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Increasing relative maturity alters the base mineral composition and phenolic concentration in avocado (*Persea americana* Mill) fruit

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ABSTRACT

The effect of increasing fruit maturity on fruit base mineral composition, phenolic content and the resultant influence on postharvest fruit quality and ripening physiology of Fuerte avocado, was investigated. Late harvested fruit with increasing maturity had reduced calcium and magnesium concentrations. A reduction in ripening time was associated with a decrease in fruit calcium concentration. The relationship, if any, between fruit potassium concentration and relative maturity was less clear. Total fruit phenolics in creased with increasing fruit maturity, and this was associated with an increase in the incidence of the cold storage browning disorder, mesocarp discolouration. Cold storage had no effect on total fruit phenolic concentration

The importance of certain minerals, particularly calcium, in fruit quality has been recognised for many years (Shear, 1975; Bangerth, 1979). During the last 40 years much attention has been focused on mineral nutrition, particularly leaf analysis and tree yield (Embleton & Jones, 1966; Koen *et al,* 1990). However, almost nothing is known about the effect of increasing relative maturity on avocado fruit mineral and phenolic composition, and in turn the effect of miner al and phenolic composition on fruit quality. However, we do know that increased calcium concentration in avocado fruit in creases the postharvest ripening time (Tingwa & Young, 1974). This has an effect on overall fruit metabolism by reducing respiration and ethylene production during ripening and delaying the onset of the climacteric (Eaks, 1985). Several studies of vacuum calcium infiltration into avocado fruit reported increases in the time it takes to ripen, and a negative to no effect on over all postharvest quality (Wills & Tirmazi, 1982; Davenport, 1985; Eaks, 1985; Wills & Sirivatanapa, 1988).

Calcium is essential in several important plant processes, such as cell wall and membrane functioning (Hepler & Wayne, 1985). This obviously has consequences for fruit quality, particularly fruit softening (Poovaiah *et al,* 1988) and disorders resulting from impaired membrane integrity (Bangerth, 1979). The role of calcium in the maintenance of good avocado fruit quality, particularly after cold storage, is speculative; with emphasis on maintaining separation of membrane bound polyphenol oxidase, browning enzyme and vacuole localised phenolic substrate (Bower & Cut ting, 1988; Witney *et al, 1990a, 1990b).*

The relationship between relative fruit maturity, fruit base mineral composition, phenolic

content, and postharvest quality does not appear to have been investigated. This information is important for avocado exporting countries such as South Africa, Chile, Israel, Australia and New Zealand. These countries are, or soon will be, characterised by exceptionally long postharvest transport and storage times of up to 30 days at temperatures of about 5,5°C.

This extended period often results in poor fruit quality, particularly the physiological browning disorders mesocarp discolouration/grey pulp and vascular browning (Leclerq, 1990) and early softening (Bezuidenhout, 1992). There are both inter and intra-seasonal trends with the worst quality occurring both early and late in the harvest season (Eksteen, 1990).

Increasing relative maturity and cold storage have both been found to affect rate of ripening, rate of water loss during ripening and the incidence of physiological disorders in avocado fruit (Cutting *et al,* 1988; Cutting & Wolstenholme, 1992). These physiological disorders are magnified by the extended harvesting period of any one cultivar (up to six months in cool areas) from different production areas and the overlap of cultivars. The Fuerte cultivar is far more problematic for sea freight export than other cultivars such as Hass.

This paper extends a study on the effects of relative maturity on avocado fruit ripening physiology and postharvest quality. The relationship between storage, fruit water status, water loss, maturity and post harvest quality has been reported (Cutting & Wolstenholme, 1992). This second paper, using the same fruit samples, discusses the effect of increasing relative fruit maturity on calcium, magnesium and potassium concentrations, phenolic content and post harvest quality on non-stored and cold stored Fuerte fruits produced under cool subtropical conditions.

MATERIALS AND METHODS

Fruit used in this study was from a five- year-old (in 1990) commercial Fuerte on Duke 7 orchard, in the cool subtropical summer-rainfall mistbelt region near Pieter-maritzburg in Natal, South Africa. Trees were subjected to normal cultural practices and were not under any obvious cultural stress when the fruits were harvested. The fruits were randomly selected for each harvest date. There were 30 fruit per harvest date, split into three groups of 10 each. All three groups were used in this study and were treated as follows: one group was sectioned and freeze-dried immediately after harvest, the second group was allowed to ripen at 21°C prior to freeze-drying and third group was stored at 5,5°C for 28 days (a simulated sea voyage), followed by ripening at 21 °C prior to freeze-drying.

The time to ripeness for each fruit was recorded. Ripe fruits were sectioned and assessed for the physiological disorders grey pulp/mesocarp discolouration and vascular browning. After freeze-drying all samples were milled and stored at 20°C. Harvesting began on 25 May 1990 (early winter) and continued at two weekly intervals until 26 October 1990 (late spring).

This gave an effective five month harvesting period, reflecting the extremes used by commercial growers in similar mesic climatic areas. As fruit-set peaked in September,

late harvested fruit entered a second growing season, and overlapped with the following season's flowering, fruitset and spring vegetative growth flush.

Mineral analysis

One gram finely milled freeze-dried samples from individual fruit were placed in porcelain crucibles and ashed overnight in a furnace at 450°C. After cooling the ash was wetted with a few drops of distilled water, followed by the addition of 2 *mℓ* conc HCl. The acid was then evaporated off on a hot plate. The ash was dissolved in 25 mℓ 0,6N HCl, with stirring, and filtered through Whatman no 1 paper. Dilutions of 1:10, 1:100 and 1:1 000 were made and calcium, magnesium and potassium determined by a commercial laboratory using atomic absorption spectrometry.

Total phenolic compounds

Total phenols were determined colourimetrically, using the method of Torres *et al* (1987).

RESULTS

Mineral composition

Calcium concentrations (Figure 1a) declined from a high of about 0,018% (180 *mg* kg^{-1} dry mass) four weeks after the first harvest date to a low of about 0,012% (120 mg kg^{-1} dry mass) at the last harvest date (a decrease of 33%). Magnesium concentrations (Figure 1b) declined from a high of 0,084% (840 mg kg^{-1} dry mass) at the first harvest date to a low of between 0,060 and 0,065% (600650 mg kg^{-1} dry mass) over the last three harvest dates. Potassium concentrations (Figure 1c) showed a distinct fluctuating trend with increasing maturity, with lows of about 0,8% (8 000 mg kg^{-1} dry mass) and highs of about 1,2% (12 000 mg kg^{-1} dry mass).

Total phenolic compounds

Total fruit phenolic concentrations in creased from a low of about 180 µg g^{-1} at the beginning of the harvest season (Figure 2), to about 500 µg g^{-1} at the end of the harvest season. Cold storage did not appear to affect the concentration of the total phenolic compounds in the fruit which remained very similar for any given harvest date.

General ripening physiology and postharvest quality

Increasing maturity (on-tree storage) reduced the time taken for the fruit to ripen after harvest (Figure 3). When fruit were not cold stored, the time decreased from about 10 days at the beginning of the sea son to about seven days by the end of the harvest season. Ripening times for cold stored fruit decreased for the first three months from about five days to three days, after which they remained constant at about three days. The regression relationship between flesh calcium concentration and time to ripening is

presented in Figure 4.

Fruit which were not cold stored did not show mesocarp discolouration when ripened, except for the last harvest date. A percentage of all fruit which were cold stored for 28 days showed mesocarp discolouration (Figure 5a). The incidence of the disorder rose rapidly toward the end of the season, showing the marked effect of advanced maturity on mesocarp discolouration in cold stored fruit, even in the cool climate in which these fruit were grown.

Fruit that were either cold stored or not cold stored showed a similar pattern of vascular browning (Figure 5b), with the incidence of this disorder increasing rapidly as the fruits reached an advanced stage of relative maturity.

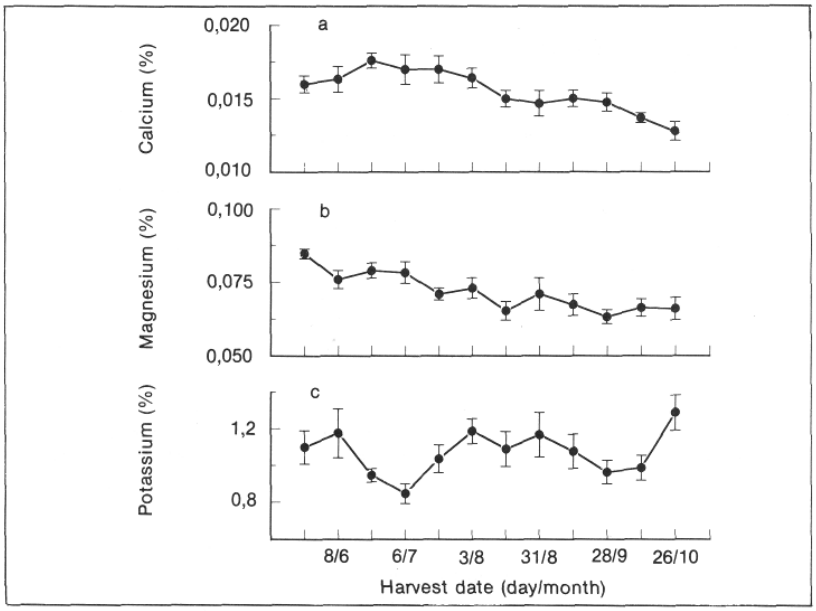

Fig 1 Relationship between increasing fruit maturity and fruit calcium (a), magnesium (b) and potassium (c) concentration in Fuerte avocado. All fruit had satisfied the minimum legal maturity requirement of less than 80% moisture. Results are presented as means with absolute standard errors (n = 30).

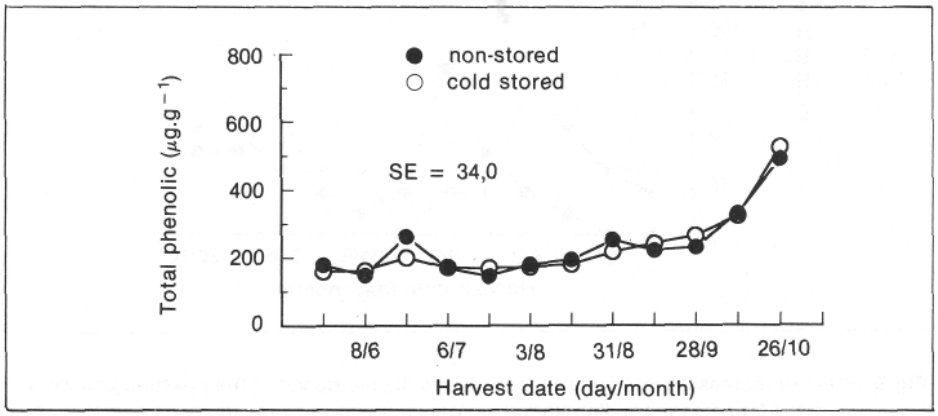

Fig 2 Effect of increasing relative fruit maturity on total phenolic concentration in non-stored and cold stored Fuerte avocado. Results are presented as the means of 10 fruits per treatment per date.

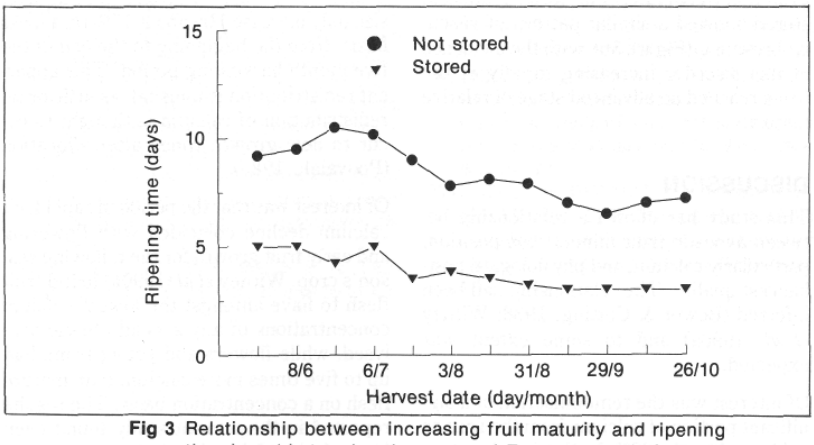

Fig 3 Relationship between increasing fruit maturity and ripening time in cold stored and non-stored Fuerte avocado fruit. All fruit had satisfied the minimum legal maturity requirement of less than 80% moisture.

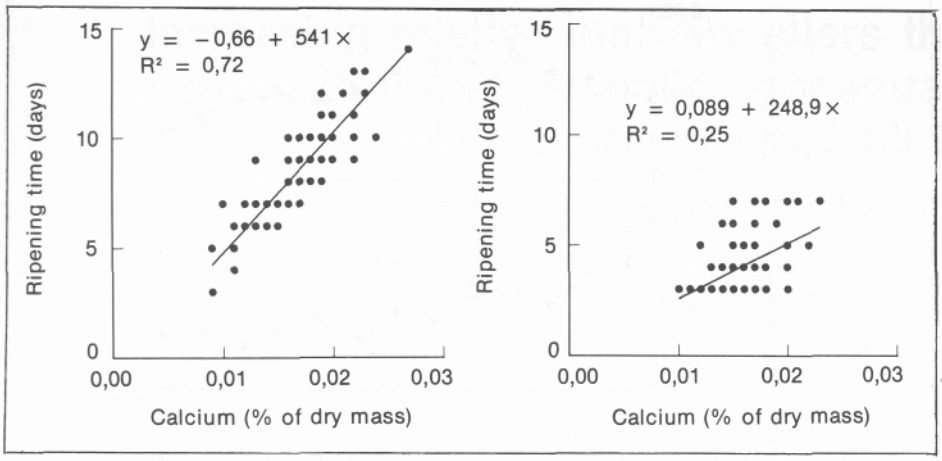

Fig 4 Regression relationship of fruit calcium with ripening time from non-stored and cold stored Fuerte avocado fruit of differing relative maturity (n = 120 per treatment).

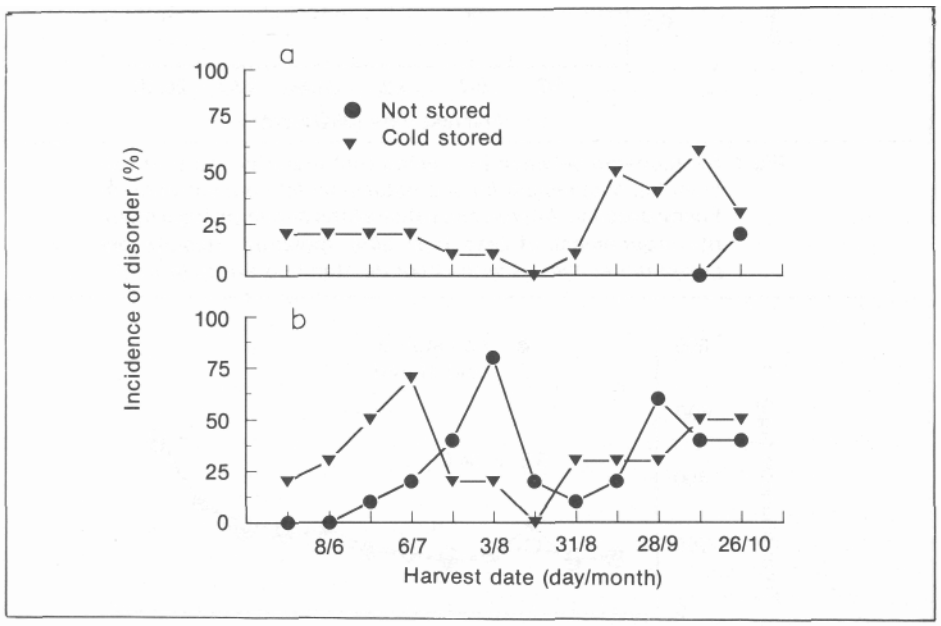

Fig 5 Effect of increasing relative fruit maturity on the incidence of the physiological browning disorders mesocarp discolouration/grey pulp (a) and vascular browning (b) in cold stored and non-stored Fuerte avocados.

DISCUSSION

This study has shown a relationship between avocado fruit mineral composition, particularly calcium, and physiological post harvest quality. The relationship had been inferred (Bower & Cutting, 1988; Witney *et al,* 1990a) and to some extent was expected.

Of interest was the remobilisation of a significant portion of calcium from the fruit as evidenced by the 33% decline in calcium on a concentration basis. This was not due to a dilution effect from the small fruit size in

crease as the season progressed, as fruit size only increased by about 15% on a mass basis, from the beginning to the end of the five month harvesting period. This apparent redistribution is unusual, as little or no redistribution of calcium is thought to occur to new growth zones after allocation (Poovaiah, 1985).

Of interest was that the period of rapid fruit calcium decline coincided with flowering and early fruit growth for the following sea son's crop. Witney *et al* (1990a) found fruit flesh to have amongst the lowest calcium concentrations of any avocado tissue analysed, while flowers and young fruits had up to five times more calcium than mature flesh on a concentration basis. The results reported in the current study found even lower fruit calcium levels (a maximum of 180 vs 700 mg kg^{-1} fruit), which the authors attribute to the increased vegetative vigour of the trees used in this study (due to both the more mesic environment and reduced *Phytophthora cinnamomi* root rot incidence) and lower soil calcium status. Fuerte avocado spring flowering and early fruit growth coincides with a vigorous vegetative spring flush.

The authors believe it unlikely that current root uptake can supply the total calcium requirement, considering the transpiration rate of the new flush versus floral structures (Whily *et al,* 1988); the greater calcium sink strength of the vegetative as compared to young reproductive structures (Cutting & Bower, 1989); and the low level of feeder root activity at this phenological growth stage (Whiley *et al,* 1988).

The authors therefore conclude that mature fruit calcium can be used to supplement the calcium requirements of the flowers and early fruit growth and/or the vigorous spring flush, when late hanging makes this possible.

The reduction in the time taken by later harvested fruit to ripen was accompanied by a decline in fruit calcium concentration. This finding is supported by many experiments where harvested avocado fruit were vacuum infiltrated with calcium and took longer to ripen than untreated fruit (Tingwa & Young, 1974; Wills & Tirmazi, 1982; Wills & Sirivatanapa, 1988).

The current study by the authors found a positive relationship between fruit calcium concentration and ripening time (R^2 = 0,72 for nonstored fruit and R^2 = 0,25 for cold stored fruit). The reasons for the variation about any one point compounded by the use of a discontinuous axis have been discussed (Cutting & Wolstenholme, 1992). However, it can be concluded that water loss (Cutting & Wolstenholme, 1992) and fruit calcium concentration exert a major influence on the rate of fruit ripening in nonstored fruit. However, this relationship is less clear in cold stored fruit where some other addition al factor is obviously involved.

No obvious relationship between fruit mineral composition, cold storage and the physiological disorder vascular browning was evident from this study. The authors therefore conclude that vascular browning is not a cold storage disorder and does not appear to be base nutrient related.

A similar result was observed by Koen *et al* (1990), when attempts were made to re late postharvest physiological disorders with soil nutrient status. The relationship between fruit potassium concentration and relative fruit maturity is less clear. A clear fluctuating trend was evident in this study. Potassium is a relatively mobile mineral in the plant (Terblanche, 1972) and the trend obtained in fruit in this study is probably related to whole tree phenological events

(Whiley *et al,* 1988), such as flower initiation or root flushing. The authors were un able to assign a function to potassium in postharvest quality. However, considering the wellknown relationship of Ca + Mg/K and fruit quality (Koen *et al,* 1990), the authors believe further research is required before conclusions can be made.

This study did confirm that mesocarp discolouration is essentially a cold storage disorder, and that it increases in severity late in the harvest season when fruit calcium concentrations are at their lowest. Associated with this poor flesh quality is a rapid in crease in total fruit phenolics. In an earlier study, where only a single harvest date was used, high levels of total fruit phenolics were observed and it was proposed (on the strength of that evidence) that fruit phenolics would not be a limiting factor in any fruit browning reaction (Cutting *et al,* 1990).

The results of the current study show that it is even more important to avoid fruit stress

and maintain membrane integrity late in the season, as polyphenol oxidase (Kahn, 1975) activity (the browning enzyme) in creases late in the season (Cutting *et al,* 1988), as do total fruit phenolics (the browning substrate). Postharvest temperature and humidity management therefore be come more important later into the season when fruits are more predisposed to physiological disorders. The decreasing fruit water percentage associated with increasing relative maturity (Pearson, 1975), would have a major effect on membrane stability and, the authors believe, explains why avocado fruit tend to develop membrane related physiological disorders such as mesocarp discolouration.

This study confirmed the hypothesis that fruit base mineral concentration, at least for calcium and magnesium, declines as fruit increase in relative maturity. In addition, cold storage disorders such as mesocarp discolouration, and to some extent early softening, are the result of increasing fruit maturity and associated decreasing water content and declining fruit calcium status. While "fine tuning" of commercial storage and transport conditions will give marginal increases in postharvest storage life, a significant advance in controlling fruit ripening (as occurs naturally in treestored fruit) is required before longer storage times can realistically be expected.

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