Avocado maturity: a review of harvest indices and how they relate to postharvest quality.

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October 2006

Report to Avocados Australia and Horticulture Australia Limited

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EXECUTIVE SUMMARY

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Report to Avocados Australia and Horticulture Australia Limited

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The Australian avocado industry is aiming to improve fruit quality so that 90% of fruit meets or exceeds consumer expectations by 2010. Maturity is one factor that could influence the ability to meet this target. This report reviews the physiological changes in the fruit during maturation, the influence of maturity on fruit quality, maturity standards in the main avocado producing countries, and technologies for assessing maturity. This information could then be used by key industry groups to develop maturity-based strategies for improving fruit quality.

Biological changes during maturation
Avocados undergo a number of changes in the flesh, skin and seed during maturation. Most harvest indices are based on the increase in flesh oil content that occurs during maturation and its close association with dry matter. However, these indices are not related to the physiological changes required for the fruit to initiate ripening, and merely reflect the accumulation of a storage product that is more affected by environmental and cultural conditions during growth. Avocados currently lack a harvest index that relates to the physiological state of being competent to ripen, and could explain why sensory quality and ripening behaviour are difficult to predict. Sugars are one component of avocado that show potential for developing more physiologically-based harvest indices, as these sugars are suggested to prevent ripening on the tree, and to regulate the initiation of ripening after harvest. Further research is required to confirm the physiological roles of these sugars in the maturation and ripening process.

Influence of maturity on fruit quality
Maturity has a strong influence on the sensory acceptability, ripening characteristics, and incidence of rots and disorders in avocados. Immature fruit are often described as rubbery, overly soft, green and watery. The sensory acceptability of the fruit improves during the harvest season until the fruit reach an overmature stage of maturity, at which stage acceptability declines from off-flavours and rancidity. Despite the link between harvest date and sensory acceptability, the current maturity indices of dry matter and oil content are only moderately associated with sensory quality. Thus the current maturity standards only estimate the minimum maturity for sensory acceptability, and are not reliable for excluding immature or overmature fruit from the marketplace.

Maturity also influences the ripening characteristics of the fruit, with early season fruit often ripening at slower rates than later harvested fruit, making early season fruit susceptible to rots. Early harvest fruit are also susceptible to developing external chilling injury, shrivel, stringiness, vascular browning and mesocarp discolouration. Late harvest fruit also have quality problems associated with premature softening, vascular browning, mesocarp discolouration, body rots and stem end rots. Many of these maturity related disorders are exacerbated by long-term storage (> ≅ 4 weeks).

Maturity standards around the world

The setting and enforcement of a minimum maturity standard is considered important in many countries to ensure that the reputation of the industry is not tarnished by selling grossly immature fruit to early season markets offering premium prices. Thus, the minimum maturity standard needs to be high enough to exclude a large proportion of immature fruit, but not so high that it precludes growers from selling genuinely palatable fruit. The most widely used harvest index around the world is dry matter, with most countries adopting the Californian minimum dry matter standard of 20.8% for 'Hass'. This standard is also recommended in Australia, although its effectiveness for removing fruit with poor sensory quality from the marketplace is questionable. Some countries have adopted higher minimum dry matter standards of 24 and 25% to improve sensory quality, to reduce the risk of developing rots and disorders during long-term storage, or to account for fruit grown in areas of drought that typically have lower moisture content. Most countries base the maturity assessment on a mean value for a batch of fruit, while New Zealand has both a mean batch value and stipulate that 18/20 fruit exceed a specified lower limit. This approach is one step that the Australian industry could implement to reduce the risk of supplying batches of early season fruit that contain unacceptably high numbers of immature fruit. Florida, USA, is one of the few production areas that does not use dry matter; instead, maturity is managed through picking dates and fruit size, where fruit can only be harvested after a specified release date and only if they meet a certain size threshold. California also uses a specified release date, where fruit are only harvested before this date if the minimum dry matter standard is met.

Technologies for assessing maturity

Several technologies have been developed and implemented to assess avocado maturity. Dry matter is favoured over oil content as it is faster, safer (no chemical solvents), cheaper and more suited to growers/packhouses for measuring maturity. The recently developed Hofshi coring machine has simplified the process for sampling avocado tissue for dry matter assessment. Near infrared (NIR) spectroscopy and nuclear magnetic resonance are two non-destructive technologies that show potential for on-line sorting of fruit in packhouses to produce lines of fruit with a more uniform maturity. NIR technology has also advanced sufficiently to produce portable devices (NIRGUN) which potentially could be used by growers to monitor maturity non-destructively within orchards and orchard blocks to facilitate more targeted picking strategies.

Key recommendations

- Determine the main causes of poor quality in the marketplace. If these problems are related to maturity, then it needs to be established if this is because of non-compliance of current maturity standards or because the current standards are inadequate
- Determine the components of quality that are important to consumers and influence purchasing behaviour
- Review the minimum maturity standard (21%) in the light of the significantly higher standards in other countries, and in particular the suggested move in California from 20.8% to 23%
- In the medium term, develop new harvest indices that determine immaturity and overmaturity more accurately and reliably, so that growers and marketers can more confidently supply acceptable quality fruit to early and late season markets.

Conclusions
This report demonstrates that maturity affects the postharvest quality of avocados. However, it remains to be established if maturity is a key cause of poor quality in Australian markets, or if it is caused by other pre- and postharvest factors. This report also highlights that the current minimum dry matter standard has a number of limitations, especially in prediction of the sensory quality of avocados. Despite these limitations, the dry matter standard is better than no standard, and its utilisation within industry should continually be refined and evaluated until new maturity standards are developed.

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INTRODUCTION

The Australian avocado industry currently comprises c. 1300 growers, producing c. 36,000 tonnes of fruit, with 70% of production being in Queensland (Avocados-Australia 2005). This industry represents c. 2% of world avocado production, and contributes less than 0.2% of the volume of avocados traded in international markets (Avocados-Australia 2005). Thus, the industry has a strong reliance on the domestic market, with less than 500 tonnes exported annually to South-East Asia, the Middle East and New Zealand (Avocados-Australia 2005). 'Hass' is the main cultivar, comprising 75% of production (www.avosource.com), with the other main cultivars being 'Shepard', 'Reed', 'Sharwil', 'Fuerte' and 'Wurtz' (Avocados-Australia 2005). Climatic differences across states and regions at any one time of the year, along with varietal diversity, enable avocados to be produced year-round in Australia, with the main production volume occurring between March and November (www.avocado.org.au). To ensure a successful future, Avocados Australia in conjunction with Horticulture Australia have devised a strategic plan to 2010, with one of the key aspirations being to improve fruit quality so that 90% of fruit meets or exceeds consumers expectations in target markets (Avocados-Australia 2005). While fruit quality is affected by many pre- and postharvest factors, maturity is one area that has been considered for improvement.

Maturity has two definitions, the first being horticultural maturity where the fruit is harvested at a stage of development that will allow the fruit to meet consumer requirements (ripen to an acceptable taste and overall quality), and the second being physiological maturity where the fruit will continue to physiologically develop (ripen for seed dispersal) after harvest (Watada et al. 1984). Avocados are unique in that they do not ripen while attached to the tree, which means the fruit can be "tree-stored" to meet supply chain requirements over an extended period of time. Despite this non-ripening characteristic, the fruit continue to undergo several biological changes which alter the ripening patterns and susceptibility to develop rots and disorders during postharvest handling. This extended period of on-tree maturation is compounded by the propensity for avocados to have a long period of fruit set, which can result in a large mixture of maturity at any one harvest. This report provides a detailed review of avocado maturity, covering four main themes:

1. The key biological changes that occur during on-tree maturation of avocados

2. The effect of maturity on fruit quality, including sensory acceptability and the incidence of defects from rots, disorders, and physical damage. This includes research from around the world, including Australia

3. The main maturity standards in Australia and different parts of the world. Discussion includes how robust the maturity standards are for determining maturity and devising picking strategies, how variable the harvest indices are for fruit from different cultivars, orchards and regions, any advantages or disadvantages of particular maturity standards, and what implications these standards have for markets

4. Technologies for assessing maturity, and any advantages or disadvantages of these technologies. Destructive and non-destructive technologies will be discussed.

The overall aim of this report is to review the importance of maturity on fruit quality and to provide recommendations that Avocados Australia and Horticulture Australia Limited can use to produce new maturity management strategies for improving fruit quality.

AVOCADO MATURATION ON THE TREE

Fruits typically have three broad stages of development, the first being growth, the second maturation, and the third ripening and senescence. Maturation is defined as "the stage of development leading to the attainment of physiological or horticultural maturity" (Watada et al. 1984). Physiological maturity is obtained when the fruit (or other plant organ) will continue to develop after harvest, while horticultural maturity occurs when the fruit is sufficiently developed to produce the desired characteristics for consumers (Watada et al. 1984). It is important to note that although very specific values are placed on horticultural maturity (e.g. >20.8% dry matter etc.), the nature of maturity is relatively "grey" in that decisions on the value chosen are made for a range of reasons. These may be influenced by a range of factors including:

- The market window opportunity and threats from competitors
- Storage requirements and duration
- The need for ethylene ripening treatments
- Historical factors such as specific quality problems encountered in the past
- The requirement to meet standards in target markets.

Fruit maturation is often marked by the cessation of growth process and the physiological attainment of being competent to ripen. The distinction between the different phases of development is unclear in avocados, since this fruit has two characteristics that do not occur in many other fruits. The first is that cell division proceeds throughout the growth curve for avocados (Schroeder 1985), yet in fruits such as apples and kiwifruit, cell division only occurs during the early stages of growth. This means that the increase in fruit size in avocados is attributed to cell division and cell expansion, while in apples and kiwifruit the growth is largely driven by cell expansion. The continuation of cell division through the late stages of growth until the time of harvest makes it difficult to determine if and when the growth phase of development ceases. The second feature of avocados is that the fruit will not ripen until harvested. This makes it difficult to determine when tree-attached fruit are competent to ripen, whereas in other fruits many of the ripening pathways are initiated on the tree and can be monitored using ripening-related harvest indices (i.e. softening, skin colour change, breakdown of starch to sugars). This lack of on-tree ripening has meant that the harvest indices developed for avocados are dominated by processes associated with growth rather than with ripening. Oil content, the basis of the main harvest indices in avocado, is considered by some to be a storage product that reflects conditions during growth rather than fruit development (Bean 1956). Currently there are no harvest indices utilised for avocados that reflect the physiological attainment of being competent to ripen.

Avocado fruit undergo a number of changes during the maturation phase of development (Table 1). For intact fruit there is a trend for reduced ethylene production, respiration, and density during maturation (Stahl 1933; Hatton & Campbell 1959; Zauberman & Schiffmann-Nadel 1972; Akamine & Goo 1973). The flesh undergoes a number of compositional changes during maturation, with increased total oil content and decreased soluble sugar content being the most pronounced changes (Hodgkin 1939; Kikuta & Erickson 1968; Liu et al. 1999). Other significant changes include decreased calcium and magnesium content, and increased total phenolic content (Cutting et al. 1992). These components are linked to the storage potential of the fruit, with calcium important for reducing the incidence of premature softening and disorders, while phenolics provide the chemical precursors for browning reactions (Cutting et al. 1992; Thorp et al. 1997). Attributes used to assess maturity in other fruits, such as firmness and starch content, do not change appreciably during avocado maturation (Hatton & Campbell 1959; Liu et al. 1999).

The skin and seed also undergo significant changes during maturation (Table 2). For the seed, its mass as a proportion of the whole fruit increases, there is an accumulation of starch, sugars and DM, and there is decline in water content and coat thickness (Stahl 1933; Bean 1956; Erickson 1966; Liu et al. 1999). The seed coat can also turn from white to brown, although the timing of this colour change can be variable (Hatton & Campbell 1959; Dool & Wolstenholme 1983). For the skin, there is a decrease in mass as a proportion of the whole fruit, and an increase in wax deposition and lenticel corking during maturation (Hatton & Campbell 1959; Erickson & Porter 1966). Skin colour changes are observed "late season" in New Zealand where the skin takes on a black appearance, the pigments associated with this being the same as those observed during ripening (Cox et al. 2004). Colouration tends to occur on the sun exposed side of the fruit.

The carbohydrate status of avocados has not received as much attention as oil content, which is probably because oil is the dominant component in mature fruit. Oil content and composition (fatty acid profile) does not change during storage or ripening (Eaks 1990), suggesting fatty acid metabolism is not a key metabolite for ripening. However, the area of carbohydrates is starting to receive more attention, and significant changes in carbohydrate composition occur in the flesh and seed during all stages of development (Liu et al. 1999). Sugars are considered important precursors for oil development in the flesh and for starch accumulation in the seed. They are also thought to provide energy for fruit growth during the early stages of development and for oil accumulation in the later stages of development (Liu et al. 1999). Mannoheptulose, one of the main sugars in avocados, is thought to be a ripening inhibitor and its continual supply during growth and maturation may explain why ripening does not occur on the tree (Liu et al. 2002). It is also suggested that these sugars could be used to predict the storage potential of avocados (Bertling & Bower 2005). Given that these sugars seem to be more closely related to ripening competence than oils, research on their value as harvest indices is merited.

Table 1. Changes during maturation for intact avocado fruit and in the flesh component.

Component	Cultivar	Change during maturation	Reference
		Whole fruit	
Ethylene production	Not specified	Decrease	(Akamine & Goo 1973)
Respiration	'Fuerte'	Decrease	(Zauberman & Schiffmann-Nadel 1972; Akamine & Goo 1973)
Density	Several cultivars including 'Hass'	Decrease, but can be variable during the season and across cultivars	(Stahl 1933; Hatton & Campbell 1959; Clark et al. 2006)
		Flesh	
Total oil	Several cultivars including 'Hass' and 'Fuerte'	Increase, but can reach a plateau or decrease late in season	(Hodgkin 1939; Kikuta & Erickson 1968; Lee et al. 1983; Eaks 1990; Hofman et al. 2000)
Saturated fatty acids	'Hass' and 'Fuerte'	Small increase (fresh weight basis)	(Kikuta & Erickson 1968; Eaks 1990)
Monounsaturated fatty acids	'Hass' and 'Fuerte'	Large increase (fresh weight basis)	(Kikuta & Erickson 1968; Eaks 1990)
Polyunsaturated fatty acids	'Hass' and 'Fuerte'	Small increase (fresh weight basis)	(Kikuta & Erickson 1968; Eaks 1990)
Dry matter	Several cultivars including 'Hass' and 'Fuerte'	Increase, can reach a plateau or decrease late in season	(Lee et al. 1983; Hofman et al. 2000)
Colour	Antillean and Guatemalan cultivars	No change	(Hatton & Campbell 1959)
Cell number	'Fuerte'	Increase	(Schroeder 1953)
Mass % of total fruit	Antillean and Guatemalan cultivars	No change	(Stahl 1933)
Firmness	Antillean and Guatemalan cultivars	No change	(Hatton & Campbell 1959)
Cell wall modifying enzymes	'Fuerte'	Decrease, can be variable	(Barmore 1976; Kaiser et al. 1996)
Starch	'Hass'	No change	(Liu et al. 1999)
Sugars	'Hass'	Decrease (dry weight basis), some variation in this trend between individual sugars	(Liu et al. 1999)
Protein	Antillean and Guatemalan cultivars	Increase, can be variable	(Stahl 1933)
Polyphenol oxidase	'Fuerte'	Increase, particularly in late season fruit	(Bower 1988; Cutting et al. 1988)
Phenolics	'Pinkerton' and 'Fuerte'	Increase, particularly in late season fruit	(Cutting et al. 1992; Van Rooyen & Bower 2006)
Calcium and magnesium	'Hass' and 'Fuerte'	Decrease	(Cutting et al. 1992; Thorp et al. 1997)

Table 2. Changes during maturation for the skin and seed components in avocado.

Component	Cultivar	Change during maturation	Reference
		Seed	
Respiration	'Fuerte'	Decrease	(Zauberman & Schiffmann-Nadel 1972)
Mass % of total fruit	Antillean and Guatemalan cultivars	Increase	(Stahl 1933)
Coat colour	Several cultivars including 'Fuerte'	Generally changes from white to brown, but can be variable as some immature fruit have brown seeds while more mature fruits can have white seeds	(Hatton & Campbell 1959; Dool & Wolstenholme 1983)
Dry matter	'Hass'	Increase	(Liu et al. 1999)
Coat thickness	'Fuerte'	Decrease	(Erickson 1966)
Coat moisture	'Fuerte'	Decrease	(Erickson 1966)
Water potential	'Hass' and 'Fuerte'	Decrease	(Kalala et al. 2005)
Starch	'Hass'	Increase	(Bean 1956; Liu et al. 1999)
Sugars	'Hass'	Decrease (dry weight basis), increase (fresh weight basis), some variation in this trend between individual sugars	(Liu et al. 1999)
		Skin	
Mass % of total fruit	Antillean and Guatemalan cultivars	Decrease	(Stahl 1933)
Cuticle wax	'Hass' and 'Fuerte'	Increase	(Erickson & Porter 1966)
Lenticel corking	Antillean and Guatemalan cultivars	Increase, can be variable	(Hatton & Campbell 1959)
Sugars	'Hass'	Decrease (dry weight basis), increase (fresh weight basis), some variation in this trend between individual sugars	(Liu et al. 1999)
Starch	'Hass'	No change	(Liu et al. 1999)

AVOCADO MATURITY AND CONSUMER ACCEPTABILITY

Maturity has a strong influence on many aspects of avocado quality. The following sections review how maturity affects the eating quality of avocados and the incidence of defects such as rots, disorders and physical damage.

MATURITY AND SENSORY PERCEPTION OF EATING QUALITY

Pioneering research in California showed that the palatability of avocados improves during the harvest season and that this improvement is associated with the accumulation of oil during growth and maturation (Hodgkin 1928; Christie 1939; Hodgkin 1939). The following sections highlight the association between sensory quality and factors such as harvest date, oil content and dry matter (DM).

Harvest date

Harvest date is known to affect the sensory acceptability of avocados, especially for early and late season fruit (Table 3). Immature fruit from California and Florida often have an unacceptable texture (watery, too soft, rubbery) and flavour (green, watery, slightly bitter), while fruit harvested later in the season have a more acceptable creamy texture and nutty flavour (Harding 1954; Lee et al. 1983). Acceptability increases with harvest date until the fruit become overmature, at which point the fruit can suffer from rancidity and off-flavours (Hodgkin 1939; Erickson et al. 1970-71). These effects of harvest date on acceptability are supported by sensory studies in Australia, where sensory acceptability (texture, flavour and colour) for several cultivars was shown to increase with harvest date from March to October, with the greatest variability in acceptability occurring in early season fruit (Lewis et al. 1979; Spraggon et al. 1989). This study also showed that there can be significant variation in acceptability for different longitudinal sections within the same fruit, and that future studies need to consider this variation when relating harvest indices to sensory quality. These studies all clearly show that the harvest season needs to be carefully managed to avoid maturity-related sensory problems in the marketplace.

Table 3. Problems associated with early and late season avocado fruit.

Factor	Early season fruit	Late season fruit	Reference
Texture	Rubbery texture, uneven ripening, too soft, stringiness		(Harding 1954; Lee et al. 1983; Pak et al. 2003)
Flavour	Watery, green, slightly bitter	Rancidity, off-flavours	(Hodgkin 1939; Harding 1954; Erickson et al. 1970-71; Lee et al. 1983)
Ripening behaviour	Inter-fruit variability in ripening rates and skin colour resulting in trays with a "checkerboarding" appearance	Premature softening	(Cutting & Wolstenholme 1991, 1992; Pak et al. 2003)
Rots	Stem end rots	Stem end rots and body rots	(Hodgkin 1939; Erickson et al. 1970-71; Thorp et al. 1997; Hofman et al. 2000; Dixon et al. 2003)
Physiological disorders	Vascular browning, mesocarp discolouration, external chilling injury, shrivel	Vascular browning, mesocarp discolouration, seed sprouting	(Hodgkin 1939; Bower 1988; Vorster et al. 1989; Cutting & Wolstenholme 1991, 1992; Hofman et al. 2000; Woolf et al. 2005; Van Rooyen & Bower 2006)

Oil content and dry matter - California

Given the influence of harvest date on the palatability and acceptability of avocados, considerable research has been attempted to identify the appropriate maturity indices to avoid harvesting immature fruit. Oil content, and more latterly DM, are the main harvest indices used commercially to assess the maturity of the fruit. However, despite DM and oil accumulation being closely related to the growth of the fruit, it has been difficult to predict sensory responses routinely according to DM and oil content, especially when comparing cultivars, growing regions and seasons.

The California Avocado Standardization Bill was established in 1925 to make it illegal to sell immature avocados. An oil content of 8% was decided as the state-wide minimum maturity standard, based on original findings that oil content increases during fruit development (Hodgkin 1939). However, no sensory studies were used to establish this threshold (Lee et al. 1983). The decision for this oil threshold was designed more to protect consumers from purchasing extremely immature fruit, such as those sold as a result of windfall, rather than to provide a basis for improved palatability. It was also thought that a minimum maturity standard for each cultivar would be too complicated, and that 8% oil is low enough to accommodate most cultivars (Christie 1939). The relationship between palatability and oil content was explored further, with palatability shown to increase with increased oil content for a range of cultivars (Hodgkin 1939). This relationship was exploited to create the Calavo brand for high quality avocados, using a much higher minimum oil content of 12-14% for 'Fuerte' (Hodgkin 1939). Further sensory studies on Californian fruit confirmed that the minimum oil content for acceptable eating quality varies considerably across cultivars (8.7% for 'Bacon', 9.0% for 'Pinkerton', 10.0% for 'Fuerte', 10.3% for 'Zutano' and 11.2% for 'Hass') and regions ('Hass'; 9.1% to 14.5%) (Lee et al. 1983). Regional differences within California and across the United States were also demonstrated for the relationship between acceptability and minimum oil content (Lee & Coggins 1982a). These results suggest that the original threshold in the California Avocado Standardization Bill was not appropriate for determining minimum maturity according to taste (Hodgkin 1928; Lee et al. 1983).

Because the techniques for measuring oil content of avocado are difficult and time consuming, DM content was developed as a more rapid and low-technology alternative for assessing maturity. Strong correlations (r = 0.96) were found between DM and oil content (Lee et al. 1983), and further studies determined the minimum acceptable DM for a range of cultivars in California (Ranney et al. 1992). Dry matter accumulation was shown to be variable across seasons, but not from different regions of California. One state-wide minimum maturity standard was suggested, and based on results from a sensory panel a minimum DM of 21.6% was recommended for 'Hass' (Ranney et al. 1992). This is contrary to results in Australia, New Zealand and South Africa, where there are strong regional differences in the rate of DM accumulation (McOnie & Wolstenholme 1982; Thorp et al. 1997; Marques et al. 2006), and different minimum standards are required in South Africa for drought-prone regions (McOnie & Wolstenholme 1982; Mans et al. 1995). The minimum of 21.6% DM for 'Hass' corresponds to an oil content of c. 10.8%, which is close to the 11.2% minimum oil content suggested in earlier sensory studies (Lee et al. 1983). The Californian Avocado Standardization Bill was modified based on these studies, with a new minimum DM of 20.8% established for 'Hass'. Later studies on Californian 'Hass' showed that batches of fruit with a mean DM of 20.8% can contain an unacceptable number of fruit with poor sensory appeal, and that a higher batch average of 23% DM may be required to improve the overall perception of a line of fruit (Figure 1) (Arpaia 2003). This study also suggested that there is sufficient sensory evidence to re-evaluate and to increase the minimum standard of 20.8% for Californian 'Hass'.

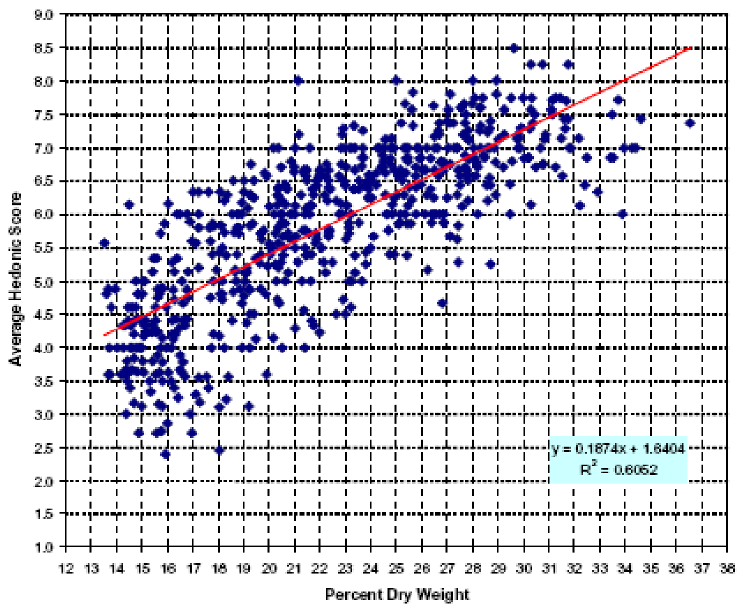

Figure 1. Sensory scores for Californian 'Hass' with different dry matter contents (Figure from Arpaia 2003). Fruit were rated on a hedonic scale of: 1 = dislike extremely, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly and 9 = like extremely.

Oil content and dry matter - Australia

The first maturity standards were introduced in Queensland in 1966 based on sensory studies for several cultivars (Hope 1963; Lewis 1978). A standard of 15% oil was established for 'Fuerte', 'Edranol', 'Zutano' and 'Rincon', and 10% oil established for all other cultivars, despite the sensory recommendation of 15% oil for 'Hass' (Hope 1963; Lewis 1978). In 1979 minimum standards were established Australia-wide, moving away from oil content to a minimum DM of 21% (Morris & O'Brien 1980). This was based on a reasonably strong correlation between oil content and DM (r = 0.83 for 'Hass', 0.87 for 'Fuerte'), and likewise a similarly strong correlation between these two variables and harvest date (r = 0.80-0.89 for 'Hass', 0.83-0.92 for 'Fuerte') (Brown 1984). The sensory acceptability of 'Fuerte' was also strongly correlated with harvest date (r = 0.79) and oil content (r = 0.72-0.75), while a weaker relationship occurred for 'Hass' when sensory acceptability was correlated to harvest date (r = 0.64-0.72) and oil content (r = 0.54-0.58) (Brown 1984). However, this study did not report some data that are important for interpreting the robustness of the conclusions. Firstly, no direct correlations between DM and sensory acceptability were reported; the only relationships reported were with harvest date and oil content. This means that the correlation between acceptability and DM is unknown for this study and could be weaker or stronger than those reported for oil content. Secondly, graphs for these correlations were not presented, making it difficult to determine the range of DM values studied, the variation in sensory responses for each DM content, and if the correlation was biased by one or two extreme outliers in DM content. Thirdly, while the mean acceptability values were reported for each cultivar at 21% DM, there was no indication of the variation around this average both for acceptability and for DM. In other words, how many of the fruit in the sample were rated unacceptable at 21% DM, and what was the true range of DM contents tested by the sensory panel? Despite the sensory limitations of this study, it successfully determined that a minimum DM of 21% was adequate for eliminating immaturity related disorders such as shrivel and flesh blackening (Brown 1984).

Given the unclear relationship between DM and sensory acceptability, further studies were performed on fruit (mainly 'Fuerte') sourced from the Brisbane and Sydney markets, to determine if there were any sensory merits in increasing the minimum standard to 24%. This study concluded that 21% was suitable for excluding the lowest eating quality fruit (Spraggon et al. 1989), but did have some limitations in that DM was assessed after delivery to the markets and not at harvest. Postharvest conditions immediately after harvest can affect the DM content of the fruit, particularly conditions that affect water loss and respiration rate (Hofman & Jobin-Decor 1999; Clark et al. 2006). This is compounded by water loss and respiration rates, both being strongly influenced by harvest date (Zauberman & Schiffmann-Nadel 1972; Cutting & Wolstenholme 1992). Thus, the relationship between DM and eating quality in this study was difficult to interpret relative to DM measures at harvest. A minimum DM of 21% is currently recommended for all cultivars, which equates to an oil content of c. 12% for 'Fuerte' and 8.4% for 'Hass' (Brown 1984). This minimum oil content is considerably lower than the 15% oil content originally suggested for palatability of 'Hass' grown in Australia (Hope 1963).

Understanding consumer preferences for texture and taste

Sensory studies in Australia and California suggest that the relationship between sensory attributes and harvest indices such as oil content and DM are variable and not clear-cut. These indices only provide a gross estimate of when batches of fruit become palatable during maturation. There is evidence that some fruit within a batch of fruit are palatable at DM contents less than 21%, while others are not palatable until well after 21% (Spraggon et al. 1989; Arpaia 2003). These results suggest that DM and oil content accumulation are only associated with, and are not the biological drivers for sensory acceptability in avocados. This relationship is also apparent when comparing cultivars that have evolved from different geographical origins, where cultivars that typically have low oil content (i.e. Antillean cultivars) can easily surpass higher oil content cultivars for sensory acceptability (Harding 1954). This lack of understanding of the biological basis for taste and palatability provides a clear disadvantage to growers wanting to exploit the high prices of early-season markets, when their fruit may be genuinely palatable, yet are regarded as too immature to harvest according to the current industry minimum standard. In addition, there is currently no basis for growers to optimise orchard management practices to produce high taste fruit, nor is there scope to differentiate their product on the basis of taste from other suppliers in the marketplace. Thus, new research is required to elucidate the biological drivers of taste and texture in avocados, so that alternative harvest indices can be developed that predict more accurately the sensory quality of fruit in the marketplace.

Most sensory studies to date have used trained panels to determine avocado acceptability, which is unusual in that acceptability is normally determined by consumer panels. The danger of using a trained panel for an acceptability study is that this panel may detect subtle differences that may not be detected, or may not be considered important by consumers. Despite this limitation, most minimum maturity standards are based on results from trained panels. Trained panels are more useful for defining the texture and flavour characteristics of fruit so that the biological basis for these characteristics can be better understood, while consumer panels are more effective at understanding purchasing behaviour and the aspects of quality that drive purchasing decisions. The other aspect of sensory quality needing improvement is to better understand the characteristic components of flavour, aftertaste, odour and texture, and then match these descriptors to market preferences. This area of sensory science has recently received some attention in New Zealand, where studies have identified some of the key sensory descriptors for avocados (Table 4) and how these descriptors change during maturation and ripening.

Table 4. Sensory descriptors of avocados (White et al. unpublished data).

Attribute	Descriptors
Flavour	Woody pine, floral, banana, citrus, canned pea, savoury, bitter
Odour	Hay (dried grass note), green (grass or green vegetable), nutty
Aftertaste	Chemical, metallic, bitter, umami
Texture	Firmness, oil release, water release, rate of breakdown, particle presence, fibrousness

MATURITY EFFECTS ON DISORDERS, ROTS, RIPENING TIME AND STORAGE POTENTIAL

The sensory acceptability of avocados is not the only aspect of avocado quality that can be influenced by maturity. The ripening rate, incidence of disorders and rots, and long-term storage potential of the fruit can all be affected by maturity at harvest. Each of these quality attributes will be reviewed separately below, as well as any inter-relations between attributes.

Ripening characteristics

The main characteristics of ripening affected by maturity are the rate of softening and incidence of uneven ripening. 'Fuerte' and 'Hass' avocados tend to ripen more rapidly (Eaks 1966; Cutting & Wolstenholme 1991, 1992) and become more responsive to ethylene as the harvest season progresses (Eaks 1966; Adato & Gazit 1974). This effect of harvest date on ripening rate is more pronounced in the first half of the harvest season, with minor or no changes in ripening rate observed in fruit harvested during the later part of the season (Cutting & Wolstenholme 1991, 1992; Thorp et al. 1997; Hofman et al. 2000). The slower ripening rate of fruit harvested early in the season can have detrimental impacts on other aspects of quality, such as increased incidence of postharvest rots (Spraggon et al. 1989; Dixon et al. 2003). Immature fruit from 'Fuerte' are also susceptible to uneven ripening, a disorder that results in fruit with overly soft distal ends and firm tissue elsewhere (Mans et al. 1995), while other cultivars may soften to an unacceptable rubbery texture. For overmature fruit the ripening rate can be rapid, which can be problematic if extended periods of storage and shelf-life are required before sale.

Rots

Stem-end rots and body rots develop during ripening and are often detected only in dark skinned cultivars (i.e. 'Hass') once the fruit is cut for consumption. This feature of rot development makes it difficult for consumers to know at the time of purchase which fruit will be free from rots and ripen to edible quality. Australian consumers are estimated to discard 30-40% of avocado purchases because of unacceptable internal quality, and often view avocados as a "hit and miss" purchase (Mason 2005). Fruit with slow ripening rates are more susceptible to developing rots, which can be problematic for early season fruit, or for fruit in storage at low temperatures where ripening may be initiated and progress at a slow rate (Dixon et al. 2003). Overmaturity also increases the susceptibility of fruit to develop rots during ripening (Hodgkin 1939; Erickson et al. 1970-71). The incidence of body rots in 'Hass' can increase from <1% to 60% from October to December in Australia (Hofman et al. 2000).

Disorders

Avocados are susceptible to several internal and external disorders that influence consumer perception of quality (Figure 2). Immature fruit are susceptible to shrivelling during softening (Hatton et al. 1964; Mans et al. 1995), and fruit harvested early in the season are more susceptible to external chilling injury during coolstorage (Vorster et al. 1989). Early harvest fruit can also be susceptible to mesocarp discolouration, also known as diffuse flesh discolouration or grey pulp, although susceptibility to this disorder is most pronounced in late season fruit for most cultivars (Bower 1988; Cutting & Wolstenholme 1991, 1992; Mans et al. 1995; Woolf et al. 2005; Van Rooyen & Bower 2006). Vascular browning in South African 'Fuerte' and New Zealand 'Hass' occurs in early and late season fruit during coolstorage (Cutting & Wolstenholme 1991, 1992; Woolf et al. 2005). For Australian 'Hass', the incidence of vascular browning and diffuse flesh discoloration can increase from <5% to 20% when harvests are extended from October to December (Hofman et al. 2000). Another undesirable aspect of overmaturity is that these fruit may contain sprouted seeds (Hodgkin 1939). The predisposition to and expression of many of these maturity related disorders are also affected by several pre- and postharvest factors, with many of these disorders exacerbated by long-term (> ≅ 4 weeks) storage (Bower 1988; Woolf et al. 2005).

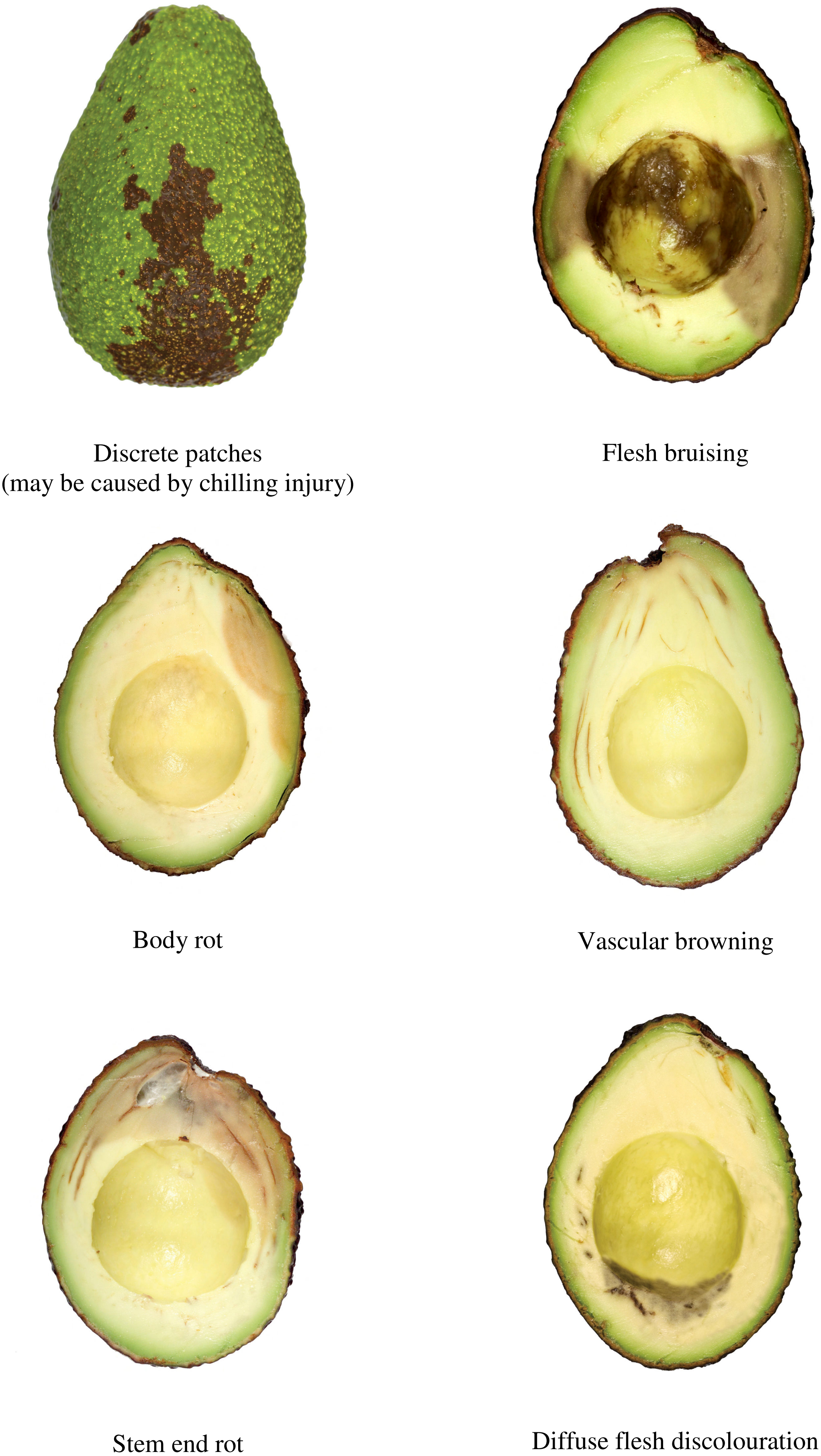

Figure 2. Common avocado disorders (photos from White et al. 2005, 2006).

Physical damage

Vibration and impact damage can result in external and/or internal damage. External vibration/abrasion damage can be evident on the skin of early season 'Hass' fruit that do not darken completely during ripening and on cultivars that remain green during ripening, but is difficult to detect on late season dark-skinned 'Hass' (Arpaia et al. 1987). Vibration/abrasion damage is more extensive when applied to soft fruit, often resulting in internal symptoms of inconsistent texture, flesh adhesion to the skin, and darkening of injured tissue (Arpaia et al. 1987). Bruising from impact damage is more prevalent in early season 'Hass' than in fruit harvested later in the season (Arpaia et al. 1987), and likewise the colour of the bruise is more intense when the damage is applied to softer fruit. While these results suggest that the severity of physical damage is due more to the ripeness/softness than maturity *per se*, the propensity for late season fruit to ripen quicker may render these fruit more prone to damage, especially if the fruit soften appreciably during the early stages of the postharvest handling chain.

Storage potential

Storage potential is an issue for fruit that need to be stored for extended times at low temperatures, such as fruit intended for export, or fruit intended to extend the supply window to exploit late-season markets with premium prices. In South Africa, the main problems encountered for long-term storage of 'Fuerte' are premature softening and disorders such as mesocarp discoloration, pulp spot and vascular browning (Cutting & Wolstenholme 1991, 1992). Storage potential of this cultivar is considered most problematic in early and late season fruit, with 'Fuerte' considered more problematic than 'Hass' (Cutting & Wolstenholme 1991, 1992). For New Zealand 'Hass', maturity has to be carefully managed to reduce the incidence of disorders and rots in export markets (Dixon et al. 2003).

Other pre- and postharvest factors

Maturity is not the only factor that affects the ripening characteristics and eventual outturn quality of avocados in the marketplace, as many of the aspects of quality reviewed in previous sections are also strongly affected by orchard and postharvest handling practices (Bower 1988; Arpaia 1989; Vuthapanich et al. 1995; Hofman et al. 2001). Orchard factors and harvest maturity predispose the fruit to develop rots and disorders, while postharvest factors such as storage time, temperature, and ripening rate influence the level of expression of rots and disorders in batches of fruit predisposed to developing these defects. It is also important to consider that harvesting the fruit at the optimum maturity only captures the quality potential of the fruit, and that stringent postharvest practices are also required to ensure that this potential eventuates as an acceptable quality in the marketplace. The importance of postharvest handling practices for maintaining avocado quality is recognised in the Avocare program, which was implemented to identify the practices that lead to poor quality in the marketplace (Hofman et al. 2001). This project identified several factors that could be improved, such as better control of rots by growers and packers, reducing the time from picking to consumption, and implementation of packaging and procedures to reduce bruising.

COMMERCIAL HARVEST INDICES AND STANDARDS

Previous sections reviewed the effect of maturity on the quality of avocados, and highlighted some of the key biological changes that occur in the fruit during maturation. This section reviews how avocado industries use standards to manage maturity, and highlights the implications of these standards in the marketplace.

MATURITY STANDARDS AROUND THE WORLD

To date, the main maturity standards used in various parts of the world have been oil content, DM, moisture content, picking release dates that do not change from year to year, fruit diameter, and ripening tests. California led the world by introducing oil content as the first maturity standard, which was enforced through the Avocado Standardisation Bill implemented in 1925 (Christie 1939; Hodgkin 1939). The benefits of standardisation were soon recognised (Hodgkin 1928; Christie 1939; Hodgkin 1939) and similar standards, whether it be regulated by government or industry groups, were introduced in various countries. In Australia the first standard was introduced in Queensland in 1966 based on an oil content of 15% for 'Fuerte', 'Edranol', 'Zutano', 'Rincon', and 10% oil for other cultivars (Hope 1963; Lewis 1978).

Dry matter has largely replaced oil content as the most common maturity standard for avocado producers around the world (Table 5). Dry matter is considered more rapid, cheaper, safer (no toxic solvents required), lower-technology, and more suited to growers or packhouses for monitoring maturity than oil content (Lewis 1973; Swarts 1978; Morris & O'Brien 1980; Lee et al. 1983; Ranney et al. 1992). The South African industry uses moisture content rather than DM as a harvest index, although both components are inversely related (total fruit mass = DM + moisture content). In this report all moisture content values are converted to DM equivalents to allow the South African data to be more easily compared with data from elsewhere. When comparing minimum DM standards from different parts of the world, most are based on the 20.8% standard derived from sensory studies in California (Lee et al. 1983; Ranney 1991). This Californian standard applies not only to fruit grown in the state, but also to fruit imported from other countries or fruit shipped from other states which are routinely checked for DM content on arrival. Thus, some countries have adopted the same minimum maturity standard as California to ensure their fruit are eligible for sale in this market. In these cases the standard is based on a marketing requirement, and does not consider that the relationship between DM content and fruit quality may differ across countries. Further sensory evaluation suggests that 20.8% DM is also suitable for Australia, although the relationships between DM and sensory acceptability can be variable (Spraggon et al. 1989). Countries such as South Africa have increased the standard to 25% to account for the reduced water content in drought conditions (McOnie & Wolstenholme 1982; Mans et al. 1995), while other countries such as New Zealand have a high DM standard of 24% to improve quality after long-term storage (Pak et al. 2003).

New Zealand also differs from other countries in its approach to managing fruit to fruit variation within early season fruit. The standard in New Zealand has a mean minimum DM for batches of fruit, but also stipulates that 18 out of the 20 fruit in maturity clearance samples must exceed 20.8% (Pak et al. 2003). Interestingly, the minimum DM of the fruit sample was shown to be the best indicator of the overall quality of batches of fruit (Pak et al. 2003). This approach should reduce the risk of mixing grossly immature fruit with other more acceptable fruit in the marketplace, and is an approach that the Australian industry could also consider. Variability in the marketplace can cause consumer uncertainty over the probable edible quality of a purchase, and given that consumers usually only purchase a small number of fruit at any one time (average of 2 fruit in Australia (Mason 2005)), the impact of an undesirable fruit can be much greater than in other types of fruit where larger numbers are purchased (e.g. bags of apples or oranges).

The avocado industry in Florida is dominated by Antillean cultivars and Antillean-Guatemalan hybrids, which tend to have low-to-moderate oil content (Knight & Campbell 1999). Oil content was not recommended as an effective harvest index in Florida on the basis that oil content can vary considerably between fruit and across orchards and seasons, that there is only a small change in oil content for Antillean cultivars early in the maturation period, and there is too much variation in oil content across cultivars making it difficult to establish one standard as in California (Hatton et al. 1957b; Hatton et al. 1957a; Hatton et al. 1964). Despite all cultivars showing a close relationship between increased palatability and increased oil content during maturation, the observation that a low oil cultivar can be more palatable than a higher oil cultivar also contributed to the exclusion of oil content as a harvest index (Hatton et al. 1964). Palatability in these cultivars was shown to be more closely correlated with picking date and fruit size than oil content, with later picked fruit or larger fruit rated more palatable (Soule & Harding 1955). The current standard is based on release picking dates that do not change from year to year, in tandem with minimum fruit diameters, where fruit can only be picked after a release date and only if they exceed the specified size criteria (Hatton et al. 1964; Barmore 1976; Lewis 1978). This is followed by a series of other dates with lower size thresholds. While this system is complicated, it does have the advantages of coping with varietal and seasonal variation that fixed universal systems such as oil content and DM cannot cope with. This system is also advantageous in that complex maturity testing facilities are not required, and it is thought to better cope with variation in maturity caused by extended periods of fruit set (Lewis 1978). California also has a release date that does not change from year to year, with growers only permitted to harvest before this date if the DM standard is met (Arpaia et al. 2001).

Australia is one of few avocado industries in the world that use a ripening test to determine the minimum maturity of avocados in tandem with dry matter. The ripening test entails placing 5-10 representative fruit at room temperature and assessing the quality of the fruit once ripe (Newett et al. 2001). The fruit are considered mature for harvest if they ripen without shrivelling to a good flavour within 7-12 days. The problem with this ripening test is that it can be a lengthy and variable process for early season fruit not treated with ethylene, and the time required to determine if the fruit are acceptable could delay the commercial harvest so that early market premiums are missed.

All the maturity standards discussed so far in this section have focused on minimum maturity standards to exclude immature fruit. Overmaturity can also be problematic for quality, especially for growers wanting to supply fruit late in the season when prices can be high. However, both DM and oil content are unreliable markers of this stage of development in Australia and other countries, mainly because the accumulation of these components cease or start to decline before the fruit are considered overmature (Erickson et al. 1970-71; Hofman et al. 2000). Thus, research is required to identify new harvest indices that exclude overmature fruit.

Table 5. Minimum maturity standards in the main avocado producing countries.

Country	Minimum maturity standard	Tissue sampling method for DM	Sample size for DM	Drying temperature for DM	% 'Hass' of total avocado production	Reference
Australia	21% DM for all cultivars, and ripening test	100 g of grated flesh from opposing longitudinal quarters	5-10 fruit	100-110 °C	75	(Brown & Trout 1986; Newett et al. 2001)
California, USA	Harvest release date and 20.8% DM for 'Hass'	Hofshi coring machine; 15.88 mm diameter flesh sample from opposing sides of the fruit equator (4-6 g)	2 sets of 5 fruit	60-65 °C	95	(Arpaia et al. 2001)
Chile	23% DM	*	*	*	93	(www.avosource.com)
Florida, USA	Harvest release date and fruit diameter	NA	NA	NA	NA – dominated by cultivars of different geographical origin	(Barmore 1976; Lewis 1978; Knight & Campbell 1999)
Israel	22% DM	*	*	*	32	(www.avosource.com)
Mexico	20.8% DM	*	*	*	95	(www.avosource.com)
New Zealand	24% DM for 'Hass' (18/20 fruit > 20.8%)	20 g of flesh peelings from one longitudinal quarter of fruit	20 fruit	60 °C	98	(Pak et al. 2003)
Peru	21.5% DM	*	*	*	100	(www.avosource.com)
South Africa	25% DM	3 x 10 g grated flesh from longitudinal sections	10 fruit	70-75 °C	36	(Swarts 1978)

DM = dry matter
NA = not applicable
* = Information not available

SOURCES OF VARIATION IN DRY MATTER AND IMPLICATIONS FOR PICKING STRATEGIES

Factors such as cultivar, region, and orchard all affect the rate of DM accumulation in avocados (Requejo-Jackman et al. 2005). For instance, in the Bundaberg region in Australia, the commercial harvest season for 'Hass' occurs later than for 'Shepard'. In this region, over the course of six weeks from April to May 2004, DM content in 'Hass' from one orchard remained constant and in a second orchard increased rapidly from c. 21% to 29% before levelling off near the end of the production season in July (Figure 3a, Requejo-Jackman et al. 2005). Similarly, DM content in 'Shepard' fruit increased at different rates in the three orchards sampled so that DM varied from c. 20% to 27% at the final harvest (Figure 3b, Requejo-Jackman et al. 2005). In New Zealand during the 2003/2004 season, commercial harvest of 'Hass' started in the Far North and Te Puke regions around mid October (Figure 4a and b). Differences in the rate of DM accumulation were observed within and between regions. By the end of March 2004 (the end of the production season), the DM level rose to approximately 34% in the Far North and 38% in the Te Puke orchards sampled.

The DM content of avocados is affected by several pre- and postharvest factors (Table 6). In Queensland, considerable variation in DM can occur for fruit from different orchard locations, and for fruit from different trees within orchards (Marques et al. 2006). Fruit aspect on the tree has also been shown to affect the DM content in New Zealand, where DM is lower in fruit from shaded parts of the tree, although the magnitude of this effect is variable and likely to depend on factors that govern the amount of light interception on the fruit such as tree size, spacing and canopy density (Hofman & Jobin-Decor 1999; Woolf et al. 1999). The presence of defects such as sunburn and ringneck can also increase DM content, as can postharvest conditions that affect the rates of water loss and respiration (Hofman & Jobin-Decor 1999). Environmental conditions such as drought are also known to increase the DM content of South African fruit (Mans et al. 1995). The extended duration and timing of fruit set also influences DM accumulation in 'Pinkerton' in South Africa, with early set fruit being smaller and having higher DM than later set fruit (Sippel et al. 1994). Similarly in Australian 'Hass', small fruit tend to have more DM than larger fruit (Hofman & Jobin-Decor 1999). In these instances it would appear that fruit size may not be a good marker of maturity, and raises the question as to which size fruit should be picked early in the harvest season. This is in contrast to the results obtained in Florida, where larger fruit are picked first on the basis that flavour generally increases with fruit size (Harding 1954; Soule & Harding 1955). Despite smaller Australian fruit having higher DM content than larger fruit, it is not clear if these small fruit are actually physiologically more mature or if they taste different from larger fruit. Further studies are required to clarify if small fruit from the early fruit set period are physiologically more mature than larger later set fruit. If this relationship is confirmed then new picking strategies based on fruit size may be required for early season fruit. However, if this relationship is not confirmed, then it raises the issue of how valid DM is as a marker of immaturity in Australian avocados.

Not only is there fruit-to-fruit variation to consider, but there is also considerable evidence that there are DM gradients within fruit. These gradients occur from the skin to the seed (external to internal gradient), and longitudinally when comparing the stem and distal ends (Schroeder 1985, 1987). These gradients may explain why some parts of the fruit ripen at different rates, and highlight the importance of standardised tissue sampling techniques when determining DM for maturity (see page 26 for tissue sampling techniques).

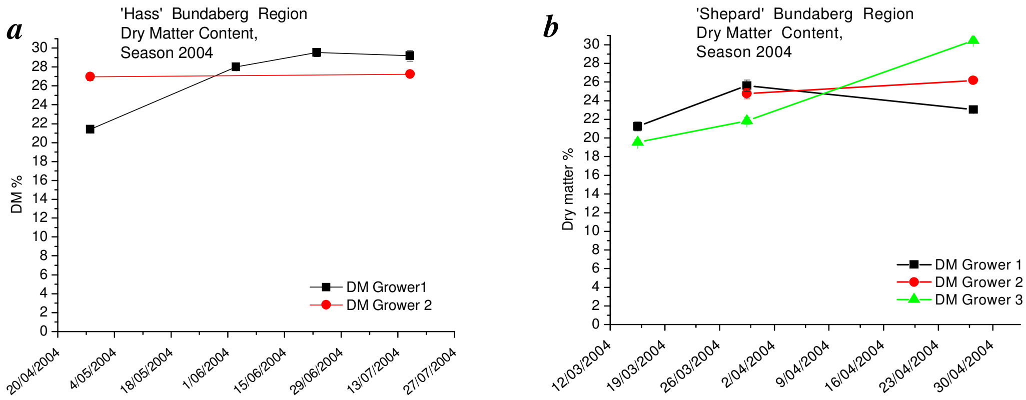

Figure 3. Percentage dry matter (DM) of 'Hass' and 'Shepard' avocados harvested from the Bundaberg region in Australia during 2004 (Requejo-Jackman et al. 2005). Each point is the mean of three replicates of 20 fruit. Vertical bars = Standard errors of mean.

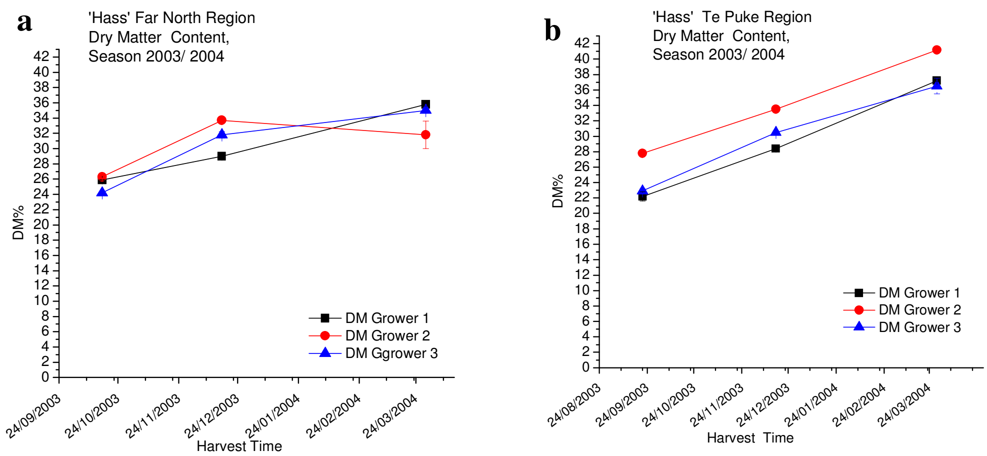

Figure 4. Percentage dry matter (DM) of 'Hass' avocados harvested from the Far North and Te Puke regions in New Zealand during 2003/2004 (Requejo-Jackman et al. 2005). Each point is the mean of three replicates of 20 fruit. Vertical bars = Standard errors of mean.

This section highlights that DM is affected by several factors, and reinforces the need to standardise sampling procedures from orchards so that the sample reflects 1) the maturity of the fruit intended for harvest, and 2) the probable quality of the batch of fruit in the marketplace. Failure to standardise sampling strategies will result in more variable estimates of the "true" DM content, and the delivery of fruit to the marketplace with quality characteristics that do not match the at-harvest specifications. This variation could then undermine the intent and value of the minimum maturity standard, and reduce the confidence of grower and marketers in the ability to deliver premium quality fruit to the marketplace.

Table 6. Variation in avocado dry matter (DM) caused by orchard and sampling factors.

Factor	Range in DM %	Cultivar	Country	Reference
Different orchard locations in south-east Queensland	26.7–29.7	'Hass'	Australia	(Marques et al. 2006)
Means for individual trees within orchards	25-30 28-30 25-35	'Hass'	Australia	(Marques et al. 2006)
Individual fruit within orchards	22-32 25-35 22-37	'Hass'	Australia	(Marques et al. 2006)
Gradients within individual fruit	22.1-30.2 20.7-30.1 18.5-29.5 19.6-28.0 20.8-32.5 20.0-29.5	'Hass'	California	(Schroeder 1985)
Fruit size	20-23 (large) 20-24 (medium) 22-25 (small)	'Hass'	Australia	(Hofman & Jobin-Decor 1999)
Fruit defects	21.3 (no defects) 22.6 (ring neck) 22.9 (sunburn)	'Hass'	Australia	(Hofman & Jobin-Decor 1999)
Aspect to sun	Early to mid harvest: 26.8 (shade) – 28.2 (sun) Late harvest: 40.8 (shade) – 49.2 (sun)	'Hass'	New Zealand	(Woolf et al. 1999)
Fruit set timing	24-27 August set 22-26 September set 20-25 October set 20-25 Control set	'Pinkerton'	South Africa	(Sippel et al. 1994)
Postharvest RH before DM assessment	22 (40% RH) 21.5 (60% RH) 20.5 (80% RH) 20.5 (100% RH)	'Hass'	Australia	(Hofman & Jobin-Decor 1999)

RH = relative humidity

IMPORTANT FEATURES OF HARVEST INDICES AND STANDARDS

Harvest indices are important for giving growers and marketers of avocados the confidence to produce a standard of quality that meets or exceeds consumer expectations, and is sufficiently robust to preclude the selling of unacceptable early or late season fruit into markets offering premium prices. To be commercially successful, harvest indices need to satisfy a number of factors. The first is that harvest indices need to determine the minimum and maximum maturity of fruit reliably across regions, states and seasons. This is essential to avoid the defects and sensory problems associated with immaturity and overmaturity. One argument is that each region could have different maturity standards, as the fruit produced in each region are likely to differ physiologically, which in turn may affect maturation rates and eating quality. However, this approach would not take into account the microclimate effects within regions, and that some orchards may share more similarities with fruit produced in other regions than those produced in the same region. Also, from an industry perspective it may be difficult to implement and regulate different standards in different regions (Ranney 1991).

Another important feature of a harvest index is that it should be based on a physiological change that reflects cessation in growth processes and the initiation of ripening. Given that oil and DM accumulation is a continuous process between the growth and maturation phases of development, it reflects neither the cessation of growth nor the initiation of maturation. It is suggested that oil may not be a reliable marker of physiological maturity because it is a storage product rather than an active metabolite, and that the rate of oil accumulation will reflect growing conditions more than physiological age (Bean 1956). Thus, while DM is better than having no standard, it may be advantageous to develop new maturity indices that better reflect the physiological changes essential for maturation and ripening.

The last feature is that harvest indices need to be easy to implement within an industry infrastructure, they need to be enforceable, and have robust sampling protocols to ensure the measure is a true reflection of the fruit intended for harvest. This is one aspect where DM is suitable, since it is a cheap, rapid and non-toxic method that growers can use to monitor maturity. However, continued efforts are required to ensure sampling strategies are standardised to account for DM variation within lines of fruit. It is also important that procedures are in place to enforce the standards, and that the penalties for non-compliance are sufficient to offset any financial advantages of selling immature or overmature fruit. The Californian minimum maturity standard is enforced through the Avocado Inspection Program administered by the Californian Department of Food and Agriculture (Arpaia et al. 2001). This standard applies to all fruit produced and sold in California, and includes fruit shipped from other states and countries. The Californian inspectors have the authority to reject lines of fruit for sale in California if standards are not met, and either destroy the fruit or send them for processing. In New Zealand, the minimum maturity standard is monitored by industry consultants (AGFIRST) on behalf of the New Zealand Avocado Industry Council, with the standard legally enforced through the New Zealand Horticultural Export Authority (HEA). This standard applies only to export fruit and does not include domestic fruit. In Australia, the minimum maturity standards and measurements protocols are specified in the Avocado Information Kit (Newett et al. 2001). These standards are no longer under government control for domestic and export fruit, with maturity monitoring voluntarily done by growers and some packhouses. There are currently no legally enforceable penalties in Australia for growers that do not meet these standards.

MARKET IMPLICATIONS OF THRESHOLDS USED IN MATURITY STANDARDS

Standards for minimum maturity are regarded as essential in many countries to prevent growers from selling immature fruit early in the season when returns are high (Lewis et al. 1979). The disadvantage of this system is that it reduces the opportunity for growers to sell fruit into premium markets, on the basis that the fruit fails the minimum standard, yet could be genuinely palatable and be free from defects. Thus, the minimum standard has to be delicately balanced to be high enough to reduce the risk of selling immature fruit, while at the same time not being so high that market premiums are missed. The problem of having a minimum maturity standard that is set too low was highlighted in California by inspectors, where some fruit were clearly immature in terms of appearance and ripening characteristics, yet these same fruit were repeatedly measured and met the 8% oil content (Wilson 1939). An issue with setting the minimum maturity standard too high is that it will shorten the early season supply window, which may force growers to exploit the late season market window to achieve premium prices. Because overmaturity is difficult to measure, there is increased risk of fruit being sold that is rancid and inundated with defects (Erickson 1964; Erickson et al. 1970-71). Another factor to consider is that the early and late season fruit may be competing with fruit from other regions, cultivars or countries which may have fewer maturity related problems.

TECHNOLOGIES FOR ASSESSING MATURITY

DRY MATTER

Dry matter is the one of the main harvest indices used to determine avocado maturity. The DM content should reflect the maturity of the fruit intended for harvest, so robust sampling strategies are required to account for fruit-to-fruit variation within orchards, blocks and trees. It also known that DM content changes after harvest, which means that if an at-harvest measure is required, then assessments need to be made as close to harvest as possible and precautions need to be taken to avoid changes from water loss or respiration. The number of fruit sampled is important to ensure a good representation of maturity in the orchard, with larger fruit numbers increasing the chances of obtaining a representative orchard or block DM value (Hofman & Jobin-Decor 1999). A comparison of countries (Table 5) suggests that New Zealand samples the largest number of fruit, 20 fruit per line, while many countries only sample 5-10 fruit. In addition, New Zealand also samples on a "block" basis, meaning that a number of samples may be required from one orchard. It is recommended that the fruit are maintained in plastic bags to reduce water loss between harvest and assessment of DM, and that fruit are harvested early in the day when fully hydrated (Woolf et al. 2003).

Detailed protocols for DM assessment in avocados have been published in most countries (Swarts 1978; Lee & Coggins 1982b; Brown & Trout 1986; Arpaia et al. 2001; Woolf et al. 2003). The basic procedure involves the removal of samples of flesh from each fruit which are then weighed, and dried, allowing calculation of the % DM as dry weight / fresh weight x 100. Despite the simplicity of this procedure, there is considerable variation around the world in how each of these steps is achieved. Flesh sampling strategies include sampling from opposing eights cut longitudinally (Arpaia et al. 2001), opposing quarters cut longitudinally (Brown & Trout 1986), one longitudinal quarter (Pak et al. 2003), or equatorial samples from the Hofshi coring system (Arpaia et al. 2001). The Hofshi coring machine (Figure 5) removes equatorial flesh samples ("cores" or "plugs") of 15.8 mm diameter, and is increasingly being used around the world because it gives statistically similar results to the more traditional opposing eighths method, yet it is faster, safer, less cumbersome, and less prone to sampling-induced variation from DM gradients in the fruit (Arpaia et al. 2001; Woolf et al. 2003). However, New Zealand has not adopted the Hofshi coring system at this point, as it may underestimate DM in early season fruit (Woolf pers. comm.). All skin and seed tissue is removed to ensure the results are for flesh tissue only, and any larger pieces of tissue are cut or grated into smaller slices (not required for Hofshi system). The fruit samples are analysed separately to identify the amount of variation between fruit, or the tissues from each fruit pooled (5, 10, 20 or 100 grams) to give a mean batch value only (Swarts 1978; Brown & Trout 1986; Arpaia et al. 2001; Pak et al. 2003). The samples are then dried using ovens, dehydrators, or microwaves until a constant dry weight is obtained, being careful to use a temperature and duration combination that will not burn the sample (Woolf et al. 2003). A temperature of 60-65°C is most common, while some protocols recommend temperatures above 100°C (Brown & Trout 1986). This overview highlights that there are many variations in the steps used to determine DM. Further research is required to determine how important these variations are for Australian growers, and then on the basis of this research, to decide whether one standardised protocol should be established.

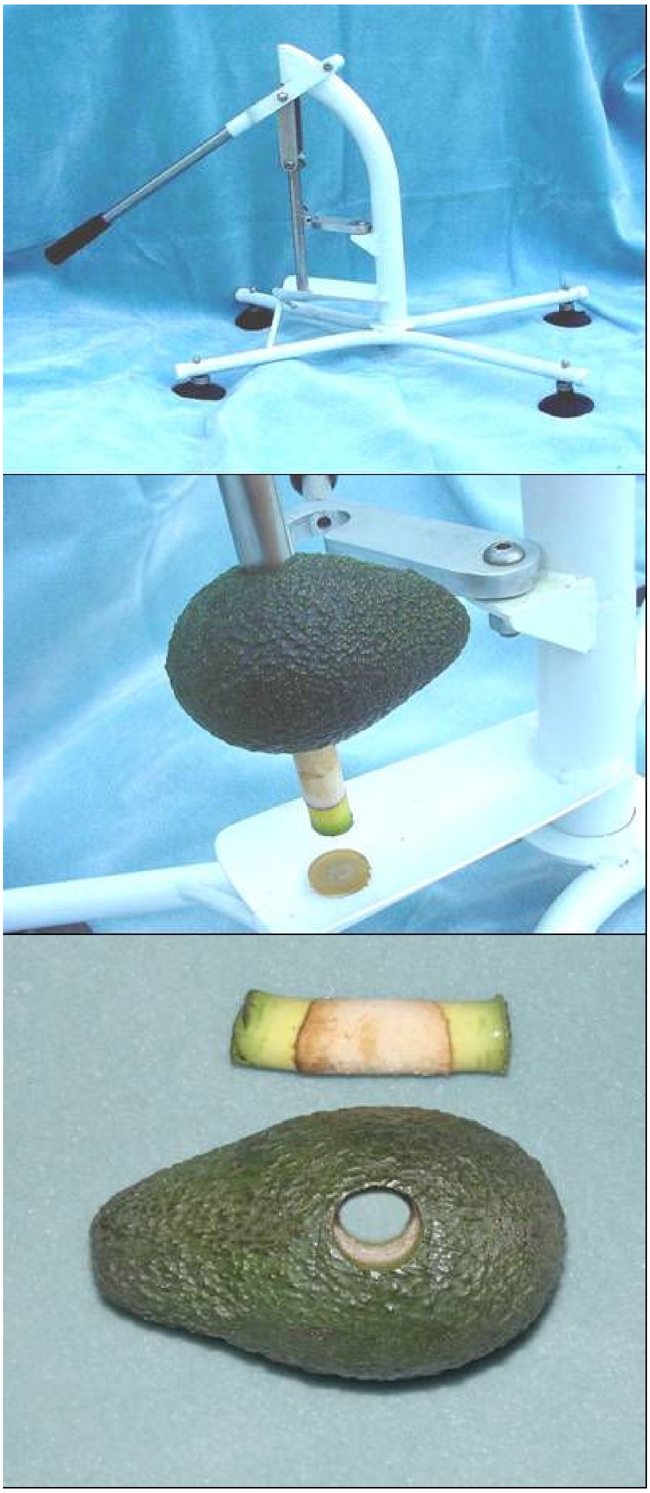

Figure 5. Hofshi avocado coring system (photos from Arpaia et al. 2001).

OIL CONTENT

Determination of lipid content is both time consuming and expensive, and can be determined by a range of techniques (Requejo-Tapia 1999). The refractometric index (RI) method was developed in 1929 using Halowax® oil (monochloronaphtalene) as the solvent, and became the official method for determining total lipid percentage in California (Lesley & Christie 1929). However, because of inconsistency of readings which are easily influenced by temperature, and equipment costs, this method was considered inconvenient for growers. RI methods are also of questionable accuracy especially when testing ripe fruit. In addition, Halowax® is a suspected carcinogen and is no longer available (Lee 1981a, b).

A Soxhlet technique using petroleum ether (a non-polar solvent – hexane) is the standard method for analysing lipid content in foods. This method can take up to 12 hours and automated systems usually only run eight samples at a time. In addition, the tissue has to be previously dried. Thus, this technique is considered too slow for the industry to be used as a routine test.

An adaptation of the Gerber method originally developed for the dairy industry showed accuracy in the determination of total lipids in avocados (Rosenthal et al. 1985). However, it not only uses a combination of flammable and dangerous solvents, but as it is an adaptation, it uses equipment used for assessing fat levels in dairy products, equipment that is not always available to the horticulture industry. Several lipid extraction methods originally developed for animal products have been used for determination of total lipid in avocados with relative success. This is the case for methods requiring chloroform/methanol (Folch et al. 1957; Bligh & Dyer 1959). However, large sample size, large volumes of solvent, a relatively high level of difficulty, and slow techniques are the main inconveniences of these methods.

Lewis et al. (1978) compared four methods of analysing lipid content of avocados including the Soxhlet method (using petroleum ether), homogenisation with petroleum ether, the Bligh and Dyer (1959) technique and the refractometric method using Halowax® oil. On average, results showed that chloroform/methanol and the refractometric method gave 5-8% higher lipid yields than the other two methods. The researchers concluded that chloroform/methanol is sufficiently polar to release some protein–bound lipids, probably comprising phospholipids and glycolipids, and that the similar results with Halowax® oil may have been due to the prolonged ball milling rather than solvent polarity.

More recently an Accelerated Solvent Extraction (ASE® 300 Dionex Corporation) system using high grade hexane has been trialled for determining the oil content of avocados. Oil yields obtained with this system are comparable to the standard Soxhlet technique (Requejo-Jackman 2005, unpublished data). With the ASE system, the dried tissue sample is grounded to a fine powder, placed inside a stainless steel cell and subjected to five extraction cycles. An extraction cycle consists of filling the cell with hexane at high pressure (1500 psi) using high purity nitrogen gas (oxygen free), applying moderate heat (60°C) and holding the cell in these conditions for 20 minutes. The main advantage of this technique is the reduced extraction time in comparison with the Soxhlet technique (<2 hours v. 12 hours respectively).

As described before, the amount of total lipids extracted in avocado could depend on the extraction technique employed and it is for these reasons that oil content as a measure of maturity has been largely replaced by DM. Dry matter is seen as a less complicated and more rapid alternative to oil content, and both variables are closely related, through oil being a major component of DM. Studies have also identified the extent of variation in oil content caused by preharvest factors such as fruit size, positioning on the tree, irrigation practices climate and growing regions (Hatton et al. 1957a; Lahav & Kalmar 1977; Lawes 1980; Lee et al. 1983; Hopkirk 1989).

NON-DESTRUCTIVE ASSESSMENTS

Non-destructive technologies are considered the future of maturity and quality management in many horticultural industries. Non-destructive technologies potentially allow individual fruit to be measured and sorted so that fruit of more uniform maturity and quality are delivered to the marketplace. These technologies also have the potential to be used by growers to monitor and profile the maturation patterns of different orchards, blocks, or trees so that more effective and targeted picking strategies can be devised. Knowledge on the maturation rates of different blocks of fruit could also be used to develop marketing plans based on preliminary knowledge of the probable harvest dates.

The potential of nuclear magnetic resonance (NMR) for avocados was first realised in destructive studies of dehydrated pieces of flesh, where NMR was strongly correlated with oil content (by Soxhlet) and DM for several cultivars (0.93-0.98 for 'Hass', over three seasons) (Barry et al. 1983). This technology was then advocated as being a faster and less toxic method than other solvent-based methods for determining oil content. Further advances in this technology allowed the oil content and DM to be measured on intact fruit moving through a prototype system at 250 mm/s (Chen et al. 1996). Although having advantages such as accuracy, simplicity and fast determination, NMR involves high equipment costs (Barry et al. 1983; Bergh et al. 1989). Nevertheless, this technology shows considerable potential for on-line sorting of fruit in packhouses at some future date.

Near infrared (NIR) spectroscopy has also shown good potential for non-destructively assessing maturity in 'Hass', with the interactance mode being more effective than reflectance, and a general trend for decreasing effectiveness in prediction of DM as the harvest season progresses (Clark et al. 2003). These results suggest that NIR maybe more effective as an early season tool for removing immature fruit, rather than for removing overmature fruit late in the season. However, DM is not a reliable marker of overmaturity and NIR may yet prove to be of value in this respect. Another attractive characteristic of NIR is that the technology is suitable for on-line sorting in packhouses (e.g. Compac Grading Systems, New Zealand), and for portable units (FQA-NIRGUN, Fruit Quality Analyser, FANTEC, Japan; and Kerry Walsh, University of Queensland-Rockhampton), which could allow the rapid uptake of this technology once the basic underlying algorithms are refined for this crop.

Other non-destructive techniques based on skin colour, absorption of short-wave radiation, and heat capacity and transfer, were all unsuccessful at detecting changes in maturity (Bean 1962). Later studies showed that ultrasound has potential for non-destructively assessing maturity, although its applicability for on-line sorting is yet to be demonstrated (Mizrach et al. 1999, 2001). The electrical impedance of the flesh also changes during maturation (Bean 1962); however, this study required probes to be inserted into the fruit and further studies are required to determine if this technique can be performed in a non-destructive sense. Microwave sensors, such as those used within the US Grain Industry for determining moisture content in homogeneous grain samples, have also been explored for use with fruit. However, their high moisture content and the presence of thick skins and seeds, each of which affects the dielectric properties of the sample, present unique problems which currently have not been overcome (Clark, unpublished data). Fruit density decreases during maturation, but this decrease it considered too variable for density to be a reliable harvest index (Hatton & Campbell 1959). Further studies with 'Hass' have also shown that whole fruit density (as can be measured by flotation) is poorly related to DM content (Clark et al. 2006).

CONCLUSIONS

This report has shown that maturity is a key factor for producing the quality of avocados expected by consumers. Maturity influences sensory quality, the ripening characteristics, and the susceptibility of fruit to develop rots and disorders during ripening. Thus, it is important that avocado industries continue to develop and regulate harvest indices, so that immature and overmature fruit are excluded from the marketplace. This report highlights that DM, the most common harvest index for avocados, is influenced by many pre- and postharvest factors and is only moderately associated with sensory acceptability.

Despite these limitations, a minimum standard based on DM is better than no standard, as it can remove grossly immature fruit that are at risk of developing rots and disorders in the marketplace. Industry has the option of increasing the minimum DM standard to reduce the risk of supplying immature fruit. However, this will have the adverse consequences of not allowing growers to exploit premium prices in early season markets when their fruit may be genuinely acceptable. If the industry wants to push the boundaries in early and late season markets, then new, more reliable harvest indices are required for each cultivar. This will require new research into understanding the biological drivers for taste and the factors that predispose the fruit to developing rots and disorders during ripening. This research could also allow growers to differentiate their fruit from other producers on the basis of taste.

RECOMMENDATIONS

Short term recommendations:

- It should be determined if the current quality problems in the marketplace can be attributed to maturity, or if they are caused by other pre- and postharvest factors. If maturity is established as one of the main problems for poor quality, then it needs to be determined if this is because of lack of compliance to current maturity standards, or because the current standards are inadequate.
- The industry needs to establish which aspects of fruit quality drive consumer purchasing behaviour in target markets, and which of these aspects can be enhanced to improve loyalty and purchase frequency.
- Consideration needs to be given to the New Zealand approach of managing fruit variation in early season fruit, where growers need to comply with both a mean standard and a standard that stipulates that 18/20 fruit must exceed a specified lower threshold.
- A review of the minimum maturity standard (21%) should be carried out in the light of the significantly higher standards in other countries, and in particular the suggested move of California from 20.8% to 23%. Decisions on minimum maturity standards need to consider the balance of being high enough to exclude most immature fruit, while not being so high that opportunities for premium prices in early season markets are lost. This decision will require industry to make a market-based decision on the maximum number of immature fruit that can be delivered to target markets that will not detrimentally affect the short and long-term reputation of Australian avocados.

Medium to long term recommendations:

- Identification of medium- and long-term target markets, and the quality standards required in these markets. If the industry wants to develop export markets, or exploit premium prices in domestic markets by extending the supply season, then long-term storage becomes an important factor and more stringent maturity standards will be required. However, if the fruit is to be stored short-term, ripened rapidly, and sold in a manner that ensures high stock turnover, then less stringent standards may be acceptable. This means that any future decisions on maturity standards need to consider carefully the quality requirements of the target market and the expected duration of the postharvest supply chain.
- Development of more reliable harvest indices to exclude immature and overmature fruit from the marketplace. Currently there are no harvest indices for overmaturity. Improved standards are also required for immaturity, as the current index (DM) is only moderately associated with sensory acceptability. This will require new sensory-based research that understands the biological basis of avocado acceptability. This area of research could also allow growers to differentiate their fruit from other producers on the basis of taste, and may allow optimisation of orchard practices to produce high taste fruit consistently. The importance of taste on consumer purchasing behaviour in target markets also needs to be determined.
- Improved understanding of the relationship between DM and other biological changes such as timing of fruit set, fruit size, growth rates and physiological maturity so that picking strategies can be based on multiple harvest indices. This could have implications for which fruit should be harvested early in the season. Most research to date has investigated each biological change individually, which oversimplifies the maturation process, and results in unreliable harvest indices. Furthermore, some of the biological changes that were originally discounted could be revisited using more modern and sensitive techniques, especially those associated with colour.

- Ongoing research in the development and commercialisation of non-destructive technologies for measuring maturity, particularly those that have shown early promise such as nuclear magnetic resonance (NMR) and near infrared spectroscopy (NIR). These lines of investigation need to be extended to evaluate on-line sorters in packhouses, and to evaluate portable devices for monitoring maturity in the orchard.

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