Long-term refrigerated storage of mangoes: What are the issues?

S A Oosthuyse

Merensky Technological Services, P O Box 14, Duivelskloof 0835

ABSTRACT

Postharvest decay resulting from pre-harvest infection by pathogens (latent infection), the incidence of which is influenced by the amount of summer rainfall and its distribution during the season, is the greatest risk to sea exports of mangoes from South Africa to western Europe. This applies to all cultivars except "Sensation" which normally exhibits a low level of decay after arrival. The primary concern of researchers confronting extended storage of mangoes should be to minimize the incidence and manifestation of latent infection, while at the same time ensuring delivery of a good quality product. Conditions relating to storage strongly influence the manifestation of latent infection and post-storage fruit quality, and hence, an understanding of their effects is vitally important.

Storage conditions having a negative or positive effect on fruit quality and the incidence of decay are discussed. Cold, transit storage of the mango cultivars exported to Europe by sea is then considered in view of cultivar sensitivity to postharvest decay. Further, research avenues of immediate relevance are suggested.

INTRODUCTION

The principal risk to sea exports of the mango cultivars Irwin, Zill, Tommy Atkins, Kent and Keitt from South Africa to western Europe is rotting caused by pathogens infecting the fruit in the field and causing decay once ripening processes are underway. Fruit begin their journey whilst in a "hard-green" state, and consequently, pre-harvest pathogen infection, termed latent infection, cannot be detected before departure. The time taken for fruit to reach their destination ranges from 21 to 28 days.

The incidence of latent infection varies greatly from season to season and correlates with the amount of rainfall received and its distribution during the period from flowering until harvest. Although complete control of disease cannot be exerted, it can be reduced to an extent by a good spraying schedule and treatments applied in the packhouse. The latter include hot-water dipping and fungicide applications. However, despite efforts to prevent or neutralize latent infection, appreciable numbers of fruit become decayed. This contrasts strongly with airfreight fruit which show relatively little decay after arrival.

Unlike the cultivars mentioned previously, the export cultivar, Sensation, is decay insensitive. This may be due to the inability of pathogens to infect fruit of this cultivar or failure of fungal "entities" to develop following infection.

As most of the mango cultivars exported are decay sensitive, it is of primary concern to minimize the incidence and manifestation of latent infection. A product that is visually appealing and has a delightful taste must still be offered. Storage temperature, picking maturity and pre-storage ripeness strongly influence the manifestation of latent infection and post-storage fruit quality, and hence, an understanding of their effect is vitally important.

Storage Conditions Favouring or Disfavouring the Manifestation of Latent Infection

Fig. 1 illustratively shows ripening of mangoes in terms of reductions in hardness from a point in time before harvest until a point in time after four weeks of cold-storage.

Fruit are generally picked for sea export when at a stage of maturity indicated by the initiation of pulp colouration. After picking, fruit begin undergo changes leading to ripening – the transformation of the fruit from a non-edible to an edible product. Thereafter, processes associated with this transformation occur until the fruit eventually becomes eat-ripe. Cold-storage has the effect of slowing processes associated with ripening, the degree to which these processes are slowed negatively correlating with the storage temperature.

Fruit may become eat-ripe during or after cold-storage, depending on the degree to which processes associated with ripening occur prior to and during cold-storage. Decay develops once fruit have ripened sufficiently for pathogen growth to occur.

In a study aimed at evaluating a number of cold-storage temperature regimes differing in coldness, it was found that the incidence of decay (percentage of affected fruit per carton) directly after cold-storage, as well as a number of days later when the stage of eat-ripeness was reached, was positively related to the degree to which ripening (softening) took place during cold-storage. The relationship between degree of ripening and percentage of fruit per carton showing signs of decay directly after cold-storage is shown in Fig. 2 for the cultivars Kent and Irwin. The relationship between percentage decay directly after cold-storage and percentage decay when the stage of eat-ripeness was reached after subsequent storage at 18 to 25°C is shown in Fig. 3 for these cultivars.

The latter relationship appeared to differ over the range in percentage decay observed. The incidence of decay when the stage of eat-ripeness was reached was dependent to a lesser extent on the incidence of decay directly after cold-storage when the latter was greater than 9% as opposed to less than this percentage. In terms of ripening during cold-storage, this signifies that for a significant reduction in the incidence of decay when the stage of eat-ripeness is reached after cold-storage, conditions must be such that fruit are greatly limited in their ability to ripen during cold-storage.

Pre-formed anti-fungal compounds, identified as 5-substituted resorcinols, were found in the skin of mango (Cojocaru, *et al*, 1986). Only after harvest did the concentration of these compounds decrease, this reduction coinciding with the appearance of decay. Moreover, ethylene treatment, which is known to hasten ripening, hastened the reduction in concentration of these

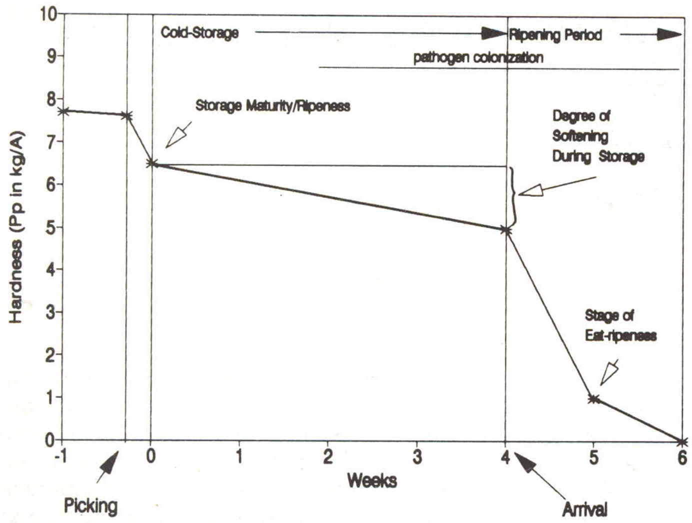

Fig 1 Representation of mango ripening in terms of reductions in hardness from a point in time before harvest until a point in time after cold-storage for four weeks.

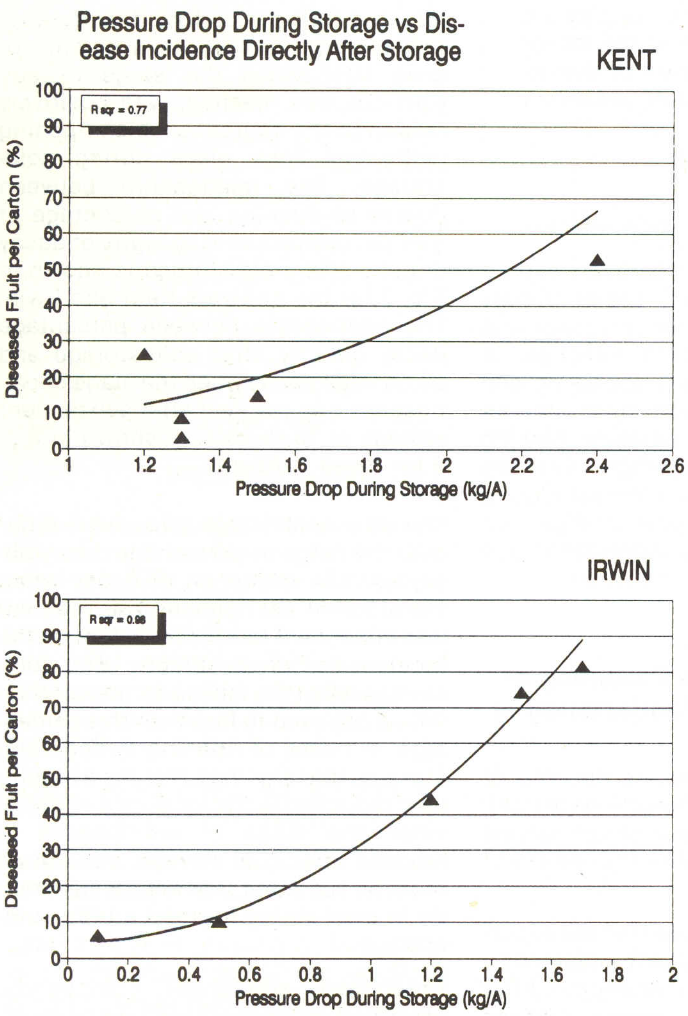

Fig 2 Relationship between degree of softening during cold-storage and percentage of fruit per carton showing signs of decay directly after cold-storage for the cultivars Kent and Irwin.

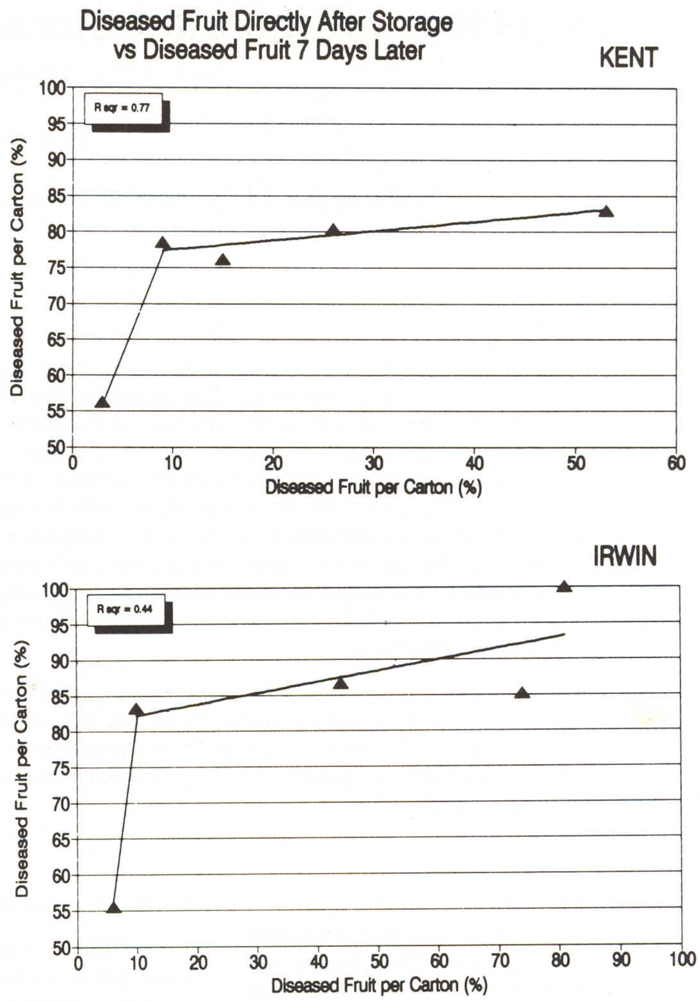

Fig 3 Relationship between percentage of fruit per carton showing signs of decay directly after cold-storage (X-axis) and percentage of fruit per carton showing signs of decay when the stage of eat-ripeness was subsequently reached (Y-axis) for the cultivars Kent and Irwin.

compounds and the appearance of decay, whereas storage under sub-atmospheric conditions, which were effective in delaying ripening, delayed the reduction and appearance of decay (Droby, *et al*, 1986). Their occurrence in several mango cultivars was stated to suggest universality in mango (Prusky, 1991). In view of these findings, a plausible explanation for the differences in percentage decay after cold-storage might be offered by equating the extent of ripening during cold-storage with the extent of a decline in anti-fungal substances in the skin.

It was recently reported by Prusky (oral presentation, IV International Mango Symposium) that exposure of mango fruit to high concentrations of CO_2 for 24 hours soon after harvest, dramatically enhanced skin concentrations of antifungal compounds, and consequently delayed the onset of decay development.

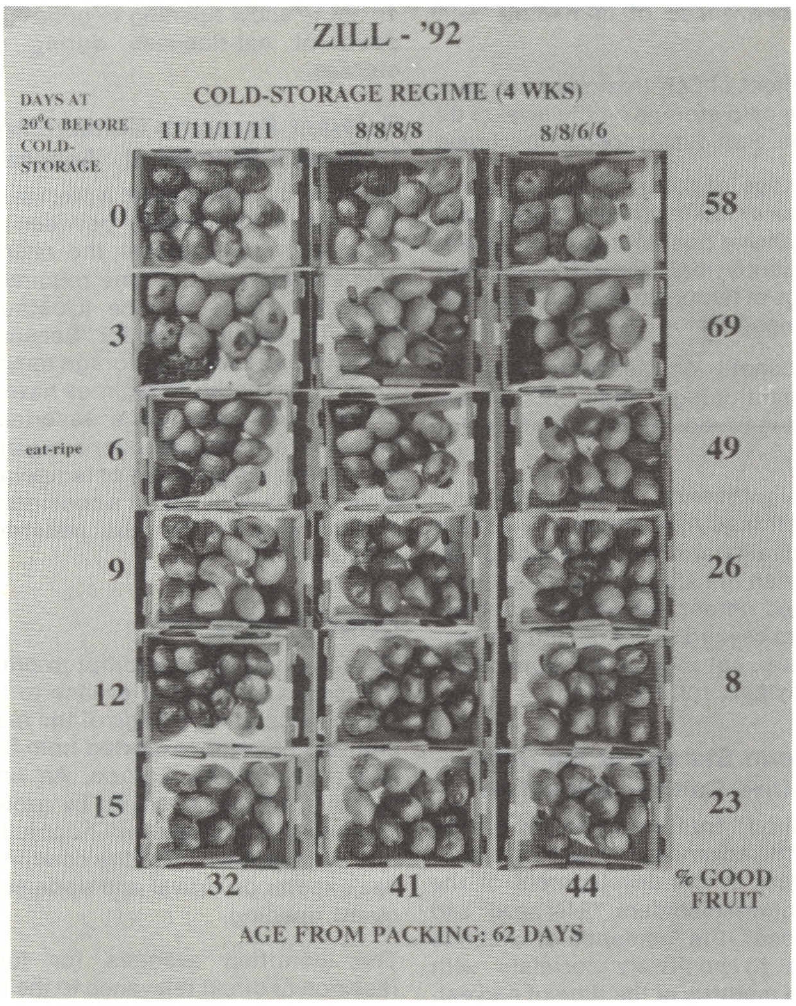

Fig 4 Results of an experiment to ascertain the effects of cold-storage regime and degree of pre-storage ripeness on the incidence of decay after storage. Top axis: cold-storage regime; *11/11/11/11*: storage for 4 weeks at 11°C; *8/8/8/8*: storage for 4 weeks at 8°C; *8/8/6/6*: storage for two weeks at 8°C followed by two weeks at 6°C. Right and bottom axes: average percentage of healthy fruit per carton (% *good fruit*). Left axis: period of pre-storage at 20°C prior to cold-storage; *eat-ripe*: stage at and beyond which the fruit entered cold-storage when having reached the stage of eat-ripeness. Post-storage temperature: 20°C.

In an experiment performed by the author on "Zill" fruit (unpublished), the degree to which ripening occurred before and during cold-storage positively correlated with the level of decay for longer than 18 days after cold-storage (see Fig. 4). The reason for the persistence with time of this correlation related to the progressive manner in which the number of affected fruit per carton increased with time. The fruit became eat-ripe within four days after cold-storage. It would thus appear that the increase in decay incidence was largely independent of whether softening was still occurring or not.

Variability between fruit in the degree to which barriers to fungal growth were removed at any one stage may explain the progressive increase in decay incidence. Alternatively, the nature of the increase might be ascribed to pathogen spread between fruit.

In view of the above, and in considering sea export of the decay sensitive cultivars to western Europe, the scenario of placing fruit directly in cold-storage after packing, storing them at a temperature low enough to greatly limit processes associated with ripening during cold-storage, and ripening them at a temperature that is sufficiently high to allow for normal ripening after cold-storage, would seem most beneficial to limit the manifestation of latent infection once the stage of eat-ripeness is reached. Treatment with CO_2 before or during cold-storage might also be considered.

The temperature regimes of four weeks at 8°C or two weeks at 8°C followed by two weeks at 6°C are effective in limiting ripening during cold-storage provided that the fruit are placed in cold-storage soon after packing (Oosthuyse, 1990, 1992). Moreover, 20°C is a suitable temperature for ripening following extended cold-storage (Oosthuyse 1992).

Factors Favouring or Disfavouring Fruit Quality after Extended Cold-storage

The low storage temperatures that are effective in limiting ripening during cold-storage, increase the risk of chilling-injury. Fruit may develop *surface scald* evident as skin discolouration or browning, or *pitting* resulting from darkened areas becoming sunken necrotic lesions (Wardlaw and Leonard, 1936; Hatton *et al*, 1965). The tissue surrounding lenticels might become darkened (*lenticel spot*) (pers obs). Indented spots may develop where the skin has been in contact with latex (*pitted spot*) (pers obs). Mottling may arise due to the failure of regions of the skin to de-green and develop colour (Thompson, 1971; Veloz *et al*, 1977; Medlicott, *et al*, 1986; Medlicott and Jager, 1987). *Black sap exudation* from the cut peduncle might be observed (pers obs). *Peripheral blanching or browning*, i.e., whitening and subsequent browning of pulp tissue beneath the skin, may occur (pers obs). *Internal breakdown* or *discolouration* may develop when the fruit become ripe (Chaplin 1987; Lizada, 1991). Pulp colouration, and the rise in total soluble solids content and fall in acid levels, might be suppressed (Kapse *et al*, 1975; Veloz *et al*, 1977; Medlicott and Jager, 1987; Chaplin *et al*, 1991).

Uneven ripening and poor flavour development have been ascribed to chilling injury (Lizada, *et al*, 1984; Snowdon, 1990). Moreover, inhibition of ripening has been observed (Chaplin, 1987; Medlicott, *et al*, 1990a; Kirsten, 1991). Also associated with chilling injury is an increased susceptibility to decay (Thomas and Oke, 1983; Oosthuyse, 1990).

The risk of chilling injury can be reduced by adopting certain measures.

Fruit picked at an advanced stage of maturity[1] are found to be less sensitive to chilling injury (Thompson, 1971; Medlicott, 1985; Medlicott, *et al*, 1987; Medlicott, *et al*, 1990a; Medlicott, *et al*, 1990b). Moreover, fruit stored when at an advanced stage of maturity are of a better quality after post-storage ripening than fruit treated identically, but stored at a lesser stage of maturity (Medlicott, *et al*, 1990a).

1. Maturity refers to the age of unharvested fruit.

Mangoes that have ripened to an extent or fully, better withstand low temperatures (Akamine, 1963; Chaplin, 1987; Thomas and Oke, 1983). The terms *temperature conditioning, temperature preconditioning, temperature adaptation, hardening, acclimation* and *acclimatization* all refer to step-wise reductions in temperature during the initial stages of low temperature storage, and likewise impart a greater tolerance to chilling injury (Mukerjee and Srivastava, 1979; Thomas and Oke, 1983). Low temperatures are, however, less effective in limiting ripening during cold-storage of fruit first stored under conditions favourable for ripening (Oosthuyse, 1992). Thus, by adopting techniques that permit processes associated with ripening to proceed to an extent prior to low temperature storage, the objective of wishing to minimize the manifestation of latent infection might be compromised.

Introducing intermittent warming cycles to the cold-storage regime is another option to reduce the risk of chilling injury. The severity of chilling injury of "Kensington" mangoes stored at 5°C was reported to be significantly reduced by introducing 24 hour-long warming cycles of 20°C to the cold-storage regime (Chaplin, 1987). The number of cycles introduced and the reduction in chilling injury observed positively correlated with the degree of softening during storage. This result would thus suggest that by adopting this option, the objective of minimizing the manifestation of latent infection might be compromised.

In considering conditions favouring fruit quality in addition to those disfavouring the manifestation of latent infection, the most obvious and practicable criterion to add to the storage scenario would seem to be that of harvesting fruit at an advanced stage of maturity. As the time from picking until the initiation of the climacteric decreases with increasing maturity (Lakshminarayana, 1973), it may be important to minimize the time from picking until the fruit are placed in cold-storage, so as to reduce the likelihood of the initiation of ripening before cold-storage.

Intermittent warming or temperature preconditioning may be beneficial, especially when it is suspected that the stage of maturity at picking was not sufficiently advanced for an adequate reduction in the risk of chilling injury.

Relevant Research Concerning Long-term Storage of the Decay Sensitive Mango Cultivars

The following would appear to be the research avenues of immediate relevance:

* The effect of CO_2 treatment before or during cold-storage on the level of decay and fruit quality following storage.
* The stage of maturity beyond which the risk of chilling injury is adequately small and post-storage fruit quality sufficiently high for extended cold-storage at temperatures that largely inhibit ripening.
* The benefit of measures such as preconditioning and intermittent warming to reduce the risk of chilling injury.
* The significance of the method of post-storage ripening as it relates to fruit quality and the incidence of decay when the stage of eat-ripeness is reached (most beneficial methods may go beyond solely raising the temperature, but include the application of ethylene, for instance).

Long-term Storage of the Decay Insensitive Cultivar, Sensation

"Sensation" fruit are generally picked when little advanced in stage of maturity for fear of the development of the physiological disorders, "jelly seed" and "soft-nose", the incidence of which is thought to positively correlate with stage of maturity at the time of harvest. Fruit exported at 8°C to western Europe during the 1991/92 and 1992/93 export seasons showed uneven skin colouration, severe lenticel spot, and internal discolouration (browning) after arrival. Furthermore, total soluble solids content did not attain an acceptable level (< 12,5% brix) and flavour was poor upon ripening. The incidence of physiological disorders was low (< 4%) (J du Preez, internal report; F Roodt, pers comm). It would appear that the fruit suffered chilling injury, the advent of which most probably had a strong bearing on the stage of maturity at harvest.

In view of the apparent tolerance of "Sensation" to pathogens causing postharvest decay, it would seem feasible to store fruit of this cultivar at a temperature or temperature regime that presents little risk of causing chilling injury. Temperatures in the range of 11 to 15°C are unlikely to cause chilling injury (pers obs). Temperatures in this range are, however, conducive to ripening during cold-storage (pers obs).

Arrival of fruit in an eat-ripe condition is undesirable in view of it having a limited shelf-life. Thus, a proviso concerning extended cold-storage of "Sensation" is that of the temperature or temperature regime adopted being cold enough so as not to allow ripening to occur to the point of eat-ripeness during cold-storage.

Relevant Research Concerning Long-term Storage of "Sensation"

Certain data indicate that a precise positive relationship exists between pulp penetration pressure at the onset of cold-storage and the time required for fruit to become eat-ripe (Oosthuyse, 1991). The relationships for "Sensation" fruit stored at various storage temperatures or temperature regimes have still to be determined. Once ascertained, they will facilitate decisions regarding the storage temperature or temperature regime to be adopted for a consignment of fruit with known pulp penetration pressure.

CONCLUSION

The foregoing is an attempt to present the issues of direct relevance to long-term refrigerated storage of the mango cultivars currently exported from South Africa to western Europe. An understanding of these issues by growers, packers and shippers will hopefully effect an improvement in the condition of sea exports on arrival and upon subsequent ripening.

The identified avenues for further research of direct relevance to the topic suggest that much still has to be learnt before precise recommendations can be made. However, improvement of the present situation, which involves cold-storage at 8°C, is envisaged if the adjustments of harvesting the decay sensitive cultivars later, and storing fruit of the cultivar "Sensation" at higher temperatures, are made. Delaying picking of the former by two to three weeks might be possible before *spontaneous ripening*[2] reaches an unacceptable level. The temperatures of 11 or 13°C may be adequate for cold-storage of "Sensation" fruit harvested at the currently adopted stage of maturity.

Susceptibility to decay compounds the problem of extended storage of mangoes. Ease in exporting mangoes from South Africa to western Europe by sea will foreseeably entail the breeding of cultivars that are resistant to pathogens causing postharvest decay, show limited ripening at temperatures that hold little risk of causing chilling injury, and ripen to become attractive products upon post-storage exposure to ripening temperatures.

---

2. Ripening whilst fruit are still attached to the tree.

LITERATURE CITED

AKAMINE E K, 1963. Haden mango storage. *Hawaii Farm Sci* **12**, 6-7.

CHAPLIN G R, 1987. Ripening in mango fruit and its manipulation by low temperature. *In* R T Prinsley and G Tucker, *eds.* Mangoes – a review. Commonwealth Science Council, London.

CHAPLIN G R, S P COLE, M LANDRIGAN, P A NUEVO, P F LAM, and D GRAHAM, 1991. Chilling injury and storage of mango (*Mangifera indica* L.) fruit held under low temperatures. *Acta Hort* **291**, 461-471.

COJOCARU M, S DROBY, E GLOTTER, A GOLDMAN, H A GOTTLIEB, B JACOBY, and D PRUSKY, 1986. 5-(12-Heptadecenyl)-resorcinol, the major component of the anti-fungal activity in the peel of mango fruit. *Phytochemistry* **25**, 1093-1095.

DROBY S, D PRUSKY, B JACOBY, and A GOLDMAN, 1986. Presence of anti-fungal compounds in the peel of mango fruits and their relation to latent infections of *Alternaria alternata. Physiol Plant Pathol.* **29**, 173-183.

HATTON T T, W F REEDER, and C W CAMPBELL, 1965. Ripening and storage of Florida mangoes. *US Dep Agric Res Rep* No. 725.

KAPSE M B, D A RANE, D N KULKARNI, and U M INGLE, 1975. Biochemical changes in Totapuri mango during ripening and storage. *S Indian Hort* **25**, 119-120.

KIRSTEN J, 1991. SA moet mango-sokkies optrek. *Landbouweekblad*, Aug 23, pp 22-25.

LAKSHMINARAYANA S, 1973. Respiration and ripening patters on the life cycle of the mango fruit. *J Hort Sci* **48**, 227-233.

LIZADA M C, 1991. Postharvest physiology of the mango – a review. *Acta Hort* **291**, 437-453.

LIZADA M C C, S KOSIYACHINDA, and D B MENDOZA Jr, 1984. Physiological disorders of mango. *In* D B Mendoza Jr and R B H Wills, *eds.* Mango: Fruit development, postharvest physiology and marketing in ASEAN. ASEAN Food Handling Bureau, Kuala Lumpur.

MEDLICOTT A P, 1985. Mango fruit ripening and the effects of maturity, temperature and gases. PhD Thesis, The Polytechnic, Wolverhampton.

MEDLICOTT A P, S B REYNOLDS, and A K THOMPSON, 1986. Effect of temperature on the ripening of mango fruit (*Mangifera indica* L var Tommy Atkins). *J Sci Food Agric* **37**, 469-474.

MEDLICOTT A P and M J JAGER, 1987. The development and application of postharvest treatments to manipulate ripening in mangoes. *In* R T Prinsley and G Tucker, *eds.* Mangoes – a review. Commonwealth Science Council, London.

MEDLICOTT A P, S B REYNOLDS, S W NEW, and A K THOMPSON, 1987. Harvest maturity effects on mango fruit ripening. *Trop Agric* **65**, 153-157.

MEDLICOTT A P, J M M SIGRIST, and O SY, 1990a. Ripening of mangoes following low temperature storage. *J Amer Soc Hort Sci* **115**, 430-434.

MEDLICOTT A P, M N'DIAYE, and J M M SIGRIST, 1990b. Harvest maturity and concentration and exposure time to acetylene influence initiation of ripening in mangos. *J Amer Soc Hort Sci* **115**, 426-430.

MUKERJEE P K and R B SRIVASTAVA, 1979. Increasing the storage life of mango (*Mangifera indica* L.) by lowering the criticl temperature. *Prog Hort* **10**, 63-69.

OOSTHUYSE S A, 1990. Effect of lowering the temperature of the cold-storage regime on the quality of export mangoes after four weeks of storage. *SA Mango Growers' Assoc Yearbook* **10**, 38-56.

OOSTHUYSE S A, 1992a. Correlating prestorage ripeness of mangoes with the proportion of good quality fruit present after four weeks of cold-storage. *SA Mango Growers' Assoc Yearbook* **12**, 80-83.

PRUSKY D, 1991. Mango diseases: an overview. *Acta Hort* **291**, 279-287.

SNOWDON A L, 1990. A colour atlas of postharvest diseases and disorders of fruits and vegetables. Volume 1: General introduction and fruits. Wolfe Scientific, London.

THOMAS P and M S OKE, 1983. Improvements in quality and storage of "Alphonso" mangoes by cold adaptation. *Scientia Hort* **19**, 257-262.

THOMPSON A K, 1971. The storage of mango fruits. *Trop Agric* **48**, 63-70.

VELOZ, C S, F E TORRES, and S LAKSHMINARAYANA, 1977. Effect of refrigerated temperatures on the incidence of chilling injury and ripening quality of mango fruit. *Proc Fla St Hort Soc* **90**, 205-210.

WARDLAW C W and E R LEONARD, 1936. The storage of West Indian mangoes. *Imp Coll Trop Agric, Trinidad, Low Temp Res Stn, Mem. No.* **3**, 47.