3.3.1 Physical Treatments

3.3.1.1 Cleaning and Washing

____ Cleaning can be accomplished using air (dry) or water (washing). Dry brushing with or without air blast may be used to remove loose scales, soil, or dust in products such as onions, garlic, potato, sweet potato, cantaloupes, and melons.

The effectiveness of the washing depends on the amount of water used, characteristics of water (acidity, hardness, mineral content, temperature, and the initial level of contamination), force applied, use of brushing and rubbing aids, etc. Washing is not an effective method for removing fungi from the infected tissues and may even predispose produce to decay organisms and deplete the protective wax layer [2]. Washing may also lead to a water-soaked appearance and moisture penetration, which may aid in pathogen access through the wounds. This is the reason why strawberries, mushrooms, cucumber, and cherries are not generally washed. The water used for cleaning should be of acceptable quality and must be filtered and sanitized before reuse. If the fruit is excessively dirty a detergent may be used prior to sanitizing treatment. The final rinse should be carried out using clean water. Removal of excess surface water by blotting rollers or blowing air over fruits may be necessary to avoid infection and subsequent decay in stone fruits and potatoes [62].

3.3.1.2 Coating and Waxing

________________________________ Rough handling, approaching senescence, and washing deplete natural waxes. Surface coating using wax or hydrophobic substances has been used since ancient times to improve the appeal and acceptability by the consumer, and the ease of packing and handling; and to extend the shelf life by reducing weight (water) loss. Retention of color, firmness, and flavor and the prevention of loss of weight result from (i) reduction in the rates of respiration and transpiration, (ii) protection from insects, pests, and fungi that cause diseases and deterioration, (iii) generation of a local modified atmosphere, (iv) protection from mechanical injuries, and (v) curing tiny injuries and scratches on the surface [2,62]. Significant economic benefits accrue by waxing owing to resultant water-loss reduction to an extent of 30%–50% in normal commercial handling and storage conditions [83]. However, coating may not be always favorable as modification of the internal atmosphere can reduce the available oxygen leading to fermentation, which can be precluded by only a thin layer of wax to allow gas exchange through it. The literature related to coatings has recently been reviewed by Baldwin [11].

Commercial formulations used in coating consist of long-chain fatty alcohols, synthetic resins, chitosans, and other sugar derivatives as active coating agents, and substances to assist in coating, for example, emulsifying and wetting agents. Commonly used waxes for coatings are Carnauba, Shellac, Candelilia, beeswax, paraffin wax, and vegetable oils. Waxing formulations can be used as carriers of chemicals for preventing fungal infestation, senescence, and other physiological disorders. Coating formulations are applied by spraying, fogging, brushing on to the produce followed by drying using cold or hot air. Examples of fruits and vegetables normally waxed are apples, pears, banana, citrus fruits, cucumber, pepper, and tomato. The sealing of the stem end of mangoes with molten paraffin or other coatings prevents spoilage due to stem end rot and anthracnose, and increases the shelf life by controlling respiration [72].

3.3.1.3 Heat Treatment

____________________________________ Deregistration of chemicals used to control physiological disorders, insect pests, and pathogens, and consumer demand for produce with no chemical exposures have fueled increased interest in the use of heat in postharvest management of quality. Heat treatment

TABLE 3.6

Typical Heat Treatments for Controlling Insects in Selected Fruits and Vegetables

Commodity	Insect	Temperature (°C)/Time	Heating Medium Used
Apple	Codling moth (*Cydia pomonella*)	44/120 min followed by 0/4 weeks	Hot air or vapor
	Leafroller (*Cnephasia jactatana*)	40/10 h and 45/5 h in reduced O_2	Hot air and CA
	Light brown applemoth (*Epiphyas postvittana*)	40/17–20 h in reduced O_2 and slightly elevated CO_2	Hot air and CA
	Obscure mealy bug (*Pseudococcus longispinus*)	40/10 h and 45/5 h in reduced O_2	Hot air and CA
	Two spotted spider mite (*Tetranychus urticae*)	45/13 min in 50% ethanol	Hot water and ethanol

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Avocado	Mediterranean fruit fly (*Ceratitis capitata*)	40/24 h	Hot air
	Melon fruit fly (*Dacus cucurbitae*)	40/24 h	Hot air
	Queensland fruit fly (*Bactrocera tyroni*)	46/3 min followed by 1/7 days	Hot water and benomyl
Citrus fruits	Mexican fruit fly (*Anastrepha ludens*)	44/2 h with CA	Hot air and 1% O_2
	Caribbean fruit fly (*Anastrepha suspense*)	51.5/125 min	Hot air
	Fuller's rose beetle (*Asynonychus gomani*)	52/8 min	Hot water
Mango	Mediterranean fruit fly (*Ceratitis capitata*)	47/15 min	Vapor heat
	Caribbean fruit fly (*Anastrepha suspense*)	51.5/125 min	Hot air
	Papaya fruit fly (*Bactrocera payapae*)	47/15 min	Vapor heat
	Queensland fruit fly (*Bactrocera tyroni*)	46.5/10 min	Vapor heat
Pear	Codling moth (*Cydia pomonella*)	44/120 min followed by 0/4 weeks	Hot air and vapor
	Light brown apple moth (*Epiphyas postvittana*)	30/30 h in reduced O_2	Hot air and CA
	Oriental fruit moth (*Grapholita molesta*)	30/30 h in reduced O_2	Hot air and CA

Source: Adapted from S. Lurie, *Postharv. Biol. Technol.* 14:257, 1998; S. Lurie and J.D. Klein. In *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks—A Draft Version of the Revison to USDA Agricultural Handbook Number 66* (K.C. Gross, C.Y. Wang, and M. Saltveit, Eds.), 2002 (www.ba.ars.usda.gov/hb66/index.html).

has a positive effect on maintaining fruit quality by preventing and controlling incipient fungal and insect infestation, reducing the rate of ripening, increasing sweetness and reducing acidity in fruits, and reducing the impact of storage disorders such as superficial scald and chilling injury [21,37–40,42–46,50]. The heating schedules have been specified in terms of temperature and time of heating for each commodity and the purpose for which the treatment is used. Tables 3.6 through 3.8 list the conditions of heat treatment used for insect disinfestations, disinfection, and control of physiological disorders and enhancing quality, respectively. The effectiveness of the treatment depends on the nature of the produce and its sensitivity to heat, temperature and time of heating, the heating method used, and any supplemental treatments such as combinations with antioxidants or CAs. Benefits may also accrue by exposing the produce to temperature-conditioning treatment before storage by incubating the produce at ambient temperature for a certain length of time.

____________________________ Hot water treatment has the advantages of low cost and relatively simple application equipment. The vapor heat treatment is relatively expensive due to costs associated with initial investment for equipment and process operation. It requires an airtight and moisture-proof treating room equipped with automatic temperature and humidity controls and a boiler for steam generation [2]. In general, both hot water and vapor heat treatment can cause excessive tissue damage and peel injury than forced hot air.

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TABLE 3.7

Typical Heat Treatments for Controlling Pathogens

Commodity	Pathogen	Temperature (°C)/Time	Heating Medium Used
Apple	Gray mold (*Botrytis cinerea*)	38/4 days	Hot air with $CaCl_2$ dip
	Blue mold (*Penicillium expansum*)	38/4 days	Hot air alone or combination with $CaCl_2$ dip
Banana	Crown rot (*Chalara paradoxa*)	45/20 min or 50/10 min	Hot water
Cactus pear	Blue mold (*Penicillium italicum*)	38/24 h or 55/5 min	Hot water or air
Grapefruit	Green mold (*Penicillium digitatum*)	46/6 h or 59–62/15 s	Hot water
Lemon	Green mold (*Penicillium digitatum*)	45/2.5 min	Hot water with 2% sodium carbonate
		36/3 days	Hot air
Mango	Black spot (*Alternaria alternata*)	60–70/15–20 s	Hot water
	Antracnose (*Colletotrichum gloeosporrioides*)	46–48/24 s to 8 min	Hot water, vapor
		51.5/125 min	Air
	Stem end rot (*Diplodia natalensis*)	51.5/125 min	Hot air and water
Orange	Green mold (*Penicillium digitatum*)	41–43/1–2 min	Hot water and 6% sodium carbonate
		53/3 min	Hot water
Papaya	Stem and surface rots (*Botryodiplodia theobromae*)	49/20 min or 32/33 min first and then 49/20 mins	Hot air
	Stem and surface rots (*Mycospharella* spp.)		
Pepper	Gray mold (*Botrytis cinerea*)	50/3 min	Hot water
Strawberry	Gray mold (*Botrytis cinerea*)	45/15 min	Hot water
Tomato	*Rhizopus stolonifer*	50/2 min	Hot water

Source: Adapted from S. Lurie and J.D. Klein. In *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks-A draft version of the revison to USDA Agricultural Handbook Number 66* (K.C. Gross, C.Y. Wang, and M. Saltveit, Eds.), 2002 (www.ba.ars.usda.gov/hb66/index.html).

TABLE 3.8

Optimum Conditions for Curing Vegetables

Commodities	Temperature (°C)	RH (%)	Days
Cassava	30–40	90–95	2.5
	25–40	80–85	7–14
Potato	15–20	90–95	5–10
Sweet potato	30–32	85–95	4–7
	29–32	80–90	4–7
	30–33	85–95	5–7
Yam	32–40	90–100	1–4

Source: L. Kitinoja and A.A. Kader, *Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops*, 3rd ed., University of California, Davis, 1995; V. Ravi, J. Aked, and C. Balagopalan, *Crit. Rev. Food Sci. Nutri.* 36:661, 1996.

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______________________ Heating may promote lignin formation and accelerate peel injury healing, which may inhibit fruit rot as reported in grapefruit [17]. Curing is a postharvest healing process of the outer tissues of root crops by the development of a wound periderm by application of heat. Periderm acts as an effective barrier against infection and water loss. The purposes of curing are (i) to heal wounds of tubers and bulbs sustained during harvesting, (ii) to strengthen the skin, (iii) to dry superficial leaves, such as onion bulbs to prevent microbial infection during storage and distribution, (iv) to develop desired skin color (onion), (v) to reduce water loss during storage in potatoes, sweet potatoes, cassavas, yams, onions, and garlic [63]. Extension of storage life achieved owing to curing offsets the initial cost of treatment [36]. Curing is carried out at the farm level by subjecting the produce to high temperature and humidity for a given duration. If local weather conditions permit, crops can be undercut in the field, windrowed, and left to dry for 5–10 days. The dried tops of the plants can be arranged to cover and shade the bulbs during curing process, protecting the produce from excess heat and sunburn [36]. The optimum curing conditions for different crops are given in Table 3.8. One day or less at 35°C–45°C and 60%–75% relative humidity is recommended if forced heated air is used for curing onions and other bulbs [36].

Heat treatment can also assist in controlling the postharvest disorders and enhance the shelf life of fruits and vegetables by formation of areas of amorphous wax and fewer surface cracks in apples after heat treatment. Heating apples to 38°C for 3 or 4 days before storage suppressed softening [37], and decreased storage disorders such as superficial scald and bitter pit [46]. The prestorage heating plus calcium dip has shown a synergistic effect in maintaining fruit firmness [44] and decreasing storage disorders. However, the synergistic effect is limited to only when the heat treatment preceded calcium dipping [40]. Prolonged exposure to elevated temperatures must be avoided to reduce weight loss and loss of ripening ability [22]. Heating at 38°C for various holding time has been found to be effective in preventing chilling injury for a produce stored at 2°C for 4 weeks (Table 3.9).

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