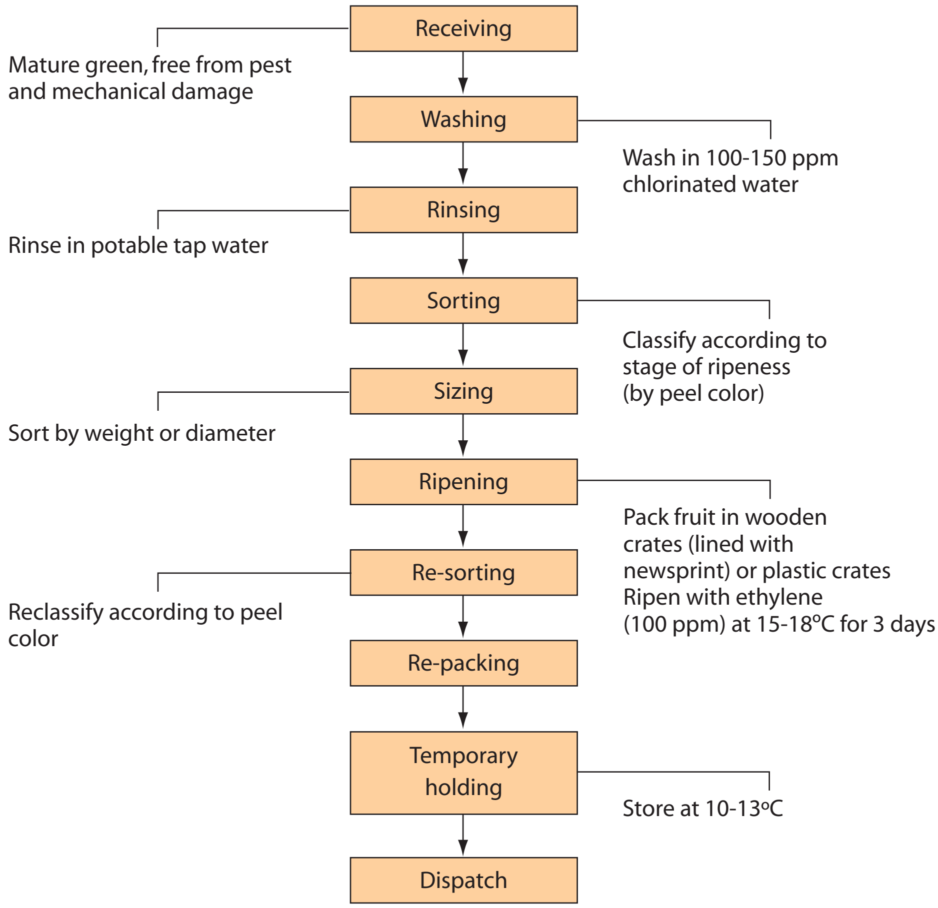


Figure 2.11 Process flow for tomatoes destined for institutional buyers or for domestic markets

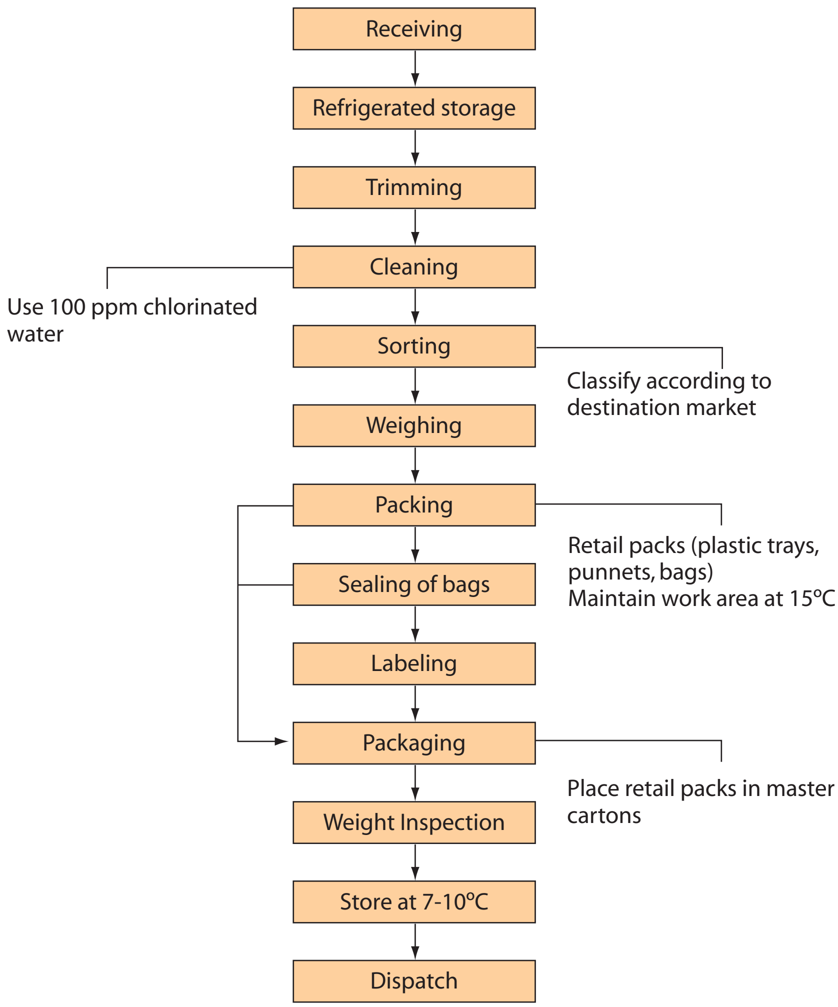


Figure 2.12 General process flow for Thai vegetables (Boonyakiat and Janchamchai 2007)

2.3 Pack-house equipment

Modern mechanized packing-house equipment is fairly common in North America and Europe. In the Asian region, Japan, Taiwan, Province of China (POC), Republic of Korea and possibly China are the only countries with a comparable degree of sophistication. Despite the fact that many Asian scientists and engineers having received training over the years, mechanization of the horticultural industry in developing countries of the region has been slow for the following reasons:

- *Small-scale farming operations* – the scale of technologies used in developed countries is, in general, too large for most Asian farmers, even when organized into cooperatives. While Japan and Taiwan, POC, manufacture equipment of a small capacity, the cost of this equipment is a major barrier to accessing this equipment in many countries of the region.

- *Prevalence of traditional marketing systems* – most consumers in developing countries procure their produce in wet markets rather than in supermarkets. In general, the low retail prices in wet markets do not allow for recovery of the costs of mechanization and refrigeration. This trend is, however, changing in some countries as major international supermarket chains move into metropolitan areas, living standards rise and consumers become more aware of quality and safety.

To reduce the costs of packing-house equipment such as sizers, waxers and conveyors, it may be necessary to compromise on sophistication, as long as food safety is not compromised. If the unit is able to perform its function reliably in a cost-effective manner, then users will be encouraged to mechanize post-harvest operations. High-technology facilities and equipment can be adopted to provide for local needs by developing modifications in user countries. This approach has been successful in some Asian countries. Locally produced small-scale pre-coolers, ice makers and cold storage facilities are used in Taiwan, POC, for example.

Materials for the fabrication of packing-house equipment

Wood or bamboo can be used for making tables, benches, bins, crates and pallets. Materials should be clean, dry and free from decay and insects. Edges should be smoothed to prevent physical injury to produce. The depth of bins and crates should not result in compression damage to produce. These materials are better suited to field operations where contamination is slightly less critical.

Work surfaces exposed to organic matter or acids and water should be fabricated from stainless steel. Type 304 or 316 stainless steel, is preferred. Steel with a brushed or grained finish should be avoided as it may be difficult to sanitize. Tungsten inert gas welding should be used for joints that come in contact with food. Metal inert gas welding is acceptable for joints with no food contact. However, all welds should be smooth and free of pits where organic matter and water can accumulate. Welds must not be cleaned with wire brushes as rust can form due to embedded iron particles (Lipschutz 2007). Plastic materials can also be used as food contact surfaces as they are easily cleaned and sanitized. However, scratches or cuts left by sharp metal objects on plastic materials can serve as accumulation sites for organic matter and bacteria.

Food-grade stainless steel should be used for washing tanks. Second hand drums (plastic or steel) should not be used as washing tanks given that residues of their original contents may be present. Dipping tanks with water pumps should make use of stainless steel pipes for handling water. Galvanized iron pipes may rust if water is allowed to stand for extended periods; organic acids from produce may also cause corrosion.

Critical elements of equipment design

Worker safety and ease of use – Workspace should be arranged so as to minimize physical stress during working. All materials and produce should be within easy reach of the packer. A sorter should not have to stretch repeatedly to grasp objects; otherwise, fatigue can easily set in resulting in careless handling of produce and reduced capacity of workers.

Workers should be provided with a flat, clean working area of an appropriate height, for packing produce. For sorting, grading and sizing operations that involve light effort, an efficient work height is halfway between the wrist and elbow (measured when the arm is held straight down). This is about 10-15 centimetres below the elbow of the average worker (whether sitting or standing) (Photo 2.17). For heavy items, the work height should be slightly lower.

Photo 2.17 Packing of citrus in cartons. The work area is divided into three levels: the top level has a conveyor for packaging materials; the middle level accepts fruit from the preparation area and presents it to the packer at a convenient height and within easy reach; the bottom level accepts filled cartons and conveys them to a dispatch area

For tasks that can be performed while sitting down, benches and stools should be provided to reduce fatigue. Table height must, therefore, be taken into consideration. As people's heights vary, small platforms should be provided for shorter individuals.

When sorters are arrayed on one side of a sorting table or conveyor, the width should not be more than 40-50 cm. If sorters can be placed on both sides, then the table or conveyor should not be more than 75 centimetres in width (Bollen *et al.* 1993) to minimize stretching.

Shields and safeguards must be installed on all equipment with moving parts such as pulleys, gears and belts. Warning labels that are easily understood and highly visible to users must be provided.

Protection of the produce – equipment should have a minimum of sharp edges and corners (Photo 2.18). Foam padding should be installed over sharp edges and corners to prevent cuts and bruises to the commodity. Where produce can impact the sides of equipment, foam padding or plastic hose (Figure 2.13) should be installed to reduce damage.

When commodities are transferred to a belt conveyor, the conveyor should not be supported underneath at the point of impact (Figure 2.14). For belts supported with rollers, the rollers at the point of impact should be removed. For belts supported with a pan, the pan should end before the area of impact (Miller *et al.* 2001).

Photo 2.18 A trimming table for fresh-cut lettuce. Note the bevelled corners and rounded edges that minimize the chances for injury to workers and produce. A chute level with the working area and leading to a prepositioned plastic crate under the table is provided for easy disposal of trimmings and rejects

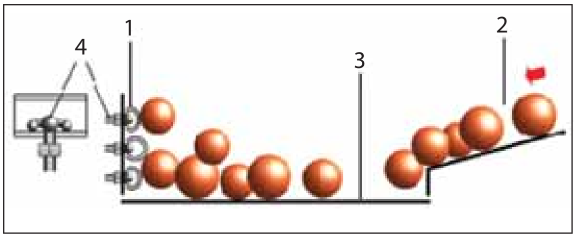


Figure 2.13 Schematic of rubber or plastic hoses used as bumpers (1) for fruit delivered from a chute (2) to a belt conveyor (3); T-bolts (4) are used to fasten the bumpers securely (Miller *et al.* 2001)

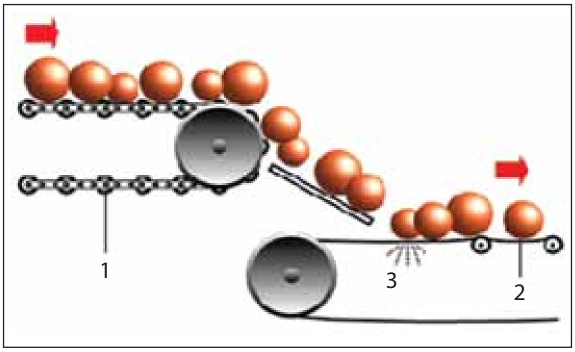


Figure 2.14 Schematic of the delivery of fruit from a roller conveyor (1) to a belt conveyor (2); The belt is left unsupported at the area where the fruit impacts (3) to reduce damage (Miller *et al.* 2001)

Dumping freshly harvested produce into water tanks (also termed *wet dumping*) minimizes mechanical damage but can increase disease development. Extra padding should be provided in order to reduce damage during *dry dumping*. Dropping during transfers between conveyors can be minimized by using ramps to reduce impact velocity. Ideally, a ramp should be long and have a low slope. Space limitations, however, make this difficult to achieve. By installing features that decrease velocity such as brushes, curtains and blankets (Figure 2.15), impact velocity can be further reduced (Garcia-Ramos *et al.* 2003).

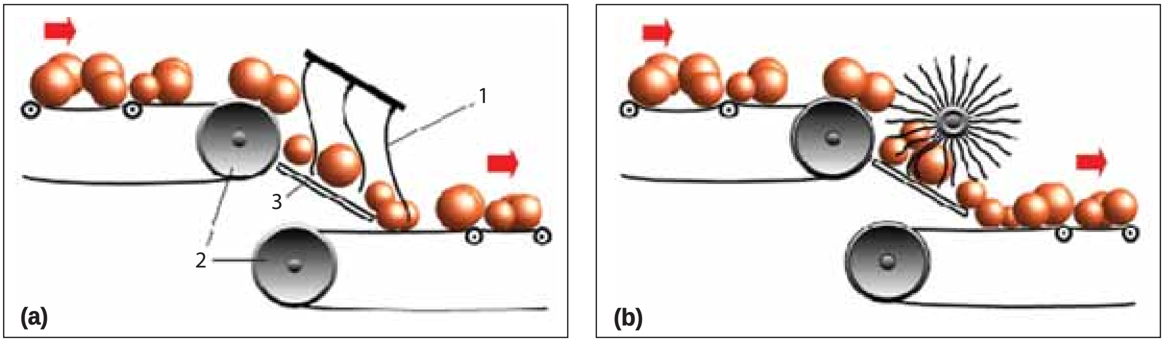


Figure 2.15 Schematic of decelerators to reduce fruit speed. (a) Multiple blankets (1) used for decelerating commodities transferred between two conveyors (2) over a padded ramp (3). The number and dimensions of each blanket used depend on the material, as well as size and weight of the commodity (Garcia-Ramos *et al.* 2003); (b) a brush-type decelerator

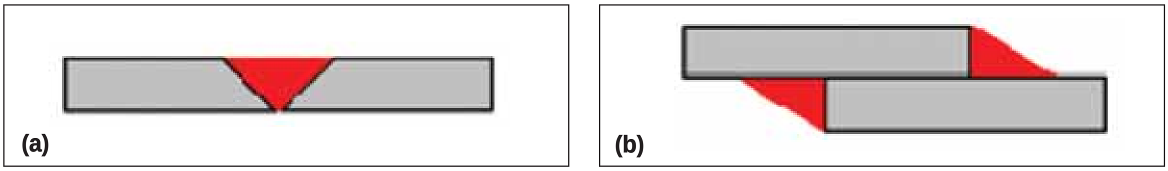


Figure 2.16 Schematic of recommended method of smoothing butt (a) and lap (b) welds to facilitate sanitizing of equipment

Equipment that makes use of rotating brushes for cleaning or waxing operations can cause damage if excessive speed is used. The design of equipment should be such that it does not cause injuries to personnel and produce, and is easy to clean and sanitize. Overlapping edges where organic matter can accumulate, cause corrosion, and encourage pest and disease development, should be avoided. Welds should be ground smooth with a portable stone grinder (Figure 2.16).

Movement of produce – packaging materials should be within arms' reach of a worker. The movement of produce should be planned so as to move commodities and/or materials toward the leading hand for more control and accuracy (i.e. for right-handed people, movement should be from left hand to right). Elimination belts, grade separation chutes and chutes for trimmings should be at the same or close to the height of the grading/sorting area to minimize lifting or arm movements (Picha 2004).

When using roller conveyors for moving commodities, the roller diameter should not be larger than three times the dimensions of the commodity. On the other hand, centre-to-centre roller distance must be large enough to allow free rotation of the rollers. Therefore, where feasible, the diameter of the roller and the distance between rollers should be minimized (Humphries 2001). This will ensure that produce is moved continuously and efficiently across the conveyor.

Mobility of equipment – equipment must be relatively easy to move around the packing-house when necessary. For this reason, facilities with smooth concrete floors are recommended so that equipment can be mounted on caster wheels. Casters/wheels should be able to support the weight of the equipment when fully loaded with water and/or produce. Various makes and models are available in plastic, rubber, steel or cast iron. A 10-cm-diameter plastic wheel can carry about 300 kilograms, while a 12.5-centimetre wheel can carry about 450 kilograms.

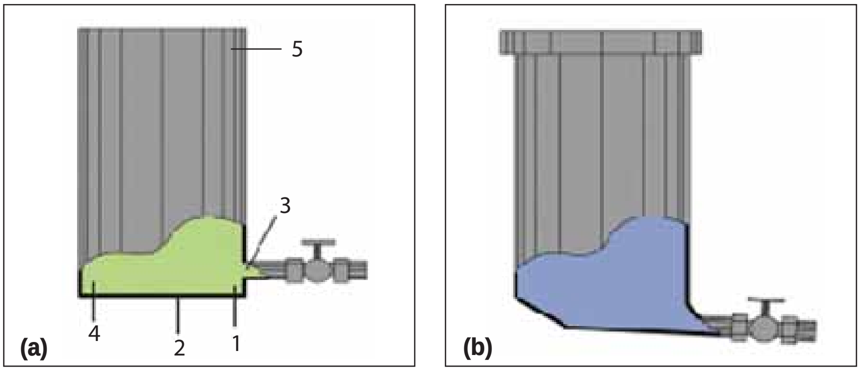


Figure 2.17 Recommended design for a tank filled with liquid: (a) A poor design may contain dead ends (1), a bottom with no slope to aid in draining (2), sharp exits (3) and corners (4), and lack a cover (5); (b) a design with improvements for hygiene (Rahman 2007)

Sanitation and hygiene – proper design of the equipment is critical to hygienic handling in the packing facility. Equipment should not harbor organic residues (latex, trimmings), dirt and dust, or other types of contaminants. Properly designed and fabricated equipment must allow all internal areas and external surfaces to be easily cleaned and drained. Inaccessible locations, including dead ends and sharp corners, may allow dirt, organic matter and water to accumulate in parts of the equipment, allowing microorganisms to multiply (Figure 2.17). If the equipment is not used for extended periods, pumps and piping should be disassembled, drained, dried, then reassembled.

Important considerations for equipment design include the following (Rahman 2007):

- Avoid pits in equipment design as these are difficult to clean.
- Sharp corners and sharp edges do not encourage liquids to flow towards drains and outlets. Corners should have a minimum radius of 3 millimetres.
- Screws and threaded bolts can provide areas where contaminants and water can accumulate, and are difficult to clean.
- Dead ends may serve as a trap for contaminants and make cleaning difficult. If a dead end cannot be eliminated in the design, then it should be as small as possible and placed in a location that can be cleaned and drained properly.
- Equipment with motors should have catch pans and drain hoses in case of spillage of lubricant oil. To the extent possible, motors should not be installed over product areas. Drain hoses should lead to floor drains or oil receptacles.
- Safety guards for chains and belts, conveyor guides and splash guards must be removable and easy to clean.

Equipment requirements for packing house operations

Weighing scales

A packing-house facility should be equipped with scales of a range of capacities. A 1-kilogram scale can be used during manual sizing for checking weights of individual fruits. A 50- or 100-kilogram scale is used for weighing incoming containers of produce, as well as for weighing outgoing containers ready for transport. Digital models are more accurate and precise when compared to spring-loaded dial-type scales.

Washers

Washing tanks or spray washers are used for removing dirt, latex and other foreign materials from the surface of the commodity. Small and simple tanks can be fabricated from stainless steel sheets shaped into semi-cylindrical shapes and mounted on stands of a suitable height. These can be arranged in series to provide a multi-stage cleaning process (Figure 2.18). The first stage involves rinsing produce to loosen decaying plant parts and dirt. The second stage makes use of chlorinated water to remove foreign material still present in tight spots. The third stage serves as a final rinse in chlorinated water.

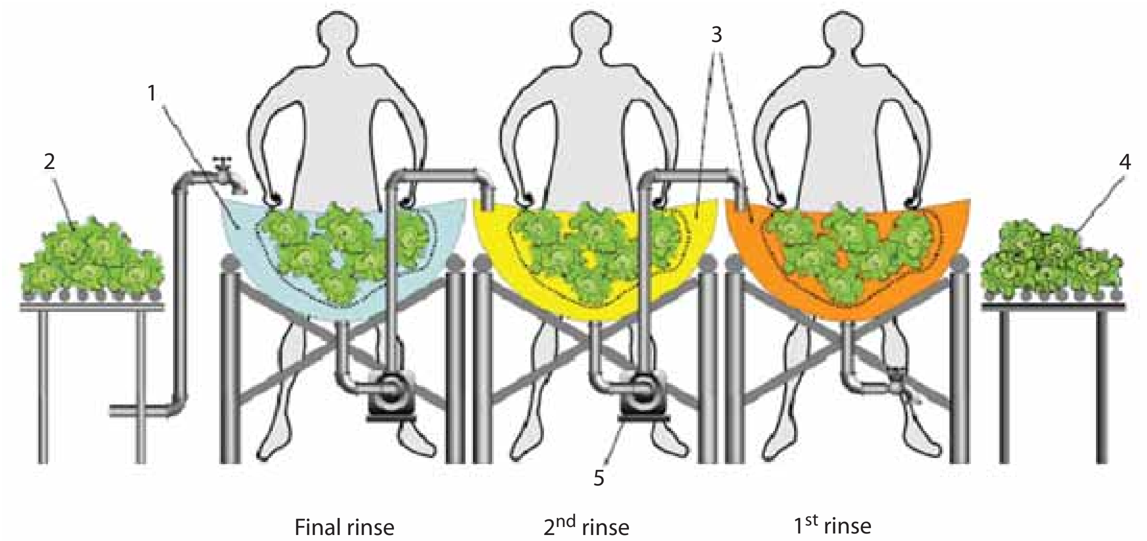


Figure 2.18 Multi-stage washing of vegetables using a series of tanks. Wash water moves in a countercurrent manner relative to the commodity: clean water (1) is used for final rinsing of washed produce (2) while reused water (3) is used for the first and second rinse of freshly harvested produce (4) small pumps (5) are used to transfer water between tanks. Vegetables can be placed in mesh bags for easier handling

To minimize water consumption, water from the third stage may be used as replacement water for the second stage; water from the second stage may be used as replacement water for the rinsing stage. Thus, water and produce move in a countercurrent manner, with the cleanest water contacting the pre-rinsed produce only as a final wash.

Food-grade stainless steel is the best option for fabricating washing tanks. Used plastic or steel tubs and drums that have previously been used for hazardous chemicals or waste products must not be used for food applications.

An Israeli system for treating mangoes and other fruits first rinses produce with tap-water to clean them; the fruits are then transferred to a treatment unit consisting of a hot water spray and rotating brushes. Fruit are rinsed with hot water at 50-65°C for 10-25 seconds as they move along the brushes; the temperature and treatment time vary according to the commodity being treated. The commodity is then dried with heated air at 40°C for two minutes inside a tunnel before proceeding to sorting and packing operations (Fallik *et al.* 2001).

Sorting Tables

Photo 2.19 shows a prototype sorting/packing table that can be used for different commodities in a small packing facility. Fruits of mixed quality or ripeness are placed on the platform at one side of the table. These fruits are sorted according to quality, with rejects being placed in a separate container. The middle section of the table is composed of three sloping bins padded with foam to protect the commodity. These are used for segregating produce according to stage of ripeness, size or quality. The slope of the bins allows produce to roll towards a packer standing on the opposite side of the table. Sorted or graded produce is then manually packed into containers.

Photo 2.19 Prototype sorting table being tested for tomatoes. Fruits of mixed ripeness (left) are sorted into different compartments (middle) according to peel colour. A packer (right) places sorted fruit into individual cartons according to peel colour

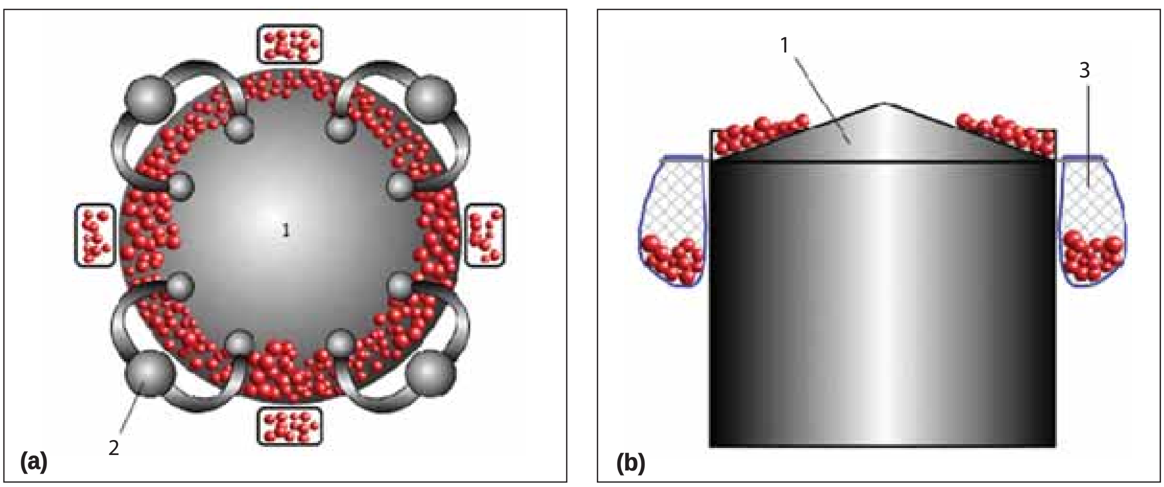


Figure 2.19 Top (a) and side views (b) of an onion sorting table. The table features a conical working area (1) where fruits are poured and allowed to roll down to the table edge. Workers (2) sort and pack bulbs into mesh bags (3) hanging from the table

Figure 2.19 shows a steel sorting table with a conical working area used for sorting and packing onions. Bulbs are poured out of their sacks at the centre and allowed to roll to the edges. Sorters positioned along the perimeter pack selected bulbs into mesh bags suspended on hooks along the side.

For larger operations, roller or belt conveyors move produce continuously in front of trained sorters who manually remove rejects (Photo 2.20 and Figure 2.20). To avoid reflective glare, the surfaces of sorting tables or conveyors should not be painted white. A grey background is sufficient for most sorting and grading purposes (Studman 2000). Some mechanized packing-houses have elimination belts or grade separation chutes. The most experienced graders should be positioned at the end of the conveyor belt to catch the culls that less-experienced graders may have missed. Top-of-the-line mechanical sorters make use of cameras linked to computer systems to automatically remove produce rejects from a continuous belt.

Photo 2.20 A roller conveyor with fluorescent lighting to illuminate the work area while sorters positioned along the sides remove fruit rejects

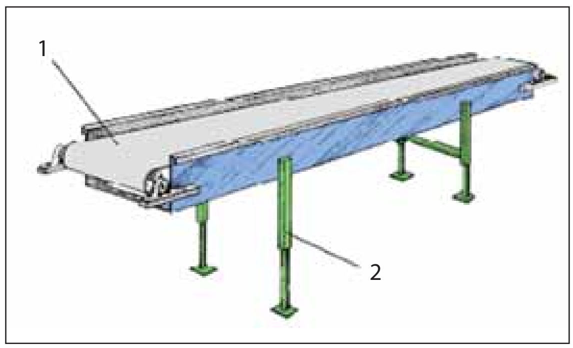


Figure 2.20 A belt conveyor with a smooth flat loop (1) of white material mounted over rotating rollers. Adjustable legs (2) allow the conveyor to be raised or lowered (Reyes 1988)

Sizers

Sizers separate produce into different classifications based on physical dimensions (length, diameter or weight). Simple sizers can be adapted for small operations.

Figure 2.21 shows a prototype sizing table for tomato and citrus developed at the University of the Philippines, Los Baños (UPLB). A series of plastic rollers is mounted on an inclined wooden frame. The frame is divided into three sections, with the distance between rollers increasing for each succeeding division. Fruits are allowed to roll down the rack; small fruits fall through the rack into a padded plastic crate placed underneath. Larger fruits continue rolling until they reach the

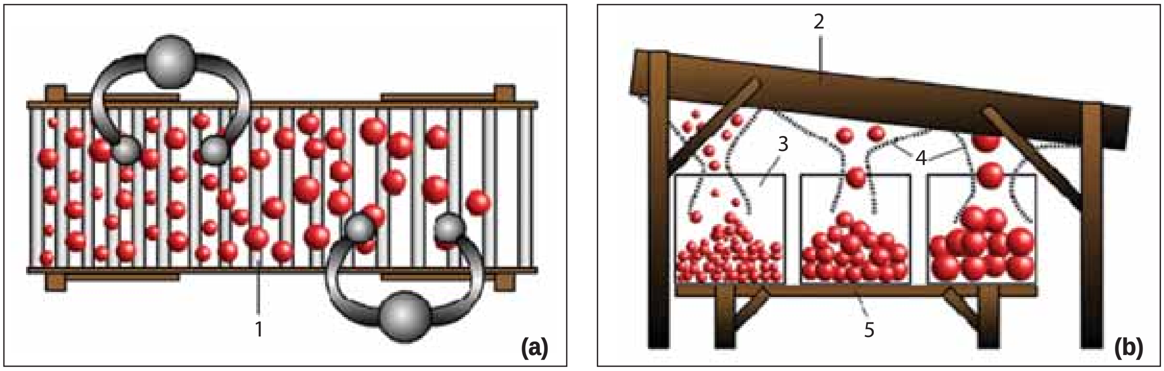


Figure 2.21 Prototype table sizer for tomato showing the top (a) and side views (b). The sizer features an inclined working area fitted with plastic water pipes (1). The frame (2) of the sizer is fabricated from wood. The working area is divided into three sections, with the gap between pipes increasing with each succeeding section. Sized fruit fall through the gaps and into prepositioned crates (3) under the table. Clean sacks (4) can be used to decelerate fruit as they fall through the pipes to reduce injuries. A platform (5) can also be used to raise the crates.

section with the correct gap. To minimize impact damage, sacks are tied under the rack to catch the fruits as they fall through to reduce their speed.

Pomelos can be sized using a simple inclined chute with gates positioned at intervals along the chute. The clearance at each gate gradually increases from one end to the other (Figure 2.22). Fruits are allowed to roll down the chute, with the largest being caught at the first gate. At each gate, fruit is captured and manually removed by workers positioned alongside the sizer. The sizer is simple to fabricate and maintain but is laborious to operate (Reyes 1988).

The dual hose sizer shown in Figure 2.23a uses two rubber hoses for conveying the commodity from one end of the sizer to the other. A gap is maintained between hoses so that produce can fall through. Because the gap gradually widens, small produce falls through first, followed by successively larger sizes. This sizer can be used for citrus, tomato (Reyes 1988) and other round commodities. A variation of this concept makes use of an inclined rotating roller bed with the gap

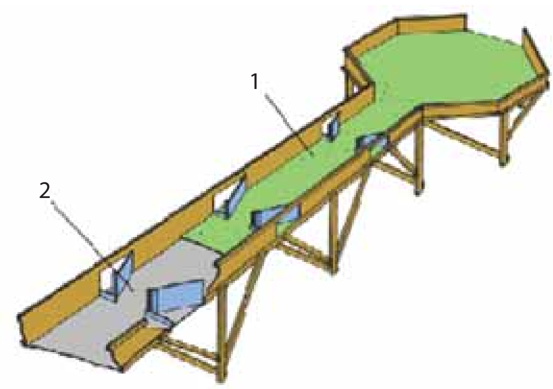
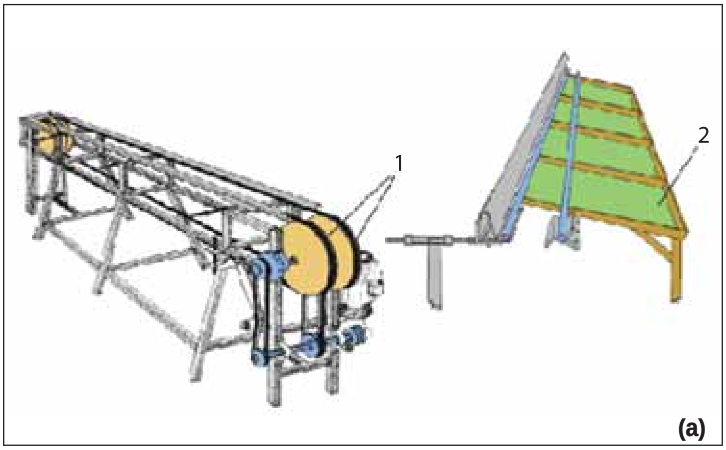


Figure 2.22 Table sizer for pomelo. The sizer has an inclined padded chute (1) where fruits are allowed to roll through gates (2). The gate opening gradually decreases along the incline. Workers positioned along the sides remove fruits at the gates and place them in containers (Reyes 1988)



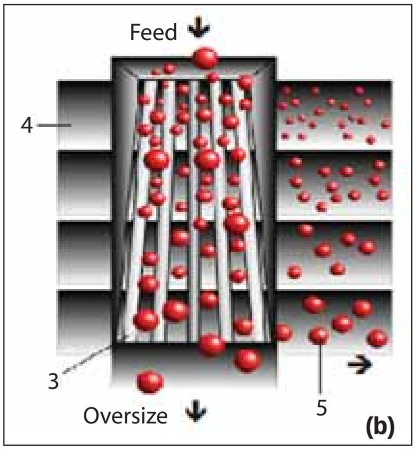


Figure 2.23 (a) The dual hose sizer makes use of two loops of hose (1) fixed to pulleys to convey fruit along the length of the sizer. The gap between each hose widens gradually and fruit fall through and drop into different bins (2) according to their respective diameters (Reyes 1988) (b) Live roller bed sizer with inclined diverging rollers (3) for sizing round produce. Belt conveyors (4) under the bed are used to carry away graded produce (5)

between each roller gradually increasing (Figure 2.23b). The rotating motion of the rollers spreads the produce evenly over the width of the bed. Small produce falls through first, followed by successively larger ones. Belt conveyors located under the roller bed bring the graded produce to bins or crates. The width of the roller bed can be adjusted to increase the capacity of the sizer.

Rotary cylinder sizers make use of a series of rotating perforated cylinders with the next cylinder having larger holes than the previous one (Photo 2.21). Fruit are conveyed from one end to the other, with small fruit separated first and the largest fruit ejected at the opposite end (Reyes 1988).

Photo 2.21 Perforated cylinder sizer for citrus makes use of rotating steel cylinders with successively larger openings to classify fruits according to diameter

Sizers that sort by weight utilize a tripping mechanism involving counterweights at different weighing stations. Photo 2.22a shows a weight sizer for mangoes. When a tray containing a fruit exceeds a preset weight, the tray is tipped and the fruits are dropped onto a padded bin.

Photo 2.22b shows a sizer suitable for small-scale operations. This sizer is suitable for pears and salad-type tomatoes. A carousel of trays moves around a central point, while a conveyor feeds each tray automatically. Weighing stations using counterweights are positioned along the perimeter of the sizer. Fruits weighing more than the preset value are dropped onto padded trays for packing into cartons.

Photo 2.22 Weight sizers for mangoes (a) and tomatoes (b)

Dipping tanks

Tanks can be used for applying chemical or heat treatments for disease control. The UPLB hot water tank (Photo 2.23) is used for dipping mango and papaya fruit for disease control. It can accommodate up to 160 kilograms per batch. Heat sources may be propane or kerosene burners or electric heaters. For larger operations, bigger tanks are used. A fruit exporter in Manila, Philippines makes use of a tank with a 500-kilogram capacity. A forklift is used to raise and lower the fruit into the tank.

The predominance of small farm sizes in Asian countries means that harvest volumes are erratic and vary widely. This makes batch-type systems more appropriate because traders and exporters can size their operation according to the actual volume of produce arriving at the facility. In comparison, continuous-type systems require a large and sustained volume of produce to operate efficiently. It is critical that water is mixed to avoid hot spots and subsequent fruit damage.

Waxers

These are used for applying food-grade waxes to reduce moisture loss, replace natural wax, apply fungicides and improve the appearance of a commodity. Methods of applying wax include foaming, spray, dipping and dripping.

Photo 2.23 Demonstration of hot water treatment of mango (left) for post-harvest disease control to a farmers' cooperative. Water temperature should be monitored carefully with an accurate thermometer to avoid heat injury to produce (right)

Blowers

These are used for evaporating surface moisture and ventilation. Ordinary room fans and automobile radiator fans can be used for drying small volumes of produce. Larger fans are used for greater ventilating effect. Roller conveyors equipped with high-capacity blowers are used for drying on a continuous basis.

Air knives make use of a directed stream of high-velocity air to blow droplets of water on the surface of produce travelling on a conveyor (Photo 2.24).

Photo 2.24 An air dryer equipped with blowers and a roller conveyor for evaporating surface moisture from mango fruit

Conveyors

Conveyors are used to move materials around a packing-house. They are useful for loading and unloading, moving produce to the next operation, as well as for removing culls from the packing-line. They can be designed and fabricated at varying lengths and widths and can also be provided with caster wheels so that they can be transferred in other areas of the packing-house where they will be needed for other operations. The height of the conveyors should be set at a level where worker fatigue is eliminated. This height generally ranges between 61 and 76 centimetres.

Gravity conveyors (Figure 2.24a) have freely rotating rollers mounted on a steel frame. They can be used for manually moving containers. Movement can be assisted by gravity by inclining the conveyor at a slight angle.

Belt conveyors are made from rubber or canvas loops suspended between two pulleys. One of the pulleys is powered by an electric motor. The loop can be provided with cleats so that produce can be lifted to a higher elevation (Figure 2.24b).

Slat conveyors have wooden slats mounted on chain loops (Figure 2.24c); chains are mounted on sprockets with one sprocket powered by a motor. Wooden cleats may also be attached to allow movement up or down an incline.

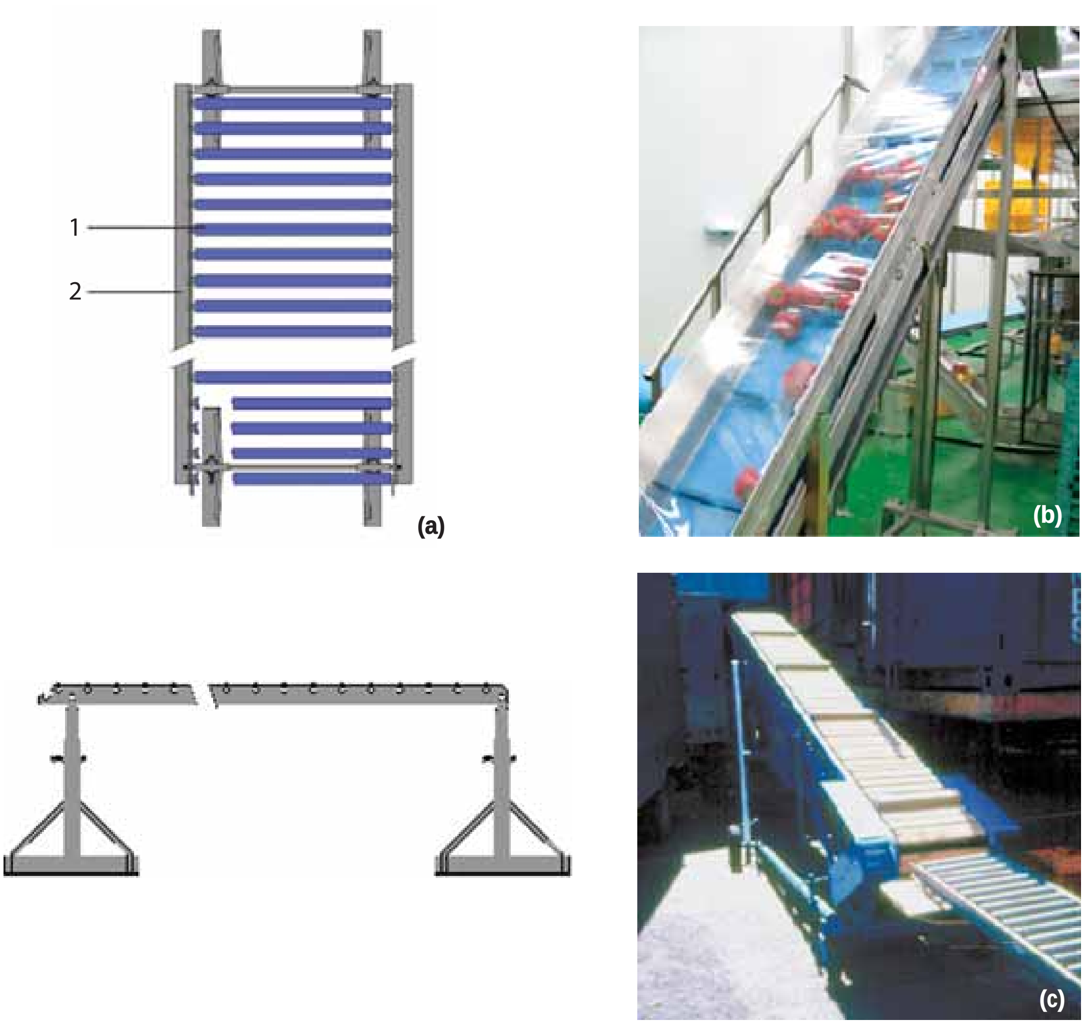


Figure 2.24 Conveyors: plan views of a gravity roller conveyor (a) with rollers (1) mounted on a steel frame (2) with adjustable legs (3); belt conveyor with cleats (b) for elevating sweet pepper; slat conveyor (c) with wooden slats and cleats mounted on chain loops for unloading banana crates

Pallets

Pallets are platforms made from wood, steel or plastic (Figure 2.25) which are used for moving stacks of containers as a single unit with forklifts. While many sizes of pallets exist, a common standard is the *metric* pallet with dimensions of 1 200 × 1 000 millimetres (Mitchell 1992).

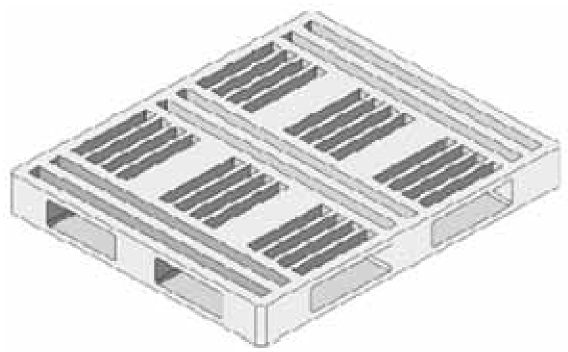


Figure 2.25 Pallet for unitized handling of containers

Containers must not overhang the edges of the pallet. Overhanging fibreboard cartons reduce the strength of the package by about 30 percent. Carton stacks can lean over and collapse. On the other hand, containers that make use of less than 90 percent of the pallet or which do not align with the pallet edge result in an unstable load, especially during transit (CAC 1995c). Figure 2.26 shows some examples of container sizes that allow full utilization of the pallet area. Fraser (1995) recommended a common 'footprint' (length by width) of 600 × 400 millimetres and three different heights (120, 195 and 315 millimetres) for a system of returnable plastic crates.

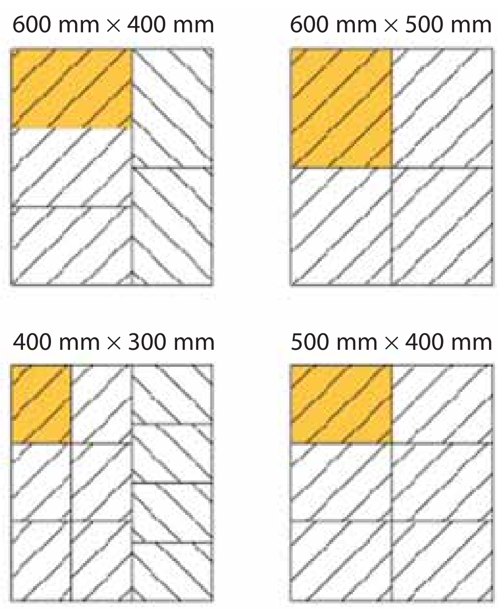


Figure 2.26 Examples of container dimensions that are compatible with metric pallets (1 200 × 1 000 mm)

If a commodity is to be placed in cold storage without undergoing pre-cooling, then containers must be stacked on pallets with spaces in between to allow heat to escape (Figure 2.27). Failure to do so would result in the cooling of produce close to the edges and corners of the stack. Produce at the centre of the stack will tend to remain warm and may deteriorate prematurely.

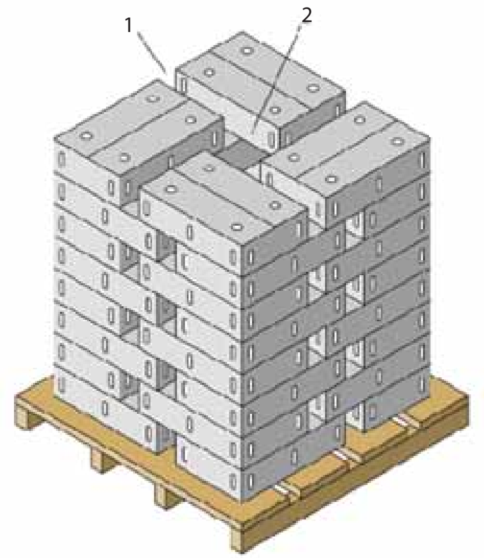


Figure 2.27 Chimney stacking pattern of cartons on a pallet. Gaps (1) and a central air space (2) are used to allow heat to escape from the cartons

Photo 2.25 Palletized cartons of mangoes with plastic strips fixed to the corners to stabilize the stack

Compatibility of pallets and forklifts must be checked before purchase. Distances between prongs of the forklift should match the openings of the pallet.

As far as possible, steel or plastic pallets should be used for loading. Wooden pallets are acceptable as long as they are clean, dry and free of decay. Direct contact between pallets and produce is not recommended. Wooden pallets must be adequately equipped with deck boards on top to support stacks of containers. This prevents collapse of the stack when the pallet is fully loaded.

Loosely piling produce on pallets is not recommended as this could result in contamination and compression injury. Produce may also fall off during handling of the pallet load, resulting in injury and contamination of the produce. Pallet stabilizers can be used to keep the stack from falling over during handling and transport (Photo 2.25). Careful handling during loading and unloading is still necessary to avoid failure of the stabilizers which could result in instability of the stack.

Carts and forklifts

Carts and forklifts are used for the simultaneous movement of several containers of produce. For small volumes, a cart fabricated from wood, steel bars/pipe and equipped with wheels can be used (Photo 2.26a, b).

Photo 2.26 Types of carts and forklifts used in pack-house operations in developing countries: (a) fruit baskets loaded on a four-wheeled cart; (b) vegetable cartons on a two-wheeled cart; (c) manual forklift, also known as a pallet jack; (d) electric cart powered by rechargable car batteries

Forklifts (manual, electric or diesel-powered) are used to move several hundred kilograms of produce at a time with the use of a pallet (Photo 2.26c). Forklifts equipped with diesel engines should not be used so as to avoid accumulation of exhaust fumes that contain ethylene. Electric forklifts are preferable for enclosed facilities and for use in storage rooms.

In some wholesale markets, motorized carts powered by rechargeable car batteries are used for hauling produce (Photo 2.26d). These carts are quiet, simple to operate, highly manoeuvreable and do not emit fumes.

Racks for air-drying, drip-drying or curing

Racks may be fabricated from steel pipe, wood, bamboo or coconut lumber. Floors and sides of the racks may be fabricated from bamboo slats (smoothened to remove sharp edges), plastic netting or cyclone wire. The surface area of the commodity or container must be exposed to air to allow for maximum ventilation and drying of the outer surfaces.

Examples of situations where drying and curing racks are used:

- For the temporary holding of produce removed from cold storage.

- Immediately after hot water treatment of mangoes, some water still remains inside the crate as well as on the surface of the fruit. Both crates and fruit must be allowed to drip-dry before proceeding to the next stage in the operation.
- Bulb onions are cured to extend storage life. Closing of the neck and drying of outer leaves retards microbial decay and enzymatic action. The bulbs are kept on racks made from bamboo slats (Photo 2.27a) that promote ventilation and ensure uniform and thorough curing.
- Pomelos must be cured after harvest to improve taste and avoid quality deterioration. Calamondin must also be cured after harvest to minimize oleocellosis. Photo 2.27b shows a shallow wooden rack used for this purpose.
- In modern cool stores pallets of produce are placed on racks to facilitate inventory control and to optimize air circulation.

Photo 2.27 Curing racks for onion (a) and calamondin (b). Note the presence of a stray animal in (b), which could be a potential source of contamination

Miscellaneous equipment

- *Plastic straps* are used to reinforce wooden crates and fibreboard cartons to prevent them from bursting during handling. A strapping tool may be used to secure the straps manually to the container. A strapping machine ties the straps automatically around the container.
- *Baggers* – Figure 2.28 shows the design of a bagger for the retail packaging of onion, garlic and bell pepper. A roll of nylon mesh is secured around an inclined plastic pipe and the produce is allowed to roll down to the closed end of the mesh. Once a suitable volume is reached, the mesh is tied off and cut.
- *Impulse sealers* make use of a thin heating element to seal plastic films for modified atmosphere packaging of produce. Heating elements may be hand-operated for small packages, or pedal-operated for larger ones.

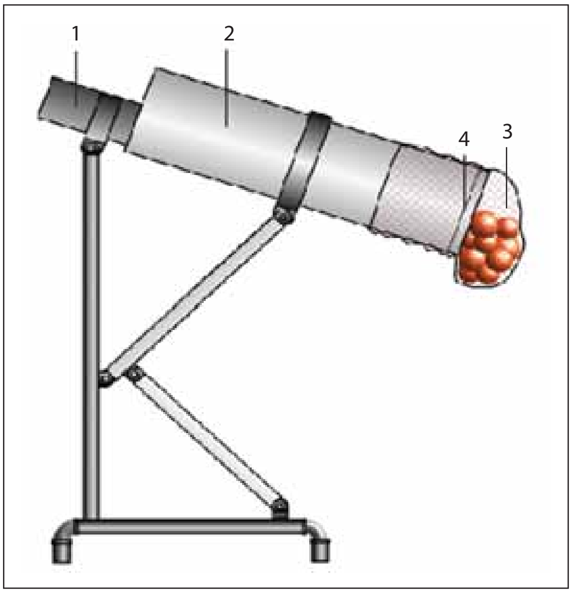


Figure 2.28 Bagger for the retail packaging of onions, bell pepper and garlic. Produce is poured into a receiving chute (1) and rolls down a plastic pipe (2) with nylon mesh (3) covering the bottom portion of the pipe. A steel spring (4) holds the mesh securely on the pipe. When the desired amount of product has been poured in, the mesh is tied off and cut

Photo 2.28 Applying sticker labels to mangoes

- *Sticker applicators* are used to place labels on individual commodities. Handheld models are available, such as the one shown in Photo 2.28.

Measuring instruments for quality control

Some simple instruments are needed for proper operation of a packing facility and for the quality testing of produce. Conditions inside the facility must be monitored to ensure the adequacy of working conditions for personnel, and that appropriate storage conditions for produce, are maintained. It may be necessary to evaluate the size, maturity, sweetness or colour of incoming produce. The thickness of packaging films may also need to be verified.

Measurement of dimensions

The simplest instrument to use for measuring length, width and diameter of an object is a ruler. These are available in wood, plastic or stainless steel. Many brands are marked off in both English and metric units of measurement. For more accurate measurements, a vernier caliper can be used; however, the level of precision of this instrument may not be necessary for most applications.

Plastic films for modified atmosphere (MA) applications must be of the appropriate thickness in order to avoid creation of anaerobic conditions after sealing. Micrometers (Figure 2.29) are accurate to 0.001 millimetres or even less; this makes them ideal for measuring the thickness of packaging films. Vernier calipers and micrometers are normally provided with scales; some models also have a digital readout.

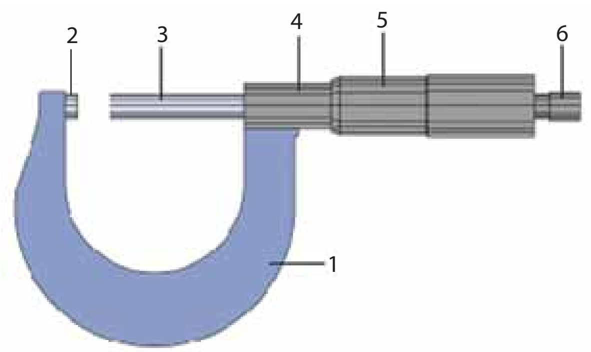


Figure 2.29 Main parts of a typical micrometer: (1) frame, (2) anvil, (3) spindle, (4) sleeve, (5) thimble, (6) ratchet

Temperature measurements

An accurate thermometer is necessary where temperature control is an important factor in determining the quality or shelf-life of a commodity. Temperature monitoring of cold storage rooms is important to ensure that the actual air temperature corresponds to the setpoint temperature. Thermometers may also be used to check water temperature in hot water tanks used for heat treating fruit. Temperature readings can be checked against the temperature setting to confirm readout of the thermostat. If the temperature reading differs significantly from the setpoints on the thermostat, then a check of the system may be needed. Thermometers are particularly important in determining the temperature of wash water, efficiency of cooling systems (pre-cooling and cold storage), and for monitoring disinfection and disinfestation treatments involving heat, among others. A simple procedure for calibrating thermometers that can be immersed in water is described in Appendix A.5.

Several types of thermometers are available; each type has its own accuracy, precision, ruggedness and temperature range.

Bimetallic thermometers make use of two different metals bonded together in a coil or strip and connected to a temperature indicator, such as a dial or pen. As temperature changes, the two metals expand or contract at different rates, causing the coil to deform in a manner proportional to the change in temperature. The measuring region of dial-type thermometers is about 5.0-6.5 centimetres from the tip of the stem. The temperature shown on the dial is, therefore, the average of temperatures along this region. Bimetallic thermometers are used to measure the internal temperature of produce. Strip-type thermometers are used to monitor air temperatures. They are attached to pens that plot temperature in hygrothermographs (Flores and Boyle 2000).

Liquid-in-glass thermometers contain a liquid (usually alcohol or mercury) with a temperature scale engraved on the thermometer stem. These may be either partial or total immersion types. Partial immersion thermometers are marked to indicate the depth of immersion needed to obtain an accurate reading. Total immersion thermometers are immersed with only a short length of the stem left exposed to allow the temperature to be read. High-end total immersion thermometers can have accuracies of 0.02-0.05°C; partial immersion thermometers have accuracies of 0.1-0.3°C.

Thermocouple thermometers make use of thermocouple wires connected to a voltmeter that converts measured voltage between measured and reference junctions of the wires into a temperature reading. Thermocouple wires are composed of two different metals connected at two junctions. The measuring junction is used for sensing temperature; the reference junction is used as a point of comparison by the instrument to calculate the actual temperature reading from the voltage difference between the two junctions.

Thermocouple combinations most commonly used include types J, T and K. Type-J wires (iron-constantan) are suitable for general use, are relatively inexpensive and can be used in oxidizing or reducing atmospheres or under vacuum. *Constantan* is an alloy composed of copper and nickel. Type-J wires can be used in the temperature range of 0-760°C with an accuracy of ±0.1°C. Type-T thermocouples (copper-constantan) are resistant to corrosion in moist conditions and can be used in oxidizing or reducing atmospheres. The operating range of type-T wires is from -160°C to 400°C, accurate to ±0.5°C. Type-K thermocouples utilize a Chromel-Alumel™ pairing. Chromel is an alloy composed of nickel and chromium; Alumel consists of nickel, manganese aluminium and silicon. Type-K wires are also widely used and suitable for oxidizing or inert atmospheres in the range of 0-1 260°C and are accurate to ±0.7°C (Flores and Boyle 2000; Simpson *et al.* 1991).

Thermocouple wires are available encased in a wide variety of stainless steel sheaths (Figure 2.30) suitable for measuring internal temperatures of different produce. Exposed sensing junctions can be used for measuring air temperature. Gauge-24 wire (0.51 millimetres) should be suitable for most applications; thinner wires may be too fragile for general use.

Resistance thermometers measure the change in electrical resistance of certain metals brought about by a change in temperature. Platinum, nickel and copper are the accepted metals used in resistance thermometry. Sensors must be encased in stainless steel sheaths for measurements in fluids (Simpson *et al.* 1991).

Glass thermometers are useful for monitoring average air temperature in a storage area. A thermometer inserted in a clear plastic flask filled with water provides a stable reading that is

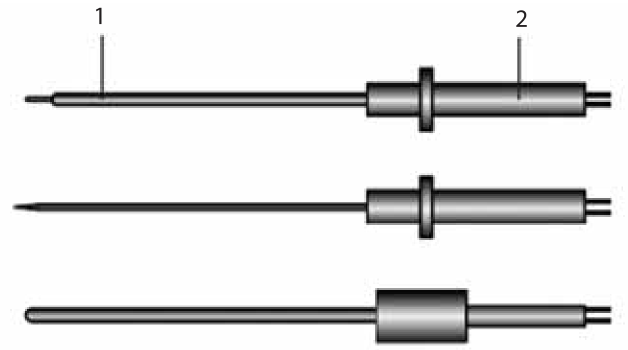


Figure 2.30 Typical general-purpose thermocouple probes with stainless steel sheath (1) and handle (2)

not readily influenced by a transient heat source, such as the entry of outside air. However, when using glass thermometers, the following precautions should be considered:

- Thermometers should be mounted away from hot or cold spots that can give a false reading of the temperature. Doorways can be a hot spot when opened, while an area receiving cold air directly from the cooling coils of a refrigeration system is a cold spot.
- As much as possible, thermometers should be non-glass to avoid the dangers of glass fragments contaminating food products; if no other type of thermometer is available, the glass thermometer should be shielded for protection against accidental breakage.
- Alcohol-in-glass thermometers are easy to read since the fluid is dyed red; mercury-in-glass thermometers should not be used because of mercury toxicity.

Colour meters

Light reflectance is the amount of light reflected off the surface of a commodity. When light falls on a commodity, approximately 4 percent of it is reflected off the surface as regular reflectance (Chen and Sun 1991). For objects illuminated with visible light (where wavelengths lie in the 400-950 nm range), this reflected radiation partially produces what is perceived as colour by the human eye, for example red, yellow or blue. Light that passes through the surface and is reflected from internal interfaces and transmitted back also contributes to the human perception of the colour of an object (Gunasekaran *et al.* 1985).

Several colour models have been developed over the years to define colour objectively. For purposes of quality control, the Hue-Saturation-Brightness (HSB) and L*a*b* models are particularly useful.

The HSB model describes three fundamental characteristics of colour based on human perception:

- *Hue* (H) is the colour reflected from or transmitted through an object. It is expressed as an angle between 0 and 360° on a standard colour wheel (Figure 2.31a). The hue of an object is commonly identified by the name of the colour such as red, orange or green.
- *Saturation* (S), also known as chroma, is the strength or purity of the colour. Saturation represents the amount of grey in proportion to the hue, with a range of 0 percent (grey) to 100 percent (fully saturated) (Figure 2.31b). On the colour wheel, saturation increases from the centre to the edge.

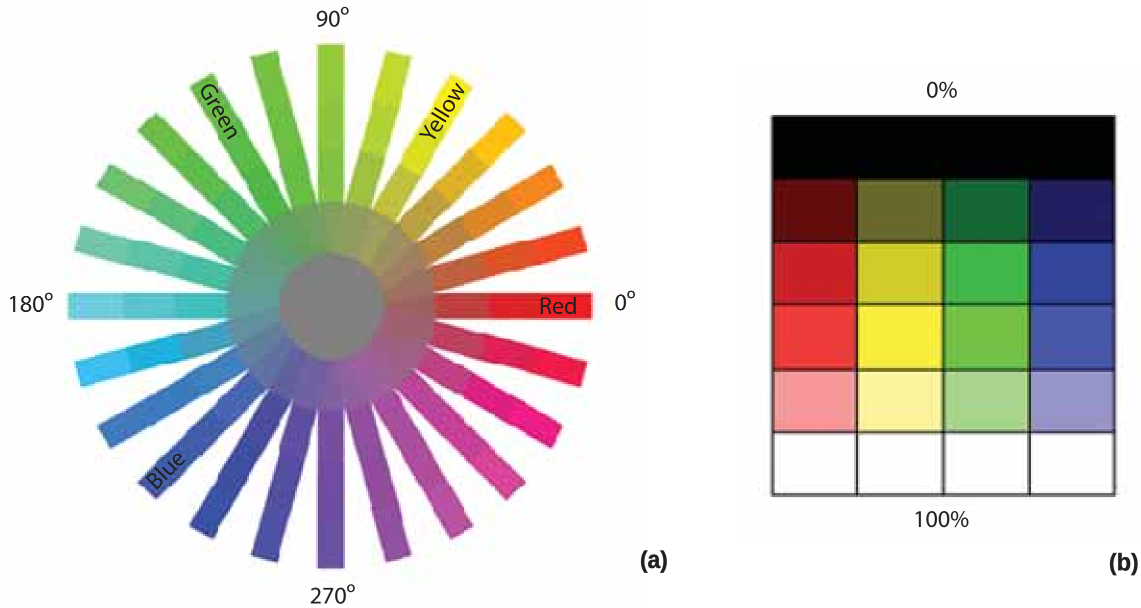


Figure 2.31 The HSB colour model. Colour wheel for determination of the hue and saturation of a colour (a). Hue ranges from 0° to 360°, saturation ranges from 0 percent (centre of the wheel) to 100 percent (outer edge of the wheel). Brightness ranges from 0 percent (black) to 100 percent (white) (b). Please note that colours shown in this figure are for illustrative purposes only and are not intended as an accurate depiction of the colour model

- *Brightness* (B), or intensity, is the relative lightness or darkness of the colour, expressed in percent from 0 (black) to 100 (white) (Adobe Systems 1998) as shown in Figure 2.31b.

The L*a*b* colour model was initially proposed in 1931 by the Commission Internationale d'Eclairage (CIE) as an international standard for measuring colour. In 1976, this model was refined and named CIE L*a*b* (Hunter 1975). This model is designed to be independent of whatever device is used for measuring the colour of an object.

The model consists of a luminance or lightness component (L*) ranging from 0-100 and two chromatic components ranging from -120 to +120: the a*-value (from green to red) and the b*-value (from blue to yellow) (Adobe Systems 1998). These components make up a colour coordinate system as shown in Figure 2.32.

L*a*b* coordinates can be converted to their corresponding HSB values by Equations 2-2 and 2-3. L* and B are defined to be equivalent to each other.

$$H = \tan^{-1}\left[\frac{b^*}{a^*}\right] \qquad \textbf{(2-2)}$$

$$S = \sqrt{\left(a^*\right)^2 + \left(b^*\right)^2} \qquad \textbf{(2-3)}$$

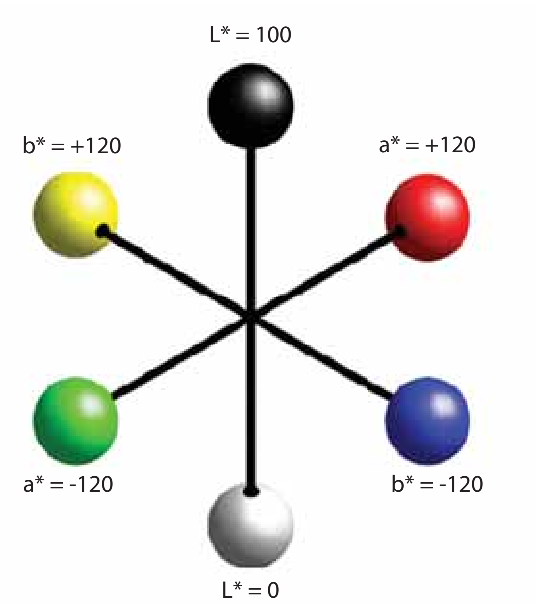


Figure 2.32 The L*a*b* colour coordinate system. Please note that colours shown in this figure are for illustrative purposes only and are not intended as an accurate depiction of the colour

The simplest method of evaluating the colour of a sample is by devising a subjective indexing system such as that given in Table 2.18. Although very simple to apply and needing nothing more than good vision and sufficient and appropriate light, the results of subjective evaluation can vary from person to person. Moreover, evaluators are subject to fatigue when many samples are to be evaluated.

Table 2.18 Subjective indices for evaluating peel colour and condition of mangoes and tomatoes

Crop	Parameter	Index	Description
Mango ('Carabao')	Peel colour[a]	1	Mature green
		2	Tinge of yellow
		3	More green than yellow
		4	More yellow than green
		5	Trace of green
		6	Full yellow
	Disease severity rating[b]	1	None
		2	First symptom evident (specks)
		3	<10% portion of fruit surface affected
		4	11-25% portion of fruit surface affected
		5	26-50% portion of fruit surface affected
		6	>50% portion of fruit surface affected
Tomato	Colour quality rating[c]	1	Fully yellow
		2	Yellow with orange patches
		3	Orange with yellow patches
		4	Orange
		5	Red with yellow or orange patches
		6	Light red
		7	Deep red

Sources: [a]Lizada *et al.* (1986); [b]Manzanilla (2004); [c]Agillon (1984)

Photo 2.29 A chromameter for measuring L*a*b* values of fruit and vegetable samples

Color can be objectively determined with the use of a chromameter (Photo 2.29) to measure the L*a*b* values of samples. As this instrument can only measure small areas of a sample, several measurements must be taken to obtain a good estimate of sample colour.

Handheld refractometer

A common index of maturity is SSC or TSS because of its high correlation with sweetness. Both parameters are measured as percent or °Brix using a refractometer (Photo 2.30). This instrument measures the refractive index of water that is highly affected by the presence of sugars. The measurement of refractive index provides a rapid estimate of sugar content, although the juice does contain other water soluble chemical components including organic acids.

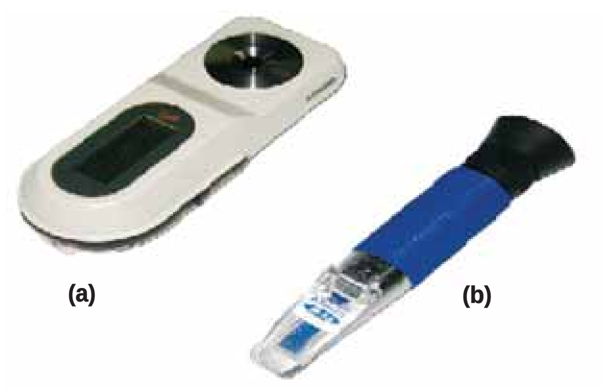


Photo 2.30 Refractometers for measuring total soluble solids in °Brix: (a) digital model, (b) sight glass type

In order to measure SSC/TSS, a sample of pulp is crushed to extract the juice. A medicine dropper or 1-mL syringe is used to place a few drops of juice extract on the measuring plate of the refractometer (refer to Appendix A.2 for the procedure). Benchtop refractometers are available for use in specialized quality control laboratories associated with the packing-house facility.

Chlorine test kits

The chlorine concentration in wash water used for disinfecting equipment, facilities, containers and contact surfaces must be determined on a frequent basis. Chlorine concentrations in water that is recycled or used repeatedly can quickly decrease owing to the presence of produce and contaminants (for example organic matter, soil). Chlorine concentrations should be monitored on an hourly basis; more frequent checks can be done if the produce is particularly dirty. Several commercially available products such as test strips and test kits are available for conducting simple tests. These can be procured from companies engaged in water testing or supply. All test solutions or strips should also be checked for their expiry dates and storage requirements, i.e. light and temperature.

pH meters

The efficacy of chlorine is affected by pH hence the use of a digital pH meter is recommended for the direct measurement of the pH of chlorinated water. In the absence of a pH meter, litmus paper can be used. The pH should be measured just before measuring the chlorine concentration and then adjusted.

Foreign material detectors

Foreign material can be detected using metal detectors, metal traps, sieves and filters, and magnets. These detectors should be tested on a regular basis to assure their working status. Metal detectors are tested using ferrous, non-ferrous and stainless steel test pieces (Bowser undated).

Chapter 3
Packing-house layout and finishing

3.1 Floor area requirements

The floor area of the packing facility must be calculated on the basis of the volume of produce and space requirement of each item of equipment and each operation. Each operation should have an estimated capacity (e.g. the number of kilograms of fruit can be sorted per minute). Capacity must be estimated for both manual and mechanical operations. After the capacity requirements for each operation is known, the capacity of the equipment and number of personnel can then be determined for a given volume of commodity.

The floor area requirement is the sum of the area required for each of the following components of the pack-house operations:

Receiving area – this is the location where newly arrived produce is held prior to market preparation. The type of container used for delivering the commodity must be known in order to be able to estimate the area required for receiving. Most bamboo and rattan baskets are structurally weak and should not be stacked when full. They, therefore, require a wider floor area than wooden or plastic crates, which can be stacked in several layers. The floor area of the receiving area should be level with the truck bed to facilitate unloading of produce.

Containers used for harvesting, hauling and transport are exposed to many types of contaminants and should be restricted to the receiving area. Once emptied, baskets or wooden crates should be kept in an area separate from the packing facility before being returned to the field or disposed of properly. Plastic crates should be cleaned and dried outside the facility and should not be mixed with crates used in clean areas; colour coding simplifies the monitoring of crates and prevents mix-ups.

Sorting area – this is the location where mixed produce is classified into different grades and culls are removed. The area required will depend on the number of grades to be classified. Removal of outright culls such as diseased, pest-damaged or mechanically-damaged produce can be performed in the sorting area. As culls are primary sources of contamination, only containers assigned to culls should be used.

Working area – this includes areas needed for washing, peeling, trimming and packing. As a rough estimate, the working area for each operation should be equal to the space occupied by the equipment (equal to area occupied by the equipment), plus area needed for movement of personnel and material (twice the area occupied by the equipment) around the equipment.

Storage area for packaging materials such as pads, liners, crates and cartons. Containers that are stackable and/or nestable occupy less floor area and maximize storage space.

Office space – This is the area set aside for an office, laboratory, storeroom for tools and equipment, and lavatories.

Area for temporary holding or cold storage room – the number and size of cold rooms is dependent on the projected volumes and temperature requirements of the different types of commodities being handled. The volume of produce for long-term storage should be known given that filled containers can be stacked closer together once the proper temperature has been reached. Pallet racks allow vertical space to be utilized (ASHRAE 1998).

Area for rejects – This area must be kept separate from packaged produce. Culls are assembled in this area and are disposed of on a regular basis to prevent accumulation of potential disease and ethylene sources.

Space needed for workflow – Personnel should be able to move readily from one area to another.

Layout of the facility

There should be a master plan depicting the physical layout of buildings and premises, personnel access and traffic ways and waste collection areas. One of the most important considerations in packing-house design is the availability of sufficient space for sanitary operations. The areas for different packing-house operations should be designed for easy cleaning and sanitation.

Premises

There should be sufficient parking space for vehicles so that traffic jams are avoided. The size of the largest vehicles that need to be accommodated by the facility should be considered. The flow of traffic should be smooth; ideally, there should be a separate entrance and exit for easy movement into and out of the facility, as well as separate docks for loading and unloading.

Docks should have sufficient space for free movement of materials and personnel into and out of the facility, and sorting and inspection of materials and equipment. For this reason, the recommended width for a dock is 9 metres (ASHRAE 1998).

Functional facilities within the packing-house

Cold storage rooms

Ideally, these should be placed as close as possible to both dispatch and finished produce areas. In this manner, packed produce can either be placed in cold storage or brought to the dispatch area for distribution. The proximity of the cold rooms to dispatch areas also minimizes condensation and rewarming when loading trucks.

Ripening rooms

These should be kept isolated from holding and receiving areas because high levels of ethylene are present in this area. Sufficient air ventilation is necessary to rapidly dissipate ethylene once a ripening room is opened; room air should be exhausted from the packing facility.

Laboratory

A small laboratory equipped with basic instruments for post-harvest quality evaluations including SSC/TSS, TA, starch content and dry matter content should be part of the facility. Depending on the scale of operations and market requirements, rapid microbial tests can also be performed.

Stock rooms

These are used for storing packaging materials (pads, liners, cartons or trays) and containers. Crates that are stackable and nestable (i.e. can be inserted in each other when empty) are preferable as they occupy less floor area and maximize space (Photo 3.1). Storage areas for packaging materials should be enclosed and pest proof. Doors of these rooms should always be kept closed. To prevent contamination, packaging materials should be stored on top of racks, pallets or shelves.

Photo 3.1 A plastic crate design that is both stackable and nestable. In the position shown, the right crate can be stacked on top of the left crate. If the right crate is rotated 180°, the two crates can be inserted into each other

A separate stockroom should be used for storing laboratory chemicals, cleaning and sanitation supplies, and other materials that could potentially leak and become a source of chemical contamination. In such an event, this will prevent the accidental transfer of chemical contaminants to packaging materials.

Tool room

A tool room should be provided for storing basic tools and equipment needed for minor repairs, as well as for the storage of minor packing-house equipment (such as weighing scales). A small workbench with a bench vise is useful as a working space for repair work.

Administrative offices

Office space for the manager of the facility should be provided, along with a small conference room for holding meetings with personnel and visitors.

Worker sanitation facilities

Lavatories/rest rooms – there should be separate lavatory facilities for male and female employees. It is recommended that one lavatory is provided for every 15 employees or any fraction of 15 and they should be located within a reasonable distance from the workers' station. If there are less than five employees, separate lavatories are not required.

Lavatory facilities should be well-lit and ventilated to outside air. Walls, floors and doors should be made of materials that can be easily cleaned. Doors of lavatory facilities should not open directly onto handling, packing or storage areas in case of malfunction or blockages (Picha 2004) that can result in overflow of toilets and sinks, or where airborne contamination could occur. Lavatory paper, trash disposal and adequate supply of water should be made available within lavatory facilities.

Hand-washing facilities – as a general rule, there should be a minimum of one hand station for every ten people. Hand-washing stations should be accessible or within easy access of personnel in the packing-house, near or in close proximity to lavatories. Proper and sufficient supplies for personal hygiene should be available at all times.

Hand-washing stations should be provided with adequate drainage and should always be kept clean and maintained in good working condition. Signage should be posted in strategic areas in order to remind personnel/workers to wash their hands after using the toilet,

Eating facilities

Eating food, drinking beverages, chewing gum or use of tobacco products should be restricted to designated areas located away from production/operation areas. Employee lunches should not be stored or placed in production or produce storage areas.

Eating in packing-houses, warehouses, laboratories or offices should be strictly forbidden. Food for consumption by personnel should be kept in the eating facilities. These facilities should be maintained in a hygienic condition.

Lockers

Lockers/gowning rooms should be directly connected to, but separate from processing areas.

Waste disposal area

Waste disposal facilities should be designed and constructed so as to avoid contamination of fruits and vegetables and of the water supply. Waste disposal facilities should be segregated as biodegradable and non-biodegradable and appropriately labelled. They should be conveniently located and accessible. These facilities should be kept clean.

Equipment layout within a packing-house facility

The arrangement of equipment in the facility must be planned according to the sequence of operations. The layout must be planned before actual commercial operations begin. It is very difficult to reorganize a packing-house while processing large volumes of produce daily at the same time. This can lead to temporary measures that are inappropriate and difficult to change as time elapses.

The floor plan of the facility as well as the layout of the equipment must be designed to facilitate produce flow and the movement of personnel and to minimize cross-contamination within the facility. For maximum efficiency, the produce should be unloaded at one end and handled towards the other end (the fewer the number of turns, the lower the damage to the commodity) as shown in Figure 3.1. This is because a straight packing-line eliminates turns and avoids cross-traffic among personnel, equipment and produce. Cross-traffic should be minimized to reduce collisions and cross-contamination.

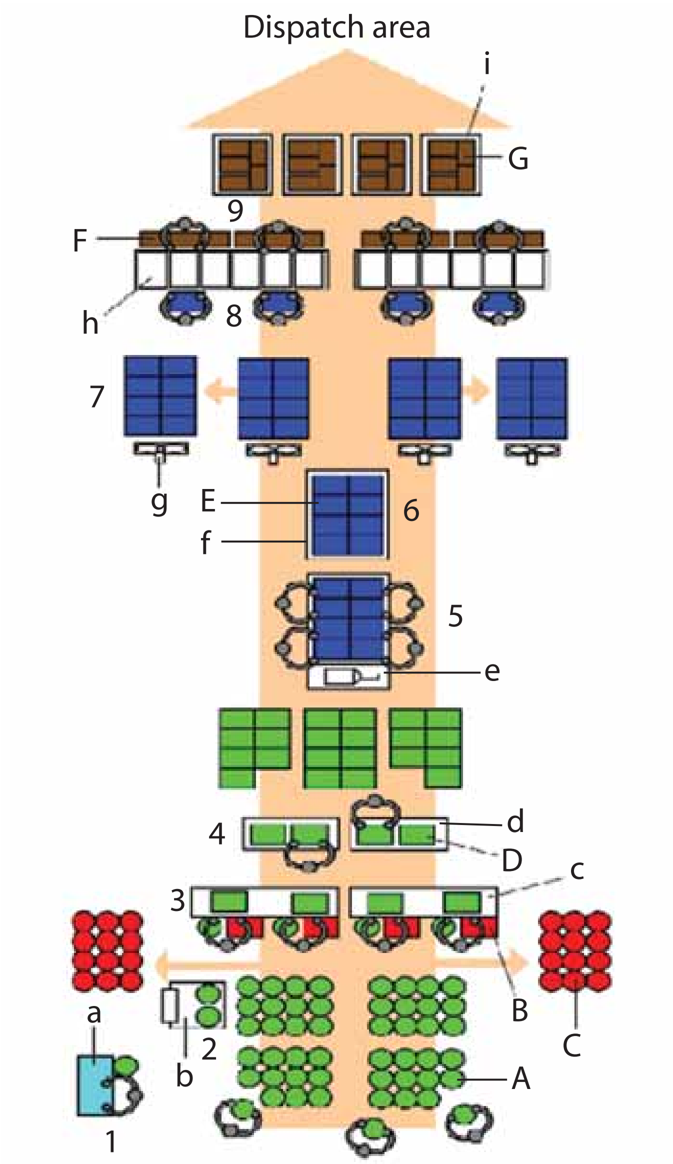


Figure 3.1 Straight-line configuration for a mango packing-house. Operations: (1) maturity test, (2) weighing, (3) sorting and trimming, (4) delatexing, (5) hot water treatment, (6) cooling, (7) air-drying, (8) sizing, (9) packing. Equipment: (a) flotation tank, (b) weighing scale, (c) sorting table, (d) delatexing tank, (e) hot water tank, (f) cooling tank, (g) fans, (h) sizing table, (i) pallets. Materials: (A) full baskets, (B) reject fruit, (C) empty baskets, (D) full crates, (E) treated fruit in crates, (F) empty cartons, (G) full cartons

Figure 3.2 shows an example of the use of gravity conveyors for the manual handling of containers, where raw material (freshly harvested mango) moves in one direction and empty containers move in the opposite direction without interfering with each other.

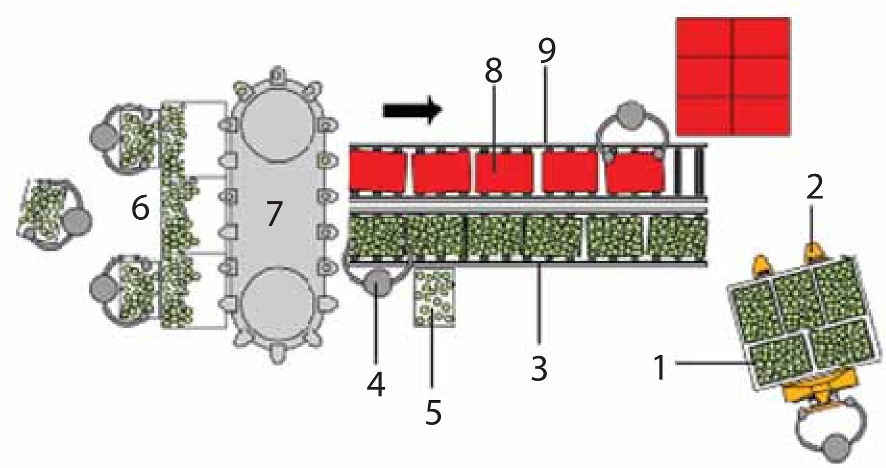


Figure 3.2 An example of gravity roller conveyors used for the manual handling of fruit crates. Newly-delivered fruits (1) of mixed sizes are brought from the receiving area by a pallet jack (2) and loaded on a conveyor (3). The fruit crates are pushed manually towards a sorter (4) who removes reject fruits which are placed in a separate crate for disposal (5); acceptable fruit are classified into different sizes (6) by a mechanical sizer (7). Empty crates (8) are placed by the sorter on a second roller conveyor (9) and are pushed in the opposite direction.

For packing-houses with limited space, the flow of the commodity can be arranged in a loop, such that freshly harvested produce being unloaded does not interfere with packaged fruit being loaded for transport to market (Figure 3.3). If higher processing capacity is needed, parallel packing-lines can be installed, with some sharing of equipment if needed (Meyer *et al.* 1999).

Containers used for hauling freshly harvested produce must travel in the opposite direction to that of the commodity being handled. Crates or baskets that may be stained with latex, or which may contain twigs, leaves, pests or soil from the production area, must be removed from the chain of operations once emptied, to minimize contamination or re-infestation. Raw material must not be stored in the same area with clean, packaged produce. In other words, the process flow must ensure that the commodity moves from an area with high levels of contamination (for example the receiving area) to an area with lower levels of contamination (for example the packaging area) without any cross-contamination occurring. Areas can be segregated into 'low-care/low-risk' and 'high-care/high-risk' areas that are divided by walls (Turatti 2007) and/or screened partitions.

For facilities engaged in quarantine disinfestation treatment, screens must prevent entry of insects into high-care areas; access points must be protected by double doorways with plastic strip curtains and by an electric insect killer. Standard practice dictates that one door must close before the second door can be opened. For facilities with washing or dipping operations, work areas with wet conditions should be kept separate from dry areas with partitions and floor drains to minimize the transfer of water between areas.

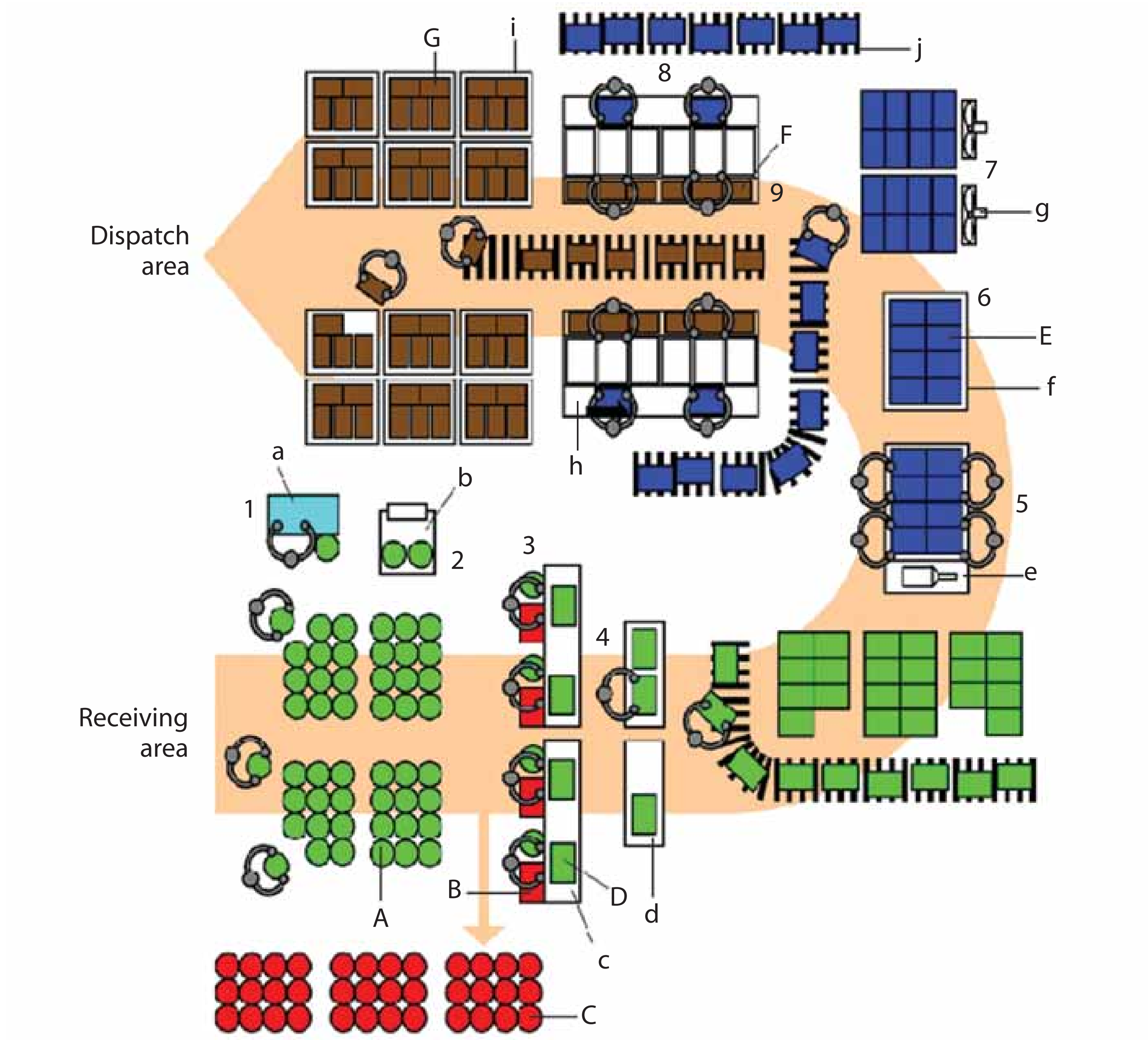


Figure 3.3 U-type configuration for a mango packing-house. Operations: (1) maturity test, (2) weighing, (3) sorting and trimming, (4) delatexing, (5) hot water treatment, (6) cooling, (7) air-drying, (8) sizing, (9) packing. Equipment: (a) flotation tank, (b) weighing scale, (c) sorting table, (d) delatexing tank, (e) hot water tank, (f) cooling tank, (g) fans, (h) sizing table, (i) pallets, (j) gravity roller conveyors. Materials: (A) full baskets, (B) reject fruit, (C) empty baskets, (D) full crates, (E) treated fruit in crates, (F) empty cartons, (G) full cartons

Sample floor plan layouts of packing-house facilities

Packing-house facilities are constructed in a variety of configurations subject to local conditions and preferences. This section will present some examples of floor play layouts of packing-houses.

Figure 3.4 shows the floor plan layout of a packing-house equipped with two packing lines. Key features of the facility include:

- The use of partially open loading docks that allow for the simultaneous parking of two vehicles used for deliveries (Figure 3.4). These docks keep vehicles outside the facility and minimize the entry of dust and ethylene. The loading docks should include a roof overhang to provide shade during deliveries and have the capacity to accommodate presorting and cleaning operations.
- The main entrance, office area and lavatories are located on one end of the facility, thereby expanding the available working area and allowing for more efficient flow of materials and personnel.

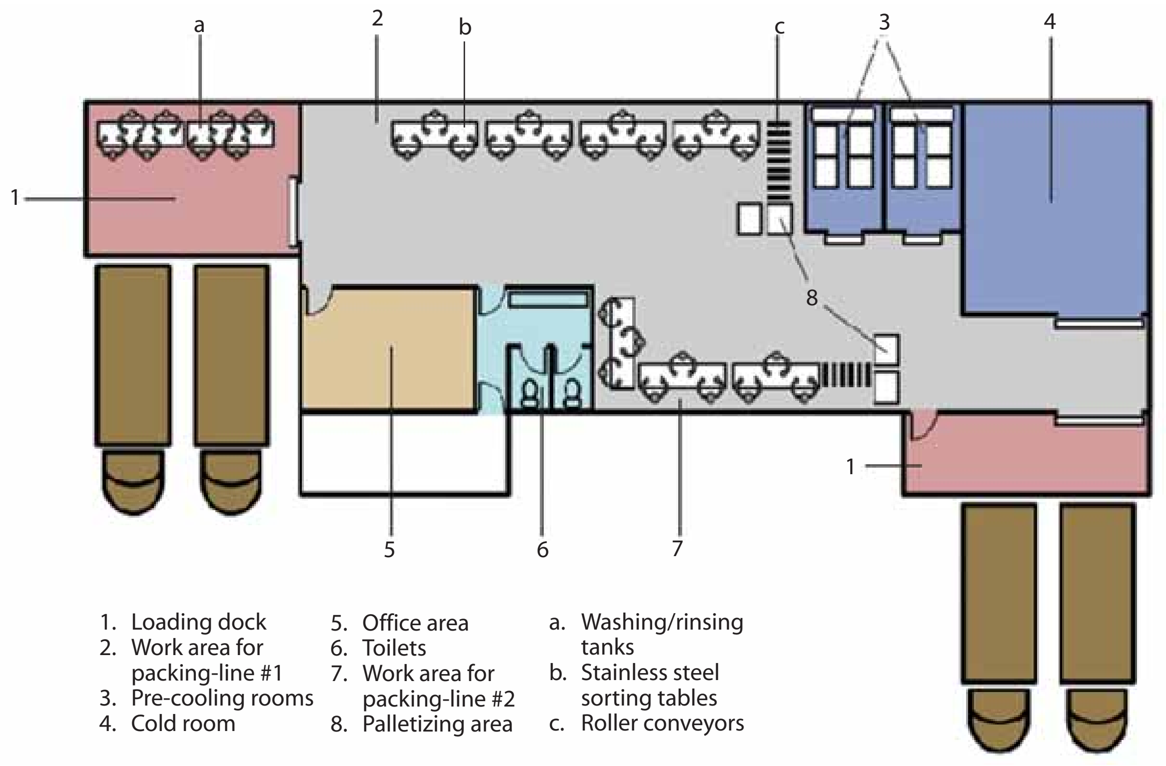


Figure 3.4 Floor plan layout of a packing-house equipped with two packing-lines (adapted from Kitinoja 2007)

Figure 3.5 shows the layout of a packing-house facility in an L-shaped configuration with a wide central corridor. The corridor begins at the main entrance from the enclosed receiving area and ends at an enclosed and refrigerated loading dock.

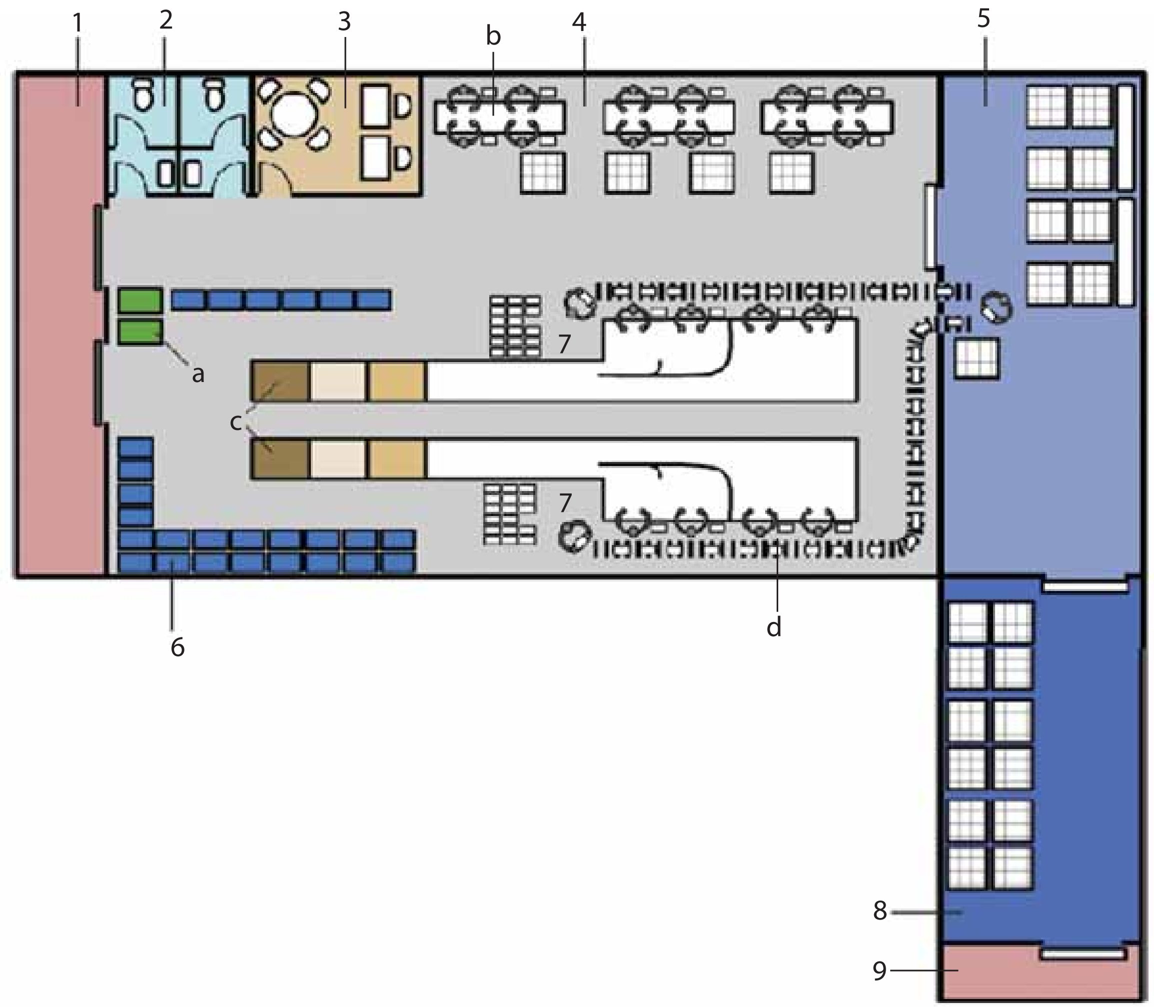
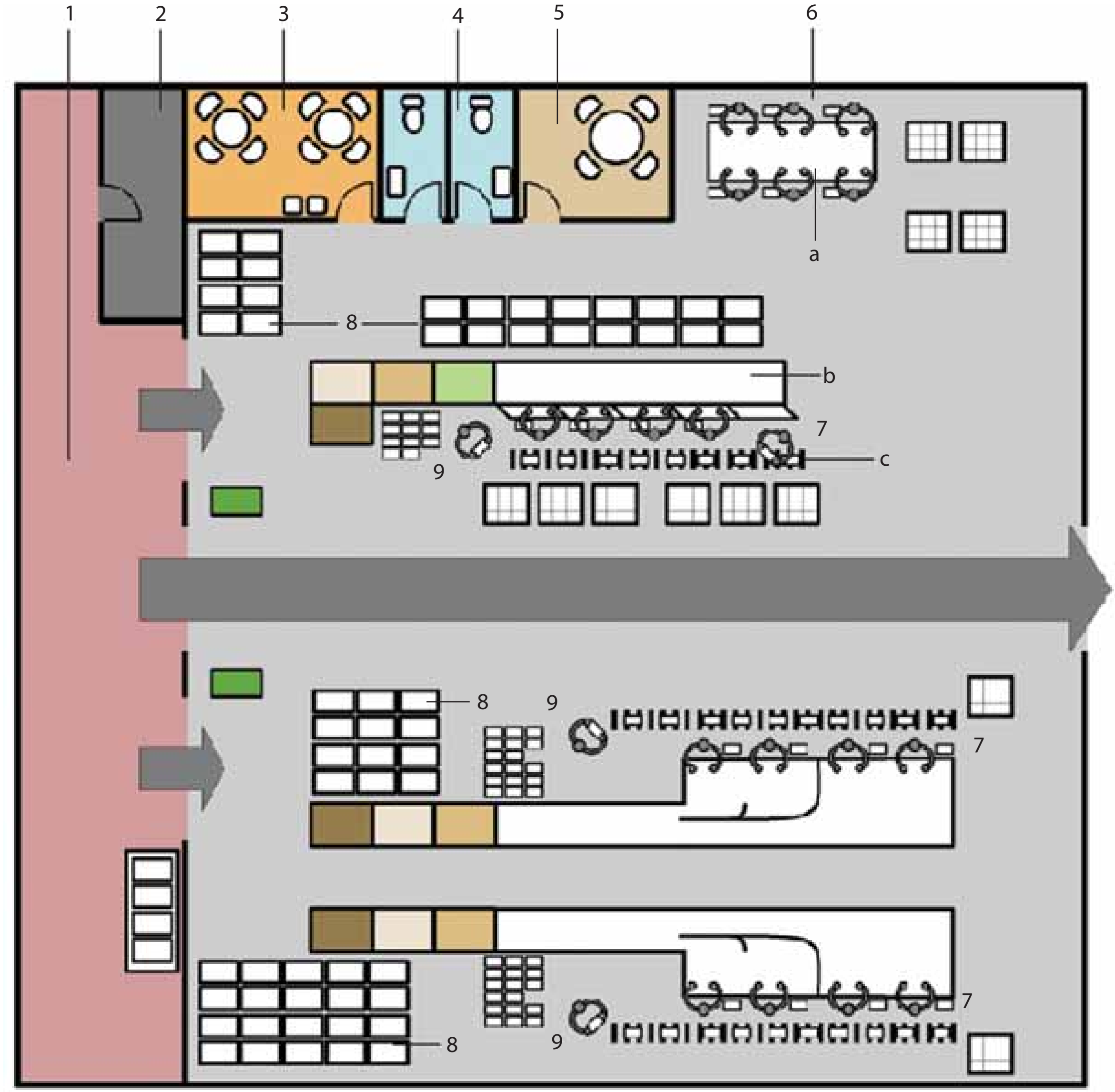


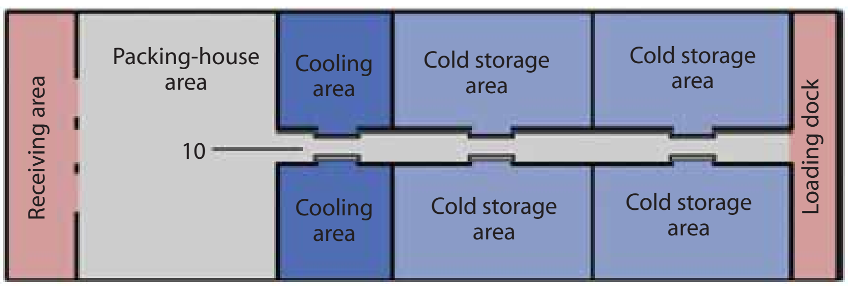
Figure 3.5 Layout of a packing-house facility in an L-shaped configuration. Areas include a receiving dock (1), restrooms (2), office space (3), packing area for small volumes of produce (4), pre-cooling area (5), temporary holding of incoming produce in crates (6), assembly area for cartons (7), cold storage (8) and a refrigerated loading dock (9). Equipment includes weighing scales (a), sorting and grading tables (b), a mechanized packing-line for large volumes of produce (c) and conveyors (d). Adapted from USAID (undated)

Figure 3.6 shows the floor plan for a facility equipped with four cold storage rooms (Figure 3.6 a, b) that offer flexibility with respect to temperature and capacity. Each room can be set to a different temperature; rooms can be shut off as produce volume decreases. The floor plan also includes four packing lines.

A cross-docking arrangement can be used for a packing facility whose main function is the distribution of multiple types of produce from a variety of sources to different clients and/or buyers. The packing facility serves to coordinate shipments from suppliers and deliveries to buyers. A cross-docking arrangement allows a significant volume of deliveries to immediately be loaded onto delivery trucks after sorting, grading, cleaning, trimming and repacking (Figure 3.7). This can result in minimal inventory, while benefiting from large-volume shipments from suppliers (Bozarth and Handfield 2008).



(a) Packing area



(b) General layout of the facility

Figure 3.6 Schematic of a floor plan for a facility equipped with four cold storage rooms. The packing area (a) includes a receiving area (1), storage room for packaging materials. (2), cafeteria (3) and toilets (4) with hand-washing facilities, an office (5), manual sorting area for small volumes of produce (6), mechanized sorting and packing areas (7), areas for temporary holding of produce in crates (8) and areas for box preparation (9). The facility also includes cooling areas and cold storage rooms (b). A central corridor (10) leads to a refrigerated loading dock. Adapted from USAID (undated)

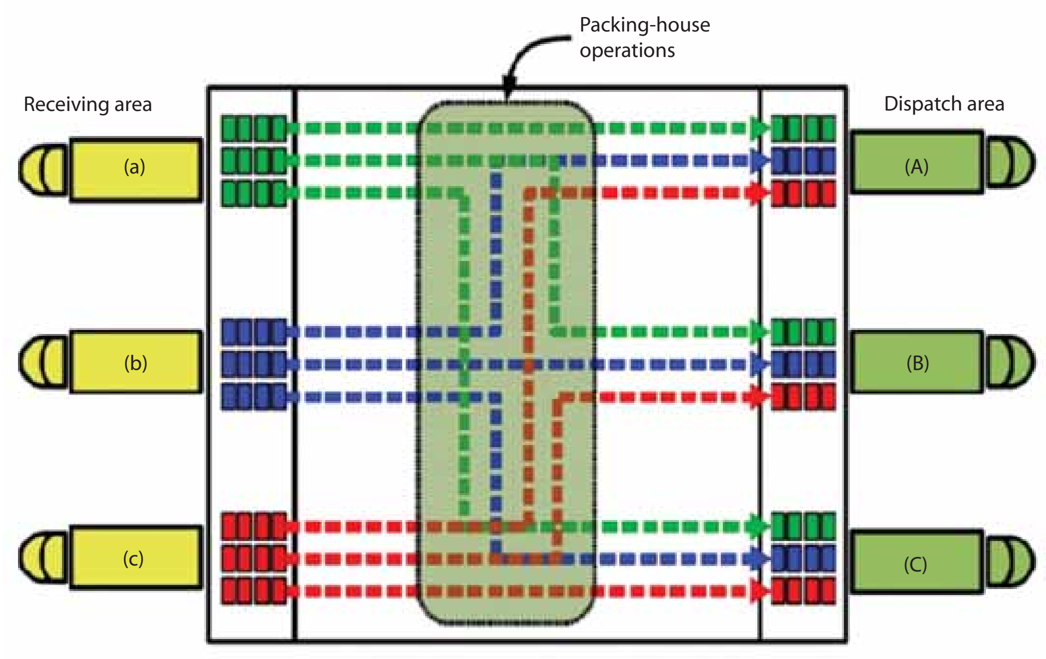


Figure 3.7 Cross-docking arrangement for a packing facility used for distributing fresh produce from different farms (a, b, c) to various market outlets (A, B, C). Produce undergoes various packing-house operations before being assembled into different queues ready for loading and dispatch into delivery vehicles

3.2 Elements of construction design and finishing

Basic structure

Roof

An overhanging roof extension gives some protection from direct sunlight and rain. An overhang of at least 1 metre is recommended for this purpose. Hanging canvas or plastic tarpaulins along appropriate sides of the structure can provide more shade.

Where cross-winds are insufficient, a monitor-type roof may be used to allow hot air to rise to the ceiling and escape through the roof, letting cooler air enter the packing-house. To take advantage of winds and improve ventilation across the facility, the roofline should be about 3 metres above the floor of the packing-house. Greater heights may improve ventilation to some extent, but will increase construction cost and allow more sunlight to enter the facility.

For facilities with a wooden roof, the wood should be treated with preservative to minimize dry rot or termite infestation. A metal roof should be coated with anti-rust paint.

Galvanized iron sheet roofs are more durable but radiate heat to the work area. Insulation (polystyrene or laminated plastic sheets) may be added to the underside of the roof to prevent this occurrence. Where possible, translucent corrugated roofing panels can be used to provide natural light within the pack-house during daytime. Any roof vents should be screened to prevent the entry of insects, birds, rodents and other animals.

Framework

By using steel materials and with a properly designed framework and trusses, structural columns or posts may be minimized to maximize the floor area of the facility and facilitate movement of material and personnel.

Due to limitations in the strength of bamboo, wood and coconut lumber, more posts and columns may be necessary when using these materials, especially for large structures. These materials are better suited for field packing sheds and stations.

Flooring

Concrete floors with a smooth finish that are impervious to water and with no seams or cracks are ideal for packing-houses. There should be no depressed areas in the flooring that would allow the accumulation of water. To facilitate cleaning, wall-to-floor junctions should be coved as shown in Figure 3.8. Corners formed by two walls and the floor should be filled in and rounded for easy cleaning.

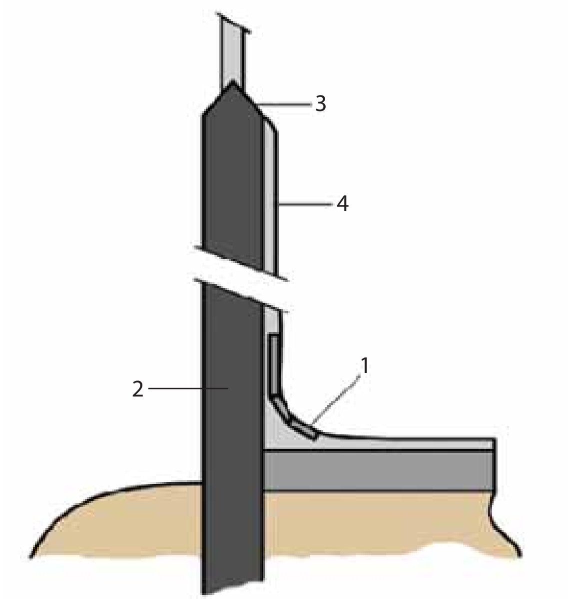


Figure 3.8 Floor and wall finishing, with corners coved in tile segments (1), smooth, hard and impermeable exterior finish (2), wall ledges inclined at 45º (3), and hygienically-surfaced interiors (4) (PAES 2002). The height of the wall surfacing should be appropriate to operations

The thickness of the floor should take into account the maximum expected load during use. For most applications, a 10-centimetre thick concrete slab reinforced with wire mesh or iron bars is sufficient. For very heavy loads, thickness should be increased to 13-15 centimetres (Flores and Gast 1992).

A produce handling area is generally always wet and must be well drained; hence, the general floor area should have a slope of 2-4 percent in the direction of a floor drain (PAES 2002). For cold storage areas, a slope of 1 percent every 30 centimetres can be used. For preparation areas with higher sanitation requirements (such as for salad vegetables), the required slope is 1.5 percent for every 30 centimetres. The direction of the slope should be from clean areas towards receiving areas for raw materials (Lipschutz 2007). Sanitary sewer lines should be separate from floor drains to prevent cross-contamination from the back flow of sewage.

The surface of the floor should be suitable for packing-house operations. Ideally, the material should be waterproof, non-absorbent, washable and non-slip. It should be easy to clean and disinfect, and should be kept in good repair. Special paints are available as a coating for concrete floors of packing facilities. The flooring should be periodically checked for deterioration such as cracks, accumulation of chemicals and plant latex. Areas of heavy use should receive special attention (for example areas with considerable forklift traffic, washing or dipping areas using chemicals).

Although more costly, it is recommended that the floor level of the packing facility be raised to the standard truck bed height to reduce worker fatigue, minimize mishandling of produce and promote the use of forklifts, pallets and roller conveyors.

- Use a height of 1.2-1.4 metre for large trucks, and 66-81 centimetres for small trucks or pickups. Adjustable ramps can help compensate for variations in the height of different vehicles (Kitinoja and Kader 1995; ASHRAE 1998).
- If sufficient space is available, the parking lot of a packing-house can be sloped down gradually so that the floor of a vehicle is level with the packing facility. The slope should not be so severe as to cause container stacks to tip over. This would be the preferred option.
- For inclined areas, the location of the site should be planned so that the floor level of the packing-house is at the same height as a standard truck bed.

Doors and doorways

To allow easy passage of palletized containers, doors should have a width of at least 1.5 metres. To prevent entry of pests, doorways can be fitted with screened doors, plastic strip curtains or air curtains. Plastic strip curtains are heavy plastic strips attached to the top jamb of a doorway. These allow passage through the doorway and fall back into place once a person has entered. Screen doors and strip curtains can, however, allow the entry of pests while a pallet load is passing through. Air curtains provide a continuous barrier of moving air but are more expensive and consume power continuously. An alternative is to construct a short passageway with screened double doors at each end (Figure 3.9).

The size of the passageway should be sufficient to allow the door at one end to close before the load starts to pass through the second door. Electrified insect killers should be installed inside the passageway to eliminate any insects that manage to enter the passageway.

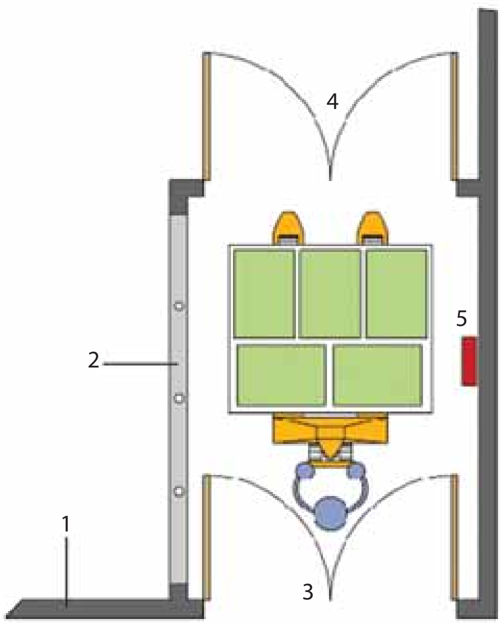


Figure 3.9 Passageway with double doors for compliance with quarantine regulations. The passageway is formed from the exterior walls of the facility (1) and a screened partition (2). The first set of doors (3) must close before the second set (4) is opened. An electrified insect killer (5) should be installed within the passageway

To eliminate hiding places for pests and accumulation points for dirt and debris, the junctions between door jambs and walls should be sealed with a sealing compound that cures and dries into a flexible seal. Solid doors should be smooth, non-absorbent and easy to clean and disinfect. Gaps between the door and door jambs should not exceed 3 millimetres. These should be checked periodically because gaps can develop over time as door hinges deform or come loose.

Walls

For a fully equipped packing facility, concrete walls are recommended. These should be made of non-absorbent, dust- and pest-proof materials. Walls should have a smooth finish and be painted in white for easier detection and removal of dirt, mould and insect infestation. As the tops of walls and ledges tend to accumulate dirt, water and debris over time, they should be constructed with a slope of 45^{o} (Figure 3.9).

To facilitate cleaning, floor-to-wall and wall-to-wall junctions should be coved to a minimum radius of 5-6 centimetres. This can be done using tile segments as shown in Figure 3.9.

Ceiling

Ceilings and ceiling fixtures should be designed for minimal accumulation of dust. Acoustic board tends to shed particles as it ages and may not be suitable as ceiling material. Painted plywood panels are more suitable. The distance between the finished floor line and the ceiling should be at least 2.4 metres. Ceilings should be painted white for easier detection of any deterioration such as flaking and accumulation of dirt, cobwebs and mould.

Windows

All windows should be screened to prevent the entry of insects, birds, rodents and other pests. Screen openings should not be larger than 3 millimetres, and should be removable for easy cleaning. To prevent window ledges from being used as shelves, they should be sloped at 45°. The windowsill should be raised 1 metre above the floor line.

Windows should be easy to clean and must be fitted with removable screens that are insect-proof. Single-pane windows are easier to clean than are jalousies/louvres. If the area is prone to windy and dusty conditions, the use of fixed windows should be considered; this will require the use of air-conditioning for comfortable working conditions.

Ventilation

Keeping an entire packing facility cool can be expensive and impractical. An inexpensive and simple method of spot cooling by convection can be done using blowers and fans directed towards the work area. Evaporation of perspiration will provide acceptable/tolerable working conditions. The use of commercially available evaporative coolers may also increase the cooling effect. However, the increase in humidity caused by these coolers may need to be offset by blowing in fresh air from the outside.

Restrooms should be equipped with exhaust fans that vent directly to the outside environment. Restrooms should not be located near clean areas or areas with finished produce. They are preferably located near receiving areas for raw material.

The use of cellulosic evaporative cooling pads as wall panels can help reduce air temperatures in the working area. Sufficient exhaust fans should be provided to ensure enough airflow through the pads. Alternatively, portable evaporative coolers can be used to provide some measure of cooling for specific work areas (Photo 3.2).

Photo 3.2 An evaporative cooler that makes use of cellulosic pads (inset) as wetted media

A good ventilation system is required to minimize odours and vapours (including steam and noxious fumes) in areas where they may contaminate the produce or packaging materials. There should be no dust or condensation in areas that can contaminate produce, packaging materials or packing-house equipment. Ventilation equipment should be provided to maintain the required air exchange rate.

Lighting systems

Adequate lighting is needed to allow proper sorting and grading. Light intensity should be high enough to minimize eye strain without producing glare. The colour of light should not hide dirt or decay, nor should it affect the colour of the commodity being sorted or packed. Ideally, the light produced should make defects stand out against the surface of the commodity (Hyde 1991). As a guide, lighting in work areas for fresh cuts should be 550-750 lumens/metre (Lipschutz 2007). Lighting requirements for other areas are given in Table 3.1. Light sources should illuminate the working area evenly. Workers should not work in their own shadows or be blinded by direct glare.

Table 3.1 Light levels and bulb requirements

A. Light levels for specified areas	
Area	**Light intensity (lux)**
Outside the facility	100
General	200
Working tables/ surfaces	500

Source: PAES (2002)

B. Bulb requirement per square metre		
Light levels (lux)	**20-W bulb**	**40-W bulb**
500	0.782	0.266
400	0.546	0.213
300	0.409	0.160
200	0.273	0.107
150	0.205	0.080
100	0.136	0.053
50	0.068	0.027
10	0.014	0.005

Overhead lighting fixtures should be installed flush with the ceiling to minimize the accumulation of dust and debris. A translucent plastic shield (Figure 3.10) should be provided to protect the work area from contamination by broken glass, dust or dead insects. When changing light bulbs located over equipment, a sheet of canvas should be used as a cover in case of accidental breakage or dropping of the bulb.

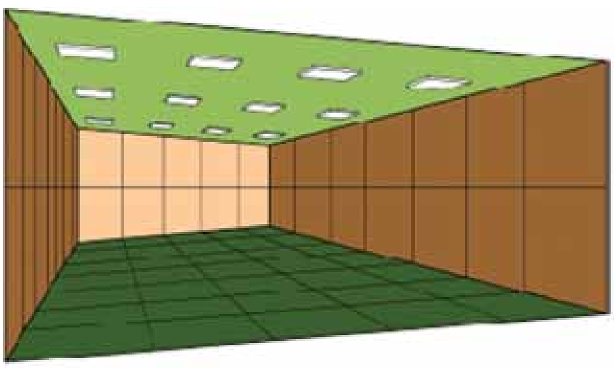


Figure 3.10 Fluorescent lighting fixtures mounted flush with the ceiling and equipped with plastic covers

Electrical wiring system

The wiring system of the facility should comply with safety standards. Wire sizes must be sufficient to carry electric current without overheating. Undersized wires can overheat, resulting in cracked or melted insulation and can cause fires in extreme cases.

The floor area of the packing facility must be free of criss-crossing cables and must allow the free movement of materials, equipment and personnel. Electrical sockets servicing equipment can be suspended from ceilings for this purpose; sockets must be lockable with plugs to provide safe and secure connections.

Water supply

Water supplies for the packing facility should be potable. Water pressure should be adequate to supply all faucets, equipment requiring water and any operations requiring pressurized water (such as washing containers). A pressure of 414 kPa (60 psi) supplying 6.3 L/sec (100 gal/min) should be adequate for general purposes. A pipe having a diameter of 5 centimetres (2 inches) for water mains and 2.5 centimetres (1 inch) for lateral supply lines should be adequate for most purposes (Picha 2004).

Sources and piping systems

For proper cleaning of a facility, sufficient hose stations positioned strategically around the structure should be installed. Hoses must be sufficiently long so as to ensure all locations can be reached without the need for draping or hanging the hose on to equipment. Ideally, each hose station should have its own hose and hose hanger. Cracked hoses should be immediately replaced.

The source of water should be identified and its microbial and chemical quality tested in order to ascertain its suitability for different packing-house operations. Water supplies should be adequate and of a quality appropriate for use in a fresh produce handling operations. The quality of water that comes in contact with fresh produce during preliminary dumping, washing, disinfecting, cooling (hydrocooling, icing), and other operations where water is used or added as in fungicide or wax application, is as a control point in a Hazard Analysis and Critical Control Point (HACCP) plan.

If water comes from wells, pump pressure should be adequate to carry water to all required locations in the packing-house. Back-flow devices can be installed to prevent contamination of clean water with potentially contaminated water (such as between potable water fill lines and dump tank drain lines). There should be separate lines, preferably using colour-coded pipes, for water used for different purposes.

Non-potable water in the facility is used for fire control, steam production or for refrigeration. Non-potable water should have its own separate distribution system that is easily identified (for example colour-coded). There should be no possibility of any backflow into the potable water system (CAC 1969).

Drainage

Drains should be constructed in order to facilitate drainage, especially in areas where floors are subject to flood-type cleaning or where operations discharge water or liquid waste on the floor. Drains should flow from the end of the packling line to the receiving area of raw materials to avoid contamination.

Backup sources

If the supply of water is subject to interruption, or pressure is too low, a storage tank should be installed outside the facility. This can be mounted on concrete pillars or a steel tower (Figure 3.11) of sufficient strength to support the load safely. The tank should be able to supply water requirements of the facility for at least 24 hours.

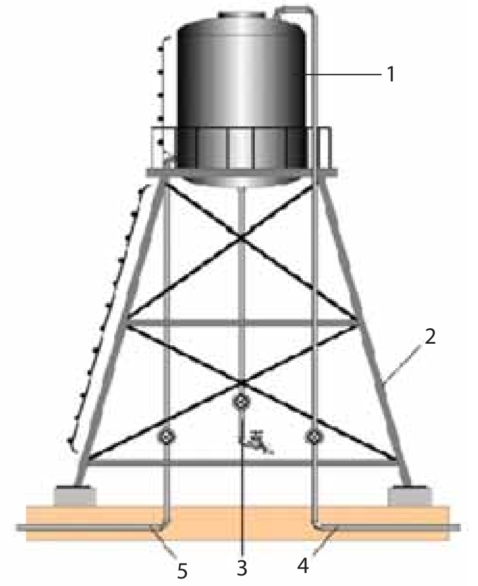


Figure 3.11 Schematic diagram of a water storage tank (1) with steel tower (2). The drain pipe (3) is connected to the lowest part of the rounded base of the tank. Separate pipes are used to supply water to the tank (4) and the packing facility (5)

The tank should have a sloping or rounded base to allow for easy draining and cleaning. It should be fitted with a drain pipe with valve at the lowest point of the base to allow accumulated sediment to be removed. The pipeline bringing water to the packing facility should tap into the tank above the base to avoid including sediment with the water (PAES 2002).

Water supplies should be sufficient, clean and potable. Water pressure should be adequate to supply all installations requiring water: lavatories hand-washing stations and preparation rooms.

Backup power

Depending on the requirements of equipment to be installed in the facility, single-phase or three-phase service may need to be installed by the power company. A backup power supply should be available to ensure that operations can continue during a power interruption. Diesel generators are usually used for large applications; the unit to be purchased should be sufficient to operate the entire facility.

Chapter 4
Operation and management of the pack-house facility

4.1 Principles of good manufacturing practice

Good Manufacturing Practice (GMP) includes a set of manufacturing and administrative procedures that ensure that produce is able to consistently meet specifications and customer expectations (de Silva 2007). The aim of Good Manufacturing Practices (GMPs) is to reduce the risk of contamination of fresh produce during handling, packing, storage and transportation. GMP is composed of three main elements, namely food safety, good practices and quality of the product. Together these elements contribute to produce that is safe and of good quality. Adoption of such protocols allows a food business to obtain a competitive advantage over other companies.

Three complementary components form the basis of an effective GMP programme: (1) manufacturing operations, (2) food control operations and (3) management (de Silva 2007).

1. *Manufacturing operations* – to be effective, all aspects of produce handling must be clearly defined and capable of achieving the desired result, which is a safe and high-quality fruit or vegetable. To be able to achieve this result, the required facilities and equipment must be provided:
   - Sufficient work space that meets national (or depending on market – international) statutory health and safety specifications.
   - Appropriate equipment that is properly maintained.
   - Personnel with the appropriate and updated training.
   - Appropriate raw material and packaging material.
   - Appropriate storage and transport conditions and practices.
   - Documented and verifiable procedures for all operations.
   - Management and supervision that is knowledgeable and updated on current issues, practices and recommendations.
   - Sufficient administrative and technical support.
2. *Food control operations* – the packing facility must have infrastructure and trained staff capable of:
   - Testing and evaluating samples.
   - Monitoring conditions during handling within the facility.
   - Transmitting feedback to the proper personnel to adjust for problems discovered during post-harvest handling and treatment.

3. *Management* – senior-level managers of a packing facility are responsible for achieving GMP objectives. Managers must be able to obtain the active participation and commitment of personnel in the packing-house, all of whom are interacting with each other. Support and commitment of suppliers of raw material and packaging materials are also needed to attain GMP goals.

   Reaching GMP goals requires a comprehensive and effective system incorporating basic concepts of quality assurance, quality control and GMP.

   Ensuring that personnel are properly trained and updated is also the responsibility of senior management.

A packing facility must be able to meet company and customer requirements, and comply with industry codes, standards and regulations. Figure 4.1 shows the basic process for producing a satisfactory end product, as well as being able to demonstrate the process used for making that product.

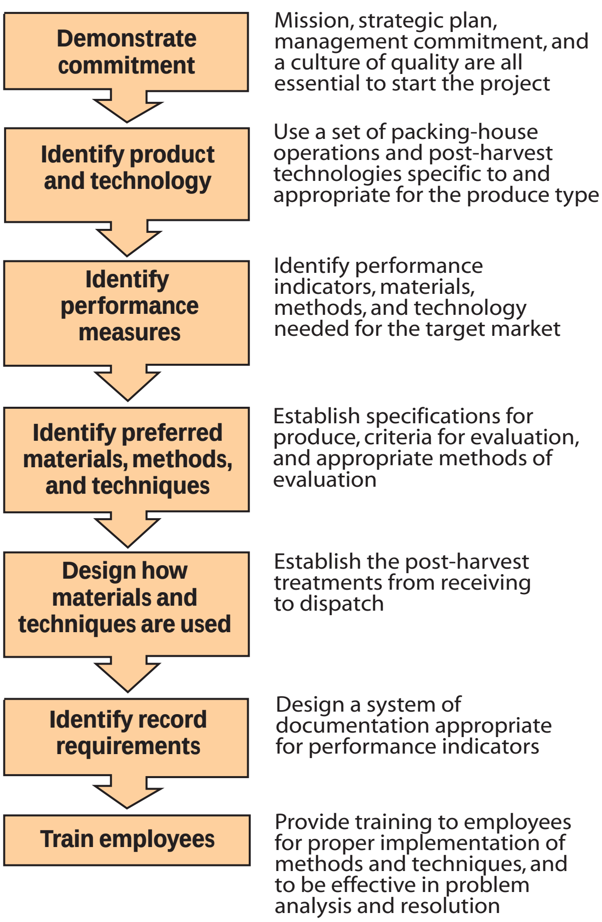


Figure 4.1 Basic steps of a GMP plan (de Silva 2007)

Benefits of applying GMP

The advantages of having a GMP system in place include:

1. Increased awareness of the importance of food quality and safety among personnel. This helps to create a culture of safety and quality within the company.
2. Confidence in safety of the produce is increased.
3. International recognition can be attained, along with expanded market access.
4. Allows the final product to meet regulatory requirements and prevents costly failures.
5. Cuts down on customer complaints and product recalls.
6. Profit is improved.

GMP activities

Activities associated with GMP include (de Silva 2007):

1. *Staff hiring* – the packing facility should be staffed with sufficient personnel with the proper qualifications and training to be able to perform their assigned duties and responsibilities. Job descriptions should be clear to personnel before starting work. If training is necessary, it should include GMP principles, hygiene and the specific task assigned.
2. *Training and personnel hygiene* – each worker must be capable of performing the assigned task, as well as being properly oriented on personal hygiene and food safety. Any training programme must be appropriate to the operations in the packing facility, and to the educational attainment of its workers.
   - Recruitment and induction:
     - o The basis for recruiting and selecting employees is their ability to do an assigned task, as well as their willingness to learn new skills should training be required.
     - o A clear description of a position or job, accompanied by the required skills and competencies, must be established and provided to prospective applicants. Senior management must then assess whether applicants are able to fulfill the requirements with their previous experience or with further training.
     - o The new employee is indoctrinated with the company culture and philosophy during the induction process. During this period, the new worker is introduced to the nature of the packing facility, its system of ensuring safety and quality, and expectations of the company. The organizational structure, duties and responsibilities of the job, and the disciplinary system of the company must be clearly explained.
   - Competence and training:
     - o By definition, a competent worker is one with the ability to use knowledge and training to fulfill an assigned task completely without the need for assistance or supervision.

- o Training programmes for the packing facility should cover principles of GMP, hygiene, quality management and basic concepts of post-harvest technologies for perishable crops. Course content should emphasize the perishable nature of fresh fruit and vegetables, the need for food hygiene and the consequences to the organization for non-compliance. Senior managers should review training requirements regularly to assess whether new training is needed, as well as for refreshing previous programmes.

- Food hygiene requirements:
  - o Requirements for maintaining food hygiene in the packing facility should be covered during training. These include wearing proper protective clothing, learning appropriate personal habits and preventing spread of disease.

3. *Design of building and facilities* – location, design and construction of the packing facility should allow individual operations to be separate from each other to prevent mistakes, cross-contamination and deterioration; however, the sequence of operations should be smooth for efficient movement of materials and personnel. Working areas and premises (interior and exterior) should be clean, orderly and constructed such that buildup of contaminants (dust, microbes and decaying organic matter) is avoided. Control of the working environment is required (lighting, ventilation, comfortable working temperature, washing and sanitary facilities), as well as the storage environment of fresh produce (temperature, RH, gas levels, odours).

4. *Design and selection of equipment* – equipment should be appropriate for its assigned use; cleaning and maintenance should be conducted regularly and repairs carried out promptly when needed. Produce contact surfaces should not be a source of contamination, (for example latex, juice). Equipment should be designed for easy cleaning, sanitizing and drying.

5. *Control of components* – fresh produce and packaging materials coming into the packing facility should only be sourced from suppliers approved by a quality control officer. Suppliers should be subjected to the following criteria to obtain accreditation:

   - The supplier must comply with company requirements (volume, frequency, reliability of supply etc.) and specifications (such as size, variation, quality).
   - The supplier must have an effective food safety programme.

   Measures should be in place to prevent contamination before delivery and once the components have been accepted. On arrival at the packing-house, status of components may be classified as follows:

   - HOLD – produce with questionable status (e.g. too small, showing signs of pre-harvest disease, etc.); state the reason for holding.
   - QUARANTINE – materials that still need to be evaluated; state the reason for holding under quarantine.
   - REJECT – materials that are damaged or diseased.
   - PASSED – materials that can be used for production.

Criteria for determining the status of components include certificates of conformance and test results, identification upon receipt of material, full analysis or a combination of these three criteria.

Holding areas for materials classified as HOLD, QUARANTINE and REJECT should be assigned and separated from other working areas. Materials should be labelled with stickers or tags showing their present status.

During storage, fresh produce and packaging materials classified as PASSED should be regularly checked to ensure that their condition remains acceptable.

All components received, issued or delivered should be documented and traceable at all times.

6. *Production and process control* – the basic requirement of a properly functioning packing-house with an effective system of GMP is that the individual operations performed during the handling and treatement of produce all work together to maintain the quality and assure the safety of produce. Effectiveness of the entire process of production can be determined prior to full-scale activities by conducting a series of carefully controlled check runs. These check runs serve to identify possible problems that may occur when the facility is operational; managers can then propose solutions for testing and evaluation. Before the start of any production activity, a thorough check should be performed to make sure that: (a) working areas are free of potential contaminants, (b) the correct packaging materials are ready and sufficient, (c) arrival of raw material is known and confirmed and (d) equipment has been pretested, cleaned and is ready for operation. Instructions for each operation should be accessible at each workstation in the form of a manual (which is laminated or protected by plastic covers for protection against moisture and stains) that uses clear and simple language and terms that can be understood by operators.

   Controls during washing and treatment:

   - All data related to treatments must be recorded, including operating conditions (air and water temperature, RH, chlorine concentration, pH etc.) and quality attributes (such as visual quality, number of defects, incidence and severity of decay). As data accumulate, statistical analysis can be performed to determine the expected range of values for various conditions and parameters. This will help locate any deviations from the norm and pinpoint possible problems immediately. Monitoring of conditions will also show if equipment is operating properly, if the level of sanitizers in wash water is adequate, if the produce is contaminated or damaged during the treatment process.
   - Any interruptions, bottlenecks, breakdowns or emergencies occurring during the process should be recorded; problems causing these events should be identified and addressed immediately. The type of tests for identifying problems must be specified, as well as the intervals of testing. The operating limits of equipment and in a process should be known.

- To enable traceability, a method of identifying batches of produce (for example, bar coding systems with stickers/tags and scanners) should be in place. Relevant information about each batch of produce including farm source, harvesting and packing dates, size and/or number of items packed, packaging material, destination market, delivery vehicle used and names of the food handlers should be recorded.

Controlling treated produce:

- Authorized personnel involved with quality control should evaluate produce prior to its dispatch to markets or clients. Produce that does not meet appropriate quality standards should be quarantined and labelled as such. Sufficient samples of produce should be gathered and an appropriate sampling protocol should be followed to ensure that results are representative of the batch of produce being tested. Produce should be kept under optimal storage conditions before and during delivery to market.

7. *Packaging* – packaging materials are often in direct contact with fresh produce and therefore, should:
   - Be manufactured using food-grade material.
   - Protect produce during its expected life span under normal conditions.
   - Act as an effective barrier against moisture loss.
   - Maintain the characteristics and integrity of the produce.
   - Be appropriate for fresh produce.

   In addition, packaging should provide sufficient information on proper storage and handling of produce, as well as a unique code to be used for identifying produce batches for recall.

8. *Cool storage* – this is needed to reduce the rate of deterioration and ageing of fresh produce, as well as materials for packaging. This involves (a) periodic inspection and evaluation of incoming and outgoing produce to detect any signs of deterioration; (b) monitoring and maintaining the correct conditions for storage of materials; (c) cleaning and sanitizing of storage space to maintain hygienic conditions; (d) controlling pests and disease; (e) maintaining proper movement and utilization of the inventory (first-in first-out, or first-expiry first-out basis); and (f) segregation of harvested produce from cleaned, packaged and treated produce.

9. *Distribution* – although this activity occurs outside the packing facility, it is essential that produce is distributed by approved shippers. All the effort expended in producing first-class produce should not be compromised by faulty methods of transporting produce to different markets. Senior management must ensure that shippers have vehicles that are in good condition and operate properly, as well as having an effective cleaning programme.

10. *Laboratory testing* – this is required to ensure that produce conforms to specifications determined by safety regulations and to requirements of target markets. Laboratory results must be reliable and trustworthy.

Requirements for good laboratory results include:

- Sufficient qualified and competent personnel with proper training.
- Documented methods of sampling (statistical design, equipment for sampling) and criteria for receiving, accepting and rejecting samples. There should be clear and complete information to facilitate traceability.
- The laboratory facility and environment should be properly maintained, compliant with regulations and suited for conducting tests.
- Equipment should be appropriate for the tests being performed, well-maintained and regularly calibrated, upgraded or replaced if necessary and with clear instructions for proper operation.
- Test methods should be acceptable; chemical reagents and other supplies should be replaced regularly, and a procedure for confirming abnormal test results should be in place.
- Records should be maintained and managed well, with a test result traceable to a specific sample, as well as the person conducting the test. Computerized records should have backup copies, be easily retrievable and unaffected by changes in software versions.
- Test reports should include the name of the laboratory, source of the sample, test method used, accuracy and precision of the test method, date of testing, test results and signature of the analyst.

11. *Documentation* – provides concrete proof that a process has been followed and was either successful or not. This activity aims to: (a) clearly define produce, treatments, control measures and final products; (b) record information on different aspects of the post-harvest system in the packing facility from receiving until dispatch; (c) minimize errors due to miscommunication; (d) assist investigations in case of problems with the produce. Documents can be classified into three main types:

    - Instructions and procedures – these describe the best way to perform a task efficiently and effectively in a safe manner. Both combine best practices gathered from previous experience.
    - Programmes – these are activities carried out by the company in order to meet objectives. They include programmes for production, training, pest control, waste disposal and sanitation and hygiene.
    - Records and reports – data gathered before, during and after the production process is needed as proof of the safety and quality of the final product.

    Documentation must be maintained even after the expected shelf-life of the produce. The duration is specified by regulations or according to company needs. For easy retrieval, correction and updating of documentation, a control system must be used. Information contained by the system may include the title, date of issue, document reference number, names and signatures of personnel, page numbers and changes made.

12. *Cleaning and sanitation* – cleaning involves removal of soil and organic residues (such as latex) from raw material, containers and equipment. Sanitation is defined as the reduction of microorganisms to a level that is safe for humans. Both processes are essential to a hygiene programme that must be evaluated for its effectiveness.

13. *Repair, maintenance and calibration* – these activities are necessary for safe, effective and efficient operation of the packing facility and its equipment.

    - Repair – the company must specify the standard of service required if repairs are performed by outside contractors. Repairs should be done under guidelines established for food hygiene and other requirements.
    - Preventive maintenance – this is needed to avoid unnecessary delays and downtime by replacing components, instruments or equipment before any serious breakdowns occur. Minor breakdowns should not be ignored and must be reported, investigated and resolved.
    - Intrusive maintenance – involves carrying out maintenance work while operations are in progress. During maintenance work, safety and quality of the product must not be affected. As contaminant levels (dust, broken glass for example) or changes in the environment (such as smoke, paint fumes) may occur, precautions must be taken to protect raw materials, packaging materials and finished products.
    - Calibration – involves adjusting a measuring instrument so that its output is within a specified range for a known value of the input. Ideally, calibration of instruments is performed by accredited organizations using a traceable standard. Frequency of calibration should depend on the nature of the measurement, the environment surrounding the instrument and deviation history of the instrument. The more critical the measurement, the more frequent the calibration should be. Instruments or equipment that do not conform to calibration standards should not be used.

14. *Pest management* – maintaining a clean facility is the most effective method of keeping pest infestation levels to a minimum. This will reduce the spread of microorganisms and attenuate contamination.

15. *Foreign matter control* – foreign matter can enter the packing facility from external and internal sources. Pests, raw materials and packaging are usually the source of external foreign matter that can include animal droppings, stones and plant matter. Specifications for raw materials should include limits on the amount of foreign matter present. Internal foreign matter can come from the facility itself (buildings, equipment), surface coatings and finishes, tools and personnel. To reduce the risk of contamination, inspections should be done at key stages of production.

16. *Waste management* – packing facilities generate much waste, mostly in the form of fruit and vegetable rejects, decaying plant material, used packaging material and used chemical solutions. Minimization of waste is very important especially with the worldwide focus on environmental management. A waste management programme must have proper procedures, accountability for concerned personnel and complete and accurate documentation.

17. *Responding to customer complaints* – customers are a good source of feedback on food quality and safety. Therefore, a procedure should be in place to receive, document, investigate and act on any complaints that may arise. Any response should be in the shortest possible time to quickly contain possible outbreaks of disease and minimize the potential damage to the reputation of the facility. The procedure must include:
    - Clear instructions for receiving and responding to complaints.
    - Designated personnel authorized to decide on the extent of investigations and corrective actions.
    - A documented process for recalling products.
    - A process for investigating and responding to complaints.
    - A process for preventing recurrence of the problem if the complaint is justified.
    - Periodic reviews of past reports to detect trends.
18. *Audits, reviews and product recalls* – audits and reviews serve to verify that GMP activities are effective. Independent examiners (auditors external to the company) conduct on-site inspections, interview personnel and check records. Reviews are regular activities that examine present GMP practices for relevance. This serves as an opportunity to propose changes in the production process. Recall of food products found to be harmful ensures that they are removed from the market completely. Other products made under the same conditions should also be considered for recall. Recalled products should be segregated and isolated from other materials and disposed of properly.

4.2 Sanitation practices

Facility cleaning and sanitation programme

Comprehensive plant sanitation covers three areas: the environment of the facility (interior and exterior), equipment inside the facility and all personnel. An employee who has completed a certified food sanitation programme should be the person dedicated to maintaining sanitation of the facility. He or she must produce a manual on sanitation that formalizes plans and procedures for the facility (Hurst 2002). This manual should include the following elements (USFDA 1998; Hurst 2002):

1. A list of specific areas that must be cleaned and sanitized daily. These areas include restrooms, eating areas, areas for waste collection and work areas (for example, receiving, packing, storage). Prior to cleaning times, any idle equipment, packaging materials, pallets and containers should be removed from the work area. Cold rooms and ripening rooms should be sanitized frequently; schedules should be based on visual inspection. Microbiological samples from work and storage areas can also be gathered to determine the specific organism present. Sanitation practices should be fully documented, including date, time, personnel involved and supervisor conducting verification.

   There should be a written schedule to assure that all listed areas are cleaned and sanitized on a regular basis. This written schedule indicates in detail the area to be cleaned including equipment, sanitation method, tool, cleaning materials and frequency of cleaning.

2. A list of packing-house equipment that should be cleaned and sanitized.
3. A daily log documenting sanitary conditions before and during operations should be maintained and properly filed. Personnel should be observant and must report any unsanitary conditions immediately to appropriate supervisors.
4. A method for identifying containers must be described. Containers used for each stage of handling (receiving, heat-treated, finished product, waste collection for example) must be easy to identify and must never be used for other purposes.

The frequency of cleaning can be daily, weekly, monthly or quarterly depending on the specific areas in the facility, type of equipment and surrounding environment (i.e. rate of accumulation of contaminants). The cleaning procedure should be fully documented and verifiable.

Cleaning and sanitizing involve the following: (1) physical removal of soil particles, dust or plant matter prior to any sanitation steps as many sanitizers are inactivated by organic materials; (2) rinsing with potable water to remove smaller particles; (3) washing with soap and detergent coupled with mild scrubbing of equipment to remove caked particles as well as biofilms; (4) rinsing with potable water to remove detergent; and (5) sanitizing with chlorine or quaternary ammonia to kill microbial pathogens (USFDA 1998) or immersing in hot water at 82°C (de Silva 2007). Directions on the label of the sanitizer and cleaning chemical should be strictly followed.

Sanitizing working areas of the packing facility

1. *Receiving and dispatch areas, and storerooms* – visible soil, dust, debris and unnecessary items should be removed from these areas continuously. A regular cleaning schedule should be followed, as well as on an 'as-needed' basis. Airborne contaminants should be minimized; these can include aerosols produced during pressurized washing.
2. *Cold rooms and cooling units* – the components of a refrigeration system must be cleaned and sanitized regularly. Evaporator and condenser coils are especially prone to accumulating dust due to tight spaces within. Frost also accumulates on evaporator coils and encourages dust accumulation. Floor areas should be kept dry.

   Condensation on cold room walls also encourages mould growth. The pathogen *Listeria monocytogenes* can multiply at low temperatures and under moist conditions. Contamination can occur if condensation manages to come into contact with produce. Quaternary ammonium compounds at 200 ppm can be used to sanitize walls and other refrigerated compartments (Price 1992).

   As evaporator coils are suspended from ceilings and go through defrost cycles, a water line should be installed to remove condensate and defrost water from a storage area. Water should not be allowed to drip onto produce. When not in use, all surfaces and refrigeration components of cold rooms should be cleaned and sanitized. Empty rooms should not be used as storerooms for packaging materials, chemicals, or waste material.

3. General sanitation of work areas and permanent fixtures:

- *Floors* – should always be maintained in a dry condition. Dust and debris must be removed using vacuum cleaners. Brooms can be used but care must be exercised to avoid suspending dust particles in air. A cleanser can then be applied, followed by rinsing and application of a sanitizer.
- *Drains* – Drains must not be used with high-pressure water jets as they can disperse water droplets into the air in an aerosol form and spread contaminants. Blocked drains can be unblocked with the use of a chemical drain opener to dissolve any organic matter causing the blockage. Alternatively, a pipe cleaning tool can be used to physically remove the blockage.
- *Overhead pipes, structural supports, ducts, and fans* – exposed pipes and ducts should be cleaned to remove accumulated foreign matter.
- *Plastic strip curtains* – should be unbroken, clean, mould- and odour-free. Broken strips must be replaced to maintain effectiveness of the curtain as a barrier to pests, air infiltration and produce contamination. When installing plastic curtains, the tip of each strip should be suspended a few millimetres off the floor to prevent contamination of the strip. Produce should not come in contact with curtain tips when passing through doorways. Open containers should be covered with an appropriate cover to prevent such contact.
- *Waste and garbage areas* – these areas should be cleaned and sanitized according to a regular schedule. Waste material should not be allowed to accumulate as this will attract pests and encourage microbial growth. Containers used in these areas should also be cleaned regularly and should not be used for other materials.

Cleaning of equipment in the facility

Standard Operating Procedures (SOPs) for cleaning and sanitation must be developed for specific items of equipment that are cleaned on a regular basis. This assures that equipment is properly cleaned regardless of the specific worker assigned to perform the task.

SOPs identify the following:

(a) *what* – identifies the task;
(b) *why* – describes the purpose of the task;
(c) *when* – frequency of the task;
(d) *who* – identifies the person responsible for the task and
(e) *how* – lists and describes the steps for completing the task.

Sorting, grading and packing equipment – these come in direct contact with fresh produce and can be the source of contamination. They should, therefore, be cleaned on a daily basis.

Sanitation of containers used in the pack-house – reusable containers (such as plastic crates) should be cleaned prior to each use. Plastic containers are preferred because they are easily washed. Wood, burlap and cartons are difficult to wash and can be sources of microorganisms and foreign matter.

Bins and containers used in the packing facility should be non-toxic and free of protruding nails, staples and splinters. They should be inspected regularly and an SOP for cleaning and sanitizing followed:

- Clean the container with detergent, then rinse.
- Sanitize with a chlorine solution using a high-pressure jet of water. As this can produce aerosols, sanitizing should be done outdoors in a clean area. The containers should not come in contact with soil.
- Air-dry containers before storing; sun-drying is recommended.

  The use of colour-coded containers is recommended to prevent cross-contamination. Containers for harvested, graded, washed and reject produce should have different colours.

Storage of cleaning materials

Brooms, mops, dust pans and and other items of cleaning equipment should be stored in a storage area. This area should be located far away from working areas where fresh produce is handled. Brooms and mops should be suspended from hooks to allow them to dry, to avoid contamination from the floor, and to prevent pest infestation. Dust bags of vacuum cleaners should be regularly washed or replaced to avoid accumulation of material in the unit. Separate tools should be used for cleaning food contact and non-contact surfaces. Cleaning tools for restrooms must not be used for other cleaning tasks. Cleaning equipment should be used only for a specific area and must be colour-coded.

Personnel

Personnel working in a packing-house – including production employees, maintenance employees, supervisors and management- can be a significant source of contamination. It is the responsibility of the management of the pack-house to educate and train all produce handlers in the sanitary handling of produce.

Employee consciousness with respect to hygiene must be raised at the start of employment; the company's rules and regulations regarding dress codes and hygiene practices should be provided to new employees. Awareness on the need for sanitation and hygiene should also be refreshed on a continuous basis (Hurst 2002).

Control of the spread of diseases

Employees with open lesions such as boils, sores, exposed infected wounds and food-borne sickness must not be allowed to work in operations in which they have direct contact with produce, during sorting or grading, packing. Bandages should be covered with non-porous covering such as plastic gloves.

Protective garments

Protective garments include aprons, gowns and smocks for the body, rubber boots for feet, gloves for hands and caps, hairnets and beard covers for head and face (Photo 4.1). These garments are generally required for workers handling washed fresh produce. Protective garments are preferably white in colour to allow easy recognition of dirt and other contaminants. Employees should refrain from touching their hair when handling produce.

Photo 4.1 Protective garments for personnel in a pack-house facility. Each worker is fitted with a hair net or cap, gown, thick apron and gloves, and boots. All garments are white for easy detection of contamination

Rubber boots or suitable shoes should be worn in washing and packing areas. These shoes and boots should be worn only in designated areas and should be removed when going outside the packing-house or in the restrooms and washing stations. As shoes and boots are potential sources of contamination, they should be frequently cleaned and sanitized. Cleaning stations for boots and shoes must be in place to reduce the amount of field dirt and contamination when field workers enter the packing-house.

Hygienic practices

Hand washing – One of the greatest potential sources of contamination of produce by human pathogens are produce handlers themselves because they are in physical contact with the produce. Proper hand washing is a necessary part of a programme of good hygiene.

The following should be available in hand-washing stations:

- Non-perfumed, neutral or medicinal soap. It is recommended that liquid soap be provided through a dispenser rather than using a soap bar to prevent cross-contamination.
- Single-use paper towels or hot air driers. Air driers can create aerosols, and should not, therefore, be located within working areas where contamination can occur.

The standard operating procedure for hand washing is as follows (Hurst 2002; Rahman 2007):

- Wash hands in warm water using a sufficient amount of antimicrobial soap; dry hands using a clean cloth or paper towels. Rubbing hands together vigorously for 20 seconds or using a brush with soap is very effective in reducing bacteria. Fingernails and spaces between fingers should also be washed in order to prevent the transmission of microbes from the hands of workers to the produce, and to reduce the population of microbes present. Antimicrobial soap is best used for food preparation and product handling. Skin cleansers with antibacterial properties are effective in rapidly killing most microbes.
- Hands should always be washed during the following times: (a) before starting each shift, (b) after using the restroom, coughs or sneezes, after a rest break, or prior to returning to the work area, (c) after contact with a non-food item (waste material, money, cigarettes/cigars for example).
- Hands must be thoroughly rinsed in water, then dipped in a sanitizing solution for 8-10 seconds before returning to the work area. A 70 percent alcohol solution can be used as a hand sanitizer (Boonyakiat and Janchamchai 2007).

Proper hand hygienic practices can be encouraged with the use of visual cues (including signs and posters Figure 4.2), by education and training and by positive reinforcement.

Figure 4.2 Samples of signage as a reminder for employees to follow and observe food hygiene practices such as hand washing (1 and 2), proper waste disposal (3), careful handling of chemicals (4), refraining from smoking in the working areas (5), and removal of personal items before handling food products (6)

Personal hygiene – the following guidelines on personal cleanliness should be followed by produce handlers (Rahman 2007):

- Fingernails must be kept short and clean. Personnel must wash facial hair a minimum of two times a week, and take daily showers or baths.
- Appropriate clothing must be worn during operations; it should be washed and changed regularly. A hairnet or cap should be used to prevent hair strands from falling onto

produce during handling and packing. Beards must be kept short and covered to prevent contamination of produce with hair strands.

- Nail polish, false fingernails and eyelashes, make-up, wristwatches, jewellery of any kind (earrings, nose rings, wedding bands, bracelets, and other similar items) cannot be used during produce handling.
- Pens, pencils and thermometers should not be kept in employees' shirt, blouse or smock top pockets as they might fall onto containers or produce. Clothes with sequins, pompons or other such embellishments should not be worn.
- Food, drink, sweets and chewing gum should be consumed only in designated areas (such as canteens, rest areas outdoors); food containers should be disposed of properly. Smoking must be prohibited within the packing facility because ethylene present in smoke can accelerate ripening and deterioration, as well as be a source of ash and cigarette ends that can contaminate produce. Spitting in the packing facility must be prohibited, even with the presence of drains.
- Staff with infections or injuries should not handle produce during the period of recovery; a handkerchief or piece of tissue should be used to cover the mouth and nose when coughing or sneezing. Hands must be washed thoroughly after coughing or sneezing. Cases of diarrhoea, fever, common cold or rhinitis should be reported immediately.

Personal habits – personnel should refrain from habits that can result in food contamination such as smoking, spitting, chewing or eating in the produce handling area, and sneezing or coughing over unshielded produce (CAC 1969).

Protective garments – when garments get soiled due to contact with the produce, they should be changed. Likewise, gloves should be changed frequently or following the same schedule as that of washing hands as follows: before starting work, after using the restroom, after handling dirty raw materials or after picking up objects from the floor. Gloves that are reusable need to be cleaned and stored properly.

Protective garments should be removed when employees leave the work areas, especially when they go to restrooms or during breaks. There should be designated areas where protective garments should be left. The possibility of cross-contamination is high if protective garments are left on worktables, on top of packaging materials and floors.

Designated areas for storage of garments should not be close to the toilet facilities.

Pest control

Pests commonly found in a packing facility can be classified into insects (flies, cockroaches), rodents (rats), reptiles (snakes, lizards), arachnids (spiders) and birds. Stray cats and dogs, while not pests because are sources of contamination (faecal matter, animal hair and parasites such as lice and ticks).

Maintaining effective control of pests is necessary to prevent disease and contamination. Pest management programmes should be fully documented and should contain the following information (de Silva 2007):

- Number, location and type of bait and traps; chemicals used for rodents, birds, insects.
- Date when traps and bait were placed.
- Frequency of baiting and trapping.
- Data on signs of pest activity (faecal matter, cast-off skin, feathers, nests, spider webs, torn bags or sacks, pest-damaged produce).
- Number and type of pests caught.
- Process for updating the programme in case of changes in the facility or production system.

If pesticides are used for controlling pests, the method of application should not contaminate raw materials, packaging materials or finished product. Only experienced and licensed contractors should be employed.

Use of rodent bait within the packing facility should not be allowed. If unavoidable, all materials should be removed before application of the bait.

Pest control measures

1. Areas immediately surrounding the packing facility should be maintained in a hygienic condition. They should be litter-free and garbage should be stored in closed receptacles. Grassy and weedy areas can serve as breeding grounds for pests and should be trimmed on a regular basis.
2. Unused bins, containers and equipment should not be allowed to accumulate inside the facility.
3. Scheduled inspections should be conducted of all areas in the packing facility for evidence of pest activity as well as for identifying potential nesting or hiding places.
4. Produce and equipment should be kept 50 centimetres away from walls to allow personnel to clean and inspect for infestation on all sides of the equipment.
5. Screened windows and vents should be installed and holes in walls, floors and doors must be blocked to prevent the entry of pests.
6. Traps or bait used for the eradication of pests must be placed in locations that will not contaminate produce or packaging materials. Traps should be inspected and cleaned on a regular basis. Trapped pests should be disposed of humanely.

Devices for pest control should be positioned as follows:

- Traps should be placed at intervals of 6-12 metres (20-40 feet) along the inside perimeter of all rooms.

- For areas within the facility, traps should be placed within 1.8 metres (6 feet) of all doors and entryways on both sides.
- Traps should be placed inside cold rooms.
- Bait stations or live traps should be placed at intervals of 15-30 metres (50-100 feet) around the exterior perimeter of the facility.
- Bait stations or live traps placed at intervals of 30-60 metres (100-200 feet) along the periphery of the facility grounds.
- Electric insect killers should be located away from food-handling areas and storage areas for packaging materials. These devices can produce aerosols containing microbes each time an insect is caught and electrocuted (American Society for Microbiology 1999 as cited by Horowitz 1999).

GMP on the use of pesticide equipment/facilities

- Equipment used for applying pesticides should be properly labelled with their contents. Separate equipment should be used for applying herbicides and insecticides.
- Pesticides should be placed in a locked room that is far away from the packing area. The room should be well-ventilated with exhaust fans that vent air to the outside (rather than to the packing area).
- Empty pesticide containers should not be used for other purposes and should be properly disposed off.

Cleaning and maintenance of pest control devices

- Non-toxic glue boards should be frequently changed.
- Old or mouldy bait should be replaced.
- Bait stations and traps should be clean and free of weeds, dirt and debris.
- Bait stations should be secure against weather or tampering.
- Pest control devices should be checked at least on a monthly basis.

Documentation of the sanitation schedule

A record of sanitation activities for all areas of the packing facility and its equipment should be maintained and readily available. Records should include:

- Dates.
- List of areas and equipment that have been cleaned and sanitized.
- Staff accountability; each task completed should be signed off.
- Verification of the completed task.
- Description of any deviation from SOP, and the reason for the deviation.
- Records should also show the frequency that cleaning tools are cleaned and sanitized.

Labelling

Materials Safety Data Sheets (MSDS) must contain information about chemicals, such as toxicity and antidotes. MSDS should be readily available in the facility in case of accidental spillage or ingestion. For chemicals that are used directly on fresh produce, copies of the regulatory approval for such use should be on record.

Chemicals transferred from their original containers should be labelled. Examples include cleaning and sanitizing chemicals, pesticides, liquid soap, waxes and rodent bait. Dilute solutions should also be labelled with the concentration level.

Microbiological tests

Microbiological testing of water used in the facility should be done at least once a year. Facilities using water from wells should have the well tested. Test results should comply with microbiological specifications required by regulatory agencies for potable water.

Testing of water sources used for making ice should also be performed. Swabs from equipment, containers, walls and other areas of the packing facility should also be taken for microbial testing.

Waste management

Waste produced by the facility should not contaminate the environment or the finished product. A waste management programme should identify the different forms of waste that are generated during operations, as well as activities of personnel. Table 4.1 provides some guidelines on the proper management of waste products.

Table 4.1 General guidelines for managing waste of the packing facility

Item	Guidelines for management
Waste receptacles	Item must be covered and located far from packing and storage areas; item must be easily accessed for removal of waste.
Wet waste (fruit and vegetable rejects, trimmings)	Dispose using metal or plastic receptacles with tight-fitting lids. Waste should be removed daily and measures taken to prevent decay and pest infestation.
Dry waste (paper, plastic, metal, glass)	Use metal or plastic receptacles with tight-fitting lids; multiple receptacles should be used to segregate waste and promote recycling.
Floor waste	Must be removed immediately and segregated into wet or dry waste, the floor should be cleaned and sanitized if necessary.
Containers/packaging for raw material	Must no be used for storing produce; empty containers and packaging should be segregated or disposed of immediately.
Used containers for finished products	Must not be used for storing chemicals, fuel, oil, other non-food items. Container should be labelled.
Used chemical solutions	Only registered chemicals should be used; follow disposal instructions on the label. Do not pour directly into waterbodies (lakes, rivers, canals).

Source: Adapted from de Silva (2007)

4.3 Personnel

Staffing patterns

In a fresh produce packing-house, the most important senior-level staff are the packing-house manager and the Quality Control Officer (QCO). A Pest Control Programme Manager (PCPM) and Plant Sanitation Manager (PSM) are in charge of implementing pest control and plant sanitation programmes of the facility, respectively. A Maintenance Supervisor is given the main responsibility of keeping facilities and equipment operational in a safe, efficient and effective manner.

Managers and supervisors should be sufficiently knowledgeable and updated on principles and practices of food hygiene. They should be able to spot and evaluate potential risks, take the proper course of action to prevent incidents of food contamination, and implement effective monitoring and supervision of activities (CAC 1969).

Duties and responsibilities

Duties and responsibilities of employees must be clear, and must be within the capability of the employee to perform. The rationale or importance of each task must be known, as well as the consequences to the facility's operations and performance due to non-compliance. The number of personnel should be sufficient, and each individual must have the necessary background for such work. Personnel should also be mentally and physically healthy to be able to perform their duties properly.

The *Packing-house Manager* is responsible for overall operation of the facility. Responsibilities of the packing-house manager include:

- Full authority and responsibility to manage packing-house operations covering all aspects of personnel, area, equipment and records.
- Sharing responsibility, with the quality control officer for product quality and approval of procedures that impact on quality, together with supporting, monitoring and controlling the packing-house environment, plant cleanliness, production validation, training of personnel and approving the supply of materials.

The *QCO* oversees all aspects of quality assurance and quality control, including establishment, verification and implementation of quality control protocols. In particular, the QCO is in charge of:

- Approving in-coming loads of produce, packaging materials and final product; reviewing procedures that have an impact on produce quality.
- Rejecting, holding or isolating produce that does not meet standards of quality and safety.
- Recommending suppliers of input material for the packing facility.
- Reviewing quality control records and other records relevant to quality control.
- Protecting produce and materials from spoilage and deterioration.

The QCO should also provide support on monitoring and control of the packing-house environment, plant cleanliness and training of personnel.

The *Pest Control Programme Manager (PCPM)* is in charge of keeping the packing facility free of pests, and assuring that all materials, food contact surfaces and utensils are free from contamination from chemicals or substances used for pest control. A system of internal communication is important to allow personnel involved in pack-house operations, to prepare the facility for pest control measures. The PCPM must continuously maintain and update a manual that documents the pest control programme for the packing facility.

The *Plant Sanitation Manager* is in charge of implementing a food safety/sanitation programme, and must maintain and update a manual that documents the food safety programme continuously.

The *Maintenance Supervisor* is in charge of preventive maintenance and the repair of instruments, equipment, and facilities, as well as the electrical and water supply system and must maintain a log of all operations undertaken.

Training

Training in food hygiene, aside from proper handling of perishable produce, is very important. All staff of the packing facility, from manager to produce handler, must have the necessary information and skills to carry out their duties properly. In addition, personnel handling hazardous chemicals must also be given instructions on proper techniques of handling and disposal.

Only qualified individuals should conduct staff training. The content of the training should be guided by programmes of the packing facility and must be approved by the QCO and the PM. Training programmes should include the following subject areas:

- *Packing-house operations* – should provide an overview of the importance of post-harvest handling, causes of losses during handling, basic and special post-harvest operations.
- *Food safety training* – key GMP rules including hand washing, eating/drinking, smoking, clothing rules; it is recommended that this is done on a quarterly basis and could be part of other training events.
- *Sanitation training* – covers the importance of proper sanitation, cleaning efficacy, how to use cleaning chemicals and how to implement SOPs.
- *Worker safety issues* – use of personal protective equipment, accident prevention, what to do in case of accidents, how to avoid electrical hazards when cleaning equipment.
- Workers should be trained in handling chemicals and sanitizers and should know which chemicals can be mixed together. Hazards often associated with chemicals and sanitizers are:
    - o Acid – corrosive to the skin, eyes, mucous membranes, vapours can cause damage to the respiratory tract.

- o Alkalis – bases are corrosive to the skin and may cause burns and scarring; bases react violently with water releasing heat and hazardous vapours and gases.

The company should have records of GMP orientation training for new staff hired, indicating topics covered, trainer name and material used and given to new personnel. These materials should be in relevant languages and cover key GMP rules including hand washing, eating/drinking, smoking and specific clothing rules. Food safety training should be given to all employees working in production and storage areas.

4.4 Documentation

Instructions and procedures

Instructions and procedures serve as a preplanned guide on how to complete tasks safely, efficiently and effectively. These are usually culled from previous experiences and incorporated into a set of Best Practices. The company must be actively involved in developing and updating instructions and procedures that must be easy to understand, relevant and appropriate. A well-designed procedure has the following characteristics (de Silva 2007):

- Explains the purpose of the task.
- Describes important steps separately and in sequence.
- Designates persons of authority for the particular task and defines their responsibilities.
- Gives guidance in case of problems encountered during performance of the task, and identifies points where decisions must be made.
- It is supported by visual aids (photos, flowcharts, drawings) for clarity.

Documents that give instructions and procedures are given in Table 4.2.

Table 4.2 Documentation for instructions and procedures

Document	Description
Specifications	For incoming produce, treatments, packaging materials, packaged produce, requirements of clients and markets, process conditions
Procedures	Procedures for purchasing, quality control, product recall, SOPs
	Instructions for production, cleaning, operation of the facility
Schedules	Maintenance, calibration, upgrading, internal audit and review

Source: Adapted from de Silva (2007)

Records for each batch of produce arriving at the packing house should be maintained. Information should include production data (from growers), water quality, pest control measures, pre-cooling methods and cold storage conditions, post-harvest treatments used (including chemicals, if any) and cleaning schedules for facilities, equipment and containers.

Both growers and packers should have a means of identifying batches of produce to allow recall programmes to trace origins of produce suspected of contamination. Batch or lot information should include harvest dates, farm site and owner, identification of harvesters and haulers, packing date and vehicles used for transport.

Traceability

Traceability is defined as the ability to follow the movement of a produce through the different stages of production, processing and distribution. A traceability system is only a tool that by itself does not improve food safety unless combined with appropriate measures and requirements. The system comprises all the data and operations used for accumulating and maintaining desired information on produce and its components as it goes through the production and utilization chain (ISO 2007).

Traceability may apply to all stages of the food chain – from production to distribution (from where the food comes – one step back, and to where the food went – one step forward). An essential part of GAP and GMP is the ability to identify the source of fresh produce, especially when the produce comes from different growers and is considered a single load. Produce items for export may come from different farms or growers. Consolidators, who are accredited by exporters, must establish systems for tracing the sources or growers/suppliers from the farm to the packer, distributor or retailer. The major components of documentation include the source (farm), date of harvest, produce handler, the grower, packer and shipper who in turn partners with distributors and retailers to develop management tools to facilitate the trace-back process.

Horticultural produce is inherently perishable; hence by the time problems of food-borne illness outbreaks are reported, it is probable that the produce is no longer on the retail shelves. If fresh produce is linked to an outbreak, current industry practices in the marketing and distribution systems, such as the use of recycled shipping crates and co-mingling during distribution or at retail, make direct identification of the source of produce very difficult. If an implicated source (such as a field packing shed) is identified, the source of contamination may no longer be present when investigators arrive on the scene. This variability and lack of a direct determination of cause have resulted in a high degree of uncertainty and in some cases false associations. The economic burden of a false association is especially troublesome for those industry segments that may later be proven not to have been involved in the actual outbreak.

Traceability systems help firms isolate the source and extent of safety or quality problems; they help reduce production and distribution of unsafe or poor quality products that in turn reduces the potential for bad publicity, liability and recalls. Thus, many buyers notably exporters and institutional buyers, are now requiring suppliers to establish traceability systems.

Objectives of traceability

A traceability system must be able to (ISO 2007):

Support the objectives of food quality and food safety programmes.

- Satisfy customer requirements and specifications.
- Determine origins of produce.

- Allow produce recall.
- Identify organizations responsible for producing and handling the produce through the food chain.
- Allow information about the produce to be verified.

Design of a traceability system

A traceability system should be both technically feasible and economically acceptable, and must be designed according to the identified objectives. The design should include (ISO 2007):

- Objectives.
- Relevant regulations and policies.
- The fresh produce item.
- Location in the food chain – suppliers and consumers must be identified.
- Required information – this must document the information to be provided by suppliers, to be gathered on the produce and its history and origins, and to be passed on to buyers or back to suppliers.
- Establishment of procedures – these must describe the flow of materials and relevant information. Procedures must include definition of the produce, definition and identification of lots, documentation of material flows, management and recording of data, and methods of information retrieval.
- Documentation – must describe the different steps in the food chain, define the responsibilities for managing traceability data, provide a description of steps taken to manage substandard products and document retention times of documents.

Recall programmes

Product recall is considered as the last line of defense in a food safety emergency. There must be an effective procedure in place for the complete and rapid withdrawal of any batch of produce from the market that has been identified as a food safety hazard. Other produce handled under similar conditions in the facility should be evaluated and may also be recalled if necessary. Withdrawn produce should be stored under strict supervision until it is determined fit for human consumption. Otherwise, it should be destroyed, used for purposes other than for food or processed into a form safe for human consumption (CAC 1969).

Product recall may be initiated by the company, performed on a voluntary basis or done at the request of the food regulatory agency because of a suspected hazard in the fresh produce. A written recall programme indicating the basic procedures and responsibilities and the contact listing of customers and suppliers should be in place. This will facilitate removal of the produce from the market.

Quality and safety-related complaints must be recorded and documented. These records are then evaluated as to the trend, frequency and severity for any immediate corrective action. The circumstances under which a recall should be done should be clearly defined. Recall procedure should:

- Designate personnel to be involved in evaluating information.
- Describe how the recall should be initiated.
- List who should be informed about the recall.
- Describe how the recall material should be tracked, segregated and disposed.

Records of traceability of raw materials, post-harvest handling and treatment, packaging materials, data and laboratory results should be kept. This will determine the effectiveness of the implementation of procedures for product recall.

Records to be kept

- *Records for the necessary monitoring activities* – they include post-harvest treatments, corrective actions taken in case of the process exceeding the established limits or discovery of foreign materials.
- *Records of wash water and ice production systems* – records of the use of antimicrobials, recycled water systems.
- *Pre-operational inspection log* – this includes general housekeeping of storage and packing-house areas, verifying cleanliness of equipment, checking of personnel's adherence to GMP requirements and corrective actions in case of non-compliance.
- *Records/data on incoming materials* – inspection of incoming materials, including product weight/volume, for the presence of defects, foreign material, decay and other food security issues.
- *Inspection logs of incoming delivery vehicles* – record of inspection done on vehicles regarding cleanliness of interior, occurrence of pests and off-odour, temperature in the case of refrigerated trucks and corrective actions.
- *Daily incident report of unusual occurrence* – this includes records or reports detailing deviations, incidents, process failures, unusual occurrences (such as foreign objects, chemical spills, rejected packaging, downtime, etc.) and the corrective actions. Other incidents which should be recorded and which will be useful or relevant with respect to product issues include loss of power, blocked drains, weather damage, earthquakes, etc.
- *Records of routine equipment microbiological testing* – there should be records of equipment microbiological swab testing for cold rooms. Choosing where swabbing should be done on the main pieces of equipment is based on risk of contamination and ease of cleaning.

4.5 Miscellaneous requirements

Maintenance of equipment and instruments

Preventive maintenance of equipment is critical to avoiding unnecessary delays and problems during actual operations. It includes routine inspections, lubrication, and replacement of components at suitable intervals, and is an essential part of an effective management programme.

All activities should be documented and recorded, including date and time of completion, specific equipment, reasons for servicing, requesting party, observations and service personnel involved.

Instruments should also undergo preventive maintenance to ensure that they are working properly during operations. This will ensure that measurements are accurate and conditions during processing are at desired levels. As some activities (calibration for example) may require that the instrument be returned to the manufacturer for servicing, this should be scheduled ahead of time or a spare instrument should be available.

Instruments that require calibration on a regular basis include thermometers, pH meters and ORP meters. The calibration procedure should describe the test standard, test method, acceptable variation and frequency of testing. Appendix A.5 provides a simple method for calibrating thermometers that can be immersed in water.

Scheduled checks

Inspections should look for signs of deterioration (corrosion, flaking paint, loose components, cracking seals, gaskets and hoses) and the presence of unhygienic material such as tape, string or cardboard. Components that require regular replacement or cleaning include rubber belts, steel chains, bearings, conveyor belts, door seals of cold rooms, light switches and bulbs, and water valves and filters.

Lubricants

Only food-grade lubricants should be used in order to avoid contamination. Lubricants with antimicrobial additives such as sodium benzoate are recommended. Excessive amounts of lubricants must not be used, so as to avoid leaks, drips and the growth of microorganisms. Excess quantities of lubricants should be wiped off.

Policies

Meetings should be conducted on a regular basis to identify potential, existing and persistent problems.

Training for new personnel, retraining or refresher courses to gain new knowledge and disseminate technology updates should be regularly conducted, especially for senior managers.

Customer complaints

There should be a documented system for dealing with customer complaints and buyer food safety complaints along with the company's response and corrective actions. These include:

- Date/time of complaint/rejection.
- Who made the complaint.
- Contact information.
- Product description.

- Where the product was purchased.
- Amount of product.
- Product code/date.
- Nature of complaint.
- Corrective actions.
- Corrective actions taken to prevent reoccurrence.

Inspections and audits

A programme should be established for periodic/internal (self-) inspections. This programme should include:

- Inspection frequency, which depends on the type and size of the operation. Packing-houses, coolers and storage operations should ideally be inspected on a monthly basis, but at least on a quarterly basis. To ensure compliance with GMP standards, Boonyakiat and Janchamchai (2007) recommend an internal audit once a year.
- The entire facility (inside and out) should be evaluated.
- Personnel who conduct the inspections.

The inspection team should consist of key packing-house personnel including management and supervisors. Self-inspection is also aimed at training employees on good procedures for impelementing food safety Practices.

Types of self-inspection

- Pre- and post-season – conducted by packing-house managers; buildings and equipment are inspected to ensure that food safety hazards are identified and eliminated.
- Daily inspection – conducted by designated personnel who should inspect the facility for hazards in their areas of responsibility.
- Monthly audit – periodic inspection conducted by the plant supervisor.

Packing-house self-inspection should be conducted at least once a month. The inspection of small packing-houses can be completed in one inspection. Larger facilities can be divided into several sections according to their functions; for example raw material receiving, pack-lines, packaging, storage areas, support areas (tool rooms, maintenance rooms, lockers), and external grounds.

Length of inspection

The duration of inspection should be about two hours and should be focused on one area at a time rather than conducting a lengthy inspection that interferes with team members' duties.

Audits by external agents

Produce destined for export or those destined for supermarket chains, may require packing-house inspection by government or other nominated audit agencies. Such audits are normally conducted for quarantine and market access reasons to ensure that processes are in place to ensure freedom from pests and diseases and to ensure that appropriate food safety protocols have been followed. Similarly supermarkets may insist on external audits to confirm adherence to their compliance requirements (such as GlobalGap). Industry-wide organizations may also insist on annual audits, depending on the structure of the sector. In any event an annual external audit is desirable to avoid continuous 'inward looking' that can result from familiarity with local systems.

Security of the packing-house facility

The perimeter of the facility should be secured with a 1.8-metre (6-foot) high fence, especially for specialized packing facilities. This is to keep out intruders and stray animals. Ideally, security systems such as key locks, security cards and pass codes should be used to block unauthorized individuals from gaining access to the facility. For simple packing sheds, fences made of closely spaced slats (bamboo or wood) or cyclone/interlink wire material (less than 10-centimetre mesh size) on sturdy concrete posts can be used. The facility should be locked down if there are no security guards on duty or it does not operate on a 24-hour basis.

To avoid tampering or contamination by intruders or animals, newly harvested fresh produce should not be left close to fences and should be covered with clean canvas.

Water supply

Piping systems should be colour-coded according to their function (supply, drainage) and quality (potable, non-potable). Faucets and outlet valves should be labelled prominently with the type of water available from that outlet. Mixing areas where sanitizing, disinfecting or treatment solutions are prepared should be secure and protected from tampering.

Chemicals

Storage areas for chemicals should be secured and locked at all times; access to these chemicals must be restricted to personnel with proper authorization and training. Chemicals for cleaning and maintenance of equipment and facility areas should be kept segregated from those used directly on fresh produce.

Packaging materials

As these materials are in direct contact with food material, they should be kept inside the facility in a secure storage area. If stored separately from the packing facility, the storage area should be fenced and must keep out intruders, sun, rain, dirt, dust and pests.

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Appendices

A.1: Ripening calculations

Table A.1.1 shows the average daily requirements of a fruit trader. Through experience, the trader knows that bananas and mangoes require two days and three days, respectively, to reach the proper stage of ripeness for marketing. Based on these volumes, a ripening facility must have sufficient capacity to accommodate this volume as well as unexpected surges in demand.

Table A.1.1 Daily fruit requirements for ripening

Day of the week	Fruit requirement	
	Banana (tonnes)	Mango (kg)
Monday	2.4	350
Tuesday	2.5	400
Wednesday	1.7	500
Thursday	2.2	500
Friday	2.5	550
Saturday	2.4	500
Sunday	3.1	600

The most convenient container for ripening is the plastic crate. A typical plastic crate having a capacity of 22 kg of mangoes and 20 kg of bananas has the following dimensions: 52 centimetres long, 36 centimetres wide, 29 centimetres high. It can be assumed that the crates can be safely stacked up to six layers high on pallets, with each layer composed of five crates. From the forecast of demand for bananas, the largest volume of fruit is to be accommodated by the ripening room on Fridays and Sundays (Table A.1.2). On Fridays, the room will contain fruit ready for disposal (2.5 tonnes), fruit still undergoing ripening and scheduled for disposal on Saturday (2.4 tonnes), and newly arrived fruit to be ripened for Sunday (3.1 tonnes). The ripening room must, therefore, accommodate a total of 8 tonnes on Fridays and Sundays. With the addition of a 20 percent factor of safety in case of unexpected increases in demand, then the required capacity of the ripening room is 9.6 tonnes of fruit. One pallet load can accommodate 30 crates or 600 kg of fruit. Therefore, approximately 16 pallet loads of bananas must be accommodated in the ripening room.

This volume of fruit can be accommodated in two ripening rooms each having a capacity of eight pallets (Figure A.1.1). Having two ripening chambers rather than one large unit ensures that operations can continue at limited capacity in case of any breakdown. Five columns of crates with six crates per column can be stacked on each pallet (total of 30 crates per pallet). There should

Table A.1.2 Daily total volume (tonnes) in the banana ripening facility

Mon	Tue	Wed	Thu	Fri	Sat	Sun
				3.1	3.1	3.1
			2.4	2.4	2.4	
		2.5	2.5	2.5		
	2.2	2.2	2.2			
1.7	1.7	1.7				
2.5	2.5					2.5
2.4					2.4	2.4

Table A.1.3 Daily total volume (kg) in the mango ripening facility

Mon	Tue	Wed	Thu	Fri	Sat	Sun
			600	600	600	600
		500	500	500	500	
	550	550	550	550		
500	500	500	500			
500	500	500				500
400	400				400	400
350				350	350	350

be a space of a few centimetres between each column to allow air circulation. A minimum gap of 8 centimetres should be maintained between pallets, and between pallets and walls to allow air movement. A central aisle having a width of 1.5 metres width should be maintained for moving pallets in and out of the chambers. This will require a floor area of 5.20 metres length and 3.66 metres width (Figure A.1.1). The height of the rooms should be at least 2.5 metres to accommodate the height of the stacks and to provide a space for air movement from the cooling coils of the evaporator unit.

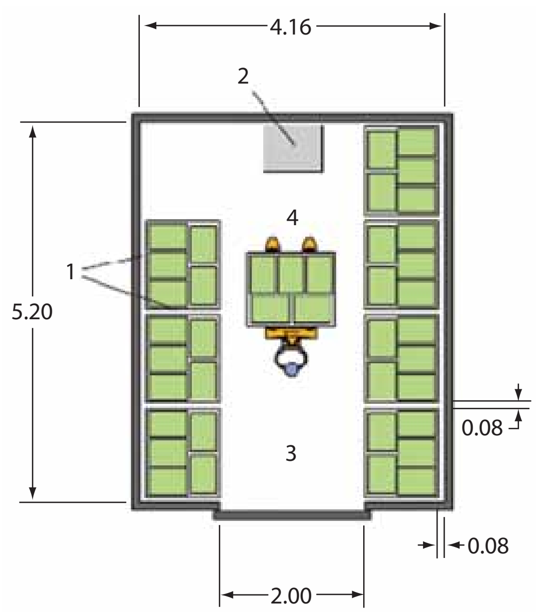

Figure A.1.1 Layout of a ripening room for bananas. Gaps between pallets and walls (1) are maintained for uniform circulation of chilled air from the cooling unit of the room (2). A central aisle (3) is kept open for movement of palletized produce (4) and to promote air movement. Two ripening rooms for banana are needed to accommodate the required volume

Assuming a required ethylene concentration of 100 ppm (Table 2.8), the required airflow rate (Q_{air}) and ethylene flow rate (Q_{eth}) are calculated as described by Sargent (2000) using Equations A.1.1 and A.1.2, where V = volume of the ripening chamber (m^3), N = frequency of air changes, and C = desired concentration of ethylene (100 ppm = 0.0001).

$$Q_{air} = \frac{V}{N} \qquad \textbf{(A.1.1)}$$

$$Q_{eth} = Q_{air} \bullet C \qquad \textbf{(A.1.2)}$$

$V = 5.2 \times 3.66 \times 2.5 = 47.58\ m^3$
N = 6 hr per air change
$Q_{air} = 47.58\ m^3/6\ hr = 7.93\ m^3/hr = 0.13\ m^3/min$

Using the conversion factors 1 m^3 = 1 000 L and 1 L = 1 000 mL:

$Q_{eth} = 0.13\ m^3/min \times 0.0001 = 0.000013\ m^3/min$
Q_{eth} = 13 mL/min

For mango ripening, the procedure is similar. Referring to Table A.1.3, the maximum volume that must be accommodated during a week is on Thursdays. The ripening facility must be able to contain a total of 2 150 kg on that day. As the lead time for mangoes is three days, this will consist of incoming fruit to be ripened until Sunday (600 kg), fruit still being ripened for disposal on Friday (550 kg) and Saturday (500 kg) and ripe fruit ready for distribution to clients (500 kg). For a safety factor of 1.2, the required capacity will be 2 580 kg of fruit. Assuming 20 kg of mangoes can be placed in crates of the same size as those used for bananas, then the number of pallets to be accommodated will be approximately five pallets. An extra pallet can be added to facilitate layout planning of the chamber for mangoes (Figure A.1.2). The extra pallet can be used for other commodities to be ripened.

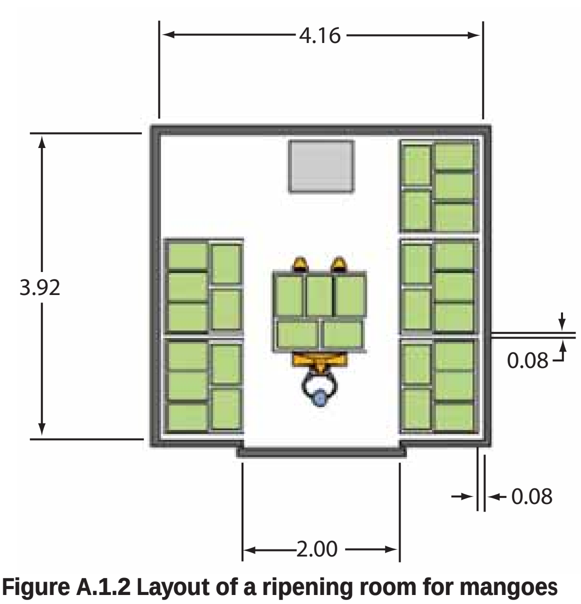

Figure A.1.2 Layout of a ripening room for mangoes

A.2: Measurement of Total Soluble Solids (TSS), Titratable Acidity (TA) and pH

Analysis of fruit pulp

1. Chop or slice the commodity into small sizes. Weigh a 50 g sample of produce using a digital weighing scale (accurate to 0.1 gram). Immediately homogenize the sample in a blender with 50 millilitres of distilled water. Filter the blended sample through filter paper or cotton placed in a funnel.
2. Using a medicine dropper, place a drop of filtrate on the measuring window/plate of the refractometer and measure the TSS in °Brix.
3. Using a glass pipette, place 20 millilitres of the filtrate in each of three Erlenmeyer flasks. Add 30 millilitres distilled water and 1-2 drops of phenolphthalein indicator fluid to each flask.
4. Using a glass burette, titrate with standard 0.1 N sodium hydroxide (NaOH) until a faint pink tinge is observed in the flask. Record the volume (millilitres) of NaOH used. Calculate TA using Equation A.2.1.
5. Using a pH meter, measure the pH of the remaining filtrate.

Analysis of fruit juice

1. Weigh the fresh sample using a digital weighing scale. Using a fruit pulper (Photo A.2.1), squeeze and extract as much juice as possible into a beaker and measure the volume of juice collected.
2. Using a pipette, place 10 millilitres of the juice into each of three Erlenmeyer flasks. Add 40 millilitres of distilled water and 1-2 drops of phenolphthalein indicator fluid.
3. Using a glass burette, titrate with standard 0.1 N sodium hydroxide (NaOH) until a faint pink tinge is observed in the flask. Record the volume (millilitres) of NaOH used.

   The sample should be thoroughly mixed during titration. A magnetic stirrer and magnet can be used to keep the sample agitated.

   Alternative method: An autotitrator (Photo A.2.2) can be used instead of a burette for more consistent and objective analysis (although this instrument is very expensive). The autotitrator automatically dispenses measured volumes of 0.1 N NaOH solution into a beaker containing 5 millilitres juice extract with 20 millilitres of distilled water; the sample is kept well-mixed with a magnetic stirrer. The autotitrator continues to add NaOH until an endpoint of pH 8.2 is reached. Once the endpoint is reached, it automatically stops and measures the total volume of NaOH dispensed.
4. Calculate TA using Equation A.2.1.

Photo A.2.1 Stainless steel pulper for extracting juice from whole samples. Inset shows a whole cherry tomato after being crushed in the pulper. A small beaker is placed under the sample togather the juice extract

Photo A.2.2 Autotitrator for determination of endpoint at pH 8.2 using 0.1 N NaOH solution

Equations

1. For titratable acidity, use Equation A.2.1 where *TA* = % titratable acidity, V_{NaOH} = volume of 0.1 N NaOH used, N_{NaOH} = 0.1, Meq = milliequivalent weight (g/meq) of the predominant acid in the sample (Table A.2.1) and W_{eq} = weight equivalent of the sample aliquot (g).

$$TA = \frac{V_{NaOH} \bullet N_{NaOH} \bullet Meq \bullet 100}{W_{eq}} \qquad \textbf{(A.2.1)}$$

Table A.2.1 Predominant organic acids found in some commodities

Commodity	Organic acid	No. of titrable H+	Milli-equivalent weight (q/meq)
Banana, mango, eggplant	Malic acid	2	0.067
Calamondin, tomato, tangerine	Citric acid (anhydrous)	3	0.064
Starfruit (carambola)	Oxalic acid	2	0.045
Grapes, tamarind	Tartaric acid	2	0.075

2. For pulp analysis, W_{eq} is calculated using Equation A.2.2, where W_f = fresh weight of the sample (g), MC = moisture content of the sample (%), $V_{aliquot}$ = volume of the sample aliquot (millilitres) and V_{water} = volume of distilled water added for homogenization (millilitres).

$$W_{eq} = \frac{W_f \bullet V_{aliquot}}{V_{H_2O} + W_f \bullet \frac{MC}{100}} \qquad \textbf{(A.2.2)}$$

Values for moisture content can be taken from published data, or measured using oven methods, where samples are taken to a bone-dry (constant dry weight) condition over several days at high temperature. Alternatively, the volume equivalent of each gram of fresh sample can be assumed to be equal to 1 and, therefore, Equation A.2.2 becomes Equation A.2.3.

$$W_{eq} = \frac{W_f \bullet V_{aliquot}}{V_{H_2O} + W_f} \qquad \textbf{(A.2.3)}$$

3. For juice analysis, Equation A.2.4 is used where V_T = total volume of juice (millilitres) extracted from the sample.

$$W_{eq} = \frac{W_f \bullet V_{aliquot}}{V_T} \qquad \textbf{(A.2.4)}$$

4. For TSS, Equations A.2.5 and A.2.6 are used, where DF = dilution factor.

$$TSS = {}^{o}Brix \bullet DF \qquad \textbf{(A.2.5)}$$

$$DF = 1 + \frac{V_{H_2O} \bullet 100}{W_f \bullet MC} \qquad \textbf{(A.2.6)}$$

or

$$DF = 1 + \frac{V_{H_2O} \bullet 100}{W_f}$$

Appendix A.6 shows a sample calculation for titratable acidity.

A.3: Principles and methods of pre-cooling

The series of steps needed to keep produce at low temperature from the time it is harvested until purchased by the final consumer is referred to as a *cold chain system.* Pre-cooling is the start of the cold chain that brings produce temperature to its optimum level. Once this condition is reached, it should be continuously maintained until the produce is sold.

Refrigerated transport vehicles and cold storage rooms are generally designed only to keep a commodity at low temperature. Warm produce should, therefore, be pre-cooled to an appropriate temperature prior to being placed in refrigerated storage or transport. However, economic constraints, the volume of production, as well as other considerations will also determine whether produce is actually pre-cooled.

Objective

The temperature of a commodity has a considerable effect on its respiration rate, ethylene production and susceptibility, and consequent shelf-life. In general, the longer a commodity remains at an elevated temperature, the shorter is its shelf-life.

The main objective of pre-cooling is, therefore, to reduce the temperature of a commodity to the optimum level as rapidly as possible after harvest without inducing physiological disorders or physical damage. Vigneault *et al.* (2004) observed the highest quality and sugar content in sweet corn when pre-cooling delay was kept at 2 hours. Nunes *et al.* (2005) observed a 25 and 24 percent increase in incidence and severity of decay, respectively, in strawberries when pre-cooling was delayed by six hours compared to a one-hour delay. Furthermore, prompt cooling decreased incidence and severity of *Rhizopus* rot by 15 and 29 percent, respectively; additionally, *Botrytis* rot incidence and severity decreased by 5 and 22 percent, respectively.

Benefits

Produce quality is maximized – Pre-cooling helps to slow ripening, reduce microbial growth and moisture loss from fresh product. This is especially important for produce with high metabolic rates (such as strawberry, broccoli, lettuce, sweet corn, peas, asparagus and okra). In fact, temperature is the single most important factor in reducing post-harvest losses of okra exported from Sri Lanka to Japan.

However, due to the high cost of equipment and operation, pre-cooling is generally widely used for select high-value crops such as lettuce and asparagus where price premiums can offset the added cost.

Refrigeration load is minimized – The heat load represented by a warm commodity (*field heat*) plus heat of respiration represent a significant portion of the heat load of a cold room or refrigerated van. The heat load of fresh produce can consume more than 56 percent of the total refrigeration requirement.

As refrigerated vehicles and storage rooms have a finite capacity for cooling, warm produce should only be loaded in limited quantities. For pre-cooled produce, however, larger volumes can be accommodated because field heat is absent. Aside from the additional work needed for cooling, warm produce also emits more moisture that can condense on the refrigeration system, reducing efficiency and requiring more frequent defrosting.

Transportation and storage of fruit is facilitated – deterioration is greatly minimized and the quality of ripe fruits can be maintained for a longer period of time.

Drawbacks

As pre-cooling must be completed relatively quickly, a high-capacity system is required. This implies the need for capital for investing in and installing equipment, as well as operating and maintenance costs. Hence, pre-cooling has been adopted mainly in developed countries. Nevertheless, some small farmers in these countries still cannot afford to pre-cool their own produce (Christenbury *et al.* 1995). The situation is even more pronounced in developing countries. Only in recent years are Asian fruit exporters even beginning to invest in pre-cooling facilities.

Prior to investing in pre-cooling equipment, potential users should consider the following questions (Boyette and Estes 1992; Brosnan and Sun 2001):

- *What are the true causes of losses in the handling chain?* Losses may be caused by periods of oversupply, careless handling during harvesting, sorting and grading, inappropriate packaging materials and poor marketing skills either singly or in combination.
- *Will the benefits of pre-cooling eventually outweigh initial investment costs and operating costs?* Potential benefits can include the total market value of saved produce, ability to provide the required quality for the target market, price premiums for pre-cooled produce or expanded market access. The ability of a target market to pay for a price premium must be confirmed.
- *Which pre-cooling method and/or equipment is appropriate to the volume and type of produce to be handled?*
- *Which marketing traditions may need to be considered in choosing a pre-cooling method?*

Methods

Over the years several pre-cooling methods have been developed that make use of different modes of heat transfer. Some are applicable to a wide variety of produce, while other methods are limited to specific types of commodities. Each method is discussed in detail below.

Room cooling

Basic principles

This method simply involves placing stacks of produce in a refrigerated space. Cold air coming from the evaporator of the refrigeration system (see Appendix A.4. for more details) is blown over and around the stacks before returning to the evaporator. Heat transfer from the warm centre of containers to cold exterior surfaces is mainly by conduction; hence, this method gives the slowest cooling rate that is appropriate only for commodities such as potatotes and onions that have a long storage life. To ensure adequate air circulation, there must be sufficient air movement produced by fans; space between packages or containers, stacks, and room walls must also be provided (see Figure A.3.1). Use of well-ventilated containers can accelerate cooling (Thompson *et al.* 2002).

Because of the low cooling rate, moisture loss can be a problem but can be minimized by providing humidified air.

Requirements

- To ensure adequate air circulation, minimum total fan airflow must be 0.3 m^3/minute per tonne of storage capacity (Thompson *et al.* 2002).
- Containers should have vents that align properly to allow airflow through stacks.
- Containers should be properly stacked to expose all container surfaces to cold air and allow air movement between stacks.
- Where possible, the use of wrappings, liners or dividers in the container should be avoided as they impede airflow and decrease the rate of cooling.

Commodities

Room cooling can be used for most commodities. However, results may be unsatisfactory especially for highly perishable commodities because of the time required for cooling. This method is usually used for unpacked cutflowers, potato, sweet potato, citrus fruits and onion.

Forced air cooling

Basic principles

As the name implies, this cooling method forces cool air to move through containers of produce, thereby providing more intimate contact between the cooling medium and the commodity. This is achieved by inducing a pressure difference between opposite sides of a stack of ventilated containers. Forced air cooling therefore takes place more rapidly than room cooling.

There are different types of forced air cooler designs in use, especially in developed countries. The most widely used method is *tunnel cooling*. Two stacks of containers are placed on either side of an exhaust fan (Figure A.3.1), leaving a space 60-90 centimetres wide between the stacks. The space is turned into a tunnel when covered with a sheet of heavy canvas or tarpaulin. When the fan is turned on, air pressure within the tunnel is reduced, forcing cool air to flow through package

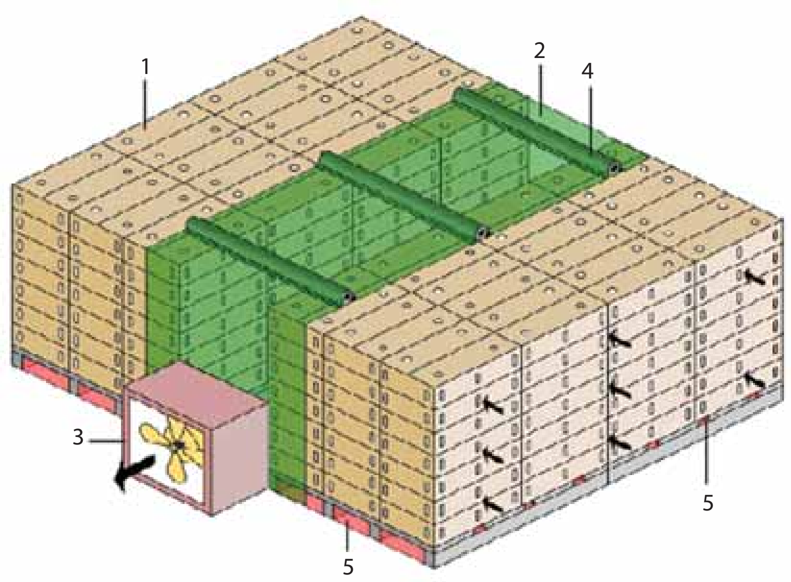

Figure A.3.1 Tunnel cooling of palletized containers (1). Pallets are arranged in two rows with a space in between to form a tunnel (2); a blower of sufficient size (3) is placed at one end of the tunnel which is covered with thick canvas or tarpaulin; when the fan is turned on, air in the tunnel is pulled out resulting in a pressure difference between the inner and outer sides of the container stacks. This forces cool air to pass through the container vents. The canvas should be reinforced with pipe (4) to prevent it from collapsing during operation. Openings in pallets should be blocked (5) to prevent air from bypassing the containers

vents towards the tunnel (Boyette *et al.* 1990). Vents must be properly located to avoid blockage and must have sufficient area to facilitate airflow. Containers must be stacked to align vents properly.

An increased cooling rate can be obtained by increasing the flow rate of cold air moving through the produce. A higher flow rate, however, requires more energy to power the fan. Increasing the number of stacks that cold air must pass through will also increase the power requirement of the fan.

As the evaporator coils of a refrigeration system (see Appendix A.4) can operate below the freezing point of water (0^{o}C); to avoid freezing injury care must be taken to ensure that products are not directly exposed to air at this temperature. Air and pulp temperatures should be monitored carefully to prevent this problem.

Some weight loss (1-2 percent) is expected with forced air cooling. To avoid this problem, some forced-air coolers use air cooled and humidified by a chilled water column; this is known as a water-wash design because the air is 'washed' by the chilled water before being used for cooling. Aside from minimizing moisture loss, this type of forced air cooler also avoids freezing injury because the temperature of the cooling medium will not go below 0^{o}C.

If sufficient refrigeration capacity is available, tunnel cooling is very simple to practise and existing cold storage facilities can be used as pre-coolers. Ideally, separate rooms should be used for pre-cooling and cold storage.

Requirements

- Sufficient vent areas must be provided in containers to allow air movement without weakening the package. Vent areas of 5-6 percent of the side or end walls of a package are recommended. Bags, liners, trays and dividers in packages can block vents and should be considered in the design of containers.
- Airflow rates of 0.001-0.002 m^3/sec/kilogram of produce provide feasible cooling rates (Thompson *et al.* 2002).

Commodities

Produce with high metabolic rates are cutflowers, edible herbs, okra, pepper, beans, cauliflower, mushrooms, cabbage and strawberry.

Hydrocooling

Basic principles

Contact with cold water is a very effective method of cooling. The specific heat of water (C_p) is defined as the amount of heat needed to raise the temperature of 1 kilogram of a substance by 1° K. As the C_p of water is much greater than that of air, it can absorb a larger amount of heat than can air. Heat transfer from an object to a liquid medium is also more rapid than heat transfer to a gas. Hence, the rate of hydrocooling is two to three times faster than that of forced air cooling. As the cooling environment is very moist, weight loss is also minimized or even reversed.

Hydrocoolers may either be an immersion-type or a shower system and may make use of ice blocks or a mechanical refrigeration system as a source of cooling. For either type, a water pump is used to circulate and distribute water. Immersion hydrocoolers make use of a large shallow tank for holding chilled water. Shower systems make use of an overhead perforated pan to distribute water over a load of produce (Photo A.3.1). Flow rates of 14-17 L/sec/m^2 of produce area are used for commodities in boxes or bins (Thompson *et al.* 2002). One problem with shower systems is uneven cooling, especially if the depth of produce is 30 centimetres or more. This is because of the tendency of water to pour through spaces where there is least resistance to flow, resulting in only partial exposure to the cooling medium. This problem can be avoided by using sufficient flow rates, shallow produce depth or reducing drainage from containers so that they are partly filled with water during hydrocooling (Talbot *et al.* 1991).

Photo A.3.1 Shower-type hydrocooler for cooling palletized vegetables

Both immersion-type and shower systems can be used on either a batch or continuous basis.

Immersion hydrocoolers make use of belt conveyors with flights to move produce through and out of the cooling tank. Shower systems make use of belt or roller conveyors to move produce through the cooling tunnel (Thompson 2004).

Accumulation of disease-causing microorganisms can occur because water for hydrocooling is recooled and recycled. Water must, therefore, be filtered and sanitized with chlorine to minimize this problem.

Requirements

- The commodity must be resistant to water damage and tolerant to wetting. For sensitive commodities such as leafy vegetables, the drop height of water should not exceed 20 centimetres (Thompson *et al.* 2002).
- Water-resistant containers with sufficient drain holes, e.g. plastic crates, waxed fibreboard cartons.
- Chlorinated water (150-200 ppm active chlorine) must be used for cooling to minimize the spread of disease. See Table 2.7 for more details.
- Strict maintenance of the cool chain (wet produce deteriorates faster at high temperatures).

Commodities

Asparagus, leafy vegetables, sweet corn, snap beans, celery, topped carrot, radish, longan and lychee are commodities suited to hydrocooling.

Vacuum cooling

Basic principles

This cooling method is based on the principle that under vacuum or conditions of reduced pressure, water attains it boiling point and evaporates at a lower temperature than at atmospheric pressure (760 millimetres Hg) (see Appendix A.4). The heat absorbed by the evaporating water is taken from the commodity. As evaporation occurs at the surface of the produce, vacuum cooling is best suited for crops with a high surface area-to-volume ratio, and particularly leafy commodities such as lettuce.

A vacuum cooler makes use of an air-tight chamber which is made of steel and is able to withstand buckling when the internal pressure is reduced, typically to 4.6 millimetres Hg (absolute pressure). At this pressure, water boils at 0°C. The vaporized moisture is collected on evaporator coils within the chamber to promote rapid cooling of the produce (Talbot *et al.* 1991).

As moisture for evaporation comes from the commodity, some weight loss is expected. About 6°C of cooling is achieved for every 1 percent of produce weight lost as evaporated moisture. To minimize moisture loss, vacuum coolers are now equipped with water sprayers to provide an external source of moisture for evaporation (Thompson *et al.* 2002).

Vacuum coolers are very costly and require a high level of technical skill for proper operation. Large volumes of produce must be cooled and the harvest season should be long enough in order to recover the initial investment and operating costs within a short time frame.

Packaging materials must also be well-ventilated to facilitate the evaporation of moisture. Modified atmosphere packages must be sealed only after vacuum cooling.

Requirements

- An air-tight chamber that can withstand vacuum.
- A vacuum pump capable of reducing pressure to 4.6 millimetres Hg.
- Cooling coils to condense evaporated water inside the chamber.
- Commodities with high surface area-to-volume ratio.

Commodities

Vacuum cooling can be used for the pre-cooling of celery, parsley, lettuce, leafy vegetables, broccoli, cabbage, bell pepper, sweet corn, sweet peas and cauliflower.

Icing

Basic principles

Icing operates on the principle of heat absorption during the phase change of a substance, such as that which occurs when water is transformed from a frozen (solid) state to a liquid form. When water in the form of ice melts into liquid, 334 kJ/kilogram of heat is absorbed to achieve the transformation (see Appendix A.4). This heat is taken from the commodity, thereby producing a cooling effect.

Package icing makes use of crushed ice packed together with the commodity in water-resistant containers. Slush icing or liquid icing is a variation of package icing where a mixture of chilled water and crushed ice is pumped into containers. Ice particles are forced into every available space in the container, thereby achieving better contact with the commodity. Specialized equipment is needed for slush icing operations – slurry mixing and pumping, ice making and handling (Talbot *et al.* 1991).

Top icing is the practice of adding a 5-10 cm layer of crushed ice on top of pallet loads of pre-cooled produce. Tests have, however, shown that the cooling effect is minimal and uneven. This method is useful only for produce that has already been cooled to optimum temperatures (Boyette and Estes 1992).

In areas where block ice is readily available, icing is used for the transportation of commodities that would otherwise be handled under very high temperature conditions. Icing machines are costly and are not readily available; hence, icing is done manually.

Requirements

As the commodity is in direct contact with ice, it must be tolerant of wetting and near-freezing temperatures and the water used for making ice must come from a sanitary source. Containers should also be resistant to water damage. Suitable containers include waxed fibreboard cartons, wooden crates, expanded or foamed plastic boxes with drainage holes at the bottom and vented plastic crates.

Commodities

Broccoli, green onion and sweet corn are suited to icing. Baby corn and strawberries must not have direct contact with the ice.

Determination of cooling rates

Half-cooling time

Cooling follows a common pattern, regardless of the type of produce being cooled. There is an initial lag phase after which temperature decreases rapidly at an exponential rate (ASHRAE 1998b). The cooling rate eventually slows down as the temperature of the produce approaches that of the cooling medium.

The duration of pre-cooling is commonly determined using the concept of half-cooling time (HCT) as shown in Figure A.3.2. HCT is defined as the time needed to reach a pulp temperature that is midway between the initial temperature of the produce and the temperature of the cooling medium. The total cooling time is then calculated as 3 × HCT, also known as 7/8th's cooling time (Thompson *et al.* 2002).

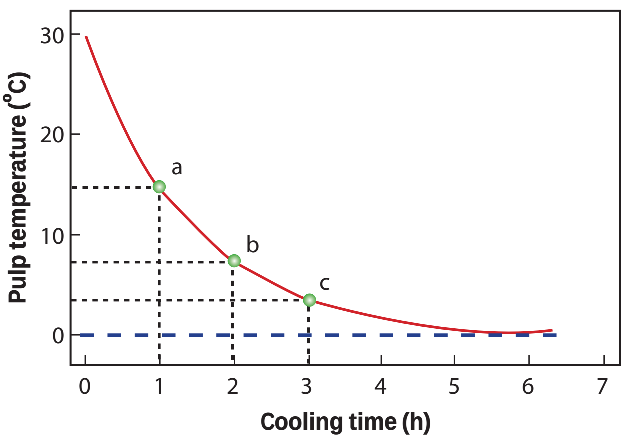

Figure A.3.2 Typical cooling curve for fresh produce. The solid line represents pulp temperature of the fruit from an initial temperature of 30°C; the dotted line represents temperature of the cooling medium (0°C). (a) 1/2-cooled: temperature after 1 h of cooling = 15°C, (b) 3/4th's cooled: temperature after 2 h of cooling = 7.5°C, (c) 7/8th's cooled: temperature after 3 h of cooling = 3.75°C

Using Figure A.3.2 as an example, with an initial pulp temperature of 30°C, an air temperature of 0°C and HCT = 1 hour:

- Initial temperature difference is 30°C-0°C = 30°C. One-half of this difference is 15°C.
- In accordance with the definition of HCT, the produce is half-cooled when the temperature will be 30°C-15°C = 15°C. This can be confirmed from Figure A.3.2: pulp temperature after 1 hour is 15°C, and it is considered as half-cooled.
- The remaining temperature difference is now 15°C-0°C = 15°C. One-half of this difference is 7.5°C. Additional cooling for 1 hour will further reduce the pulp temperature to 15°C-7.5°C = 7.5°C. This corresponds to Figure A.3.2; after 2 hours of cooling (or 2 HCTs), pulp temperature has reached 7.5°C. The produce is now considered as 3/4th's cooled.
- The remaining temperature difference is now 7.5°C-0°C = 7.5°C. One-half of this difference is 3.75°C. Additional cooling for 1 hour will reduce pulp temperature to 7.5°C-3.75°C = 3.75°C. Hence, a total cooling time of 3 hours (3 × HCT) is needed for pulp temperature to reach the target temperature of 3.75°C. Once the produce has reached this temperature, it is considered as 7/8th's cooled and pre-cooling can be stopped.
- From Figure A.3.2, it can be seen that further cooling after 7/8th's cooling results in only minimal reduction in temperature; additional cooling will only result in more weight loss and added power consumption.

Some examples of HCT are given in Table A.3.1 for different commodities. These are results from laboratory experiments and handling trials conducted at the Postharvest Horticulture Training and Research Center (PHTRC) of the University of the Philippines at Los Baños.

Table A.3.1 Half-cooling times for different commodities and packing methods

Commodity	Cooling method	Conditions during cooling	HCT[a]	Sources
Roses	Forced air	Packed in styrofoam box	35-40 min	Agravante *et al.* (2000)
Broccoli	Package icing	Packed in PEB[b] and placed in polystyrene box	1.1 hours	Serrano *et al.* (2000)
	Forced air	Placed in polystyrene box	1 hour	Serrano *et al.* (2000), unpublished data
Lettuce	Forced air	Placed in polystyrene box	1 hour	Serrano *et al.* (2000), unpublished data
Strawberry	Package icing	Packed in plastic trays and placed in styrofoam box	1 hour	Serrano *et al.* (2000)

[a]HCT = half-cooling time; [b]PEB = polyethylene bag

The definitions of cooling time given here are adequate for general applications. More detailed procedures for determining cooling times can be used, but these involve more complicated calculations. These methods utilize the mass-average temperature of the produce to correctly determine cooling times. Some also allow comparison of pre-cooling methods regardless of differences in size of produce and non-uniform temperature of the cooling medium. Detailed discussions are given in Goyette *et al.* (1996), ASHRAE (1998a), Brosnan and Sun (2001) and Becker and Fricke (2002).

Temperature measurement

Air or water temperature during pre-cooling should be measured with a properly calibrated thermometer (see Appendix A.5). Any type of thermometer can be used, as long as it is water-proof, and this is of particular importance in hydrocooling operations. Measurements should be made at different points within the cooling tank in order to detect the presence of hot or cold spots.

Pulp temperatures should also be measured at different points in a stack of produce using steel-sheathed thermocouple probes (Figure 2.32) . Periodic readings will show the cooling rate of the commodity as well as the uniformity of temperature distribution. The cooling time required for a particular commodity should be based on the location with the slowest cooling time to ensure adequate cooling of the entire batch of produce.

Low cost alternatives to conventional pre-coolers

Room cooling using a truck body – a cooling chamber can be constructed from the insulated bodies of used refrigerated trucks, provided they are still in good condition. The condition of rubber gaskets, door seals and locks, and the integrity of seams and joints should be verified. In situations where the integrated cooling unit is too small for forced-air cooling, a high-pressure fan should be used for air handling, possibly using the tunnel method described earlier.

Pallet cooling system – Boyette and Rohrbach (1993) describe a system for the forced-air cooling and shipping of a variety of fruits and vegetables. The main components of the system include an insulated cooling container fabricated from 51-millimetre polystyrene sheets bonded to 6.4-millimetre plywood and a refrigeration unit (RU) powered with a cooling capacity of 10.4 kW from a 220-V source.

Cool air is circulated by the RU within a closed loop. Air from the RU is supplied via a flexible tube connected to one side of the container. Cool air is forced by the RUs fan through the stacks of produce and through an outlet tube connected to the intake of the RU, thereby completing the loop. Once the commodity is sufficiently cooled, the tubes are detached and the inlet and outlet holes of the container sealed. The container is then ready to be used for transporting the cooled produce to market.

Portable forced-air cooler – Talbot and Fletcher (1993) developed a mobile unit configured for tunnel cooling with the following components: two 10.5-kW air conditioner units, a 1.1-kW high-pressure fan and a self-constructed chamber insulated with polystyrene. The cooling units are installed directly in one wall of the chamber. The high-pressure fan is used to force cool air through stacks of produce. As the system is mounted on a trailer, it can easily be pulled to different areas requiring a pre-cooling unit.

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A.4: Fundamentals of refrigeration

Refrigeration is a method of removing heat from an enclosed area (such as a cold storage room, cargo space of a refrigerated truck) and releasing this heat to the outside environment. This process is generally mechanical in nature, although other methods have been developed. It is the most effective method of prolonging shelf-life and maintaining the quality of many commodities, including horticultural perishables. This discussion will deal mainly with the use of mechanical refrigeration for storage and transport of fresh produce at low but non-freezing temperatures. The term *refrigeration* in this discussion will conventionally refer to systems using a vapour-compression cycle as described below.

Objectives of refrigeration

- To slow down biological activity of a commodity by keeping it at its optimum storage temperature without inducing physiological disorders.
- To control disease by continuously maintaining low temperatures and preventing the accumulation of surface moisture on the produce.
- To minimize weight loss of the commodity by keeping humidity levels high during the holding period.

Benefits of refrigeration

- *Allows farmers to wait for a better price for their produce.* Without refrigerated storage, many farmers have no choice but to dispose of their produce as quickly as possible before ripening and/or deterioration sets in. This puts them at a disadvantage when negotiating prices with a potential buyer.
- *Evens out the supply of a commodity during the year.* An oversupply of many commodities is common during the harvesting season, resulting in very low farm-gate prices that discourage farmers from harvesting their crop.
- *Increases the volume of sales and income by reducing spoilage.* The reduction in temperature slows down deterioration and ripening, reducing the number of rejects and increasing selling prices.

Basic concepts of heat transfer

Modes of heat transfer

- *Conduction* – refers to the transfer of thermal energy through solid matter from an area of high temperature to another at a lower temperature.
- *Convection* – refers to heat transfer through the movement or flow of liquids or gases; heat transfer by convection does not occur in solids. Heat transfer can occur through both *diffusion* or *advection*. Diffusion refers to the random movement of individual

particles (such as molecules) in the liquid or gas, while *advection* refers to movement of currents.

- *Radiation* – objects at a certain temperature generate thermal radiation from heat produced within atoms; heat is produced from the movement of charged particles within the atom itself. Emitted radiation can travel through empty space until it encounters a body that can absorb it; hence, no physical contact is needed for radiative heat transfer to occur.
- In actual situations, heat transfer occurs as a combination of these different modes.

Phase changes during heat transfer

Matter can exist in three forms or phases: solid, liquid and gas. Water (H_2O) can, for example, exist as ice (solid), liquid water and water vapour (gas). In order to move from one phase to another, sufficient heat must be absorbed or released by the substance. The amount of heat required to complete a change in phase is known as *latent heat*. During the process of phase change, no change in temperature of the substance occurs. On the other hand, heat loss or gain accompanied by a change in temperature is known as *sensible heat* transfer. Sensible heat (Q_s) can be calculated using Equation A.4.1 (ASHRAE 1998) where m = mass of the substance (kg), C_p = specific heat at constant pressure (kJ/kg/K), ΔT = change in temperature (K or °C).

$$Q_s = mC_p\Delta T \qquad \textbf{(A.4.1)}$$

Specific heats for H_2O at different phases are:

solid – 2.09 kJ/kg/K;
liquid – 4.19 kJ/kg/K;
gas – 2.08 kJ/kg/K.

Heat of fusion (H_f) is the amount of heat lost or gained for a substance to transform from solid to liquid or vice versa. Similarly, *heat of vaporization* (H_v) is the heat needed for a substance to change from liquid to gas and back. For H_2O, H_f = 334.94 kJ/kg and H_v = 2 258.55 kJ/kg.

Figure A.4.1 gives an example of the changes in the state of water as it is heated from -5°C to 150°C. Water is in a frozen state at an initial temperature of -5°C. As the ice absorbs heat, its temperature changes from -5°C to 0°C. For a 1 kg mass of frozen water, the amount of heat absorbed would be (from Equation A.4.1) $1 \times 2.09 \times [0 - (-5)]$ or 10.45 kJ. As soon as the ice temperature reaches 0°C, further heating results in transformation of the ice into liquid water and does not produce any change in temperature. The total heat required to melt the entire block of ice is 334.94×1 or 334.94 kJ. Once all of the ice has melted into liquid water, further heating once again results in an increase in temperature. The amount of heat absorbed to increase the temperature of liquid water from 0°C to 100°C is 1×4.19 x (100-0) or 419 kJ. At 100°C (boiling point of water), further heating causes liquid water to vaporize without any change in temperature. The total heat required to vaporize all of the water is calculated as $2\,258.55 \times 1$ or 2 258.55 kJ. Additional heat required to raise the temperature of the vapour from 100°C to 150°C is calculated as $1 \times 2.08 \times (150\text{-}100)$ or 104 kJ.

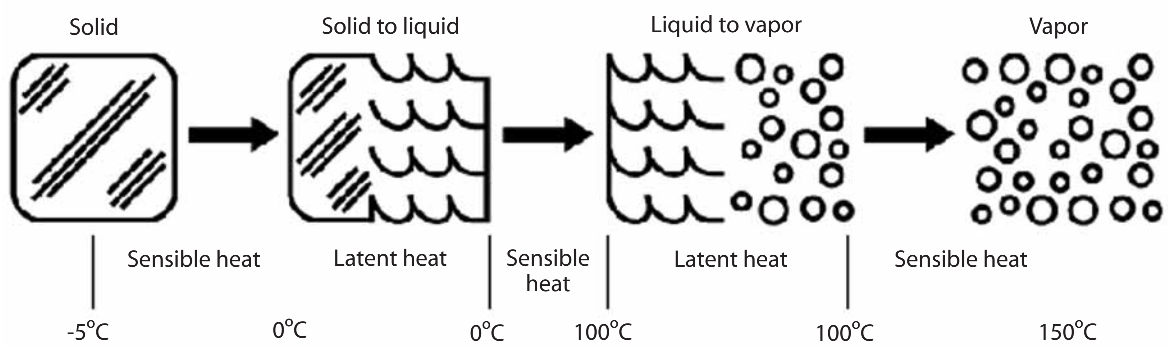

Figure A.4.1 Phase changes of H_2O during heating from -5°C to 150°C

The boiling point of a substance is the temperature at which the vapour pressure of the substance is equivalent to atmospheric pressure (1 atm = 101.3 kPa = 760 millimetres Hg). Hence, boiling point is affected by the pressure of the surrounding environment. If pressure is reduced (for example at higher elevations, or inside a vacuum chamber), the boiling point is also correspondingly lowered.

The vapour-compression refrigeration cycle

A refrigeration system has four main components: an evaporator, compressor, condenser and expansion valve (Figure A.4.2). These are connected in a closed circuit, with *refrigerant* as the working substance in the system. Refrigerant is constantly transformed between liquid and vapour states as it ejects and absorbs heat, respectively.

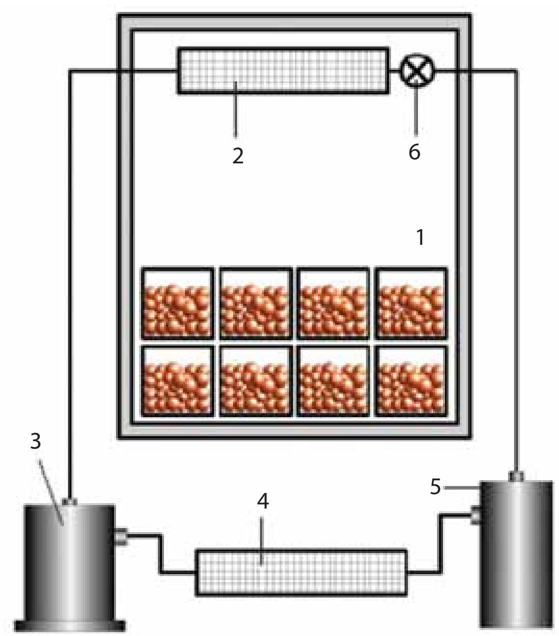

Figure A.4.2 Schematic diagram of a vapour compression refrigeration system for cooling a storage space (1). Major components shown are the evaporator (2), compressor (3), condenser (4), liquid receiver (5) and expansion valve (6)

The **evaporator** is composed of finned aluminium coils with attached fans for forcing storage air past the coils. The fins facilitate heat exchange between the coils and air by increasing the surface area of the coil. The evaporator is located inside the storage area and serves as a heat exchanger. Cold liquid refrigerant travels through the coils, which absorb heat from the storage air as it passes through the coils. As the pressure inside the evaporator is kept low, the boiling point of the refrigerant is lower than the temperature of the storage space. For example, if the temperature of the cold room is set at 10^{o}C, the pressure in the evaporator is reduced such that the refrigerant boils at a temperature below 10^{o}C. The refrigerant transforms into vapour as it absorbs heat.

The **compressor** is considered as the heart of the system and is located outside the storage room. It serves as a pump to circulate the refrigerant throughout the system. In the process, the compressor pressurizes the vapour refrigerant, resulting in a simultaneous increase in temperature above ambient levels. The increase in pressure also elevates the boiling point of the refrigerant.

The **condenser** is a heat exchanger similar to the evaporator, but is located outside the storage area. Hot pressurized vapour refrigerant is pumped into the condenser. Since its boiling point is higher, the refrigerant is able to condense at temperatures above ambient. As it condenses back into liquid form, heat is released, which is ejected out of the condenser. A liquid receiver placed after the condenser stores refrigerant that is metered out to the evaporator as needed. Condensers may be air- or water-cooled, depending on the size of the refrigeration system.

The expansion valve regulates the flow of liquid refrigerant to the evaporator to maintain a constant temperature difference between the coil inlet and outlet. A gas-filled sensing bulb connected to the valve controls the amount of refrigerant supplied to the evaporator. A rise in temperature in the cooled space causes gas in the bulb to expand, opening the valve and allowing refrigerant to pass through. As pressure in the evaporator is kept low, the sudden pressure drop causes temperature of the liquid refrigerant to decrease as it leaves the valve. This allows the refrigerant to absorb heat once again from the cooled space, thereby completing the refrigeration cycle.

Refrigerant is used to carry heat absorbed from the storage space through the evaporator. Once the compressor has pressurized the refrigerant it is hot enough to eject heat to the outside environment through the condenser. The choice of refrigerant depends on its cost, compatibility with system components and materials, toxicity to commodities and humans (Thompson 1992a), and environmental impact.

Many types of refrigerants have been developed over time. Ammonia (NH_3) has a long tradition of use, but was replaced by chlorofluorocarbon (CFC) compounds because of its toxicity and corrosion problems. CFC compounds are non-toxic, non-corrosive, non-irritant and non-flammable. However, environmental concerns with respect to ozone layer depletion and global warming are forcing manufacturers to gradually phase out CFC refrigerants as well as their substitutes, the hydrochlorofluorocarbon (HCFC) compounds. Possible alternatives that have minimal impact on the environment include hydrocarbons, hydrofluorocarbons (HFC) and inorganic compounds such as CO_2, NH_3 and air. Perez *et al.* (1998) proposed proper design and observance of safety practices in using NH_3, which can produce savings of 15 percent in electrical consumption, as well as reductions in repair and maintenance costs.

Basic requirements for refrigerated storage

Sufficient refrigeration capacity

For a cold storage facility, the capacity of the refrigeration system to be installed must be large enough to handle the maximum volume of produce that can be loaded into the storage space, as well as other sources of heat. (Refer to Appendix A.4 'Heat calculations'.)

Sufficient and continuous air circulation

If air movement is adequate, temperature throughout the storage space will be uniform. Otherwise, there will be hot spots within different parts of the load, while chilling injury may occur where cold air is being discharged. Ethylene gas may also accumulate along with other gases such as carbon dioxide, resulting in premature ripening and/or deterioration. Air circulation can be expressed in two ways:

1. As the number of air changes per unit time; calculated from the volume of an empty cold room or refrigerated truck or van.
2. As the volume flow rate (m^3/minute) per tonne of produce, based on the maximum capacity of a cold room. Circulation rates during storage should range from 60-120 m^3/minute of air per tonne (Thompson 1992a).

Proper and adequate insulation

Installing the proper type of insulation of sufficient thickness minimizes heat transfer from the outside environment into the storage space. It also avoids hot spots. Insulation also prevents condensation on the walls or ceiling. Good insulation also reduces variations in temperature. Some common insulating materials and their properties are given in Table A.4.1.

Table A.4.1 Thermal conductivity[a] of some insulation materials

Material	Conductivity (W/m/K)	Sources
Cellular foamglass	0.050	Dossat (1998); Stoecker (1998)
Cellular polyurethane	0.023	
Expanded polystyrene	0.035	
Extruded polystyrene	0.027	
Glass fibre	0.036	
Corkboard	0.0433	
Polyisocyanurate	0.020	

[a] Refers to the ability of a material to conduct heat. It is expressed as the number of watts of heat conducted per metre of thickness of the material per degree Kelvin of temperature difference between the two faces of the material (W/m/K).

It may be less costly to install thicker insulation than is needed during construction, rather than to add insulation later. A vapour barrier made of thick plastic film installed on the warm side of walls and ceiling of a cold room reduces infiltration of outside moisture through walls. This moisture can condense on insulation material, causing deterioration of the material and reducing its insulating efficiency. Modern facilities make use of prefabricated panels where the insulating material is sandwiched between two sheets of treated steel that is totally impermeable to moisture. In comparison, plastic films do not constitute a total barrier to moisture and may tear as the panel expands and contracts.

Light-coloured walls and roof – to minimize solar heat load, exterior walls and roofs of cold storage facilities should be painted white or grey to reflect more sunlight. Reefer vans and trucks should also be similarly painted. The difference in temperature between a light- and dark-coloured wall can be as much as 11°C. A flat dark roof can be 4.2°C warmer than the ambient air temperature (Thompson 1992b).

Shape of the facility – the perimeter of a cold storage room should be square rather than rectangular. A square facility has less wall area, therefore cost of construction is reduced and less heat is transmitted through walls.

Barriers to air infiltration – The use of heavy-gauge plastic strips installed in doorways (Photo A.4.1) can reduce air infiltration during loading and unloading of cold rooms by 85 to 90 percent. When strips become stiff and brittle they should be replaced. Strips may present difficulties for forklift operators (Stoecker 1998). If plastic curtains are not available, the refrigeration system should be shut off when the doors are open.

Photo A.4.1 Plastic strip curtain installed in a doorway to reduce entry of warm air

Heat load calculations

Psychrometry

Psychrometry is the study of moist air (a mixture of air and water vapour) and its properties. It has many applications in the heating, ventilating and air-conditioning industry and in meteorology (Table A.4.2). Common properties of interest include the dry bulb temperature T_{db} (°C), wet bulb temperature T_{wb} (°C), relative humidity (RH, %), humidity ratio ω (kg moisture/kg dry air), enthalpy h (kJ/kg/K), specific volume v (m^3 moist air/kg/dry air) and dewpoint temperature T_{dp} (°C).

Table A.4.2 Air properties at ambient and storage conditions

Ambient conditions	Storage conditions	
Given values	Dry bulb temperature (°C)	35
	Dry bulb temperature (K)	308
	Relative humidity (%)	60
Values from psychrometric chart	Enthalpy (kJ/kg/K)	89.6
	Specific volume (m^3/kg dry air)	0.903
	Humidity ratio (kg/kg dry air)	0.0212
Calculated values	Air density (kg/m^3)	1.131
Given values	Dry bulb temperature (°C)	25
	Dry bulb temperature (K)	298
	Relative humidity (%)	90
Values from psychrometric chart	Enthalpy (kJ/kg/K)	70.6
	Specific volume (m^3/kg dry air)	0.869
	Humidity ratio (kg/kg dry air)	0.0718
Calculated values	Air density (kg/m^3)	1.171

Enthalpy is the amount of heat contained (internal energy) per unit mass of moist air. The importance of dewpoint temperature has been discussed earlier in the main text. Any refrigeration textbook can be consulted for a more detailed discussion on these properties. The relationships between these variables are usually summarized graphically in a psychrometric chart (Figure A.4.3).

Knowledge of at least two variables is needed to determine air properties. This can be any combination of the variables mentioned above, but the most commonly used is the T_{db}-T_{wb} pair.

T_{db} can be measured with any ordinary thermometer. T_{wb} is measured using a thermometer with a wet cloth wick enclosing the sensing bulb. Some means of moving air past the wick must be used to get a correct reading. Instruments combining both types of thermometers (with or without a built-in fan) are called *psychrometers*.

The intersection of the T_{db} line and the T_{wb} line indicates the location of the air condition on the chart. The corresponding values for the other properties are then read off their respective scales.

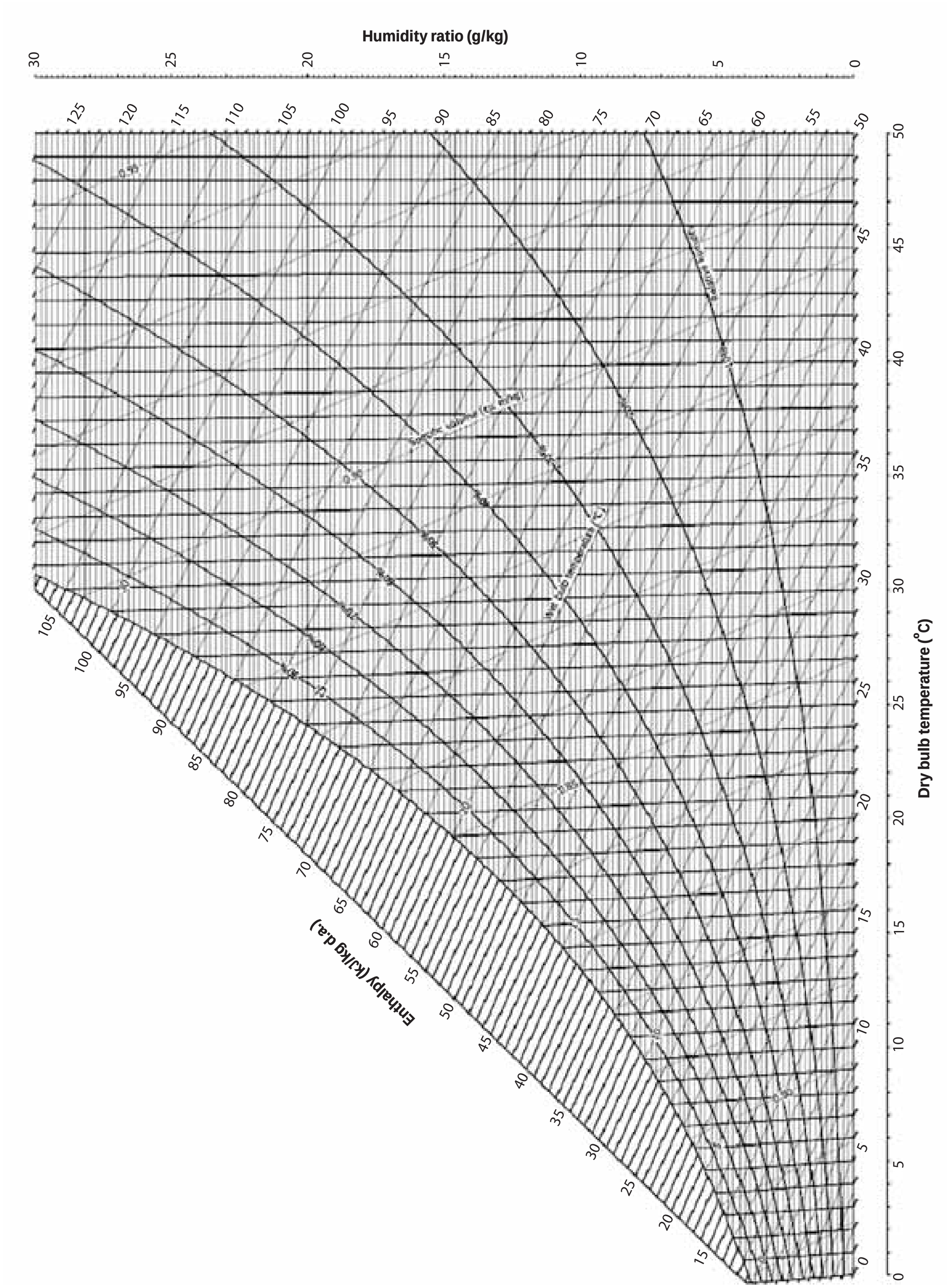

Figure A.4.3 Psychrometric chart for determining different air properties

For example, the properties for air with T_{db} = 35°C and T_{wb} = 32°C are:

RH = 81.2%

ω = 0.0290 kg water vapour/kg dry air

h = 109.6 kJ/kg/K

v = 0.915 m^3 moist air kg/dry air

T_{dp} = 31.2°C

To determine density of moist air ρ (kg/m^3), values for v and ω are read off a psychrometric chart and substituted in Equation A.4.2:

$$\rho = \frac{\omega + 1}{v} \qquad \textbf{(A.4.2)}$$

From the example above ρ = 1.1 kg/m^3 of moist air.

Heat sources

The refrigeration requirement of a cold storage facility is estimated from the *peak refrigeration load*. This quantity is the projected maximum amount of heat that must be removed by the refrigeration system. It is affected by the volume of produce arriving daily, produce temperature during loading, ambient temperature, specific heat (C_p) of the commodity and final storage temperature (Hardenburg *et al.* 1986; Gross *et al.* 2004). Refrigeration load may be expressed in kilowatts (kW), kilojoules per hour (kJ/hour) or tonnes of refrigeration. One standard tonne of refrigeration is defined as the amount of heat required to melt 1 tonne of ice at 0°C in 24 hours. In metric terms, this corresponds to 12 687 kJ/hour or 3.5 kW.

The process of calculating cooling load is described below and is adopted from ASHRAE (1998) and Stoecker (1998); this is a more detailed procedure that accounts for most of the possible heat sources in a cold room.

Transmission load is heat flow through walls, ceiling and floor areas of the building due to temperature differences between the interior and exterior of the storage area. This quantity is affected by insulation material, thickness of panels, surface area of the structure and difference in temperature between the storage space and ambient air. Heat gain by transmission q_{trans} (kJ/hour) is calculated using Equation A.4.3:

$$q_{trans} = 3.6 \cdot (UA\Delta T) \qquad \textbf{(A.4.3)}$$

where U = overall heat transfer coefficient (W/m^2/K), A = surface area (m^2) of the storage room and ΔT = temperature difference between inside and outside air (°C or K). From Figure A.4.4, U is calculated using Equation A.4.4:

$$U = \frac{1}{\frac{1}{f_i} + \frac{\chi_1}{k_1} + \frac{\chi_2}{k_2} + \frac{\chi_3}{k_3} + \frac{1}{f_o}} \qquad \textbf{(A.4.4)}$$

where f_i = convection coefficient for the inside wall (W/m/K), f_o = convection coefficient for the outside wall (W/m^2/K), k_1, k_2 and k_3 are thermal conductivities of wall materials (W/m/K) and χ_1, χ_2 and χ_3 are thicknesses of the respective materials (m). For still air, $f_i = f_o$ = 9.3 W/m^2/K); for a surface exposed to wind with speeds of 24 kilometres per hour this value increases to 34 W/m^2/K (ASHRAE 1998).

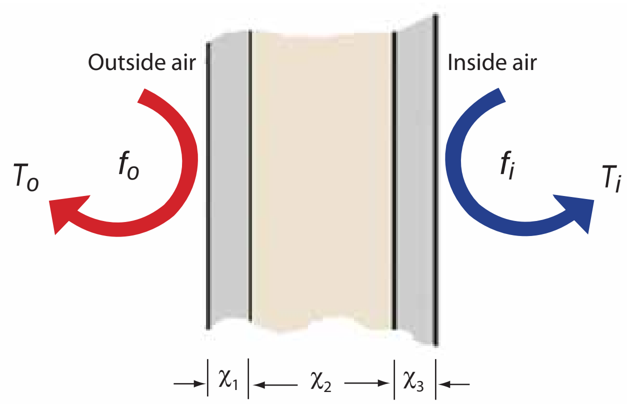

Figure A.4.4 Section of an insulated panel

Product load is the sum of field heat and heat of respiration. *Field heat* (q_{field}) is defined as the amount of heat to be removed to cool a commodity at field temperature down to the desired storage temperature. Heat contained in packaging materials is also included in field heat. This quantity of heat is affected by the initial temperature of the product T_i (K), its specific heat C_{prod} (kJ/kg/K), total mass of the commodity m_{prod} (kg), final storage temperature T_f (K) and the desired cooling time t (h) (Equation A.4.5).

$$q_{field} = \frac{m_{prod} C_{prod} (T_i - T_f)}{t} \qquad \textbf{(A.4.5)}$$

Horticultural perishables respire and release heat as stored energy reserves are consumed. Respired heat varies with the type of commodity and its temperature. Heat of respiration q_{resp} (kJ/hour) is calculated using Equation A.4.6 where RR = respiration rate at the desired storage temperature (mg CO_2/kg/hour).

$$q_{resp} = 0.0107 \cdot (RR)\,(m_{prod}) \qquad \textbf{(A.4.6)}$$

Product load q_{prod} is then calculated as $q_{field} + q_{resp}$.

Internal load – q_{int} (kJ/hour) – is made up of heat produced by internal sources such as lights, personnel working in the storage space, forklifts, electric motors and fans that are not part of the refrigeration system. Heat load from packaging material is calculated by substituting values for weight and specific heat of packaging materials into Equation A.4.5.

Equation A.4.7 is used to estimate heat produced by one person, q_{person} (kJ/hour), where T = temperature of the storage space (°C).

$$q_{person} = (272 - 6T) \cdot 3.6 \qquad \textbf{(A.4.7)}$$

Air infiltration load is associated with heat gained by entry of outside air through door openings during loading and unloading of the storage area. Heat gained through air infiltration q_{air} (kJ/hour) is calculated from Equation A.4.8:

$$q_{air} = qD_tD_f\,(1 - E)(3\,600) \qquad \textbf{(A.4.8)}$$

where q = sensible and latent refrigeration load for fully established airflow (kW), D_t = doorway open time factor, D_f = doorway flow factor, and E = effectiveness of the doorway protective device (for example plastic strip curtains). Equations A.4.9 and A.4.10 are used to calculate q and D_t, respectively:

$$q = 0.221\,A_d\,(h_o - h_i)\,\rho_i \left[1 - \frac{\rho_o}{\rho_i}\right]^{0.5} (gH)^{0.5}\,F_m \qquad \textbf{(A.4.9)}$$

$$D_t = \frac{P \cdot \theta_p + 60 \cdot \theta_o}{3\,600 \cdot \theta_d} \qquad \textbf{(A.4.10)}$$

where A_d = doorway area (m^2), h_o = enthalpy of ambient air (kJ/kg), h_i = enthalpy of storage air (kJ/kg), ρ_o = density of ambient air (kg/m^3), ρ_i = density of storage air (kg/m^3), g = gravitational constant (9.8 m/sec^2), H = doorway height (m), F_m = density factor, P = number of times door is passed through, θ_p = time needed for a door to open and close each time someone passes through (second/passage), θ_o = time that the door stays open (minute) and θ_d = amount of time a facility is in use daily (h). Values for enthalpy and density of air can be determined from psychrometric charts. Equation A.4.11 is used to calculate F_m:

$$F_m = \left[\frac{2}{1 + \left(\frac{\rho_i}{\rho_o}\right)^{1/3}}\right]^{3/2} \qquad \textbf{(A.4.11)}$$

Equipment-related load consists of heat added by equipment of the refrigeration system. This heat may come from fans for air circulation, humidity control systems and defrosting systems. This component is generally minor at storage temperatures above -1°C. When artificial heat loads are not present, total equipment heat load is about 5 percent of the first four components of the total refrigeration load (Equation A.4.12).

Calculation of heat load and refrigeration requirement

For illustrative purposes, a sample problem on determination of the heat load and required refrigeration capacity of a small storage room is given here.

The required refrigeration capacity of a cold room for storing 10 tonnes of pre-cooled bananas is to be determined. Fruit will be stored in wooden crates that contain 20 kilograms of fruit per unit. Storage conditions are 25°C and 90 percent RH; ambient conditions are 35°C and 60 percent RH.

Transmission load – for a total load of 10 000 kilograms of fruit and 20 kilograms of fruit per crate, the total number of crates to be loaded is 500. This can be stacked on nine pallets in a 3- × 4-crate column that is five layers high on each pallet. To accommodate this load, a room with a floor area of 7.5 × 4.5 metres and a ceiling height of 2.4 metres is needed. Therefore, volume = 81 m^3 and surface area = 91.4 m^2. A door is provided that is 3 metres wide and 2 metres high.

The storage room is to be insulated with 80-millimetre thick polystyrene panels sandwiched between two 6-millimetre plywood sheets. Thermal conductivity for expanded polystyrene and plywood is 0.035 (Table A.4.1) and 0.130 W/m/K (TETB 2005), respectively.

Substituting values into Equation A.4.4 and A.4.3:

$$U = \frac{1}{\frac{1}{9.3} + \frac{0.006}{0.13} + \frac{0.08}{0.035} + \frac{0.006}{0.13} + \frac{1}{9.3}} \quad U = 0.386 \text{ W/m/K}$$

$$q_{trans} = 3.6 \text{ x } 0.386 \text{ x } 91.4\ (35\text{-}25) = 1\ 269 \text{ kJ/hour}$$

Product load – as the fruit and its container has been pre-cooled to 25°C, $q_{field} = 0$.

The respiration rate of banana at 25°C is 227 mg CO_2/kg/hour. Using Equation A.4.6:

$$q_{resp} = 0.0107 \times 227 \times 10\ 000 = 24\ 289 \text{ kJ/hour}$$

$$q_{prod} = 0 + 24\ 289 = 24\ 289 \text{ kJ/hour}$$

Internal load

Lights – assume heat generated by lights to be 5 W/m. Hence, for lighting heat load q_{light}:

$$q_{light} = 5 \times 7.5 \times 4.5 = 169 \text{ W} = 608 \text{ kJ/hour}$$

(*Note:* 1 W = 3.6 kJ/hour)

Personnel – about four persons are assumed to be working inside at any one time. From Equation A.4.7:

$$Q_{person} = (272 - 6 \times 25) \times 3.6 \times 4 \text{ persons} = 1\ 757 \text{ kJ/hour}$$

Motors – for cooling and air circulation within the cold room, four 0.8 kW fans are needed. An electric motor of this size operating in the cold room can be assumed to generate 993 W of heat (ASHRAE 1998).

$$Q_{motors} = 993 \text{ W} \times 4 \text{ fans} = 14\ 299 \text{ kJ/hour}$$

Hence, for total internal heat load q_{int}:

$$q_{int} = 608 + 1\ 757 + 14\ 299 = 16\ 664 \text{ kJ/hour}$$

Air infiltration load – the following doorway factors are assumed:

E = 0.95 (for newly installed strip doors)
D_f = 1.1 (for cyclically operated doors with temperature differentials less than 11°C)
θ_p = 15 seconds (time to open/close door per passage)
θ_o = 40 minutes (total daily time door is left open)
θ_d = 8 hours (number of working hours per day)
P = 24 (number of times of door passages)

Using a psychrometric chart, values of h, v, and ω of moist air can be determined at ambient (subscript o) and storage conditions (subscript i). Air density, ρ is then calculated using Equation A.4.2. Air properties at ambient and storage conditions are summarized in Table A.4.2.

Ambient conditions (T_{db} = 35°C, RH = 60 percent):

h_o = 89.6 kJ/kg/K
v_o = 0.903 m^3/kg
ω_o = 0.0212 kg vapour/kg dry air
ρ_o = 1.131 kg/m^3

Storage conditions (T_{db} = 25°C, RH = 90 percent):

h_i = 70.6 kJ/kg/K
v_i = 0.869 m^3/kg
ω_i = 0.0178 kg vapour/kg dry air
ρ_i = 1.171 kg/m^3

Using Equation A.4.11:

$$F_m = \left[\frac{2}{1 + (1.171/1.131)^{1/3}}\right]^{3/2} = 0.991$$

The door area $A_d = 2 \times 3 = 6\ m^2$. Substituting values for air properties and door dimensions into Equation A.4.9:

$$q = 0.221 \times 6 \times (89.6 - 70.6) \times 1.171 \times (1 - 1.131/1.171)^{0.5}\ (9.8 \times 2)^{0.5} \times 0.991 = 24\ \text{kW}$$

Using Equation A.4.10:

$$D_t = (24 \times 5 + 60 \times 40)/(3\ 600 \times 8) = 0.096$$

Using Equation A.4.8:

$$q_{air} = 24 \times 0.096 \times 1.1 \times (1 - 0.95) \times 3\ 600 = 455\ \text{kJ/hour}$$

Equipment-related load – using Equation A.4.12:

$$q_{equip} = 0.05 \times (1\ 269 + 24\ 289 + 16\ 664 + 455) = 2\ 134\ \text{kJ/hour}$$

Total heat load – using Equation A.4.13:

$$q_{total} = 1\ 269 + 24\ 289 + 16\ 664 + 455 + 2\ 134 = 44\ 811\ \text{kJ/hour}$$

Adding a safety factor of 10 percent to the total heat load, the required refrigeration capacity is therefore 44 811 × 1.1 or 49 292 kJ/hour (13.7 kW). Refrigeration capacity is often expressed in terms of tonnes of refrigeration; 1 tonne of refrigeration is equal to 3.5 kW. Hence, the required refrigeration capacity is about 3.9 tonnes of refrigeration.

$$q_{equip} = 0.05 \cdot (q_{trans} + q_{prod} + q_{\text{int}} + q_{air}) \qquad \textbf{(A.4.12)}$$

The total heat load is therefore the sum of the five components (Equation A.5.13); a safety factor of 10 percent is often added to the calculated heat load to get the required refrigeration capacity.

$$q_{total} = q_{trans} + q_{prod} + q_{\text{int}} + q_{air} + q_{equip} \qquad \textbf{(A.4.13)}$$

A sample calculation for determining heat load and refrigeration capacity is given in Appendix A.6.

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A.5: Calibration of a thermometer

Calibration is needed to determine the accuracy of a measuring instrument and the degree of deviation from a known standard. The difference between the reading of the instrument and the standard (either a more accurate calibrated instrument or a fixed-point environment, for example triple point of water at 0ºC) is the correction factor (CF) for that instrument (Simpson *et al.* 1991).

To calibrate a thermometer, the following items are needed: (1) 500 to 1 000-millilitre container (preferably insulated), (2) distilled water, (3) crushed ice made from distilled water and (4) a precalibrated thermometer for use as the standard. Calibration proceeds as follows (adopted from Flores and Boyle 2000):

1. Place the crushed ice in the container and put just enough distilled water to produce an ice bath with more ice than water.

2. Place the standard thermometer in the ice bath, making sure that it does not touch the sides or bottom of the container. Immersion depth should not be less than 6.5 centimetres.

3. Check the temperature reading of the standard thermometer. A thermometer traceable to the National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce should read 0ºC after stirring the ice bath for ten minutes. If the reading is above 0ºC, add more ice. If the standard thermometer still reads above 0ºC, then it should be replaced.

   AS NIST-traceable thermometers may be too expensive and difficult to procure for most ordinary users; liquid-in-glass thermometers may be purchased in any local laboratory supply house or drugstore and calibrated in an ice bath as described above. The temperature reading should be within ±0.5ºC of 0ºC. Once the ice bath and thermometer have equilibrated, the temperature reading should be recorded and used as the CF for that particular instrument. For example, for a thermometer with a CF of 0.5ºC, the corrected temperature for a reading of 21.5ºC is 21.0ºC.

4. Immerse the thermometer to be calibrated into the ice bath to a minimum depth of 6.5 centimetres without touching the sides or bottom of the container. After about one minute, compare the reading of the thermometer with the reading of the standard thermometer. The difference between temperature readings of the test thermometer and the standard thermometer is the CF for the test unit. If the CF is greater than ±0.5ºC and the unit cannot be physically calibrated, the thermometer may be defective and should be checked or replaced.

   The use of laboratory-type water baths equipped with water circulators is recommended for uniform temperature distribution during calibration (Photo A.5.1).

5. For greater accuracy, calibrate at temperatures other than 0°C; water circulators often also come with heaters and automatic temperature control so that the temperature of the water bath may be varied. For example, if the test thermometer is to be used at a temperature range of 10-25°C, the user may wish to check the accuracy of the instrument over this range. Distilled water with temperatures progressively adjusted to 10, 15, 20 and 25°C with the water bath may be used to determine CF of the test thermometer at each temperature setting to produce a calibration curve. The water bath should be well-insulated to reduce heat transfer between water and the environment.

Photo A.5.1 An insulated water bath with water recirculator and ice-water mix for calibration of temperature probes. The recirculator also comes with a heater for controlling temperature of the bath

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A.6. Sample calculations

Determination of volume of 5.25 percent NaOCl solution

The desired chlorine concentration is 100 ppm for a total volume of 200 litres. The volume of pure NaOCl (V_{NaOCl}) needed to produce 200 litres of solution is calculated using Equation A.6.1 where V_{Total} = total volume of solution.

$$\frac{\text{Desired concentration (ppm)}}{1\,000\,000} = \frac{V_{NaOCl}}{V_{Total}} \qquad \textbf{(A.6.1)}$$

Using Equation A.6.1:

$$\frac{100}{1\,000\,000} = \frac{V_{NaOCl}}{200\,L}$$

or V_{NaOCl} = 0.02 litres NaOCl or 20 millilitres of NaOCl. NaOCl is commercially available as laundry bleach at concentrations of 5.25 percent. Equation A.6.2 is used to get the volume of 5.25 percent solution ($V_{5.25}$) where C = concentration of laundry bleach.

$$V_{5.25} = \frac{V_{NaOCl}}{C} \qquad \textbf{(A.6.2)}$$

Using Equation A.6.2:

$$V_{5.25} = \frac{V_{NaOCl}}{C} = \frac{20\,mL\,NaOCl}{\left[\dfrac{5.25\,mL\,NaOCl}{100\,mL}\right]} = 381\,mL$$

Therefore, to make 200 litres of chlorine solution with a concentration of 100 ppm, 381 millilitres of 5.25 percent NaOCl solution are needed.

Calculation of titratable acidity

After titration with 0.1 N NaOH, the volume of NaOH solution used was 0.35 millilitres. The volume of the sample aliquot used was 5 millilitres, fresh weight of the sample was 20 grams and the milli-equivalent of the predominant acid was 0.067. The volume of distilled water used was 60 millilitres.

The weight equivalent of the aliquot was calculated using Equation A.2.3:

$$W_{eq} = (20\text{ g}) \times (5\text{ mL}) / (20\text{ g} + 60\text{ mL}) = 1.25\text{ g}$$

Titratable acidity (TA) was calculated using Equation A.2.1:

$$TA = (0.35\ mL) \times (0.1\ N) \times (0.067) \times (100) / (1.25\ g) = 0.19\%$$

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