Quality of Mature Zill Mangoes after Long-term Refrigerated Storage as Determined by Pre-storage Ripeness and Cold-storage Regime

S.A. Oosthuyse
Merensky Technological Services, P.O. Box 14, Duivelskloof 0835

ABSTRACT
Pre-storage at 20°C for 72 hours before cold-storage, and various four-week-long cold-storage regimes differing in their ability to suppress the ripening of mangoes, were evaluated. Zill fruit picked when at an advanced stage of maturation were either pre-stored or placed directly in cold-storage. The cold-storage regimes of four weeks at 11°C, four weeks at 8°C, and two weeks at 8°C followed by two weeks at 6°C were adopted. After cold-storage, the fruit were stored at 20°C for a further 18 days.

Firmness decreased, and skin and pulp colouration increased during pre-storage. During cold-storage, the extent of skin colouration was greatest at the 11°C regime and least at the 8°C regime, and was greater at each regime when pre-storage preceded cold-storage. Total soluble solids content directly after cold-storage was commensurate with prior softening. In the directly stored fruit, the extent of softening during cold-storage was positively related to temperature. In the pre-stored fruit, no such relationship was apparent, as these fruit all softened to the point of eating-ripeness during cold-storage.

Skin colouration just prior to and its increase during cold-storage were directly related to the percentage of fruit showing signs of disease (soft-brown rot) after cold-storage, and almost entirely accounted for the differences in percentage disease due to treatment two days after cold-storage. Severe symptoms of chilling injury were absent. Pre-storage reduced the sensitivity of the skin to lenticel damage and shriveling, but not to sap-pitting. The incidence of each of these disorders was inversely related to cold-storage temperature.

The beneficial effects of pre-storage were offset by the negative effects of an increased incidence of disease and overripeness after cold-storage. Direct placement in cold-storage at 8°C was deemed the best storage option.

UITTREKSEL
Opberging by 20°C vir 72 uur voor koelopberging by verskeie koelopbergings programme, wat verskil ten opsigte van hul vermoe om rypwording van mango's te onderdruk, is geevalueer. Zill vrugte, gepluk op 'n gevorderde stadium van volwassenheid, is vooraf opgeberg of is direk in koelopberging geplaas. Koelopbergings programme van vier weke by 11°C, vier weke by 8°C en twee weke by 8°C gevolg deur twee weke by 6°C is gebruik. Na koelopberging is die vrugte by 20°C vir 'n verdere 18 dae gestoor.

Vermheid van die vrugte het afgeneem terwyl skil en pulp verkleuring het toegeneem gedurende vooraf opberging. Gedurende koelopberging was die mate van skilverkleuring die grootste by 11°C en die minste by 8°C, dit was ook groter in die gevalle waar vooraf opberging koelopberging vooraf gegaan het. Totale oplosbare suiker inhoud direk na koelopberging was proportioneel aan vooraf versagting. By die vrugte wat direk in koelopberging geplaas is, was die mate van versagting direk gekoppel aan temperatuur. By die vooraf gebergte vrugte was daar geen suike verwantskappe sleg nie, aangesien hierdie vrugte almal tot eetyp sagtheid versag het gedurende koelopberging.

Skil verkleuring net voor, en verhooging gedurende koelopberging was direk verwant aan die persentasie vrugte wat siekte teksens (sagte bruinvrot) na koelopberging getoon het, dit het die verskille in persentasie siekte voorkom die ongeveer van behandeling twee dae na koelopberging teilik heetemal verkaal. Erenstige kouseskade simptome was ook afwesig. Vooraf opberging het die sensitiwiteit van die skil vir lenticel skade verkreukeling verlaag, maar die voorkom van latex holtes is nie verlaag nie. Die voorkom van elk van hierdie afwykings was invers aan die koelopbergings temperatuur.

Die voordelige effekte van vooraf opberging is oorskudda deur die negatiewe effekte soos verhoogde siekte voorkom en oorrypheid na koelopberging. Direkte plasing in koelopberging by 8°C word as die beste opsie beskou.
INTRODUCTION

The principal risk to sea exports of the mango cultivars Irwin, Zill, Kent, and Keitt to Europe, is pre-harvest latent infections of the pathogens Colletotrichum gloeosporioides (Wehner, Bester and Kotze, 1982) and Nattrassia mangiferae (Roux, 1993), which cause the postharvest diseases anthracnose and soft-brown rot respectively. These cultivars are exported at 8°C, the duration of the journey to Europe varying from 21 to 28 days.

The incidence of latent infection varies greatly from season to season, and is apparently influenced by the amount and distribution of rainfall during the period from flowering until harvest. Although complete control of latent infection is not possible, the incidence of postharvest disease is reduced to an extent by pre-harvest fungicide sprays, a postharvest hot-water dip, and a postharvest fungicide application. Despite these efforts, appreciable numbers of fruit become diseased following sea shipment. By contrast, fruit that are shipped by air show a low incidence of disease upon and after arrival.

Buyers at markets in Europe are quick to recognize disease, often refusing to purchase mangoes showing only incipient signs of decay. On the other hand, skin blemishes unrelated to disease are tolerated to a large extent. There is also resistance towards the acceptance of soft fruit by distribution agents, due to such fruit having a limited shelf-life. Fruit that are firm, or even 'hard', and show good ground skin colouration (> 50%), are preferred.

In a prior experiment aimed at evaluating a number of four-week-long cold-storage regimes for sea export (Oosthuysen 1990, 1992), the percentage of diseased Irwin or Kent fruit after post-storage placement at temperatures exceeding 18°C, was found to be positively related to the extent to which ripening had occurred during cold-storage. Upon full-ripening, fruit that had ripened least showed the lowest incidence of anthracnose and soft-brown rot.

Refrigerated storage, particularly at temperatures that are effective in suppressing ripening, can adversely affect the quality of mangoes. Fruit may develop surface scald, made evident by skin discolouration or browning, or they may become pitted as a result of parts of the darkened areas becoming sunken and necrotic (pitting) (Wardlaw and Leonard, 1936; Hatton et al, 1965). Tissue surrounding lenticels may become darkened (lenticel damage). Indented spots may develop where the skin has been in contact with sap (sap pitting). 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 and Jeger, 1987). Black sap exudation from the cut pedicel may be observed. Peripheral blanching or browning, i.e., whitening and subsequent browning of pulp tissue just beneath the skin, may occur. Pulp discoloration may develop during ripening or afterwards (internal browning) (Chaplin 1987; Lizaola, 1991). The development of pulp colour, the rise in total soluble solids content and the fall in acid levels associated with normal ripening, may also be suppressed (impaired ripening) (Kapse et al, 1975; Veloz et al, 1977; Medlicott and Jeger, 1987; Chaplin et al, 1991).

The occurrence of various cold-related disorders has been found to negatively correlate with the degree of maturation at harvest (Thompson, 1971; Medlicott, 1985; Medlicott et al, 1987; Medlicott et al, 1990a; Medlicott et al, 1990b). It has also been observed that mangoes having ripened to an extent or fully prior to cold-storage, better withstand low storage temperatures (Akamine, 1963; Chaplin, 1987; Thomas and Oke, 1983). Moreover, cold-storage temperatures which favour ripening are less likely to cause cold damage (Oosthuysen, 1990).

In view of the apparent situation of opposing conditions favouring fruit quality and the manifestation of latent disease infection, the present study was performed. Pre-storage at 20°C for 72 hours and various cold-storage temperature regimes differing in their ability to suppress ripening were evaluated for commercial transit-storage of Zill mangoes picked when at an advanced stage of maturation. The manifestation of disease after cold-storage was considered to be an important criterion in the analysis.

MATERIALS AND METHODS

In mid-December 1991, thirty six, 4 kg cartons of newly packed Zill fruit (count 12) were obtained from a commercial packhouse. The fruit were picked when at an advanced stage of maturation, as indicated by the extent of pulp colouration shown, and were acquired within a period of 24 hours after picking. Treatment prior to packing respectively incorporated a soap wash, a five minute, 52°C hot-water dip, a one minute dip in water at ambient temperature, and waxing with a polyethylene wax. The dipping-water contained prochloraz (810 ppm).

Six cartons were immediately placed in each of three identical cold-storage rooms (temp. and humidity control: ± 0.5C; 90–95% RH). The remaining cartons were immediately placed in a well ventilated ripening room (20±1C; 80–90% RH) for 72 hours before being placed in the above mentioned cold-storage rooms in equal numbers. The cold-storage temperature regimes of four weeks at 11C (11/11), four weeks at 8C (8/8) and two weeks at 8C followed by two weeks at 6C (8/6) were adopted, the first regime being less effective in suppressing ripening than the second and third regimes. After cold-storage, the fruit were stored at 20°C for a further 18 days in the aforementioned ripening room.

Just prior to cold-storage, one fruit was randomly selected per carton, and the degree of ground skin colouration (Sc), the degree of pulp colouration (Pc) and pulp penetration pressure (Pp) were assessed for each fruit. Directly after cold-storage, and two, four and six days subsequently, one fruit per carton was randomly selected, and total soluble solids content (TSS), Pp, Sc and taste were assessed for each fruit. Care was taken here to exclude the effect of localized decay, by cutting away the diseased portions of the fruit before measurements were taken. Directly after cold-storage, and two, four, 10, 14, 16 and 18 days subsequently, the percentage of diseased fruit per carton was assessed. The percentage of fruit per carton with skin disorders was assessed once symptoms were clearly evident, either four or six days after cold-storage (pulp disorders were not apparent).

In determining the Pp of a fruit, the fruit was first peeled with a potato peeler to a depth of 2 to 3 mm at three symmetrically situated sites. Pp was measured at the centre of each site with a hand-held penetrometer (FT 327, Facchina, Alfonisio, Italy) to which a 6 mm plunger was attached. The mean of the three readings was recorded, the unit of measurement being kg/A, where A is the piercing surface area of the 6 mm plunger.

Sc and Pc were assessed visually against colour standards, the rating given for each being either 0, 25, 50, 75 or 100%.
### Table 1 Means, and significance levels (p-values) for the various sources of variation in the analyses of variance.

| Cold-storage regime (T) | A  
| QTSS(% brix) | B  
| $P_p$(kg/A) | C  
| $S_c$(%) | D  
| Disease(%) | E  
| Lenticel damage(%) | F  
| Sap pilling(%) |
|---|---|---|---|---|---|---|---|
| 11/11 | 15.0  | 16.1  | 1.86  | 2.61  | 45.8  | 79.2  | 4.2  | 14.6  | 4.2  | 5.2  | 0.0  | 0.0  |
| 8/8  | 13.4  | 16.3  | 0.45  | 3.32  | 2.5  | 50.0  | 0.0  | 3.1  | 25.1  | 11.7  | 3.9  | 5.2  |
| 8/6  | 12.7  | 16.9  | 0.70  | 3.11  | 2.5  | 50.0  | 0.0  | 3.1  | 25.1  | 11.7  | 3.9  | 5.2  |

**ANOVA RESULTS - P values**

**Source of Variation**

- Interaction-PT: 0.030  0.008  0.626  0.202  0.159  0.893
- Main effect - P: - - - 0.004  0.001  0.020  0.516
- Main effect - T: 0.001  0.000  0.022  0.017
- Linear: 0.014  0.845  0.231  0.477
- Quadratic: 0.864  0.244
- Direct: 0.368  0.204
- Pres-store: 0.577  0.428

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**RESULTS**

On average, $S_c$ was 17 (± 4.5) %, $P_p$ was 5.02 (± 0.1) kg/A, and $P_c$ was 21 (± 3.6) % when the fruit were obtained. $S_c$ and $P_p$ of the pre-stored fruit averaged 25 (± 5.7) %, 3.88 (± 0.2) kg/A, and 32 (± 5.6) %, respectively, just prior to cold-storage, indicating that ripening was initiated during pre-storage.

TSS immediately after cold-storage was directly related to the extent of prior softening (reduction in $P_p$) (Table 1-A). Softening during cold-storage differed with respect to time of placement in cold-storage, as is indicated by significant factor interaction (Table 1-B). In the fruit placed directly in cold-storage, softening was limited and occurred to a lesser extent at 8/6 and 8/8 than at 11/11. In the pre-stored fruit, the extent of softening bore no relation to cold-storage temperature, as these fruit all softened to the point of eating-ripeness ($P_p < 2$ kg/A) during cold-storage.

The effects of pre-storage and cold-storage regime on the increase in $S_c$ during cold-storage were additive (Table 1-C). The increase was greater in the pre-stored than in the directly-stored fruit, and for each of these fruit groups, was least at 8/8, and greatest at 11/11. Increase in $S_c$ and softening during cold-storage were poorly correlated ($r = 0.23$; $p$ (linear reg.) = 0.18).

The directly stored fruit took between two and four days to soften to the point of eating-ripeness after cold-storage (Table 2). Six days after cold-storage, the differences in firmness between all of the fruit were marginal. After cold-storage, the directly stored fruit attained $S_c$ and $P_p$ levels that were comparable to those of the pre-stored fruit, despite the strong suppression of ripening during cold-storage of the fruit stored directly at 8/8 and 8/6 as is indicated by the changes in $P_p$ and $S_c$ of these fruit during this period.

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1. Total soluble solids content directly after cold-storage; 2. Pulp penetration pressure reduction during cold-storage; 3. Skin colouration increase during cold-storage; 4. Percentage of fruit per carton showing signs of disease two days after cold-storage; 5. Percentage of fruit per carton with noticeable lenticel damage after cold-storage; 6. Percentage of fruit per carton with noticeable sap pitting after cold-storage; 7. Fruit placed directly in cold-storage; 8. Fruit pre-stored prior to their placement in cold-storage; 9. Treatment combination mean; 10. Significance level in the analysis of variance depending on the extent of the transition in colouration associated with normal ripening in Zill.
Six days after cold-storage, there was no reason to discriminate on taste with respect to treatment. The average taste rating for the directly-stored fruit was 0.56 (± 0.16), and that for the pre-stored fruit was 0.61 (± 0.12).

The 1991 growing season was abnormally dry. The reduction in rainfall would have influenced latent disease infection in the sense of its incidence and the prevalence of a particular organism causing infection. The disease symptoms that developed during and after cold-storage were typically those of soft-brown rot. Symptoms of anthracnose were not evident.

Only the fruit stored at 11/11 showed signs of disease directly after cold-storage. The percentage of diseased fruit per carton was greater in the pre-stored (10.1 % ± 2.7%) than in the directly stored fruit (4.1 % ± 3.3%).

Two days after cold-storage, the occurrence of disease had increased. The effect of each factor on percentage disease was additive (Table 1-D). The incidence of disease was greater in the pre-stored than in the directly-stored fruit, and for each of these fruit groups, a direct relationship existed between cold-storage temperature and the incidence of this disorder.

The incidence of disease increased progressively during the days that followed (Table 3). The correlation between the percentage of diseased fruit per carton two days after cold-storage, and the percentage of diseased fruit per carton 4, 6, 10, 14, 16 or 18 days after cold-storage was highly significant in each instance [p (linear reg.) < 0.001], the correlation coefficients varying from 0.56 to 0.68. This result signifies that the nature of the differences in disease incidence established two days after cold-storage persisted with time. Thus, at any stage after cold-storage, the incidence of disease was a reflection of the conditions of storage to which the fruit were exposed prior to their removal from cold-storage.

To evaluate the progression of certain ripening events prior to the termination of cold-storage as determinants of the level of disease two days after cold-storage, a stepwise variable selection procedure was employed (Statgraphics, STSC Inc., Rockville, USA). Percentage disease was stipulated as the dependent variable, and Sc, Pp, and Pc just prior to cold-storage and the change in Sc and Pp during cold-storage, were stipulated as independent variables. Sc just prior to cold-storage and its increase during cold-storage were selected, and accounted for 98% of the variation in percentage disease due to treatment. The contribution of Sc just prior to cold-storage was 40%, and that of its increase during cold-storage was 58%. This result signifies that the incidence of disease two days after cold-storage is almost entirely explicable in terms of the effects of pre-storage and cold-storage regime on Sc.

Lenticel damage, sap pitting and shriveling were the only skin disorders observed after cold-storage.

Table 1 -E shows the mean percentages of fruit per carton showing noticeable lenticel damage (at least 25% skin coverage) after cold-storage. The effects of pre-storage and cold-storage regime were additive. The directly stored fruit showed greater susceptibility than the pre-stored fruit, and for each of these fruit groups, an inverse relationship existed between cold-storage temperature and the incidence of this disorder.

The percentage of fruit per carton showing sap pitting after cold-storage bore no relation to the time of placement of the fruit in cold-storage (Table 1-F). However, an inverse relationship existed between cold-storage temperature and the incidence of this disorder.

Table 1 -E shows the mean percentages of fruit per carton showing noticeable lenticel damage (at least 25% skin coverage) after cold-storage. The effects of pre-storage and cold-storage regime were additive. The directly stored fruit showed greater susceptibility than the pre-stored fruit, and for each of these fruit groups, an inverse relationship existed between cold-storage temperature and the incidence of this disorder.

Only the fruit placed directly in cold-storage and stored at 8/6 and 8/8 were prone to shriveling. After cold-storage at the former regime, an average of 6.3% (± 4.7%) of the fruit per carton were noticeably shriveled (at least 25% skin coverage), and following cold-storage at the latter regime, an average of 3.8% (± 2.6%) of the fruit per carton showed noticeable shriveling.
DISCUSSION AND CONCLUSION

Prusky (1991) inferred that the understanding of the physiological and biochemical basis for fruit storage and pathogen development in ripening fruits was one of the most important aspects that should be explored in order to try to regulate disease development after harvest, and thereby enable extended fruit storage. The results of the present study expressly indicate that the level of disease at any stage after cold-storage is dependent on the degree to which ground skin colouration occurs prior to fruit removal from cold-storage.

Pre-formed anti-fungal compounds, identified as 5-substituted resorcinols, were found in mango skin (Cojocaru et al., 1986). The concentration of these compounds was found to decrease after harvest. The occurrence of these compounds in several mango cultivars was stated to suggest universality in mango (Prusky, 1991). Ethylene treatment, which hastens ripening, was found to hasten the reduction in concentration of these compounds as well as the appearance of disease, whereas storage under sub-atmospheric conditions, which are effective in delaying ripening, was found to delay the reduction in concentration and the appearance of disease (Droby et al., 1986).

A plausible explanation for the differences in disease incidence existing two days after cold-storage might be offered in equating the increases in skin colouration before fruit removal from cold-storage with reductions in the concentration of anti-fungal substances in the skin. Verhoeff (1974) suggested that latent fungal infection might, in addition to the presence of anti-fungal compounds, result from insufficient enzyme production in unripe fruit or inadequate nutrient levels. A positive association between skin colouration and the removal of these limitations may therefore be considered to have also been of significance.

The reason for the persistence with time of the nature of the differences in disease incidence established two days after cold-storage, appeared to relate to the progressive manner in which the number of diseased fruit increased with time. Accordingly, the rate of increase appeared to be largely independent of whether softening or skin colouration was still occurring or not. This suggests that the disappearance of barriers to fungal growth was progressive, and continued to be so even after the fruit had softened and developed fully in colour. Alternatively, the progressive nature of the increase in disease incidence might be ascribed to pathogen spread between the fruit.

Temperatures of less than 12°C are considered to be too low for the storage of mangoes, due to the high likelihood of these temperatures causing chilling injury (Medlicott and Jeger, 1987). The absence of severe symptoms of chilling injury or of a higher incidence of the cold-related skin disorders observed, may relate to stage of maturation at picking, which was advanced.

The inverse relationship between cold-storage temperature and the incidence of lenticel damage, sap pitting or shrivelling, indicates that these skin disorders are in fact adverse effects of cold-storage. In the case of lenticel damage and shrivelling, this is further supported by the observation of the sensitivity to these disorders being reduced following pre-storage in conditions favourable to ripening. The incidence of sap pitting related directly to cold-storage temperature. This might be expected in view of the skin having to be predisposed to this disorder by exposure to sap flow.

Lakshminarayana (1973) found, after storing Alphonso mangoes at 24 to 28°C, that the time required from picking until the initiation of the climacteric decreased with the advancement in fruit maturation. The fact the ripening was initiated during pre-storage may thus relate to the stage of maturation at picking.

It would appear that pre-storage, in enabling ripening to be initiated before cold-storage, gave rise to full mesocarp ripening during cold-storage. Skin colouration during cold-storage was always suppressed, however. The apparent independence between processes associated with colouration of the skin and mesocarp ripening has previously been encountered (Oosthuyse, 1990). The relationship between skin colouration and cold-storage temperature was not direct, 8/8 having been more effective in suppressing skin colouration than 8/6 or 11/11. The enhancement of skin colouration after storage at temperatures of less than 8°C as opposed to at higher temperatures, has been previously observed in Irwin, Zill, Sensation, Kent, and Tommy Atkins (Oosthuyse, 1990). Additional reports of or studies indicating the biochemical basis for an increase in skin colouration following storage of mangoes at reduced temperatures are not available. A positive relationship between post-storage skin colouration and storage temperature is generally recognized.

In considering post-storage fruit quality in terms of marketability in Europe, the beneficial effect of a reduced incidence of cold-related skin disorders resulting from pre-storage at 20°C for 72 hours, was offset by an increased incidence of disease and over ripeness. Taking this point into consideration, as well as the various responses to the treatment combinations adopted, direct placement in cold-storage after packing and adopting the cold-storage regime of four weeks at 8°C, was seen as being the most beneficial method of storage of those investigated.

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LITERATURE CITED


