

15 Postharvest Technology and Quarantine Treatments

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15.1 Introduction

Postharvest handling of mangoes is the last phase (from the tree to mouth) of an agribusiness venture. To optimize productivity, profitable uses for all grades of fruit should be sought, and stable employment provided for key skilled staff. Sustainable land and water management, and compliance with health, safety and financial obligations to employees are also necessary. Increasingly, Good Agricultural Practice (GAP) protocols need to be observed (GAP, 2003; FFTC-GAP, 2007).

This chapter reviews the technology and quarantine treatments that have been developed for the postharvest handling of mangoes. Peacock (1986), Ledger (1986, 1991b) and Opara and Nguyen (1999) have previously reviewed postharvest handling of mangoes, while several others have reviewed specific aspects of the topic (Johnson and Coates, 1993; Heather, 1994; Jacobi *et al.*, 2001b; Singh *et al.*, 2004; Yahia, 2006). Less than 10% of total world mango production is exported. Export markets for mangoes have expanded because of social changes and rising demand, increased international air cargo space for some sectors and promotion of export fruit production in developing countries (Procter and Cropley, 1994; FAOSTAT, 2008). Expansion of production to meet the supply requirements of export and distant domestic markets has been possible because of successful integrated management strategies and disinfestation technologies to control diseases and insects (Johnson and Coates, 1993; Johnson and Heather, 1995; Ploetz, 2007), and increased land availability due to deforestation and diversification away from rice. Market development has also been facilitated through harmonization of the rules of trade between nations and regions at global and near global levels (WTO, 2008), agreement on pest and disease risk management under the International Plant Protection Convention (IPPC), various bilateral and regional Free Trade Agreements (FTA, 2007), and the global expansion of supermarkets. Simultaneously, knowledge of and concerns about exotic pest risks to domestic fruit production, socio-political concerns about chemical residues on food, environmental management and labour conditions, and rising production and marketing costs, have impinged upon market access and stimulated international dialogue and research initiatives which address these concerns (Buchanan, 1994; Gullino and Kuijpers, 1994; Ploetz, 2003, 2007).

15.2 Considerations Influencing Postharvest Requirements

Market and consumer research

Strategies and procedures for horticultural market research have been outlined by Minnis (1993, 1994), Hall *et al.* (2001) and Kitinoja and Kader (2003). Increasingly, a supply chain approach is being taken (Johnson and Hofman, 2004). Hofman and Ledger (2006) proposed that the supply chain approach should be used to guide research and development and that there needs to be a champion in the supply chain with significant influence and a desire for improving chain status and performance. Key features are identification of market demand, through-put, price and profit flows, seasonal fluctuations in availability and demands, supply competitors (and their commodity statistics), importer-buyer requirements and relationships, options for value-adding, and consumer expectations and sales promotions. Point-of-sale transaction data from supermarkets and other sales outlets in target markets can be an invaluable source of intelligence and can be purchased from marketing information specialists. Detailed supply chain assessments can guide options for innovation and improvement (Johnson and Hofman, 2004).

The volume, grade and quality of product available for export requires analysis in relation to buyer specifications, retail customer and provedore preferences, technological and regulatory requirements for supplying the market, and the production, packaging, cooling and transportation protocols/options that are needed/available or specified under agreed codes of practice (NRI, 2008a). Procter and Cropley (1994), Mahendra *et al.* (2002) and the Natural Resources Institute (NRI) (2008b) provide some perspectives on these issues.

Quality assurance (QA) and Good Agricultural Practice (GAP)

Postharvest handling assures timely delivery of a product that closely matches buyer specifications and complies with mandatory regulatory requirements. Satisfying customers underpins quality assurance (QA) and observance of GAP (Box 15.1), which aims to produce a product of the desired standard, compliant with regional or internationally agreed standards in production and handling, and encourage regular, larger and more frequent purchases, and brand loyalty. As export markets become increasingly competitive, responsive observance of QA and GAP certification can be vital for maintaining and expanding market niche (Johnson and Coates, 1991; Askar and Treptow, 1993; Ledger and Premier, 2006). Piñeiro *et al.* (2004) provide generic guidelines for the development of quality and safety guidelines for fresh produce, and Ledger and Premier (2006) provide guidelines for a Mango Quality Plan.

Components of a postharvest handling system may be developed in commercial confidence to enhance brand-name reputation and increase market share. Increasingly they are also agreed under contractual agreements

Box 15.1. What is Good Agricultural Practice (GAP)?

GAP enhances trader-buyer relationships and the reputation of producers and traders for the suitability of produce and environmental care. A key feature of GAP is the role of independent certifying authorities (usually private sector) in accreditation and compliance monitoring, to provide additional assurance to buyers of certification credibility. GAP can be applied to any farming system or scale. Key elements include: sustainable practices such as integrated pest management (IPM), responsible fertilizer use and care for the environment. It relies on four key principles (Wikipedia, 2007; NRI, 2008b):

- Economic and efficient production of adequate supplies of safe and nutritious foods or other agricultural commodities.
- Compliance with sustainable practices which improve natural resource availability.
- Assuring the economic and environmental sustainability of the farming enterprise.
- Meeting social and cultural norms and expectations in production and marketing.

GAP has gained global prominence because of the trend to making it a 'compulsory standard' for exporters to Europe. A private sector initiative, EurepGAP sets 'voluntary standards' for agricultural product certification anywhere. It involves partnership between farmers and retailers wanting to establish and implement procedures and standards for certifying application and compliance in GAP. It is applied before the farm-gate (from planting to market dispatch), and is not necessarily a standard that is displayed to customers. EurepGAP involves an array of documentation including general regulations, control points, compliance criteria and checklists (EurepGAP, 2007).

In 2007, EurepGAP transformed into GLOBALGAP (GLOBALGAP, 2007) that could be tailored and adopted anywhere in the world. In parallel with the EurepGAP process, the South-east Asian countries have been working towards Association of South-east Asian Nations (ASEAN) GAP standards suited to fruit marketing within ASEAN (ASEAN-GAP, 2007; FFTC-GAP, 2007; Johnson *et al.*, 2008).

with supermarkets or exporters. No regulations govern the pursuit of superior but legal agribusiness practices that may enhance grower and seller reputations or provide additional advantages. Regulations govern chemical residues, pests, diseases, product and packaging specifications. The sections that follow need to be considered in developing the postharvest components of GAP protocols and dynamic QA systems.

Regulatory restrictions and quarantine treatments

Quarantine treatments disinfest produce of target pests. They are a critical component of protocols designed to satisfy market-stipulated prohibitions against pest entry to countries, or regions within countries. Protocols stipulate procedures for monitoring, detecting, eliminating and handling pest-affected

produce. Frequently, a detailed pest risk analysis (PRA) is required, protocol efficacy against pests of quarantine concern must be demonstrated, applicator integrity scrutinized and market-access requirements and rights approved by regulatory and agricultural authorities in the importing and exporting country or region. Increasingly, systems approaches are being applied. These minimize the need for reliance on quarantine treatments by including PRA, production-based pest management systems, consideration of establishing pest-free areas or identifying commodities which are non-hosts of quarantine pests.

Restrictions or limitations on pesticide residues and other contaminants in marketed produce are also considerations in the choice of quarantine treatment and market access. Pesticide residue monitoring protocols are often required (Johnson and Heather, 1995; Sharp and Heather, 2002; McMaugh, 2005). By restricting or preventing market access, quarantine and pesticide residue restrictions can unintentionally operate as quasi-trade barriers, effectively reducing competition with domestic production of the same or alternative products. However, this is decreasing because of better adherence to science-based decision making as the foundation for quarantine restrictions (WTO, 2008). Government authority web sites and export agencies can provide information on quarantine and tariff barriers, pesticide use restrictions, inspection, packaging and labelling regulations (PPQ, 2007; IPPC, 2008) (see Disinfestation section under 15.6 Packhouse Measures, this chapter). Phytosanitary requirements for fresh mango exports to some markets are shown in Table 15.1. Marketing through reputable exporters, known to the importing country as suppliers of produce that comply with regulatory restrictions, can encourage producer and importer confidence.

Limitations of the product

Mangoes ripen rapidly and have low tolerance of temperatures $<10^{\circ}\text{C}$. Post-harvest handling procedures for mangoes aim to optimize quality and minimize premature ripening and fruit damage. Precise maintenance of fruit quality and the storage environment demands inputs at every stage from picking to the consumer (Ledger, 1991b; Milne, 1994; Ledger *et al.*, 2002b).

Supply, logistics and transport

Market development cannot succeed without a reliable supply of suitable or market-compliant produce. Production seasons are usually short (2–8 weeks), cultivar appearance and flavour diverse, maturation time variable, and orchards sometimes small and scattered. Practical solutions to these limitations (i.e. sourcing from a range of ecoclimates with differing maturation dates, or flower-induction technologies) are critical for industry development. Competitive air-freight rates and rapid road transport, combined with cool-chain handling and atmosphere management can make nearby export markets almost as accessible as distant domestic markets. Special perishable produce rates may be negotiated or subsidized by government, especially during industry establishment. Sea freight is necessary for moving large volumes when air freight is uneconomical. Out-turn problems often arise,

Table 15.1. Typical phytosanitary requirements for mangoes for some countries.

Country	Phytosanitary requirements ^a (usually for mangoes from individual countries or regions on a case-by-case basis)
Australia	Approved treatment for fruit fly, area free of pulp weevil (<i>Sternochetus gravis</i> (F.))
Canada	No phytosanitary certificate required
China	Phytosanitary certificate required. Field management measures for specific pests of quarantine concern to China plus approved disinfestation treatment for fruit flies
EU	Phytosanitary certificate required
Indonesia	Phytosanitary certificate required plus grown in area free of Queensland and Mediterranean fruit fly
Japan	Phytosanitary certificate required plus disinfestation schedule approved for nominated mango cultivars and fruit fly species and inspection of approved quantity of fruit (2–5%)
Korea	Phytosanitary certificate required, combined with field surveys
Malaysia	Must be free of seed weevil on inspection
New Zealand	Phytosanitary certificate required plus approved disinfestation schedule for nominated fruit fly species
Saudi Arabia	Phytosanitary certificate required. Require destructive test of 2% of consignment for seed weevil, or field survey verification of block freedom
Singapore	No restrictions
United Arab emirates	Phytosanitary certificate required. Require destructive test of 2% of consignment for seed weevil, or field survey verification of block freedom
USA	Phytosanitary certificate required plus disinfestation approved for nominated mango cultivars and fruit fly species

^a General requirements: Prior approval to import is required to access the market of many countries. Packhouse and disinfestation treatment/facility inspections may be required by exporting and importing regulatory authorities. Import permits may cover multiple importations but usually require renewal every 3–12 months. Phytosanitary certificates must be issued by a government authority. Fruit must be free of soil and debris and packed in clean, new containers. Timber packaging and pallets will be subject to additional requirements. Consignments found to contain quarantinable pests will be rejected, and either re-exported or destroyed.

especially during market development (Snowdon, 1994). Insurance should be arranged to cover losses. Specialist inputs may be required to identify causes of the out-turn problems and in the apportionment of liability amongst producer, shipper and marketer (Snowdon, 1990, 1994).

Personnel

QA systems and GAP protocols must encompass the human component of an organization or business (Bunt and Piccone, 1994; Rolle, 2006; Sonneveld, 2006; FFTC-GAP, 2007). Market agents, exporters, farm/packhouse suppliers, finance providers and transport personnel and companies need to be selected and worked with from the quality perspective. Human resource development, training and education have been of major significance in the success of many industries.

Ledger and Bagshaw (1994) refer to three general styles of management: (i) defect detection; (ii) defect prevention; and (iii) continuous improvement. They consider that quality management of horticulture has traditionally been the defect detection style, but it is now moving to the continuous improvement style via the implementation of QA, total quality management and supply-chain improvement systems. Key ingredients of successful implementation of quality systems and supply chains are: (i) unqualified commitment by the owner and senior management of the human, material and other resources needed to introduce and maintain the system; and (ii) employee understanding and active participation in the process (Ledger and Bagshaw, 1994).

Profitability and sustainability

Higher freight rates, tariffs and taxes, pesticide-use monitoring and quarantine and security clearance times can affect sales negotiations and profit margins, as can socio-cultural differences among retail buyer, importer, exporter and producer during marketing negotiations and exporter and buyer perceptions and consumer expectations of quality. Intended markets, retailers and regional trade fairs should be visited to make personal contacts and to assess suitability of the market and retailing facilities, conditions and prospects. Ongoing market monitoring is vital, with regular out-turn inspections by trained personnel, and contingency arrangements for product regrading at destination if required. Prompt, personal attention to client concerns or product problems can be essential for continuing success (Johnson, 1997; Vinning and Young, 2006).

15.3 Preharvest Management

The effects of production practices on fruit quality have been reviewed by Arpaia (1994), Hofman and Smith (1994), Hofman (1998) and Hewett (2006). The fruit characteristics influenced by preharvest factors include internal and external colour, shape, size, sweetness, vitality (the inherent capacity to maintain quality after harvest) (Hofman *et al.*, 1997b), cleanliness and residue levels, and the occurrence of pest or disease infestations or biotic/abiotic damage. The main production factors influencing at-harvest quality apart from genotype include chemical treatment regimes and orchard hygiene, weather conditions before and at-harvest, irrigation, pruning systems and tree nutrition.

Maturity

Peacock (1986) considered that fruit maturity referred to its stage of ontogeny, with fruit of different maturities being at different stages of ontogeny. Fully mature mango fruit are strictly those which have produced a fully developed seed and which have reached their full physiological potential in

relation to size increase and dry matter accumulation within the constraints of the growth environment. When fruit size and dry matter concentration reach a plateau, climacteric fruit such as mango can undergo ripening, where colour, texture, flavour and aroma may change (Watada *et al.*, 1984). In these fruit, a sharp rise, followed by a decline in respiration also accompanies the transformation from not-ready-to eat (unripe), to edible (ripe), to senescent (overripe). Ripening signals the completion of seed ontogeny, and encourages dispersal of the seed by attracting vertebrate fructivores (Cipollini and Stiles, 1992). If fruit are not harvested, maturation and ripening occur on the tree. Ripe fruit fall to the ground, or are consumed by bats, primates, phalangers, birds or humans, either on the tree or after detachment.

Softening and sweetening of fruit flesh and colour changes can occur at any stage of ontogeny, even in pea-sized fruit (Oosthuysen, 1995). Fruit drop at any stage of development is preceded by these events, and the likelihood of their occurrence increases as fruit size and dry matter levels approach their maxima (Singh *et al.*, 2004). Although the changes constitute some of the components of ripening, they can only be regarded as such if the fruit have attained physiological maturity, i.e. 'the stage of development when a plant or plant part will continue ontogeny even if detached' (Watada *et al.*, 1984; Yashoda *et al.*, 2006).

When fruit are removed from the tree several days before the onset of ripening, they are initially hard and green. The fruit progressively soften, change colour and develop aroma at a rate determined by cultivar, storage environment and at-harvest maturity. Ideally, fruit are picked, treated, packed and transported while hard-green, and arrive at retail markets at some pre-determined stage of colour development (usually more yellow or red, than green, and 'sprung', but still firm). The rate at which ripening will occur under particular storage conditions depends upon the stage of ontogeny at harvest. More mature fruit will ripen more rapidly than less mature fruit.

Accurately estimating when the fruit are ready for harvest is critical to consistently meet customer expectations. This is called horticultural maturity, and several criteria of horticultural maturity are possible. One is a legal minimum or buyer-specified standard of maturity, which confirms that the fruit would be acceptable for consumption or processing when ripe or ready to eat for green-eating types. Maturity estimation often relies on visual or calendar-based (days from flowering) assessment or in some cases the application of a simple test (e.g. dry matter or flesh colour assessment). In more exacting cases, more accurate estimates of horticultural maturity may be required to assess product suitability for more stringent or narrower quality specifications, as may be required for contract sales or sea-export consignments.

In both cases, easy to assess harvest indices relying on visual, chemosensory or fruit-age attributes are needed, and they must correlate with the commercially relevant fruit characteristics measured in prescribed tests. Peacock (1986), Harvey (1987) and Askar and Treptow (1993) reviewed methods for assessing fruit maturity. In mango, dry matter, flesh colour, skin colour, fruit shape, Brix, specific gravity or days from flowering or heat accumulation

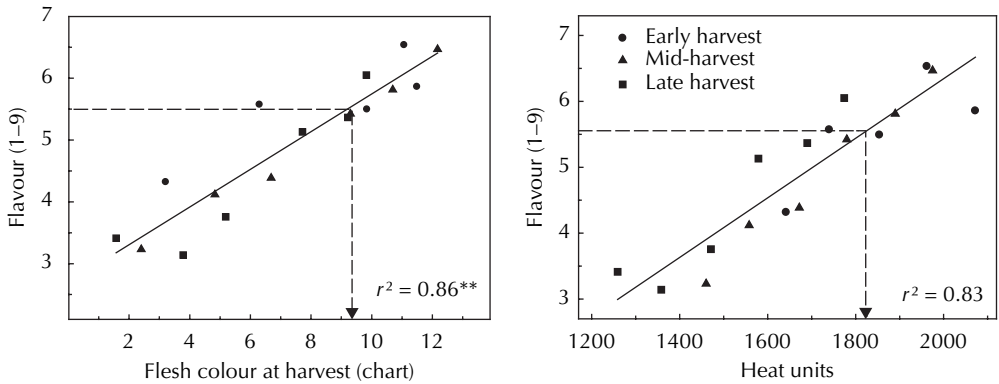


Fig. 15.1. Relation between flesh colour (1 = white; 15 = very yellow) and accumulated heat units (>10°C) with flavour of ripe 'B74' mango grown under Australian conditions.

**= Significant to $P = 0.01$. (Source: Hofman and Marques, unpublished data).

units (e.g. degree-days) have been used (Baker, 1986; Hofman and Ledger, 2006). In South Africa flesh colour is favoured, while in Australia, skin colour, dry matter and accumulated heat units are considered as well (Fig. 15.1). Using several maturity indicators will usually increase the accuracy of predicting the first acceptable harvest date. Information would be cultivar-specific. In some cultivars there may be few reliable visible indicators of maturity that allow picking of the most mature fruit on the tree, particularly when flowering has occurred over many weeks. In these instances it is very difficult for pickers to spot pick the more mature fruit in a cost-effective way. Variation in maturity between fruit can also be influenced by where fruit develop on the tree. In the cooler subtropical areas of the southern hemisphere, fruit on the northern or western side mature more quickly than fruit on the southern side (Hofman *et al.*, 1995; Oosthuysen, 1995; Hofman *et al.*, 1998). In these situations, it may be more feasible for growers to map the maturity of their blocks or orchards to identify groups of trees that have more mature fruit, and/or identify parts of the tree (e.g. the northern/western side in the southern hemisphere) that generally hold more mature fruit. Pickers can then be instructed to pick all the fruit on a specified canopy position and from specified areas of the orchard in order to harvest more mature fruit. This can be more cost effective than selectively picking from individual trees. New technologies such as portable near infrared spectroscopy (NIRS) units may assist in non-destructively mapping maturity profiles across orchards (Subedi *et al.*, 2007).

The maturity of fruit at harvest is important for determining fruit quality at out-turn in overseas markets (see 15.8 Pre- and Post-shipping Storage section, this chapter). If fruit in a carton or pallet are of uneven maturity, it may be impossible to find an effective storage regime(s) which will ensure good quality of all fruit on arrival. One fruit of more advanced maturity in a box or pallet can accelerate the ripening of other fruit, which can then arrive with

disease symptoms and with little or no shelf life. Variable maturity within treatment lots can also adversely affect product quality after heat disinfestation (Jacobi *et al.*, 1995).

On-farm record keeping and analysis of date of flowering, seasonal product maturity, orchard management schedules, environmental data, transport regimes, market destinations and out-turn problems may enable some prediction of at-market quality and better selection of the appropriate destination market. Recent research is focusing on non-destructive methods that could be used for checking fruit maturity in automated grading systems (Joyce *et al.*, 1993; Subedi *et al.*, 2007). Improvements in product quality and performance resulting from the effective use of such systems over several seasons, can provide considerable competitive advantages when developing buyer relationships or consumer 'brand' / country-of-origin loyalty.

Adjusting maturation time

Flowering may be hastened or delayed by pruning, flowering inducers or growth regulators (Davenport and Núñez-Elisea, 1997), to move the fruit-set period into a different time period, and bring forward or delay the harvest date to coincide with higher demand and market prices. Disadvantages could include higher at-harvest temperatures or greater risk of rainfall prior to harvest adversely affecting fruit quality.

Some cultivars and growing conditions are more favourable for manipulating flowering date than others. In the Philippines, manipulation of 'Carabao' flowering with potassium nitrate (KNO₃) helps spread production and market supplies year-round (Bondad and Linsagan, 1979). The treatment also increases 'Kent' flowering but does not alter timing (Goguey, 1993). By contrast, chemical manipulation of flowering has not been effective on 'Kensington Pride' (Barba, 1974).

Evenness in flowering within and between tree/block/farm lots can contribute to product uniformity and increased customer confidence. Treatments that increase evenness of flowering can have commercial benefit in this regard also.

Skin colour and lenticel damage

Skin colour can affect sales, with markets preferring colour (green, yellow, orange, red blush) familiar to past purchase experience, known use and cultivar knowledge, or ethnic-group preferences. Fruit position on the tree affects red colour development, since sun exposure is important for anthocyanin development. Likewise, bagging of fruit can decrease red and green skin colour on ripe fruit (Hofman *et al.*, 1997a). Nitrogen (N) can increase the proportion of the ripe fruit with green skin (Fig. 15.2) by retaining skin chlorophyll (McKenzie, 1994; Nguyen, 2003; Nguyen *et al.*, 2004; Bally, 2007). In cultivars susceptible to green skin at ripeness, N fertilization rates should be

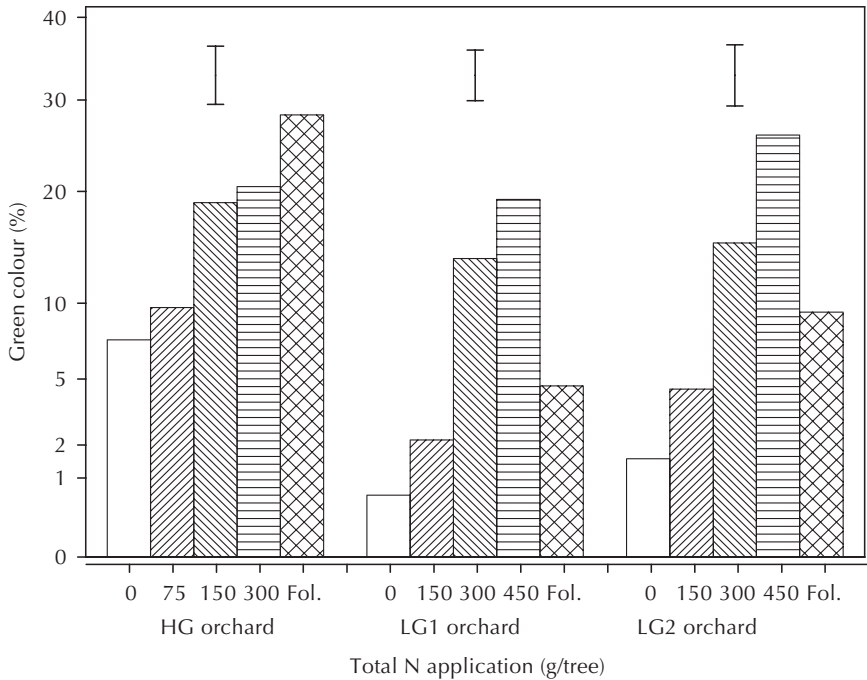


Fig. 15.2. Percentage of green skin colour on ripe 'Kensington Pride' mango fruit from trees in three different orchards (coded HG, LG1 and LG2) following application of N (0–450 g/tree). (Source: H. Nguyen *et al.*, 2004). Fol. = foliar N sprays to a total of 50 g/tree. Bars represent least significant difference (LSD) at 5%.

balanced between improving yield and reducing quality. Applying N to trees soon after harvest can minimize these negative effects in the subsequent crop. Additional N can be applied just before flowering as long as leaf N concentrations are below a certain level (Whiley and Hofman, 2007). This level may vary with cultivar. Excessive fruit calcium (Ca) concentrations in mango will also retard green colour loss during ripening (Wills *et al.*, 1988). Some cultivars are marketed green (e.g. 'Keow Savoy'), which are consumed mature-green before softening and colour development occur.

Enhanced prominence or damage to lenticels on the skin can affect visual appearance (Plate 81). Various terms have been used, including lenticel damage, discoloration and spotting. Symptoms can be caused by darkening of the cells immediately around the lenticel producing a brown or black spot, or by a red or green halo around the lenticel with or without the black or brown spot in the centre (Bezuidenhout *et al.*, 2005; Self *et al.*, 2006). Recent studies suggest that the discoloration is not primarily caused by loss of cellular function, but rather by the deposition of phenolic pigments in the cell wall (du Plooy *et al.*, 2006). It is possible that leakage of precursors (elicitors) from adjacent resin canals into the cell wall next to the lenticels contributes to pigment formation. Lenticel discoloration may be a stress-related self-defence

Table 15.2. Effects of leaf:fruit ratios on quality of 'Kensington Pride' mango fruit after ripening at 22°C (Source: Simmons *et al.*, 1998).^a

Leaf:fruit ratio	Fruit mass (g)	Dry matter (%)	Lenticel spotting (1–5)	Disease	
				Severity (1–5)	Incidence (%)
Control	441.4 ^c	13.0 ^b	3.5 ^c	1.2 ^c	13.3 ^b
30	363.2 ^d	12.0 ^c	3.5 ^c	1.8 ^b	40.0 ^{ab}
60	532.5 ^b	13.7 ^b	3.9 ^b	2.0 ^b	43.3 ^{ab}
120	696.6 ^a	15.1 ^a	4.2 ^a	2.7 ^a	63.3 ^a

^a Treatments were applied by girdling individual branches. Control fruit were from non-girdled branches. Values are means of 30 fruit per treatment. Values with different letters within columns are significantly different at $P < 0.05$.

mechanism against foreign particles and infection entering through the lenticels (Bezuidenhout *et al.*, 2005; du Plooy *et al.*, 2006).

The severity of lenticel damage is often difficult to control, but strategies for minimizing damage exist. There are cultivar differences in susceptibility (Oosthuysen, 1999), possibly related to differences in lenticel, wax and/or cuticle structure or composition (du Plooy *et al.*, 2004). Strong negative correlations have been found with maximum and minimum temperature and Class A pan evaporation, and strong positive correlations with maximum relative humidity (RH) and rain at harvest (Oosthuysen, 1998). These results suggest that cool, humid and wet conditions around harvest increase the risk of lenticel damage. Increased damage following excess irrigation during the latter stages of fruit growth (Simmons, 1998) support the above conclusions. Lenticel damage can also be more severe in larger fruit obtained from branches with higher leaf:fruit ratios (Table 15.2), possibly because of greater damage to the lenticels during fruit growth (Simmons *et al.*, 1998).

Storage life and physiological disorders

Physiological disorders include a range of symptoms that affect shelf life and marketability (Johnson *et al.*, 1996). These generally result in either premature ripening of parts of the fruit (e.g. soft nose and jelly seed) or tissue breakdown (i.e. stem-end cavity) (Winston, 1986; Mead and Winston, 1991; Whaley, 1999) and tissue breakdown in 'Keitt' (Bally, 2007). These disorders are more severe in more mature fruit (Young, 1957; Katrodia, 1989; Mead and Winston, 1991) and are often evident on the tree or after ripening without storage.

Mango disorders are affected by growing conditions (Young, 1957; Young and Miner, 1961). Production away from the coast, and higher altitude and/or lower temperature are associated with lower incidence of spongy tissue (Subramanayam *et al.*, 1980; Katrodia, 1989), and susceptibility to the disorder is also affected by rootstock (Joshi and Roy, 1985). Stem-end cavity appears to be more severe in wet conditions near harvest (Wainwright and

Burbage, 1989; Mead and Winston, 1991). Incidence of spongy tissue has been reduced by mulches that decrease radiated and reflected field heat (Katrodia and Sheth, 1989). Severity of watery pulp breakdown in 'Keitt' is lower with higher crop loads from similar size trees (Bally, 2007), possibly because of smaller fruit size at high crop loads.

Several reports suggest links between low fruit Ca and mango disorders. High leaf Ca has been related to reduced soft nose (Young and Miner, 1961) and reduced stem-end cavity (Mead and Winston, 1991). Soil Ca applications can reduce stem-end cavity incidence (Whiley, 1999), but these responses are not always consistent. Applications of Ca to 'Keitt' from just before flowering onwards did not increase leaf or fruit Ca during fruit growth or at commercial harvest (Bally, 2007). However, soil characteristics may also affect responses to soil Ca applications. In the sandy soils typical of Australian orchards, and even in the heavier clay subtropical soils with low cation exchange capacity, Ca can be rapidly removed from the top soil profile, resulting in little long-term increase in soil solution Ca (Hofman and Mullen, 2005; Bally, 2007). Regular (two/week), small applications are required to consistently increase solution Ca (Hofman and Mullen, 2005). Other factors (e.g. vegetative vigour and water status) can influence fruit Ca uptake (Hofman and Smith, 1994).

Foliar Ca treatments have produced inconsistent effects, in some cases having little or no effect on fruit Ca concentrations or quality (Singh *et al.*, 1987; Simmons *et al.*, 1995), and in other instances reducing internal disorders (Chitarra *et al.*, 2001). Postharvest dips have also had mixed results, with both positive (Wills *et al.*, 1988; Singh *et al.*, 2000) and nil or very small effects (Joyce *et al.*, 2001) reported. As a result there is little commercial use of foliar or postharvest Ca treatments in mango. Future development of more labile Ca formulations may provide more consistent results.

Other nutrients have also been associated with fruit quality (Hofman and Smith, 1994). There are relatively few reports of potassium (K) and magnesium (Mg) effects on mango fruit quality. Higher Ca and Mg, and a tendency towards lower K in mango fruit, have been noted in fruit from orchards with no incidence of soft nose, compared with fruit from orchards with high incidence of the disorder (Burdon and Moore, 1991). Conversely, K levels are positively correlated with disease resistance; Karunanayake (2007) reported reductions in disease on mango fruit from trees receiving additional K. Application of triple the recommended level of K significantly reduced stem end rot caused by *Lasiodiplodia theobromae*, while the severity of anthracnose was most reduced by application of the recommended level of K compared to nil and triple rate treatments.

Excess N can reduce storage life and quality, and excessive levels cause deterioration of avocado fruit quality (Wolstenholme, 2004) where its effect may be mediated through vegetative:reproductive balance and crop load (Hofman and Mullen, 2005). High N has been associated with increased disorders in mango (Young and Miner, 1961; Mead and Winston, 1991), possibly through the dilution effect of increased fruit size on Ca concentrations; however, soil N applications later during fruit growth do not affect watery pulp

breakdown in fruit 'Keitt' fruit (Bally, 2007). Heavy rain late during fruit development can release soil N previously unavailable to trees due to low soil moisture, potentially resulting in high fruit levels. Boron (B) deficiency has been related to abnormal fruit development (Lahav and Whiley, 2002) and increased fruit storage disorders (Yogaratnam and Johnson, 1982; Smith *et al.*, 1997). It may also be important in mango (Coetzer *et al.*, 1991). The effect of larger fruit size and maturity on shelf and storage life (Seymour *et al.*, 1990) can also be mediated through production factors influencing fruit set and leaf:fruit ratio. Fruit position in the canopy may also play a role here (see above).

Pests and diseases

Postharvest diseases and pests are reduced by various preharvest control measures including orchard hygiene, manipulation of flowering, integrated management and the use of chemical and biological controls (Johnson *et al.*, 1989a; Johnson, 1997; Fonseca *et al.*, 2004b; Ploetz, 2004; Akem, 2006; Astridge and Baron, 2007a, b, c; Chin *et al.*, 2007; Diedhiou *et al.*, 2007). Prusky *et al.* (Chapter 7, this volume) and Ploetz and Freeman (see Chapter 8, this volume) reviewed preharvest management of several postharvest diseases, while Dann *et al.* (2005, 2007) reviewed novel treatment options. Under the range of subtropical to tropical and dry to wet ecoclimates, combinations of treatments have been recommended to protect vegetative growth flushes, flower panicles and developing fruit from infections that lead to anthracnose, bacterial spot, powdery mildew, scab and stem-end-rot symptoms on fruit during development or after harvest (Poffley *et al.*, 1999; Ledger, 2004; Stovolt and Dirou, 2004; Akem, 2006).

Lonsdale (1993) found that monthly applications of copper oxychloride ($\text{CuCl}_2 \cdot 3\text{Cu}(\text{OH})_2$) in combination with mancozeb controlled most mango postharvest diseases. Copper (Cu) alone was less effective in controlling anthracnose. Copper sprays also provide protection against bacterial spot, while mancozeb can provide protection against scab (Poffley *et al.*, 1999; Ledger, 2004). Timmer and Zitko (1996) and Hardy *et al.* (2004) discussed the application of copper treatments to citrus for disease control. Formulations differ in their weather hardiness and indicated that retention of copper oxide (CuO) is superior to retention of copper chloride (CuCl_2) or oxychloride, and application of Cu with the pH <7–6 can damage fruit and leaves. Lonsdale (1993) considered there was no disease control benefit on mango by alternating Cu with prochloraz sprays, but Ledger (2004) recommended their strategic application every 3–4 weeks in rotation with mancozeb and Cu when rainy conditions favoured anthracnose on developing fruit.

Azoxystrobin (Amistar[®]) and other strobilurin fungicides effectively control anthracnose, alternaria and powdery mildew on mango (Reuveni *et al.*, 1998; Willingham *et al.*, 1999; Reuveni, 2000; Sundravadana *et al.*, 2006, 2007), *Botryosphaera parva* (Syn., *Dothiorella dominicana*) and *Phomopsis* sp. causing stem end rot (Everett *et al.*, 2005), and *Cercospora* leaf spot (Ane-siadis *et al.*, 2003) on other hosts. In Australia, no more than three strategic

applications of azoxystrobin are recommended for field control of anthracnose on mango in alternation with Cu, prochloraz and mancozeb schedules. Azoxystrobin should be applied as one or two applications at flowering and/or early fruit set at no less than 14-day intervals, and again at 21 and 7 days before harvest (Stovolt and Dirou, 2004). Application of azoxystrobin to control anthracnose on mango leaves significantly reduces subsequent fruit disease and boosts yield (Sunarharum, 2007).

Recent research has also focused on the potential of defence-boosting treatments, applied before or after harvest to reduce disease impacts on yield and shelf life (Terry and Joyce, 2004; Dann *et al.*, 2007; Karunanayake, 2007). Anthracnose on mango fruit can be reduced by salicylic acid, its functional analogue benzothiadiazole (BTH) (= acibenzolar-S-methyl = Bion[®]), and ultraviolet (UV-C) irradiation with variable results, including phytotoxic effects (Zainuri *et al.*, 2001; Zeng and Waibo, 2005; Zainuri, 2006; Zeng *et al.*, 2006; Karunanayake, 2007).

Orchard hygiene, including reduction of inoculum by removal of old fruit and branches, and removing prunings from the orchard, can reduce anthracnose and stem end rots on fruit after harvest (Johnson, 1994; Ledger, 2004; Ploetz, 2004). Some field diseases can disfigure fruit. Following heavy rain close to harvest, bacterial spot can appear as discrete raised lesions, followed by fruit cracking or rupture and fruit drop. Black spot orchard management practices (i.e. windbreaks, Cu sprays and use of resistant cultivars) can reduce the risk of damage on fruit (Johnson *et al.*, 1996; Dodd *et al.*, 1997; Ploetz and Prakash, 1997). In cool conditions, powdery mildew infection on young fruit can cause a ghosting symptom on mature fruit similar to that caused by powdery mildew on apples. Scab and sooty moulds can disfigure fruit. Generally, spray programmes for anthracnose will control scab (Condé and Pitkethly, 2007), while sooty moulds are managed through integrated management of scale insects and by postharvest brushing (Johnson and Coates, 1993).

Tree nutrition can affect fruit disease incidence and severity. High Ca can reduce fruit diseases in many fruit crops (Hofman and Smith, 1994). Nitrogen application before flowering can increase mango fruit disease (H. Nguyen *et al.*, 2004); applications up to 6 weeks after flowering can increase anthracnose severity (Bally, 2007). Negative correlations occur between exocarp N percentage and antifungal resorcinol concentrations.

Poffley *et al.* (1999), Peña (2004) and Peña *et al.* (see Chapter 10, this volume) discussed integrated pest management (IPM) for reducing pest damage and quarantine hazards associated with fruit. Preharvest control measures for fruit flies, seed weevils, scales and other skin defect-causing pests contribute significantly to product quality improvement. IPM strategies can adequately control orchard pests while reducing reliance on pesticides (Cunningham, 1986, 1991a, b, c; Vijayasegaran, 1994; Peña, 2004; Peña *et al.*, Chapter 10, this volume). Bagging of developing fruit can reduce or eliminate disease infection (Hofman *et al.*, 1997a) and fruit fly infestation (Kitagawa *et al.*, 1992). However, for export market access, and regardless of effective field control, postharvest disinfection measures are often mandatory.

Weather conditions

Rain before harvest, and high RH and temperatures can increase disease levels, fruit susceptibility to heat and brush damage, lenticel damage and reduce storage life (Dodd *et al.*, 1991a; Estrada *et al.*, 1993; Prusky *et al.*, 1993a, b; Cooke and Johnson, 1994; Oosthuysen, 1998; Jacobi *et al.*, 2001b). Disease risk prediction based on the monitoring of environmental variables to determine fungicide application frequency, can reduce pesticide residues (Fitzell and Peak, 1984; Fitzell *et al.*, 1984; Peak *et al.*, 1986; Dodd *et al.*, 1991a, b, 1992; Prusky *et al.*, 1993b). Irrigation frequency and water availability for tree growth can significantly impact postharvest diseases and disorders (Simmons, 1998).

15.4 Flavour and Aroma

Flavour is largely determined by sugars and volatiles in the ripe fruit, both of which increase in more mature fruit. The aroma produced by ripening and ripe mango can help attract customers, and provide some indication of flavour development. In mango fruits, more than 280 different aroma volatile compounds have been reported (Singh *et al.*, 2004). Variation in the constituent aromatic compounds in mango cultivars results in aroma and flavour diversity (MacLeod and Snyder, 1985; MacLeod *et al.*, 1988; Torres *et al.*, 2007). The high fruit levels of α -terpinolene contribute to the characteristic flavour of stronger-flavoured cultivars such as 'Kensington Pride' (Bartley and Schwede, 1987; MacLeod *et al.*, 1988). 'Kensington Pride' harvested at the green-sprung stage have higher concentrations of total aroma volatiles compared with fruit harvested at the hard-green or coloured stages (Lalel *et al.*, 2003b). Most of the glycosidally bound aroma compounds increase in the pulp as the fruit matures, which contribute to improved flavour. During the first 7 days of ripening, α -terpinolene is the major volatile compound, but in the later stages of ripening ethyl octanoate dominates (Lalel *et al.*, 2003a).

15.5 Harvesting and Transport to the Packhouse

Harvesting of mango is determined according to attainment of acceptable/required maturity: (i) for arrival at market during the time of peak demand/highest price to maximize the chance of early sale; or (ii) to minimize loading wait at the shipping port. Fruit is generally picked into field crates or bins, with or without the use of mechanical picking platforms.

Timing

Maturity is determined by assessing variables such as days from flowering, accumulated heat units, flesh dry matter percentage, flesh colour or fruit shape/skin colour (see Maturity section under 15.3 Preharvest Management,

this chapter). Fruit water potential fluctuates diurnally, and can affect fruit quality. The water potential of fruit at harvest can affect susceptibility to handling, heat damage and product storage potential (Joyce and Patterson, 1994). In hot weather, fruit should be harvested in the coolest part of the day to reduce fruit overheating and energy requirements for postharvest cooling, and to minimize worker discomfort. Harvest during rain can reduce fruit quality (see Weather conditions section under 15.3 Preharvest Management, this chapter).

Sapburn

Severing the stem from the fruit causes relatively large volumes of latex to spurt or ooze from the cut stem. The sap is of low pH and high oil content and can burn the surface of the fruit (Bagshaw and Brown, 1989). The oil fraction contains terpinolene and resorcinols and is the fraction of the latex that causes the damage. Skin damage is particularly severe with 'Kensington Pride' (O'Hare, 1994), and less serious in Florida cultivars. In Pakistan, 'Chausa' is more susceptible than 'Sindhri' and 'Dashehari' (Maqbool *et al.*, 2007). O'Hare (1994) observed that latex levels are lower and less phytotoxic in 'Nam Doc Mai', 'Nang Klang Wun', 'Tong Dum' and 'Keow Savoey' (0.16–0.48 ml/fruit), than in 'Kensington Pride' (1.67 ml/fruit). The oil component of the latex of Thai cultivars is much lower than that of 'Kensington' (O'Hare, 1994; Hassan, 2007). The concentrations and ratio of the two main resorcinols, 5-*n*-pentadecylresorcinol and 5-*n*-heptadecenylresorcinol, differ among cultivars (Hassan, 2007).

Factors affecting the potential of latex to cause sapburn are not well understood. It appears that both the terpene in the oil fraction of the sap, and adequate polyphenol oxidase (PPO)/peroxidase concentrations in the skin are required to develop sapburn; PPO and resorcinols in sap are less significant (Loveys *et al.*, 1992; Robinson *et al.*, 1993; John *et al.*, 2002). Rain near harvest and high N in fruit result in more severe sapburn in 'Kensington Pride'. However, negative relationships have been observed between exocarp N concentration and alkyl resorcinols (Hassan, 2007). Sap from fruit harvested early in the day causes less sapburn than sap from fruit harvested later in the day, although early-harvested fruit exude more sap than late-harvested fruit (Maqbool *et al.*, 2007).

Latex may provide protection against infestation by fruit fly larvae (Joel, 1978, 1980) and may also contribute to disease tolerance. The 5-substituted resorcinols have antifungal properties (Cojocarú *et al.*, 1985; Droby *et al.*, 1986, 1987; Prusky and Plumbley, 1992). Karunanayake (2007) extracted a resorcinol and a resorcinol derivative from the dichloromethane phase of Sri Lankan mango peel extracts that had antifungal properties. Differing relationships occur between resorcinol levels and relative susceptibilities of different mango cultivars to anthracnose (Karunanayake, 2007; Hassan *et al.*, 2007). Strong positive relationships occur between resorcinol concentration in the peel and latex, and fruit resistance to artificially inoculated anthracnose.

'Kensington Pride' has more non-aqueous latex, higher concentrations of resorcinols and greater tolerance of anthracnose than 'Nam Doc Mai' (Hassan, 2007). Less anthracnose occurs on fruit ripened with an intact stem, compared with de-sapped fruit. Hegnauer (1994) reviewed the phytochemistry of *Mangifera*.

Cultivars that are prone to sapburn can be harvested with 10–20 mm stems attached, and re-trimmed at the packhouse. Latex does not usually exude from longer stems because there is no continuity between the fruit and stem resin ducts (Joel, 1980), and the fruit lactifers are not severed; however, stems can break in transit to the packhouse, resulting in latex leakage and sapburn. Long stems left on the fruit to reduce sapburn has variable effects on disease depending on disease type and storage time. With shorter storage periods, anthracnose and stem-end-rot incidence and severity can be lower in fruit with stems attached due to higher levels of resorcinols (Hassan, 2007), but during longer storage stem-end-rot levels can increase due to the higher levels of inoculum associated with the retained stalk (Johnson *et al.*, 1993).

Mango latex can cause skin disorders in humans (Keil *et al.*, 1946; Oka *et al.*, 2004). Bandyopadhyay *et al.* (1985) noted that resorcinol derivatives are allergens in the Anacardiaceae, and suggested that the 5-substituted resorcinol in mango latex causes dermatitis. Both heptadec(adi)enyl resorcinols and pentadecylresorcinol can elicit an allergic reaction in sensitive patients (Oka *et al.*, 2004). Harvesting and packhouse personnel must avoid contact with the latex of high-risk cultivars.

Harvesting and desapping

Rough handling at harvest can cause skin damage and internal fracturing or bruising. Using hooked sticks or shaking the tree to detach fruit causes skin damage and flesh fracturing (Ledger, 1991a; Abu-Goukh and Mohamed, 2004) and sapburn. Mechanical damage during harvest also causes soft, darkened areas and bruises on fruit following hot water treatment. Mangoes should be handled as if they were eggs. Long-handled secateurs cut and grip the stem, allowing the fruit to be carefully lowered to the picking bin. Contact with soil and soilborne pathogens should be avoided (Johnson *et al.*, 1993).

In cultivars where sapburn is a problem, latex should be drained from the fruit (desapping or bleeding) to minimize the incidence and severity of sapburn. Several systems have been assessed for reducing damage (Brown *et al.*, 1986; Ledger, 1991b; Holmes *et al.*, 1993; Lim and Kuppelweiser, 1993; O'Hare and Prasad, 1993; O'Hare, 1994; Shorter and Joyce, 1994). In Australia, the main commercial practices (Plate 82) are:

- Desapping in the field with harvest aids using detergent. The basic design characteristics include detergent spraying onto a tarpaulin, a trough with the same detergent and a final spray before fruit are placed in a field bin. The fruit are either hooked from the tree in the direction of the harvest aid and onto the catching surface or the fruit are snapped directly off the tree and placed onto the tarpaulin. The fruit roll from the tarpaulin into

the trough containing detergent and then into 300–400 kg field bins. Alkaline detergents that deactivate damaging sap components are most effective; high concentrations of surfactant in the detergent are not required. The crucial factors are that fruit should be exposed to detergent for at least 90 s, the detergent is either not recycled, or replaced before sap accumulation in the detergent causes other damage such as skin browning (Bally *et al.*, 1997; O'Hare *et al.*, 1999).

- Another design includes a motorized hydraulic ladder (cherry picker) with the fruit desapped for 1–2 s before placing in a basket containing a spray of alkaline detergent. This system is particularly effective for tall trees, but care must be taken that fruit are covered by the detergent for at least 90 s.
- Picking fruit with long stems into small 18 kg crates and desapping in the shed. The fruit are dipped into detergent before desapping and placing on a long conveyor system that holds the fruit inverted and provides detergent/water sprays for a few minutes. The fruit are inverted for *c.* 20 min before drying and packing.

In these systems, the detergent is not strongly alkaline, but the surfactant should be of sufficient concentration to provide a protective coating around the fruit before desapping. Stem breakage must be minimized in the crates, as this can cause sapburn and quality loss (Holmes *et al.*, 1993; Holmes and Bally, 1994). Latex must not spray or drip onto fruit being desapped. Workers who are sensitive to mango sap should wear hand protectants, aprons and footwear to minimize skin contact. The detergent must reduce sapburn and skin browning without causing other damage (i.e. lenticel spotting) (Fig. 15.3). Desapping in the field by inverting fruit directly onto racks without detergents has been used for sensitive cultivars and when particular growing conditions have increased fruit susceptibility to lenticel spotting or other damage from detergents; however, labour costs are becoming prohibitive, requiring compromises between cost and quality. Desapping by inverting and placing on the ground significantly increases the incidence and earlier appearance of stem end rot caused by soilborne *L. theobromae*, and is not recommended (Johnson *et al.*, 1993).

Harvest aids have reduced in-shed desapping. Holmes *et al.* (1993) found 9–16% of fruit in field crates were affected by sapburn when harvest aids were not used. Harvest aids provide the greatest reduction in total sapburn (from 69% to 15–18%). While harvest aids can significantly reduce sapburn, inappropriate use can increase some forms of skin browning (Bally *et al.*, 1997). Underhill and Dahler (1995) described four types of skin browning which produce symptoms distinct from the sapburn caused by the oil phase of latex. Several forms of skin browning involve tissue reactions with sap/detergent mixtures. Symptoms vary if latex enters fruit through micro-cracks in the cuticle or the lenticels (O'Hare *et al.*, 1999). Holmes (2003) developed guidelines for the use of harvest aids.

Cost savings associated with the use of harvest aids can be lost if fruit-to-fruit or fruit-to-ground impact is not minimized during harvest. Rough

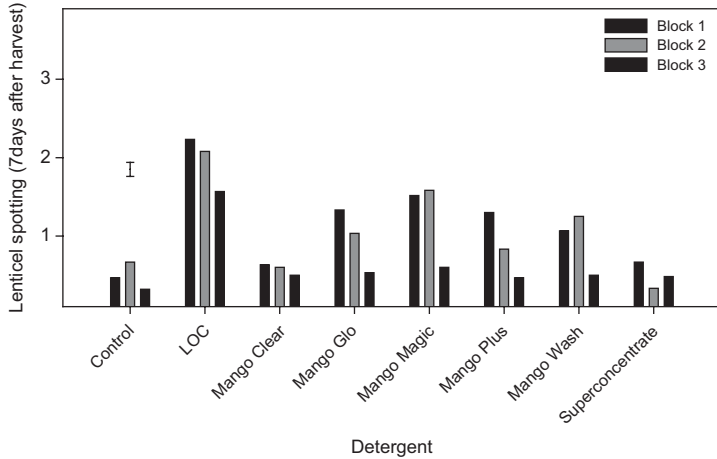


Fig. 15.3. Effect of detergents on lenticel spotting on skin of 'B74' mango (0 = no lenticel spotting; 4 = severe spotting). Fruit were obtained from three different blocks in two orchards, dipped in detergent for 2 min, then held at 20°C for 7 days (Source: Hofman and Ledger, 2006). The bar represents the least significant difference (LSD) at 5%.

harvesting can increase the incidence of bruising and internal fracturing, and lower wholesale returns. Thorough training of picking crews and supervision of their performance is required to maintain good practice.

Transport to the packhouse

Harvested fruit should be transported to the packhouse as soon as possible, with no prolonged exposure to the sun. Rough handling and transport must be minimized. Roads/tracks from orchard to packhouse should be smooth, with transport vehicle tyres correctly inflated, and special suspensions to reduce vibration and damage.

15.6 Packhouse Measures

Harvested fruit are transported to a central packhouse which provides shelter from rain and sun, and facilities for cleaning, treating, packing, cooling and storing fruit until consignment to market (Schoorl and Holt, 1982, 1985). Mechanized packhouse systems can offer labour savings and increased returns (Murray and George, 1994). When manual handling was reduced from five to two steps, fruit appearance improved, disease losses were lowered, sizing accuracy improved, packing rate increased and space, labour and supervisory requirements were reduced (Murray and George, 1994).

A typical packhouse sequence is shown in Fig. 15.4. In packhouses that include a disinfestation facility, the sequence must be modified to allow for

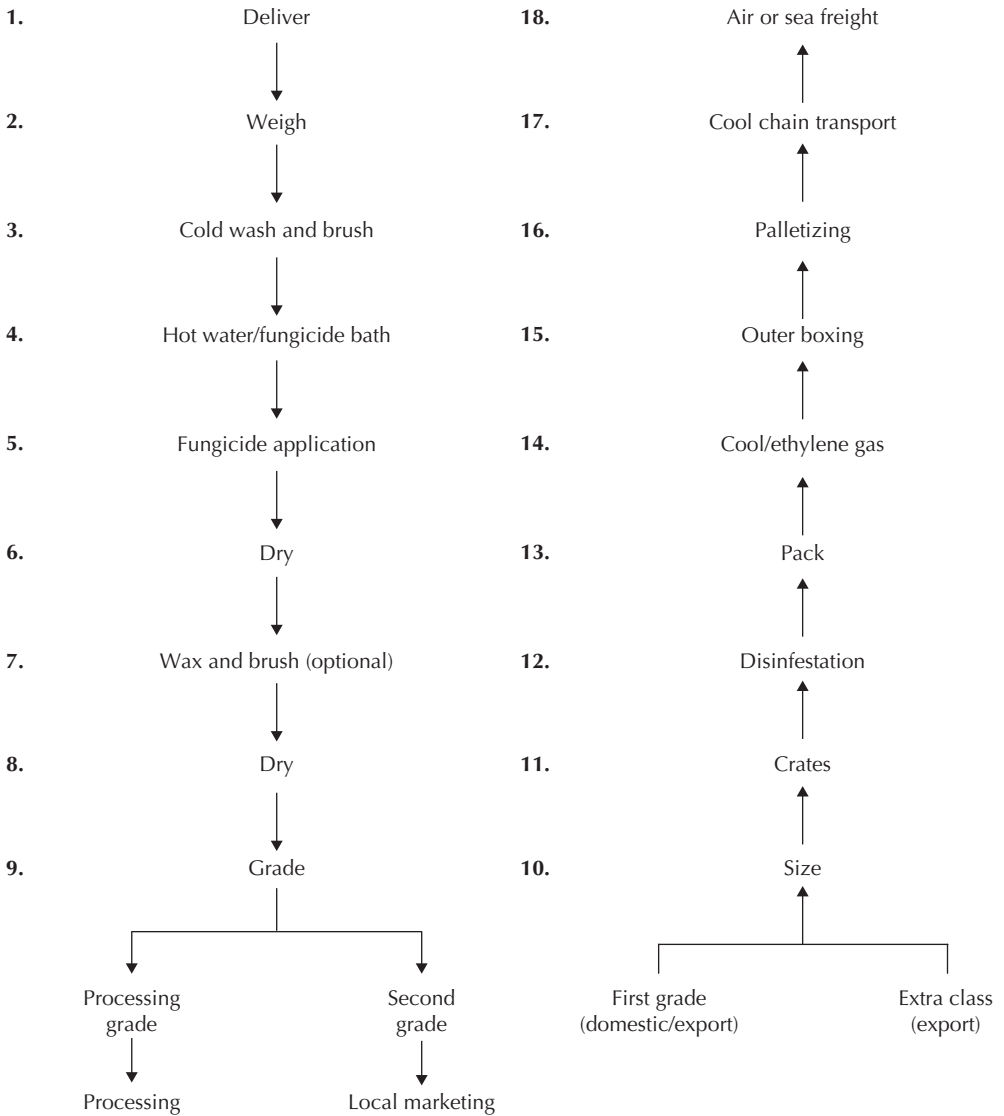


Fig. 15.4. Packhouse and marketing activities for mango. Waxes are not applied in some countries because of abnormal ripening and off-flavour development. When disinfestation is not required, steps 11, 12 and 15 would be omitted. When fruit are heat disinfested, they may be packed into an inner box prior to cooling. For some markets accessible by air, the fruit may be treated with ethylene and stored until near ripe. The boxed fruit may then be packed into an outer carton prior to palletizing. Pre-ripening allows fruit to be rechecked prior to despatch, with fruit of unsatisfactory appearance (e.g. skin damage) redirected to domestic market or processing.

sizing before disinfestation, with tray packing after treatment. Packhouse design and installation consultants can provide substantial savings by eliminating bottlenecks and minimizing product damage points.

Delivery inspection and traceability

Harvested fruit in field crates should be treated, packed and cooled as soon as possible. Quality and contaminant management systems may require that a record system tracks the block or trees from which each bin of fruit is harvested. This enables records to be kept of tree or block yield, quality performance and defect levels as well as labour performance rates and pesticide residues. Individual fruit in a tray can be traced back to the tree or block from which it was harvested. Block/tree-to-tray traceability systems and pack-out records allow problems (i.e. excessive or unapproved pesticide detections) to be traced to the site of the problem and relevant action taken. They can also be used to motivate producers or picking teams to deliver high quality produce.

At the packhouse, samples of fruit should be evaluated immediately for maturity, blemishes and disease and pest incidence and recorded in an appropriately designed computerized system. Preharvest orchard inspections can reveal the defects that can be anticipated in the packhouse. Some degree of in-field sorting can occur at the point of harvest, and soft or damaged fruit collected separately and discarded.

Desapping and washing

Unloading should avoid dropping, damaging and wounding of fruit. Fruit are normally unloaded from field bins into bin dumps if desapping is unnecessary or removed manually from the crates for desapping (see Harvesting and desapping section under 15.5 Harvesting and Transport to Packhouse, this chapter). Detergents and sanitizers are sometimes added to washing water. Their use requires careful consideration. Some may cause fruit damage, or promote early fruit disease expression (Korsten *et al.*, 1993). Chlorine is added and carefully regulated to wash and/or rinse water in some packhouses, but this is not essential. Quaternary ammonium disinfectants should not be added to wash water as their direct application to foodstuffs is generally not permitted.

Disease control

Hot water and fungicide application

Hot water dips, or sprays over brushes, with or without fungicide, and fungicide sprays or dips, can eradicate quiescent fungal infections that have been established on and beneath the cuticle and within the pedicel prior to

harvest (Johnson *et al.*, 1989a, b, 1991, 1992; Kernot *et al.*, 1999; Poffley *et al.*, 1999; Plan *et al.*, 2002). Suslow (2000) provides generic recommendations for the postharvest handling of produce. Postharvest disease treatment efficacy varies with infection level, cultivar, ripening status and storage regime. Hot water treatment also cleans fruit, but can contribute to increased skin damage (Cooke and Johnson, 1994). Anthracnose caused by *Colletotrichum gloeosporioides* Penz. and *Colletotrichum acutatum* Simmonds, is controlled more readily than stem end rots (or soft brown rot) caused by anamorphs of *Botryosphaeria* spp. (*Fusicossum* spp., *Neofusicocum* spp., *L. theobromae* (Pat.) (Griff. and Maubl.)) (Johnson, 1994; Slippers *et al.*, 2005; Crous *et al.*, 2006) and *Phomopsis mangiferae* Ahmad, and alternaria rot caused by *Alternaria alternata* (Fr.) Keissler. The latter is generally only a problem in fruit from dry regions or in fruit from more humid areas during storage for 3 weeks or more (Prusky *et al.*, 1980, 1993a, b, and Chapter 7, this volume; Johnson *et al.*, 1990b).

Fruit are moved through a water bath for 5 min at 48–50°C for less mature fruit and hot-water-damage-susceptible cultivars (e.g. 'Zill' and 'Irwin') and at 50–55°C for mature fruit and less susceptible cultivars (Anonymous, 1994b). Treatment for 3 min may be adequate for control of anthracnose, while immersion for up to 7 min may enhance control of stem end rot (Muirhead and Grattidge, 1986; Sepiah, 1986; Johnson *et al.*, 1989b). In large-scale facilities, dip tanks may range from 3000 to 5000 l, with fruit immersed and moved through the tank by a series of paddles. In tank construction, non-corrodible materials such as stainless steel and fibreglass are preferred, and the conveyor system that contains the paddles should travel along the bottom of the tank to reduce damage to fruit that sink. Accuracy in temperature control, efficacy of the heating unit and timing of fruit flow through the bath are critical. Temperature probe placement at pump inlet and outlet and thorough water circulation to ensure accurate temperature reading and to minimize hot spots are critical. Impurities (e.g. minerals, sediment and debris) in dip water can affect fungicide performance and stain or damage the fruit. In-line filters in the inlet and pump circulation systems should be installed and cleaned regularly.

Where acceptable, carbendazim can be added to the hot water at the recommended rate, and topped up and replaced regularly, to provide improved control of stem end rot and anthracnose at lower temperatures (52°C). Benomyl has been withdrawn for postharvest use, but much of the benomyl use information (from earlier research) is relevant for carbendazim (Johnson *et al.*, 1997). Also, hot thiabendazole (TBZ) is generally as effective as hot benomyl for controlling stem end rot, but may provide inferior control of anthracnose (Coates *et al.*, 1993). The active component of benomyl and TBZ in plants, carbendazim (MBC), is identical (Erwin, 1973; Muirhead, 1976); however, TBZ also contains sulfur (S) which affects its rate of breakdown and spectrum of activity (D. Guest, personal communication, Melbourne, 1995). Benomyl penetrates plant tissue more effectively than TBZ, carbendazim or thiophanate methyl (Eckert, 1983).

Dipping fruit in hot, dirty, latex-contaminated water can increase phytotoxicity and lenticel damage. Hot fungicide dips lose efficacy due to sap

Table 15.3. Registered uses of prochloraz for postharvest treatment of mango (Source: adapted from Lunn, 2004).

Country	Form ^a	Method	Rate (kg ai/100 l)
Australia	ec	30 s spray	0.025
Brazil	ec	2 min dip	0.05
China	ec/wp	1 min dip	0.05–0.1
Colombia	ec	Not specified	0.025
Peru	ec	Not specified	0.02–0.045
South Africa	ec	20 s dip	0.08

^aai, active ingredient; ec, emulsifiable concentrate; wp, wettable powder.

build-up in the dip tank and stripping out of fungicide (Wells and Littlemore, 1989). Ledger (2004) optimized dip:fruit ratio and dipping practices. Prochloraz provides good control of anthracnose and alternaria rot, but does not provide control for stem end rot (Johnson *et al.*, 1990b; Johnson and Coates, 1993). In South Africa, for local markets prochloraz is added at 405 ppm of active ingredient (ai) of a 45% emulsifiable concentrate (ec) formulation; for export markets, 810 ppm prochloraz is used. Fruit are immersed for 20 s. In Australia, prochloraz at 250 ppm is applied by overhead spray, and fruit require 15–20 s to pass through the prochloraz spray race on a roller conveyer system.

A maximum residue level (MRL) of 7.0 mg/kg for prochloraz for assorted tropical and subtropical fruits with an inedible peel is recommended (CODEX-MRL, 2008). This group MRL replaces individual fruit commodity MRLs, and takes into account the lower residues in the flesh compared to the skin (Muller and Burt, 1989). Some registered use-rates for postharvest application of prochloraz are listed in Table 15.3.

Hot water sprays over brushes (55°C for 15–20 s) is an effective alternative to hot water dips containing prochloraz for controlling alternaria rot (Prusky *et al.*, 1999, 2006). Application of hot water spraying and brushing for 15–20 s (HWB) followed by a spray of 50 mM hydrochloric acid (HCl), alone or in combination with prochloraz, also improved control of alternaria rot (Prusky *et al.*, 2006). These treatments have not been tested for anthracnose. Using 2,4-dichlorophenoxyacetic acid (2,4-D) diluted in wax after HWB and prochloraz reduces stem end rot (Kobiler *et al.*, 2001). A hot water and benomyl combination treatment followed by a prochloraz spray provides effective control of anthracnose, stem end rot and alternaria rot during longer storage (Johnson *et al.*, 1989a, 1990b). Similar benefits are now attributed to hot TBZ dip and cold prochloraz spray (Ledger, 2004).

When fungicides are used in the packhouse, spent dip suspensions and fungicide containers must be disposed using approved methods, often included with supplier recommendations. Carbendazim suspensions can be drained into a trench filled with stones, but runoff must be avoided. Carbendazim and other benzimidazole fungicides are toxic to earthworms (Wright and Stringer, 1973).

Heat

Pest disinfestation treatments involving heat provide some control of anthracnose, but do not adequately control mango fruit pathogens for export. Temperature and time combinations suitable for non-deleterious fruit disinfestation are sublethal to a significant percentage of quiescent infections beneath the fruit cuticle and pedicel tissues (Coates and Johnson, 1993). In many regions, fruit skin temperatures frequently approach the mid-40°C range during pre-harvest development, a natural selection pressure favouring heat-tolerant fungal infection structures. For 'Kensington Pride', hot benomyl in combination with either prochloraz or vapour heat at 46.5°C for 20 min controls stem end rot more effectively than hot benomyl alone and TBZ, alone or in combination with vapour heat, during storage at 23°C for 15 days (Coates *et al.*, 1993). Disease control in combination with heat disinfestation has been reviewed by Coates and Johnson (1993) and Jacobi *et al.* (1994, 2001a).

Future options

Heat is an ideal disease control treatment, since it is environmentally safe and non-chemical. Its effectiveness would be enhanced if fruit tolerance could be increased by genetic manipulation or the development of pre-conditioning treatments. Pre-treatments to render quiescent structures of pathogens more susceptible to heat would also improve disease control. Measures to increase efficacy could include other energy sources, chemicals, adjuvants, fumigants or microorganisms to damage or soften fungal wall structures.

Treatments to delay fruit ripening also limit or reduce disease losses. Storage quality would benefit from the development of cultivars or pre-conditioning treatments to improve tolerance of fruit for cool storage or controlled atmosphere (CA) and modified atmosphere (MA) storage (Brecht and Yahia, Chapter 14, this volume). With increasing concerns about the use of chemicals on food (Gullino and Kuijpers, 1994), and in view of current limitations on heat treatment and storage regime disease control efficacy, non-deleterious alternatives to synthetic fungicides are required. Alternatives to fungicides for controlling postharvest diseases have been reviewed by Johnson and Sangchote (1994) and Korsten (2006). Options include: (i) biological control, i.e. the use of microorganisms to control pathogens (Wilson and Pusey, 1985; Jeffries and Koomen, 1992; Korsten *et al.*, 1993, 1994; Korsten 2006); (ii) enhanced exploitation of naturally occurring antifungal compounds in fruit (Prusky *et al.*, 1982; Johnson *et al.*, 1998; Joyce *et al.*, 1999; Zainuri *et al.*, 2003; Hassan *et al.*, 2007); (iii) application of fruit coatings such as chitosan with both MA and antifungal effects (El Ghaouth *et al.*, 1992a, b; Wilson *et al.*, 1994; El Ghaouth and Wilson, 1995); (iv) exposure to UV-C light (wavelength <280 nm) (Chalutz *et al.*, 1992; Wilson *et al.*, 1994). Zainuri (2006) reported some promise in the use of UV-C radiation for control of anthracnose, but fruit damage risks and treatment dose accuracy were critical; (v) containment of fruit in atmospheres containing high levels of carbon dioxide (CO₂) for 24–48 h after harvest (flushing) (Prusky *et al.*, 1992, 1993c); (vi) regulation of fruit ripening (Brady, 1994); and (vii) application of naturally occurring plant products (Fallik and Grinberg, 1992; Wagner and Flores, 1994). Many of these

options may delay disease development by eliciting increases in antifungal compounds in the fruit (Prusky and Keen, 1993; Wilson *et al.*, 1994; Zainuri, 2006).

What are the alternatives to synthetic fungicides for controlling mango diseases? Bacteria active against mango isolates of *C. gloeosporioides*, stem end and soft brown rot pathogens have been evaluated (Koomen *et al.*, 1990; Korsten *et al.*, 1991, 1992, 1993; Jeffries and Koomen, 1992; Coates *et al.*, 1995; Korsten, 2006). Antifungal resorcinols in the peel of mango fruit interfere with the development of anthracnose and alternaria rot (Cojocarú *et al.*, 1985; Droby *et al.*, 1986, 1987; Prusky and Keen, 1993; Zainuri, 2006; Hassan, 2007), with higher levels present in some cultivars (Hassan, 2007; Karunanayake, 2007; Hassan *et al.*, 2007). Lonsdale (1992, 1993) found that enclosure of 'Keitt' in high-density polyethylene bags with 30% CO₂ and 15% oxygen (O₂) for 24 h at 11°C prior to storage, improved control of anthracnose. However, 24 h exposure to 20% CO₂ significantly increased the incidence of soft brown rot (stem end rot) in 'Keitt' and 'Kent' compared to untreated fruit, especially in the absence of O₂. UV irradiation of fruit for 10–30 s in combination with wax prior to storage is similar to hot water in reducing the incidence of soft brown rot compared to untreated fruit.

Brushing

Brushing on mango packing lines can occur after, or at the same time as, hot water and fungicide treatments. Hot water treatment washes sap away, and loosens superficial debris, scale insect carapaces and sooty mould, which are removed as the fruit pass over rotating brushes. Brushing also removes superficial deposits of fungicides that accumulate on fruit from orchard application of Cu fungicides (Lonsdale, 1993) and incorrect mixing or sedimentation of benzimidazole fungicides resulting from sap accumulation in dip tanks (Wells and Littlemore, 1989). Soft, non-damaging brushes should be used, washed every day and replaced seasonally.

For 'Kensington Pride' mangoes harvested after rain, skin marking, fruit shrivel and weight loss increase significantly on fruit treated with a hot water and fungicide dip or a hot water and fungicide dip followed by treatment with prochloraz, when fruit brushing followed either or both treatments relative to untreated and untreated/brushed fruit. Prochloraz before brushing resulted in fruit quality similar to untreated or brushing only (Cooke and Johnson, 1994). Brushing can increase lenticel spotting (Oosthuysen, 1999). Therefore, the number and type of brushes must remove foreign matter and polish the fruit, while not increasing risk of brush and lenticel damage, especially during wet weather and with heat treatments (see Weather conditions and Skin colour and lenticel damage sections, both under 15.3 Preharvest Management, this chapter).

Grading and sizing

The purposes of grading are to sort fruit into defined categories of uniformity and to divert out-of-grade fruit from the pack line to either a second

grade, processing or reject line. Mangoes with defects outside acceptable limits as defined in a grade schedule or chart are manually removed and transferred (by conveyer belt) to seconds or processing lines as appropriate. The purpose of sizing is to categorize fruit into size or weight groups for packing. Fruit must be sized prior to disinfestation with hot water or vapour heat to ensure consistent treatment responses. Typical systems include automatic graders that separate fruit by weight into groupings that correspond to pre-determined categories (Schoorl and Holt, 1982, 1985). Camera vision systems can separate for colour, defects and shape. Fruit usually accumulate in separate bins for packing into cartons or into bulk containers for processing or disinfestation. The fruit are packed manually into single-layer trays, with plastic or cardboard liners that have depressions designed to accommodate fruit of a particular size. The depressions provide some support for individual fruit during packing, while the cardboard liners also provide some additional buffering against impact damage. The pattern of the depressions facilitates most efficient utilization of carton space. Mango tray liners commonly accommodate 12–25 fruit for 6.5 kg trays. Some tray liners may be inappropriate for sea export due to interference with vertical airflow.

Organic materials (i.e. paper, leaves or shredded wood) have been used to cushion individual fruit in cartons. These materials can harbour pathogens, for example *Rhizopus stolonifer* (Ehrenb. Fr. Lind.), which causes transit rot of mangoes and has been detected in shredded wood used in mango packaging. Shredded wood creates micro-wounds in the fruit skin, providing points of entry for hyphae growing on the wood. Losses are more severe when fruit have been removed from cold storage, allowing condensation to develop on the fruit and shredded wood (Muirhead and Grattidge, 1986).

Grade standards

The International Standardisation Organisation (ISO) is a non-governmental organization (NGO), and is a network of national standards institutes (157 countries). ISO is the global leader for development and publication of standards. ISO publishes a range of standards for fruit and vegetables, testing, crop and postharvest management procedures and food safety, system auditing and nutrient and water testing that are relevant to mango systems' benchmarking and improvement. A range of standards may also be defined within GAP certification protocols and nationally developed marketing arrangements. Agreed grade standards provide a reference point for producers and traders in production and marketing (EurepGAP, 2007; ISO, 2008). The CODEX Alimentarius Commission also oversees the development of standards for fresh and processed fruit with the CODEX Committee on Fresh Fruit and Vegetables (CODEX, 2008a). CODEX standards for fresh fruit specify provisions for quality, sizing, tolerances, presentation, marking and labelling, and contaminants (CODEX, 2008a). There are CODEX standards for fresh mangoes, canned mangoes and mango chutney (CODEX, 2008b).

Minimum requirements for grade standards specify that fruit intended for international trade should be intact, firm, fresh in appearance, sound, clean, free from black stains and bruising, free from damage caused by low temperatures and free from pests and pest damage. Fruit should be carefully picked at the stage of physiological development which will allow transport and handling and continuation of the ripening process so that fruit will ripen to consumer expectations. Class standards can depend on customer specifications, and can be based on fruit size and appearance. Colour illustrations in Anonymous (1993) and Amesbury *et al.* (2002) are indicative of some of the quality standards that can be specified for appearance, shape and colour, and tolerance levels for superficial skin defects. Similar charts are often available for individual cultivars and are produced during the development of QA systems for specific marketing groups and customers.

Packing-line QA inspections

Packing-line control inspections are used to monitor grading efficacy and packing-line damage. Packing-line inspection samples are taken soon after fruit pass points in the line at which defects are most likely to be overlooked and/or induced. For start and end-of-line pack-out checks, and out-turn inspections, randomly selected cartons are unpacked, and all fruit are checked for compliance with preset quality parameters. Most value is gained from quality control checks if records are kept and evaluated, with feedback/trouble shooting as necessary, to constantly improve the system (Ledger and Bagshaw, 1994; Ledger and Premier, 2006). Computer analysis of such information provides a seasonal benchmarking record of QA improvement, and highlights areas for attention in packing-line improvement and personnel training. Record keeping is mandatory under GAP certification systems.

Future options

Greater automation of grading and packing will become necessary as production and labour costs increase, and as customers become more demanding (Hilton, 1994). Recent advances in computing have made possible high-speed sorting using visual systems for colour, shape and externally visible defects. Also, NIRS systems can now be used in-line to sort for flesh characteristics that influence flavour. In mango, percentage dry matter and flesh colour are related to ripe fruit flavour, and can be estimated using NIRS (Saranwong *et al.*, 2004; Subedi *et al.*, 2007). Estimation is sufficiently accurate to allow acceptable separation into several categories for final flavour. NIRS may also be useful for predicting ripening behaviour and weight loss during ripening (Mahayothee *et al.*, 2004). Given the influence of weight loss in chilling injury (CI) development during cold storage (Bower *et al.*, 2003), NIRS may also be able to estimate potential for CI during cold storage.

There is interest in other non-destructive quality assessment for the pack-house. Joyce *et al.* (1993) noted that future innovation could lead to proton magnetic resonance imaging (MRI) technology suitable for packing-line applications to allow non-destructive detection of internal disorders and pest infestations. X-ray imaging may have potential for detecting seed weevil

damage in mangoes (Thomas *et al.*, 1995; Reyes *et al.*, 2000), but recent investigations suggest that neither X-ray imaging nor MRI is sufficiently reliable for quarantine purposes, particularly where larvae are small (R.A. Jordan, personal communication, 2007). New methods of nuclear magnetic resonance (NMR) (Marigheto *et al.*, 2008) may distinguish internal disorders such as jelly seed. Acoustic/ultrasonic methods can sort for fruit firmness (Mizrach, 2008) and may help identify softening fruit with internal disorders and reduced storage life. Robotics in sorting and packing will be used increasingly where labour costs and availability are high.

Disinfestation

Disinfestation treatments, backed by integrated field control programmes and/or area freedom stipulations under market access approvals, provide assurance to authorities of an importing country that the commodity will be free of target pests and not pose a quarantine threat (Johnson and Heather, 1995; Follett and Nevin, 2005). Market access application and approval arrangements for most countries operate under national legislation and regulations formulated under the framework of the IPPC and the World Trade Organisation (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (IPPC, 2008; SPS, 2008). Key aspects of quarantine regulation of crop pests are covered by International Standards for Phytosanitary Measures (ISPM), developed and agreed in consultation with signatory countries to the IPPC under the Food and Agriculture Organization (FAO) (ISPM, 2007a). ISPM (2007b) cover guidelines on the phytosanitary measures for regulated pests. Under the IPPC, a technical panel on phytosanitary measures has oversight of international guidance on phytosanitary treatments including assessment and recommendations for use as international standards. In addition to ISPM, a range of regional plant protection measures has been established. It has been agreed internationally (ISPM, 2007b) that phytosanitary treatments should fulfil the following requirements:

- Provide effective destruction, inactivation or removal of pests or render them infertile or devitalized. Normally, stipulation of the destruction efficacy level, with quantification or statistical benchmarking, is required. When experimental data are unavailable or inadequate, other evidence is needed to support a claim of efficacy, for example historical/practical experience.
- The technology and treatment regime used should be: (i) clearly delineated, with evidence to confirm adequate adherence to scientific methods in generating data (experimental designs). Data in support of the treatment efficacy should be verifiable, replicable and statistically valid, and preferably published in a peer-reviewed journal; (ii) appropriate for use in international or regional trade and research; and (iii) safe to apply, with no undesirable impacts on treated commodities or the environment.

Approvals for disinfestation treatments and market access are obtained on a country-by-country basis. A starting point for intending exporters is to

Table 15.4. Examples of summary information for exporting Australian mangoes to the EU and New Zealand (Source: adapted from AQIS, 2008b).

Documentation	Required for	
	EU	New Zealand
Import Permit	No	No
Phytosanitary Certificate	Yes	Yes ^a
Additional Declaration	No	Yes ^b
Post Entry Quarantine	No	No
EX188	No	No
EX46	No	No
Radiation Statement	No	No

^aTreatment details, including date of treatment, are to be endorsed on the Phytosanitary Certificate in the treatment section. The treatment is to be shown as: irradiation at minimum 250 gray.

^bThe mangoes in this consignment have been treated in accordance with Appendix 12 of the Bilateral Quarantine Arrangement between New Zealand Ministry of Farming and AQIS.

determine the disinfestation requirements for mangoes entering target markets, for example the import health standards for New Zealand (BANZ, 2008) and the Plant Protection and Quarantine (PPQ) manuals for the USA (PPQ, 2007). Australian exporters can use the Australian Quarantine and Inspection Service (AQIS) phyto exports database (AQIS, 2008b). The AQIS web site plant product export database provides summary information (Table 15.4) and detailed information on phytosanitary requirements for potential exporters.

Follett and Nevin (2005) noted that increased trade has increased exotic pest threats and attention to quarantine and regulatory issues. Risk-based alternatives were replacing the probit 9 standard for quarantine efficacy. Cultivar testing was seen as necessary only for some treatments and commodities, and generic treatments for broad groups of pests and commodities were seen as a means of enhancing trade. Area-wide pest management was valued for preharvest pest control and improvement of quarantine security for export products. However, some treatments such as γ irradiation were not accepted by all countries and this slowed their adoption. Follett and Nevin (2005) concluded that efforts for standardization of phytosanitary measures and research would improve information exchanges and market access negotiations.

Target pests

A pest of regulatory concern that could become established in an area where it is not found is a quarantine pest risk, and requires quarantine action. Mango fruit pests include internal pulp feeders (i.e. fruit fly immatures), seed and fruit pulp pests (i.e. mango weevils and fruit caterpillars) and external pests (i.e. scales, mealybugs, thrips and mites) (see Peña *et al.*, Chapter 10, this volume). External pests pose detection risks as surface hitchhikers that

can be detected visually by inspectors. Such pests need to be controlled in the field and removed before the fruits are exported. Internal pests, such as weevils, fruit fly immatures or larvae of Lepidoptera, pose additional risks because of difficulties of detection and their potential to damage fruit flesh and/or mango seed. Immatures of mango seed weevil (*Sternochetus mangiferae* (F.)) occur in mango seed (but not flesh) in most of Africa, Asia, Australia, the Pacific and the Caribbean (Waite, 2002), and are difficult to kill *in situ* without damaging the market quality of the treated mangoes. Orchard-control measures and surveying are discussed by Hansen (1991, 1993), Waite (2002) and Wittenberg (2007). The mango pulp weevil (*Sternochetus gravis* (F.), syn. *Sternochetus frigidus* (F.)) occurs in India, Bangladesh, part of the island of Palawan in the Philippines and a few other regions in South-east Asia (Waite, 2002; Astridge and Baron, 2007c; Catindig and Kong, 2007; Walker, 2007a). It causes severe damage to the fruit pulp only (de Jesus *et al.*, 2007).

Follett and Gabbard (2000) concluded that mango seed weevil does not seriously affect mango yield or marketability. Nevertheless, the seed weevil is a major quarantine concern for countries which have not recorded it or claim area freedom, that is Middle Eastern countries and China (Waite, 2002). Seed and pulp-attacking Lepidoptera pests are quarantine risks in some countries (Waite, 2002; Walker, 2007b; Yarrow and Chandler, 2007). Entry of mangoes from countries having mango weevil and other *Sternochetus* species may be restricted or prohibited into countries free of these pests. Extensive surveying, sampling, implementation of field control measures and/or area-freedom certification and maintenance may be necessary for approval of market access (Johnson and Heather, 1995; Waite, 2002). Disinfestation treatments that ensure weevils are not able to reproduce may be acceptable when dosages for mortality damage fruit excessively.

Fruit fly disinfestation

Tephritidae are the most important mango pests and occur wherever mangoes are grown (Waite, 2002). Eggs are oviposited below the peel. The wound provides an opening for microorganisms and scars the peel. Larvae feed and tunnel throughout the pulp. Fruit flies infest tropical and temperate fruits. It is the risk to temperate climate fruits and commodities produced in fly-free areas that has prompted the development of quarantine restrictions and treatments for fruit fly hosts.

At present, quarantine treatments against fruit flies are not required for fruit entering the European Union (EU), despite the large production of temperate fruit in fruit-fly-free regions. Fly infestation has not been perceived as a threat because winter temperatures throughout much of the region effectively prevent establishment of the flies, despite geographical continuity with the distribution range of the Mediterranean fruit fly (*Ceratitidis capitata* (Wiedemann)). Canada does not require fruit fly disinfestation of tropical produce for the same reason. Exotic fruit fly pests could become established in southern Florida, Texas and California because of their subtropical climate. The USA requires that mangoes be disinfested by vapour heat, irradiation, hot water or hot air.

In Queensland, Australia, fly larvae infestation of mangoes in the marketing chain is rare, despite the widespread occurrence of endemic species of fruit flies (*Bactrocera* spp.). Preharvest control measures, and grading out of coloured fruit at the packhouse, effectively eliminate infestation of most commercial consignments; however, mangoes consigned to the Australian states in temperate regions free of the flies must be disinfested against fruit flies to help ensure area freedom of temperate-fruit-production areas (RSPM, 2004; Jessup *et al.*, 2007). When effective field control and grade-out of ripening fruit is in place, the mandatory disinfestation of mature-green mangoes entering the exclusion zone is probably unnecessary.

Potentially acceptable quarantine treatments that disinfest mangoes include vapour heat, hot air, hot water immersion, irradiation, quick-freezing, combination treatments and some miscellaneous treatments (Taylor *et al.*, 2002; Ducamp Collin *et al.*, 2007). The major constraints in the development of treatments have been the susceptibility of mangoes to heat, cold and irradiation damage and O₂ depletion, and the extensive research and negotiation required to obtain market access approvals to high-end markets (i.e. the USA, the EU and Japan). Treatments need to be verified as non-damaging to a range of cultivars by fruit size by environments likely to be encountered (Jacobi and Gowanlock, 1995; ISPM, 2007b). Treatments that cannot be used because they lower fruit quality at dosages that kill pests are methyl bromide fumigation (Spalding *et al.*, 1977) and cold temperature storage (Kane and Marcellin, 1978).

Vapour heat

Vapour heat treatment (VHT) involves heating air that is nearly saturated with moisture, and passing the air stream across the fruit (Jacobi *et al.*, 2001b). When the temperature of the mango fruit is at or below the dew point of air, condensation occurs on the fruit surface and rapidly heats the fruit by conductive energy transfer. The core of the fruit next to the seed is heated to c. 45°C for the required time before cooling. Fruit have to be sorted for size before treatment because of different rates of attaining the required core temperature.

Vapour heat is used worldwide to disinfest mangoes of fruit flies. Jacobi *et al.* (2001b) list the VHT protocols approved for importation of mangoes into Japan from the Philippines, Taiwan, Thailand, Australia and Mexico. Conditions range from 43–47°C pulp core temperature for 10 min to 6 h; however, the most common treatment conditions are 46–47°C for 10–30 min. Melon fruit fly (*Bactrocera cucurbitae* Coquillett) immatures in mangoes from Okinawa were killed at $44 \pm 0.3^\circ\text{C}$ core temperature for 3 h (Sunagawa *et al.*, 1987). Taiwanese mangoes infested with melon fly can be disinfested with vapour heat at 47.5°C until the centre pulp is $>46.5^\circ\text{C}$ for 45 min (Kuo *et al.*, 1987).

A VHT schedule was approved against Queensland fruit fly (*Bactrocera tryoni*), in 'Kensington Pride', 'R2E2', 'Keitt', 'Palmer' and 'Kent' from Australia for the Japanese market (AQIS, 2008b), which consists of a core temperature of 47°C for 15 min. The United States Department of Agriculture,

Animal and Plant Health Inspection Service Plant Protection and Quarantine (USDA-APHIS PPQ) approved VHT as a quarantine treatment for Mexican fruit fly (*Anastrepha ludens* (Loew)) and other *Anastrepha* species in 'Manila', and for mangoes from Taiwan infested with oriental fruit fly (Anonymous, 1994a). Generic guidelines for use of VHT in treating commodities for the USA market are provided by the USDA-APHIS PPQ manual on vapour heat. Mangoes from Taiwan imported into Australia must be treated until the pulp temperature has been 46.5°C for 30 min (AQIS, 2008a).

Hot air

Hot or forced hot air systems also heat the air to 40–50°C, but at a lower RH. Relative humidity usually remains >50%, depending on ambient RH, but is never high enough to produce condensation. Heat is transferred to the fruit by convection, with no condensation of water on the skin (Gaffney and Armstrong, 1990; Jacobi *et al.*, 2001b). Relative humidity should be high enough to prevent fruit desiccation during treatment. Transfer of heat from the air to the skin is slow compared with VHT. Mangan and Ingle (1992) reported that a mean centre pulp temperature of >47°C killed all stages of West Indian fruit fly, *Anastrepha obliqua* (Macquart), in Mexican mangoes, and Sharp (1992) found a centre pulp temperature of >46°C killed all stages of Caribbean fruit fly, *Anastrepha alletis* (Loew), in Florida-grown mangoes.

Hot water

Provided that fruit are not damaged, hot water immersion is environmentally safe and efficient for killing mango pests. Use of hot water to kill fruit fly eggs and larvae intensified in the USA when the Environmental Protection Agency (EPA) removed ethylene dibromide from the market as a chemical fumigant because of health concerns (Anonymous, 1983). Sharp and Spalding (1984) showed that mangoes could be disinfested of Caribbean fruit fly using hot water. The work led to more studies in Haiti and a disinfestation method for West Indian fruit fly (Sharp *et al.*, 1988), as well as Mediterranean fruit fly and other *Anastrepha* spp. in Texas and Mexico (Sharp *et al.*, 1989a, b), Puerto Rico (Segarra-Carmona *et al.*, 1990) and Peru (Sharp and Picho-Martinez, 1990). Nascimento *et al.* (1992) developed a hot water treatment for fruit flies in mangoes in Brazil. Hot-water-treated mangoes may be imported into the USA from Mexico, Central America, South America and the West Indies (Anonymous, 1994a). Typical treatments include 46.1°C for 65 min for smaller fruit to 90 min for larger fruit (Jacobi *et al.*, 2001b). Large commercial hot-water-treatment facilities have been constructed, certified by the USDA-APHIS PPQ, and used in Mexico, Central and South America, and the West Indies. Generic guidelines for the use of hot water are provided by the USDA-APHIS PPQ manual for hot water treatment.

In Australia, Smith (1992) showed that immersing five Australian mango cultivars in 48°C water for 30 min killed eggs and larvae of *Bactrocera aquilonis*; however, 'Kensington Pride' is more sensitive to hot water than to vapour heat, so the latter has been adopted for disinfestation of mangoes in Australia (Jacobi *et al.*, 1994). Grové *et al.* (1997) found that treatment of several cultivars

in hot water at 46.1°C for 90 min followed by refrigeration for 24 h did not damage fruit, although some cultivars showed severe lenticel damage. Refrigeration of 'Tommy Atkins' fruit immediately after treatment resulted in scald development. Weevils in 'Alphonso' mangoes from India were not killed when infested mangoes were immersed in water at 48–52°C for up to 90 min and 54–70°C for up to 5 min (Shukla and Tandon, 1985).

Compared with hot air treatments, hot water treatments can damage the skin, partly because of rapid heat transfer from the water to the skin compared with from the skin to the centre of the fruit. Damage includes skin scalding, lenticel damage, cavities, white starchy areas in the flesh and delayed ripening (Jacobi *et al.*, 2001b). Several factors influence damage severity after heat treatment, for example cultivar, temperature and duration (Jacobi *et al.*, 2001b). Immature fruit have low heat tolerance, and small fruit are damaged by heat more readily than large fruit. Conditioning treatments (i.e. 37°C core temperature, for at least 12 h in air) can reduce injury, and preharvest conditions, especially rainfall before harvest, can increase skin damage (Esguerra and Lizada, 1990; Esguerra *et al.*, 1990; Jacobi and Wong, 1992; Jacobi *et al.*, 1994, 1995; Jacobi and Giles 1997). Better understanding of these influences could increase the commercial potential for hot water disinfection.

Hot water dips could pose human health risks. Sivapalasingam *et al.* (2003) reported that an outbreak of *Salmonella enterica* that infected 72 patients from 13 USA states may have been due to contamination of hot-water-dipped mangoes from a single farm in Brazil. No outbreaks were reported among consumers in the EU of mangoes from the same farm, and the EU does not require hot water disinfection.

Irradiation

Irradiation involves γ rays (at <1000 Gy), X-rays, electrons and microwaves (Thomas, 1986; Velasco and Medina, 2004; Follett *et al.*, 2007; Moreno *et al.*, 2007). A 2005 FAO/International Atomic Energy Agency (IAEA) report indicated that >20 irradiation facilities have been planned, constructed or renovated in ten countries, some of which are mango exporters (Eustice, 2007). Radiation treatments have been developed for fruit flies in mangoes from Florida, Mexico, India and Australia. Von Windeguth (1986) treated mangoes with 76 Gy and disinfested them of Caribbean fruit fly eggs and larvae. Third instar Mediterranean fruit fly larvae in Mexican mangoes irradiated with 250 Gy did not emerge from pupae, and 60 Gy applied to third instar Mexican fruit fly, and West Indian fruit fly in Mexican mangoes prevented adult emergence (Bustos *et al.*, 1992). Bustos *et al.* (2004) recommended a generic dose of 150 Gy for control of Mexican fruit fly (*A. ludens*), the West Indian fruit fly (*A. obliqua*), the sapote fruit fly (*Anastrepha serpentina*) and the Mediterranean fruit fly (*C. capitata*) in mango. 'Kensington Pride' mangoes infested with eggs and larvae of Queensland fruit fly and *Bactrocera jarvisi* (Tryon) are disinfested with 74–101 Gy (Heather *et al.*, 1991).

International guidelines for the use of irradiation as a phytosanitary measure are available (ISPM, 2003), and recently a fast track process has been proposed as an Annex to ISPM 28 (ISPM, 2008), which endorses irradiation

at 70 Gy as a generic treatment to control *Anastrepha* spp. in fruit and vegetables by extrapolating work on mango by Bustos *et al.* (2004). Heather (2004) provides generic guidelines for the development of irradiation protocols for disinfestation. Fruits are never exposed to radioactive materials (Anonymous, 1986) and most modern treatment units use an electron beam process rather than a radioactive source for irradiation.

Irradiation can be used for controlling seed weevil and lepidopterous pests in fruit. Seo *et al.* (1974) reported that 206 and 329 Gy killed mango weevil in Hawaiian mango. Thomas (1975) showed that 500 Gy killed all mango weevil larvae and pupae and 750 Gy prevented adults from emerging from mangoes in Africa. A dose of 500 Gy, however, did not disinfest 'Alphonso' mangoes of seed weevil (Shukla and Tandon, 1985). Indian mangoes from approved packhouses must be irradiated with a minimum of 400 Gy at an approved and certified irradiation treatment facility using Cobalt-60 (APEDA, 2007). A quarantine treatment of 300 Gy has been approved to sterilize mango seed weevil in mangoes exported from Hawaii to USA mainland markets (Follett, 2004). Follett and Lower (2000) demonstrated control of *Cryptophlebia illepidia* (Butler), *Cryptophlebia ombrodelta* (Lower) and *Cryptophlebia illepidia* (Lepidoptera: Tortricidae), and an irradiation quarantine dose of 250 Gy has been approved for Hawaiian mangoes. The treatment also controls fruit flies (Follett, 2004).

USA regulations covering irradiation are described in the *Code of Federal Regulations* GPO Access (2008), revised annually (Wall, 2008), and this summarizes approved treatments for a range of pests (EPA, 2002) (Table 15.5),

Table 15.5. Minimum absorbed dose of gamma irradiation required by USDA for specific pests (Source: adapted from EPA, 2002).

Scientific name	Common name	Minimum absorbed dose (Gy)
<i>Anastrepha ludens</i>	Mexican fruit fly	70
<i>Anastrepha obliqua</i>	West Indian fruit fly	100
<i>Anastrepha serpentina</i>	Sapote fruit fly	100
<i>Anastrepha suspensa</i>	Caribbean fruit fly	70
<i>Bactrocera cucurbitae</i>	Melon fruit fly	150
<i>Bactrocera dorsalis</i>	Oriental fruit fly	150
<i>Bactrocera jarvisi</i>	Jarvis fruit fly	100
<i>Bactrocera tryoni</i>	Queensland fruit fly	100
<i>Brevipalpus chilensis</i>	False red spider mite	300
<i>Ceratitidis capitata</i>	Mediterranean fruit fly	150
<i>Cryptophlebia illepidia</i>	Koa seed worm	250
<i>Grapholita molesta</i>	Oriental fruit moth	200
<i>Sternonchetus mangiferae</i>	Mango seed weevil	300
All other fruit flies of the family Tephritidae which are not listed above		150
Plant pests of the class Insecta not listed above, except pupae and adults of the order Lepidoptera		400

many of which can infest mangoes. The USDA-APHIS PPQ manual on irradiation provides generic guidelines. Irradiation was approved for the USA market as a phytosanitary treatment for all fresh fruits and vegetables from all countries in 2002. Effects of γ -irradiation on mango fruit quality and disease control have been reported (Mitchell *et al.*, 1992; Moreno *et al.*, 2006; Reyes and Cisneros-Zevallos, 2007; Wall, 2008). Only marginal disease control was obtained with 'Kensington Pride' at the highest non-deleterious doses for mature-green fruit (300 Gy), with additive effects of disease control treatments and irradiation on disease reduction (Johnson *et al.*, 1990a). Disease control may be more effective in cultivars with greater tolerance of irradiation (van der Linde and Thord-Gray, 1986; Johnson *et al.*, 1990a). Other types of irradiation have been evaluated for mango disinfestation but none has been adequately suitable.

Quick freezing

Quick freezing of mango, lowering the temperature to -17°C and holding at -6°C or below for 48 h is used to disinfest mangoes for processing (Anonymous, 1994a; PPQ, 2007). The process is not approved for importing mangoes with seeds from most of the West Indies, French Guiana, all countries outside of North, Central and South America, Oceania, Hawaii, South-east Asia, the Philippines and the Republic of South Africa into continental USA because mango weevil could be present (Anonymous, 1994a; PPQ, 2007).

Fumigation

Fumigation is an ideal methodology for ensuring effective control when the fumigant is effective and safe to use. Until 1994, New Zealand required fumigation of mangoes from Australia, the Cook Islands and the Philippines using 33, 29 or 22 g/m³ ethylene dibromide at 10–15, 15.5–19.5, or 20°C and above, respectively, at normal atmosphere pressure (NAP) to disinfest mangoes of fruit flies before entry. As part of the international phase-out of ozone-depleting substances, the process was banned in 1994 (Anonymous, 1992; N.W. Heather, personal communication, Brisbane, 1994) and most applications as a fruit fumigant have ceased worldwide. Methyl bromide was phased out completely in the USA in 2005, but some emergency uses for quarantine applications may be permitted, e.g. to destroy a serious quarantine pest in an imported consignment or to meet official requirements of an importing country (EPA, 2008). Mangoes imported into Australia from countries where fruit flies occur must be fumigated with 16–35 g/m³ ethylene dibromide for 2 h at 21–26°C or above (Anonymous, 1985, 1988).

Phosphine is widely used as a fumigant of durable produce (grains and tobacco). It provides effective control of fruit fly larvae and other pests in temperate fruits under experimental conditions (Horn and Horn, 2004). However, phosphine when mixed with water is highly explosive and the vapour is toxic to humans, so prospects for utilization are not strong.

Miscellaneous treatments

CHEMICAL TREATMENTS. Postharvest chemical treatments using dimethoate are effective against Queensland fruit fly with 'Kensington Pride' (Swaine *et al.*,

1984). The treatment is required for Australian-grown mangoes entering all Australian states except Queensland and New South Wales, but is under review. The USA and the EU do not allow the use of chemicals to disinfest mangoes.

NATURAL PRODUCTS. The short shelf life of mango and the high level of insect mortality required obviates the use of natural products for disinfestation. Suhaila and Halim (1994) reported the potential of low toxicity, insecticidal compounds from edible plants that may be effective for topical application to harvested fruit. Extracts of black pepper (*Piper nigrum*) were particularly active in laboratory tests against vinegar fly (*Drosophila melanogaster* (Meigen)).

ATMOSPHERES. CA and MA regimes could have potential for disinfesting mangoes, but there has been less interest in the technology because heat treatments and irradiation are faster (Ke and Kader, 1992; Yahia and Tiznado-Hernandez, 1993; Yahia and Vazquez-Moreno, 1993; Yahia, 1994; León *et al.*, 2000). Treatments are limited to regimes which do not adversely affect ripe fruit quality. León *et al.* (2000) found that CA of 1% O₂ and 30 or 50% CO₂ disinfested 'Manila' mangoes of *A. obliqua*, but damage (as spongy tissue) was unacceptably high.

Shrink-wrapping has been ineffective as a quarantine treatment to disinfest mangoes of fruit fly immatures. Gould and Sharp (1990) reported that the time needed to disinfest Florida-grown mangoes infested with Caribbean fruit fly eggs and larvae exceeded the shelf life of wrapped mangoes.

COMBINATION TREATMENTS. Serial applications of two or more treatments, which alone do not achieve quarantine security, have been used to disinfest mangoes. Seo *et al.* (1972) reported that eggs and larvae of Mediterranean fruit fly, oriental fruit fly and melon fly were killed in mangoes immersed in water at 46.3°C for 120 min and then fumigated with ethylene dibromide. Lin *et al.* (1976) reported that all oriental fruit fly and melon fly larvae in Taiwan-grown mangoes were killed when fruit were immersed in 48–50°C water for 120 min, hydrocooled, dried and cooled, and then fumigated with ethylene dibromide.

Controlled Atmosphere/Temperature Treatment System (or CATTs) technology applies a short heat treatment in a low O₂/high CO₂ environment, and controls quarantine insect pests while maintaining commodity quality (Mitcham, 2007; Neven, 2008). Trials using CATTs with mangoes have been conducted in Australia with promising results. Varith *et al.* (2007) evaluated a microwave-vapour heat treatment (MW-VHT) disinfestation technology for mangoes: the microwave component for pre-heating and the VHT component for the holding process. Temperatures of 46–55°C and holding times of 2–20 min effectively disinfested fruit of oriental fruit fly eggs without effects on physico-chemical parameters, compared to untreated fruit. There was less heat damage compared with conventional VHT only fruit. MW-VHT shortened the process time by 90% compared with the conventional VHT.

PACKAGING. Some markets, for example Japan and the USA, require that fruit must be packed into insect-proof packages following disinfestation to preclude

reinfestation during transportation or storage. The disinfestation facility feeds fruit into an insect-proof area within which waxing (optional), grading and packing occur.

15.7 Preparing Fruit for Market

Surface coatings

Surface coatings are used to improve fruit appearance and to alter gas permeability to reduce moisture loss or retard ripening. Commercial use of surface coatings on mango fruit needs to be considered carefully because of the fine balance between beneficial and undesirable effects on fruit quality. Negative effects of coatings include reduction in chlorophyll loss (Fonseca *et al.*, 2004a), anaerobic conditions and off-flavours (Amarante and Banks, 2001) and skin damage, possibly due to cytotoxic reactions with other components in the coating formulation (Bower *et al.*, 2003). Generally, coatings have less effect on delaying ripening during cold storage, compared with extending the shelf life at typical ripening temperatures (Amarante and Banks, 2001). Less significant effects are observed in more mature and in ripening fruit. Coatings often delay skin colour change rather than softening, which increases the risk of soft, green fruit with less consumer appeal.

Coatings are generally emulsions of synthetic (e.g. polyethylene) or natural (e.g. polysaccharides, carnauba, beeswax, etc.) origin. Surface coatings containing waxes, oils (e.g. carnauba, beeswax, etc.) and resins (e.g. shellac) have a greater effect on limiting water loss than reducing O₂ and CO₂ permeability, compared with those containing polysaccharides, (e.g. those based on cellulose) (Amarante and Banks, 2001). Formulations based on shellac result in a shinier appearance than those based on carnauba wax and polysaccharide-based waxes (Baldwin *et al.*, 1999; Hoa and Ducamp, 2008).

Factors other than coating formulation can affect fruit gas permeability, i.e. cultivar, variations in skin permeability between fruit, inconsistency in coating thickness during application, interference from water during application causing coating cracking and coating thickness and evenness-of-spread over the fruit surface. The effect of coating on fruit quality can vary with holding conditions because of larger temperature effects on respiration rate than on coating permeability.

Shorter and Joyce (1994) found commercially formulated Avocado and Passionfruit Wax, a polyethylene and shellac emulsion, and Technimul 9122 Wax, a polyethylene-based emulsion, were acceptable with 'Kensington Pride' mango, while Peach Wax, a polyethylene-based emulsion and starch solution was unacceptable. With Peach Wax, deleterious modified atmosphere effects on colour development, softening and flavour were obtained (El Ghaouth *et al.*, 1992b; Shorter and Joyce, 1994). Coating 'Tommy Atkins' mango with a carnauba-based coating and BeeCoat (based on beeswax) reduced water loss, shrinkage, chlorophyll breakdown, CI and decay after cold storage, and BeeCoat also reduced red lenticel discoloration (Feygenberg *et al.*, 2005). With

'Tommy Atkins', polysaccharide and carnauba-based coatings modified the atmosphere within the fruit and reduced decay, but only the polysaccharide-based coating delayed ripening (Baldwin *et al.*, 1999). The carnauba-based coating significantly reduced water loss compared with the polysaccharide-based treatments; carnauba-based coatings result in lower water permeability and higher O₂/CO₂ permeability.

Coatings may reduce surface defects. Excessive water loss is associated with increased skin CI in avocado and mango, and carnauba-based coatings reduce CI in cold-stored mangoes (Bower *et al.*, 2003). In this study, the carnauba-based coating contained numerous holes, which allowed respiration gas exchange (thereby preventing anaerobic respiration), while still providing efficient control of water loss. Surface coatings may also reduce sapburn, skin browning and lenticel damage (Shorter and Joyce, 1994), but incorporating these potential benefits into commercial systems may be difficult.

Waxes should be applied by roller brushes in a specifically designed wax applicator or by very light hand application. Dipping fruit in a wax emulsion is not recommended. A uniform flow of fruit through the wax applicator must be maintained to prevent uneven wax application. Fruit should be dry before entering the wax applicator, otherwise foaming of water-emulsion waxes may occur. Brushes on the wax applicator need to be completely saturated with the wax mixture before any fruit passes over them. Complete coverage of the entire fruit surface is essential. Patchy application can be caused by insufficient wax, too few brushes following application (minimum of six brushes required), poor and/or inadequate drying facilities, and overloading of the unit. Brushes should be kept soft with regular washing with hot water.

Packaging

Packaging provides conveniently sized carriage units for product, protects individual fruit from contact rub and compression damage, and excludes dirt, pests and contaminants. McGregor (1987) and Hilton (1994) discussed key aspects of packaging for tropical produce. Packaging is also a marketing tool. Design and colours of symbols and text on carton exteriors portray a marketing image. Manufacturers of consumer products exploit packaging to great advantage (along with advertising) to increase both first-time and repeat sales. Marketing and design professionals may be involved in the development and customer evaluation of product packaging. Cultural preferences need to be considered, e.g. use or avoidance of red for some Asian markets. Packaging is the external face of brand loyalty. Consistent product performance and quality is the core.

Some constraints to packaging may be specified by market regulations, including carton dimensions and labelling requirements. Country of origin, cultivar, grower, packing shed, market agent, count (number per carton and weight range) and class may be required. The word 'mangoes' should be clearly visible (Anonymous, 1993). The information appears on the narrow

sides of the cartons. Storage and product use information can also be printed on the cartons. Many QA systems require adequate labelling linked to appropriate record keeping for plate-to-farm traceability. Clear labelling facilitates correct delivery, allows immediate buyer recognition of product profile and ensures maintenance of accurate sales records. An exporting country may find it of value to identify individual packers by barcoding or numbers stamped on cartons, so that sources of faulty packaging can be traced. Some countries also use date codes which enable exporters to determine the freshness of the produce at the point of export and evaluate an importers' capacity to achieve adequate turnover of the fruit without prolonged storage. It also provides invaluable feedback on the efficiency of the total distribution chain.

Cartons used for export should be clean, strong, unbroken and new. The water absorption capacity of the material should be evaluated as excess absorption will lead to collapse on the pallet. The cartons' strength will depend on the starch used by the manufacturer, the outer liner and the direction and numbers of fluting in the carton (Anonymous, 1994b). There is increasing pressure in the EU for recyclable packing material. Cartons that are recyclable should be marked with the appropriate international symbol. Returnable plastic crates are increasingly being used for domestic trade, but the return cost would make this less profitable for international trade.

Inspection

In some countries, independent inspectors check the fruit prior to palletizing to ensure that the relevant marketing, residue and phytosanitary standards have been met. Fruit for Japan is disinfested under the supervision of a Japanese inspector. Further inspections are usually made at the port of exit. Some exporting countries require a declaration by the grower to ensure that fruit will comply with the standards specified by importing countries.

Palletizing

Handling mangoes on pallets allows convenient movement of large volumes of fruit. McGregor (1987) described critical features and arrangements for loading. The disadvantages of pallets for export are the cost, lower numbers of cartons per sea container and loss. Some domestic markets have pallet share systems. Relevant markets and transporters should be consulted concerning required pallet dimensions and appropriate access for fork-lift systems. The correctly sized pallet, for example as designated by the ISO, which is designed to fit snugly into a standard sea container, should also be used for the local market.

Precision stacking with each box fitted exactly on top of the one below minimizes risk of damage. Collapsed or lopsided pallet stacks have usually been due to careless stacking and/or loose placement in the shipping container. Pallet slats should not block ventilation holes in the cartons. Cartons

should be register-stacked so that ventilation is continuous. Link sheets, which bind the cartons together at intervals, should also be designed to ensure continuous ventilation through the pallet. In the cold room, pallets should not be stacked against a wall or placed directly against each other (Boelema, 1987).

Precooling

Precooling removes field heat from the product and lowers the temperature to that required for ripening, transportation or storage. Precooling also reduces the cooling demand on any in-transit cooling system. Precooling concepts and systems are described by Thompson *et al.* (2002). Forced-air cooling systems efficiently and rapidly remove field heat, and are preferred for bringing fruit to storage temperature. High RH systems are preferred as they reduce fruit water loss. Hydrocooling can increase the risk of infection by wound pathogens (i.e. *Rhizopus* spp.) and are less effective with large fruit. Kitinoja and Kader (2003) describe low-cost cooling facilities for use in developing countries.

Ethylene and ripening

Induction of ripening is routinely employed with mangoes. There are effective low technology methods involving calcium carbide (releases acetylene which mimics ethylene) or the leaves of particular trees (Lizada, 1994). More sophisticated systems include generation of ethylene from ethanol using catalytic conversion, pure ethylene gas, or a mixture of ethylene and an inert gas (CO₂ or N₂) to reduce the risk of explosion with 3–30% ethylene in air (Reid, 2002). A number of automatic ethylene control systems are available (PDS, 2008) to maintain ethylene concentrations within required limits.

Climacteric fruit have differing sensitivities to ethylene. 'Kensington Pride' mango is sensitive to concentrations as low as 0.01 µl/l (O'Hare *et al.*, 1994). Ripening is enhanced with concentrations up to 5–10 µl/l, with very little benefit at >50–100 µl/l (Nguyen, 2003). There is more yellow colour on the ripe fruit when ripened at 20°C with 10 µl/l ethylene for 3 days compared with no ethylene, resulting in a more attractive appearance. Also, diseases are generally less in these fruit (Table 15.6), presumably because fruit ripen more quickly with less time for disease development. Good ethylene treatment can improve presentation appearance and increase saleable life (defined as the days from when the fruit reach at least 60% yellow skin colour to when the fruit had lost saleability because of disease) (Ledger *et al.*, 2002a).

Ethylene can also reduce quality if not used appropriately. Ripening 'Kensington Pride' fruit at <18°C with ethylene can result in soft fruit with less yellow skin colour, most likely because ethylene stimulated softening to a greater extent than chlorophyll loss (Nguyen, 2003). Ripe fruit disease can also be greater. These effects can be aggravated with concentrations above 100 µl/l (Fig. 15.5). 'Kensington Pride' fruit must be cooled to <24°C before

Table 15.6. Days for fruit to reach the eating soft stage (days to ripe at 20°C), percentage weight loss/day and percentage of fruit surface area affected by stem rots in ‘Kensington Pride’ mango fruit treated with 25 µl/l 1-methylcyclopropene (1-MCP) for 14 h at 20°C followed by exposure to 100 µl/l ethylene for 24 h at 20°C. Fruit were then ripened at 20°C. Means followed by the same letter in each column are not significantly different ($P > 0.05$) (Source: Hofman *et al.*, 2001).

Treatment	Days to ripe	Weight loss (%)	Stem rots (%)
Untreated	13.6	0.3	9.6
Ethylene	7.9	0.4	1.3
1-MCP	18.7	0.3	18
1-MCP + ethylene	18.2	0.3	25.8

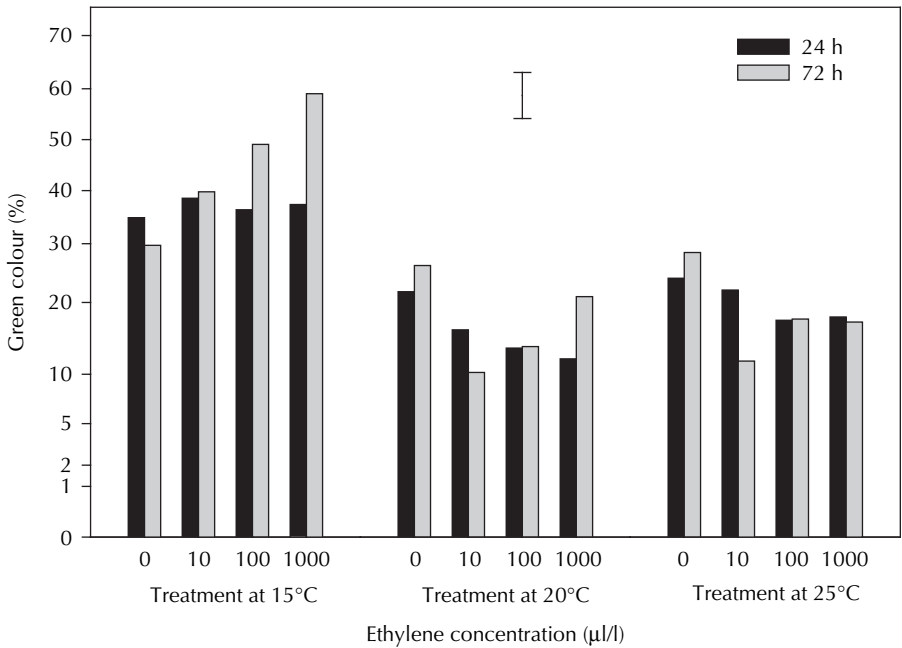


Fig. 15.5. Effect of ethylene concentration and time in ethylene and ripening temperature on the percentage skin surface area with green colour of ‘Kensington Pride’ mangoes at eating soft; least significant difference = 5.16 ($P < 0.05$) (Source: Nguyen *et al.*, 2002). Note the increased green colour on the skin of ripe fruit with lower ripening temperature and higher ethylene concentrations and duration.

the start of ethylene treatment; otherwise, skin spotting can develop (Ledger, 2003a). Ripening at 18–22°C is recommended for maximum yellow skin colour, less disease and higher flavour volatiles (Hofman, 1997; Lalel *et al.*, 2004).

The relatively high respiration rate of ripening mangoes can result in CO₂ accumulation in the ripening room, particularly if the room is full and there is poor ventilation. Carbon dioxide concentrations up to 5.3% have

been recorded in ripening rooms (Ledger, 2007), which can cause more green colour and a dull appearance on the ripe fruit (Nguyen, 2003). Ripening room CO₂ concentrations should be maintained at <1% with adequate ventilation to minimize fruit quality loss (Kernot *et al.*, 1999; Ledger, 2007).

Accidental exposure of mangoes to ethylene and its analogues from adjacent ripening rooms, exhaust fumes from internal compression engines or wound ethylene produced from damaged/ripening fruit can cause premature ripening. Various systems can remove unwanted ethylene, for example oxidizing mechanisms such as potassium permanganate either in sachets or in ethylene scrubbing units in storage rooms, catalytic oxidizers or ozone-based systems (Reid, 2002). Smartfresh™ (active ingredient 1-methylcyclopropene; 1-MCP) is a relatively new approach for preventing undesirable ethylene effects. 1-MCP is a structural analogue of ethylene and irreversibly binds to the ethylene receptors in the plant, thus preventing ethylene-initiated ripening. Ripening re-commences as additional ethylene-receptor sites are produced in the fruit (Blankenship and Dole, 2003). Generally, Smartfresh™ treatment is applied in well-sealed cold rooms or plastic tents as soon as possible after packing. 1-MCP concentrations of 250–200,000 µl/l for 12 h are optimum for delaying ripening (Jiang and Joyce, 2000; Hofman *et al.*, 2001; Adkins *et al.*, 2002; Penchaiya *et al.*, 2006), although most reports state 250–1000 µl/l. 1-MCP treatment completely negated any effect of subsequent ethylene on ripening, and can almost double the days to eating soft compared with ethylene-treated fruit ripened at 20°C (Table 15.6) (Adkins *et al.*, 2002). However, the 1-MCP effects were less in more mature fruits (Alves *et al.*, 2004), and ethylene exposure before 1-MCP will negate any 1-MCP benefit (Adkins *et al.*, 2002). Any beneficial effects of 1-MCP also appear to be less with longer-term storage (Hofman, unpublished results). 1-MCP treatment can cause more disease on ripe fruit, because the longer days to ripen allows more disease development (Hofman *et al.*, 2001). Sourcing fruit from well-managed orchards can help minimize this effect (Adkins *et al.*, 2005).

For some domestic markets, on-farm treatment of mangoes with ethylene is used to ensure that fruit have more attractive colour when they are displayed at the wholesale market 48–72 h after dispatch from the farm. This practice improves returns as fruit can be delivered to retail outlets ready-to-eat. Ethylene induction of ripening is undesirable for more distant markets because fruit arrive at the market too ripe for sale, with greater risk of bruising and disease.

15.8 Pre- and Post-shipping Storage

Cool storage

Cool storage is important when delivery time from harvest to the consumer exceeds the typical ripening time (5–10 days). The ideal storage temperature is dictated by the risk of CI, fruit ripening and disease development during storage, and storage time. CI is first noted as greying of the skin, which intensifies

with lower temperatures and longer duration (Phakawatmongkol *et al.*, 2004; Suresh *et al.*, 2004). In more severe cases flesh discoloration and abnormal ripening can occur. CI development can occur at regimes of 3–12°C (Sadasiyam *et al.*, 1971; Thomas and Oke, 1983; Chaplin *et al.*, 1986 a, b, 1991a, b; Smillie *et al.*, 1987; Thomas and Joshi, 1988; Medicott *et al.*, 1990b). Longer storage times require greater care with temperature selection, the quality of the fruit being stored and conditions before and after harvest. Storage should be for the minimum period necessary. The following factors affect the optimum storage temperatures and durations:

- Genetic differences – cultivars differ in chilling sensitivity (Phakawatmongkol *et al.*, 2004).
- Maturity – less mature fruit ripen more slowly at a given temperature, and are more prone to CI and other storage-related disorders (Medlicott, 1985; Medicott *et al.*, 1987, 1990 a, b; Oosthuysse, 1993). Such fruit may not soften at all when exposed to temperatures that are suitable for storage of more mature fruit. In South Africa, adequately mature fruit can be stored at 8–10°C for 21–28 days (Oosthuysse, 1994). Placement in cold storage without delay and post-storage exposure to temperatures that promote ripening (e.g. 20°C) are important preconditions for success.
- Duration of storage – ‘Kensington Pride’ mangoes can be stored at 10°C for 3 weeks or at 7°C for 2 weeks, after which skin colour development can be affected (McLaughlan and Wells, 1994). Generally, the shorter the storage time, the greater the tolerance to storage temperatures outside the 10–12°C range.
- Delays between harvest and cold storage, and ripeness stage – the longer the delay between harvest and cold storage, the greater the risk of ripening during storage. This applies particularly for more mature fruit. If prolonged, a delay may render refrigerated storage ineffective in preventing fruit from becoming soft during transit, despite the apparent absence of softening on dispatch (Oosthuysse, 1994). Fruit should be picked, packed and placed in cold storage within 24 h. For fruit that have ripened, storage temperatures of less than 8°C can be used for up to 21 days without deterioration in quality during storage; however, the fruit will deteriorate rapidly after removal from storage (Van Straten and Oosthuysse, 1994). Some cultivars may be more sensitive to ripe storage, since ‘Kensington Pride’ fruit at the mid-climacteric stage will start to lose appearance after 3 days at 10°C because of increased disease and mild CI (H. Nguyen *et al.*, 2004).
- Disease load and fruit tolerance of disease – certain mango cultivars are very tolerant of postharvest pathogens (e.g. see Hassan, 2007). The conditions under which mangoes are grown may be unfavourable for infection. In these situations, storage temperatures can be higher to reduce the risk of CI.

Development of CI in mango and other fruits is closely associated with antioxidant activity (Arafat, 2005; Kondo *et al.*, 2005). Mango fruit held at 6°C for 10–20 days had lower antioxidant activity in the skin compared with fruit

stored at 12°C. Application of several jasmonate derivatives before storage reduced CI at 6–7°C (González-Aguilar *et al.*, 2000; Kondo *et al.*, 2005), possibly through an antioxidant mechanism. Other chemical treatments can also reduce CI. Polyamines occur naturally in fruit and decrease during storage under chill-inducing conditions, and application before storage can reduce CI (Nair *et al.*, 2003). Salicylic acid appears to be involved in cell wall stability. Application of methyl salicylate, which breaks down to salicylic acid, significantly reduced CI in 'Zill' mangoes stored at 7°C (Han *et al.*, 2006). 2,4-D can also reduce mango CI, possibly through interaction with natural plant hormones and antioxidant levels in the fruit (Wang *et al.*, 2008). Some of these treatments could have commercial application, but may have residue implications.

Decay is a major limitation to storage life. The incidence of postharvest decay on fruit that ripen after refrigerated storage is positively related to the duration of storage and the extent of ripening during storage (Oosthuysen, 1991, 1992, 1994). Disease development after post-storage exposure to ripening temperatures can be reduced by minimizing the shipping period and by storing fruit at temperatures that inhibit softening and ground skin colour development. If CI occurs, disease develops earlier and will be more extensive (Oosthuysen, 1990).

Controlled and modified atmosphere storage

Decreasing the O₂ and/or increasing the CO₂ concentration can have several advantages with respect to storage (i.e. reduced ethylene production, better flavour retention, slowing softening and green skin colour loss and reduced CI) (Thompson, 1998; Yahia, 2006). However, if the O₂ concentration is too low (dependent on cultivar, storage temperature, fruit maturity and ripeness stage) anaerobic respiration will commence, with associated production of ethanol and acetaldehydes, leading to off-flavours and physiological disorders (Bender *et al.*, 2000). Atmosphere modification generally has less benefit for tropical fruit compared with temperate fruit, but does have commercial potential for sea freight to distant markets. Atmosphere control can be active or passive, or combinations of the two. Surface coatings (see Surface coatings section under 15.7 Preparing Fruit for Market, this chapter) also provide modified atmosphere inside the fruit.

With CA systems, O₂ and CO₂ concentrations are actively monitored and controlled by injecting N₂ and CO₂, or bleeding air into the container as required. In more passive systems, such as the MaXtrend® system (Maxtrend, 2008) fruit respiration directly lowers O₂ concentrations, and its concentration is monitored and manipulated by venting as required. In some cases, the container is flushed with N₂ at the start of storage to rapidly establish the desired atmospheres. Excess CO₂ is absorbed with hydrated lime. In MA systems, atmospheres are modified by placing a semi-permeable membrane around the fruit (usually plastic film), and relying on fruit respiration to modify the atmosphere.

McLauchlan and Barker (1994) suggested 4% CO₂ and 2–4% O₂ for CA storage of 'Kensington Pride' mangoes at 13°C, and recommended further research on atmospheres <2% O₂ and >10% CO₂. Oxygen had the biggest effect on retarding skin colour and softening, with significant retardation when decreasing from 4 to 2%. Subsequent research suggested that concentrations of 1.5–2% may be more effective in retarding softening, although these concentrations may increase the risk of off-flavours. 'Tommy Atkins' and 'Haden' can tolerate 2–3% O₂ for 2–3 weeks at 12°C, but lower concentrations were not tested (Bender *et al.*, 2000). In 'Kensington Pride' there was little additional capacity for CO₂ concentrations between 6 and 10% to retard softening or loss of green colour (McLauchlan and Barker, 1994), although there may be some benefit for storage of 1–2 weeks at concentrations >10% (Bender *et al.*, 2000). For 'Delta R2E2' mangoes 3% O₂ and 6% CO₂ have been recommended (Lalel and Singh, 2006); however, this is a firm-fleshed cultivar, which can perhaps tolerate higher O₂ concentrations to improve volatiles, compared with the softer 'Kensington Pride'. Longer storage times with CA could cause higher disease levels (Johnson *et al.*, 1990b), higher acidity in the flesh at eating soft (McLauchlan and Barker, 1994; Bender *et al.*, 2000) and slower loss of green colour compared with non-stored fruit (Bender *et al.*, 2000). For cultivars that normally have higher acidity, CA-stored fruit may need to be ripened for several more days to lower acidity.

Cold storage and CA can reduce volatiles production following ripening at room temperature. As the skin CI severity increases with decreasing storage temperature, total volatiles production appears to decrease (Singh *et al.*, 2004). In 'Kensington Pride' and 'R2E2', CA storage significantly reduces total concentrations of aroma volatile compounds compared with air-stored fruit, irrespective of storage period between 24–38 days (Singh *et al.*, 2004; Lalel and Singh, 2006). Decreasing the O₂ concentration from 3 to 1% at 6 or 8% CO₂ or increasing CO₂ concentration from 6 to 8% significantly increased most of the monoterpenes, including terpinolene. Cold-stored fruit are known to have less aroma than those ripened without storage.

Fruit can tolerate short periods with <1% O₂ or >20% CO₂ (Yahia, 2006). This has been utilized for insect disinfestation (see Disinfestation section under 15.6 Packhouse Measures, this chapter). Mango can tolerate low O₂ concentrations for 5 days at 20°C (Yahia, 1994). These short-term CA treatments may improve storage life or reduce CI during subsequent cold storage without atmosphere modification; this has been noted with avocado (Truter and Eksteen, 1987; Pesis *et al.*, 1994). Preliminary investigations suggested little benefit of 20–60% CO₂ for 1–8 days before cold storage of 'Kensington Pride' (Meiburg *et al.*, 1998).

The optimum conditions for storage of each product to provide maximum storage life without quality loss must be determined taking into account cultivar, season and growing conditions. Measurement of chlorophyll fluorescence has been used to monitor product performance under CA, with adjustment of gas conditions to achieve the optimal storage-life/quality balance. Changes in chlorophyll characteristics and therefore chlorophyll fluorescence under CA occur before CI symptoms are obvious (DeEll and Toivonen,

2003a). Thus monitoring changes in chlorophyll fluorescence characteristics can provide advance warning of the potential for CI, and allow adjustment of storage conditions to minimize its development (DeEll and Toivonen, 2003b). This concept has now been marketed as 'HarvestWatch' (Harvest-Watch, 2008), and some preliminary success has been obtained with apples (Stephens and Tanner, 2005; DeLong *et al.*, 2007).

Modified atmosphere packaging (MAP) generally cannot reliably achieve the low O₂ concentrations required to significantly delay softening without damaging the fruit, but MAP can still have beneficial effects relative to the costs of CA (Pesis *et al.*, 2000; Rosa *et al.*, 2001; Singh *et al.*, 2001; Castro *et al.*, 2005; Yahia, 2006). However, MAP can reduce quality if the cultivar/holding temperature/film permeability/storage time combination is not optimal (Sornsrivichai *et al.*, 1989), resulting in anaerobic conditions and off-flavours. Excess moisture retention inside the bags can increase disease problems (Joyce and Patterson, 1994). Special films have been developed with higher water vapour transmission rates (Pesis *et al.*, 2000) or moisture absorption materials can be included. Ethylene absorption sachets can reduce chlorophyll loss and red discoloration around the lenticels (Rosa *et al.*, 2001).

MAP reduces weight loss (Singh and Janes, 2001; Bower *et al.*, 2003), which maintains saleable weight, but may also reduce CI. There may be a direct relation between these, since weight loss can contribute to CI in avocado, and the reduction in CI obtained in mango through the use of wax coatings has been attributed to the same mechanism (Bower *et al.*, 2003). Pesis *et al.* (2000) considered that lenticel discoloration is a symptom of mild CI, and noted that MAP reduced the red coloration around the lenticels in the blushed area and the green coloration around the lenticels in the green area of 'Keitt' mangoes. Less lenticel spotting occurs in 'Kensington Pride' mangoes stored under MAP (Yuen *et al.*, 1993). It is not clear whether the reduction in lenticel damage was due to CO₂/O₂ or humidity modification.

Cultivar, film type, number and mass of fruit per package, temperature, RH, time of storage, maturity of the fruit and production conditions are important for developing MAP systems (Brecht *et al.*, 2003; Yahia, 2006). Important challenges are the differential effects of temperature on fruit respiration and film permeability, resulting in differing gas concentrations around the fruit as temperature fluctuates. Success with MAP depends on a consistent or at least predictable cold chain removal of the plastic film before significant temperature fluctuations are likely to occur and using MAP films that are unlikely to cause anaerobic conditions within the temperature range experienced in the cold chain. Brecht *et al.* (2003) suggested an approach to designing flexible CA/MA systems to account for variations in the cold chain.

15.9 Transport

Transportation of tropical fruit and vegetables has been reviewed by McGregor (1987) and Thompson (2002). For local markets (<3 h access), transportation of fruit in non-refrigerated carriers is feasible, particularly if the fruit has

been precooled and transported at night with few stops. Fruit must be sheltered from direct sun and rain. For sea export, fruit must be cooled to the required vessel carrying temperature (or within 2°C thereof) and the cold chain must be maintained until the fruit is displayed for purchase.

Some retailers prefer fruit that are ready to eat within 1–2 days of receipt. In these situations, the ideal scenario is to ripen the product as close as possible to the retail outlet to minimize physical damage to the soft fruit. However, where end-market location and transport arrangements allow delivery to market within 3 days, ripening on-farm has advantages by reducing costs for growers, and extending ownership of the product. Transport time is a major consideration for determining optimum systems (Ledger, 2003b) (Table 15.7).

When the export dispatch facility is >1 h away from the packhouse, the following road transport recommendations apply:

- The refrigerated truck should be clean and in good mechanical condition. The insulation and floor should be in a sound condition, the door seals must be intact and the doors must close very tightly.

Table 15.7. Ripening and transport recommendations for ‘Kensington Pride’ mango within Australia, to cater for the ‘ripe-for-tonight’ programme of major retail chains (Source: Ledger, 2003b).

System	Aim	Recommended handling conditions
System 1 – ripen at market	To deliver uniformly backward fruit to the market destination and then use ethylene to ripen fruit ready for retail sale. Temperature is managed through the chain to prevent mixed ripening and to avoid temperatures >22°C. This is the preferred system for Northern Territory and northern Western Australia growers sending >2000 km to market	Precool fruit to transport temperature within 12–15 h of packing Transport at 12–16°C for trips of 1–2 days and 12°C for longer trips Ripen at the market using 10 ppm ethylene for 2–3 days at 18–20°C Continue to hold fruit at 18–20°C until ready for sale Store at 10–12°C to slow ripening for a maximum of 3 days
System 2 – ripen on farm	To deliver fruit to the market destination ready for retail sale within 1–2 days. Fruit are ripened evenly using ethylene to colour stage 3 (30–50% yellow) before transport and temperature is managed through the chain to avoid high temperatures >22°C. Ripening on farm is not recommended for transport times >4 days	Precool to 18–20°C within 12–15 h of packing Ripen using 10 ppm ethylene for 2–3 days at 18–20°C Hold at 18–20°C until colour stage 3 (30–50% yellow) Transport at 12–16°C for trips of 1–2 days and 12°C for 3–4 day trips Hold at market at 18–20°C until ready for sale Store at 10–12°C to slow ripening for a maximum of 3 days

- The refrigeration equipment must be correctly set on air delivery and must be calibrated for each journey. Equipment needs to function reliably and receive regular servicing. Air should be delivered at the set point and fluctuations should not exceed $\pm 0.5^{\circ}\text{C}$ from set point. Refrigerated vehicles should be fitted with temperature loggers monitoring the delivery air, and with a digital display on the outside of the box. Refrigerated vehicles are not usually designed for, or capable of, lowering fruit temperatures so the fruit must be at the relevant shipping temperature when loading.
- Because of the shorter time involved, air-transported fruit may have less stringent temperature requirements than sea-export fruit. Airlines carrying cargo may need to be consulted concerning the normal hold temperatures in their aircraft.
- Sea-export fruit should be held under refrigeration until loading. Sea transport can be in refrigerated vessels, with entire refrigerated decks filled with pallets, or in sea containers, each of which is linked to a central ducted refrigeration system in refrigerated container vessels. Alternatively, integral containers with their own individual cooling systems or integral CA containers may be used.

Close temperature monitoring on the vessels is essential. By monitoring delivery air temperatures (DAT) and return air temperatures (RAT), it is possible to assess whether fruit is heating up due to respiration or inadequate precooling, and to take necessary steps (Anonymous, 1989; Eksteen, 1990). While most refrigerated container vessels monitor individual container air temperatures, including DAT and RAT, it is sometimes advisable to include additional temperature loggers which can measure air and fruit pulp temperatures for an entire journey.

The sea-freight component is generally the most time-consuming part of the whole field-to-supermarket voyage (for example see Table 15.8). Essential activities before and after transport can be significant, for a relatively perishable product like mango. Minimizing time delays in each component of the distribution chain is important. To reduce product deterioration,

Table 15.8. Typical packing and shipping schedules for mangoes consigned by sea to the EU from South Africa.

Operation	Days required
Picking and packing	1
Precooling and accumulation of load	4
Transport to port	2
Port handling and accumulation of load	3
Voyage time	17
Discharge handling	1
Transport and distribution	2
Total	30

producers and marketers should encourage training in perishable product handling and QA systems for personnel from trucking, sea-freight and air-freight companies who are responsible for loading, unloading and maintaining storage facilities.

Co-shipment or storage with fruit or flowers that produce high levels of ethylene can cause unanticipated triggering of mango ripening. Co-shipment with papaya (*Carica papaya*) increases mango ripening (O'Hare *et al.*, 1994). Conversely, co-shipment of carambolas (*Averrhoa carambola*) with mangoes caused ripening of the carambolas. The development of specialized packaging materials to eliminate extraneous ethylene may reduce the risk of unwanted ripening, although mixed transport should be avoided.

15.10 Marketing

Modern supermarket chains require large quantities of uniform produce that can be purchased on contract for delivery at a particular time to stores across a city or country. This allows the supermarket chain to promote the product at a special price. Mangoes are generally priced per fruit rather than by weight, although this is changing. Barcoding and/or Price Lookup Codes (PLU) on the labels of individual fruit for electronic checkout processing improves monitoring of purchase habits and stock control. The International Federation of Produce Standards (IFPS) (2008) provides a forum for standardization of produce labelling and the PLUs are applicable internationally. Proctor and Cropley (1994) cautioned the need to ensure that label adhesives comply with food additive restrictions in the EU.

Networks and cooperatives

Marketing cooperatives or networks can assist individual producers to obtain critical mass in an industry, and fulfil buyer expectations of large supply and seasonal spread of production (Glogoski, 1995; Griffin, 1995; Higginbottom, 1995; M.C. Nguyen *et al.*, 2004).

Promotion and consumer education

Mangoes are increasingly popular among affluent consumers in the EU, North America and northern Asia. In the tropics, they are reminders of a non-urban living, which has become less common because of rapid industrialization and migration to the cities. Whether for domestic use or export, mangoes must compete in the fresh market with other equally attractive, nutritious, aromatic and tasty fruit. Mangoes must also increasingly compete with the snack food, beverage and entertainment industries.

Consumer education can encourage consumption and sales. Customers can be educated how to select and store mangoes and how to use both the

fresh and the processed products in a variety of ways, thereby increasing total demand. Production of mango slices in take-away packs can tap domestic and export markets for ready-to-eat, healthy products and circumvent some disinfestation requirements (see Raymundo *et al.*, Chapter 17, this volume). Siriphanich (1994) has reviewed minimal processing of tropical fruit and noted the advantages of gaining market access and reducing transportation costs.

15.11 Conclusions

Mango production has been based almost entirely on *Mangifera indica*, albeit a variable meld of thousands of cultivars which may be derived from interspecific hybrids of a few closely related species (Kostermans and Bompard, 1993). Given its perishable nature, capitalizing more on the diversity of existing germplasm to develop cultivars with superior storage traits linked to customer appeal could deliver major benefits.

Future improvements in postharvest technology and quarantine treatment will come from refinement of preharvest management, for example reducing disease inoculum and increasing fruit resistance to disease, reducing harvest costs and fruit damage, improving postharvest treatments and systems, and supply chain approaches to enhance fruit longevity and quality and reduce the risks of product damage. Improvements will also accrue from the provision of user-friendly information for supply chain personnel, but only if the information is utilized and implemented. Increases in throughput via the automation of harvesting and treatment systems for fruit will increase as production and marketing costs escalate. Labour saving and work efficiency will also become more critical. Innovative transport arrangements may become necessary as regional development places greater pressures on transport systems. International, collaborative joint-marketing ventures will ensure year-round supplies of uniform quality fruit, and per capita consumption of mangoes will increase (Johnson, 1995).

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