

Avocado Quality Assurance: Who? Where? When? How?

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ABSTRACT

This is a quality management paper in which the onus is placed on the growers and their grower organisations to ensure that a quality product reaches the consumer. The avocado fruit is identified as a living entity which must be treated as such. Aspects such as respiration, ethylene production, transpiration and the effects of time, temperature and controlled atmospheres, are reviewed in relation to quality control.

The impact on quality of orchard factors such as irrigation, nutrition, mulching, fruit maturity, diseases, picking and transport to the packhouse are briefly discussed.

Critical control points where quality should be monitored are then dealt with. These include packhouses, road transport, the docks, sea transport, arrival overseas, pre-packers (ripeners), supermarkets and the consumer.

The role of research is dealt with briefly. Finally, emphasis is placed on the role of grower organisations in ensuring the application of appropriate quality control systems.

INTRODUCTION

QUALITY

•Who pays the penalty?

Whether due to climatic extremes, pre-harvest diseases, bad handling during picking and delivery to the packhouse, bad handling or cooling at the packhouse, poor cooling en route to the market, whether by land, sea or air, poor storage conditions at the market, losses during ripening and pre-packing, losses at retail outlets and incorrect usage by the consumer, **it is in every case the grower who pays the penalty due to losses in quality.**

•Who is responsible?

Responsibility is allocated to a great many people and organisations in the whole process of producing and marketing avocados. These include the grower and his employees, packhouse management, transporter staff, shipping and airways staff, local or overseas wholesalers, pre-packers, ripeners, retailers/supermarkets and even the consumer.

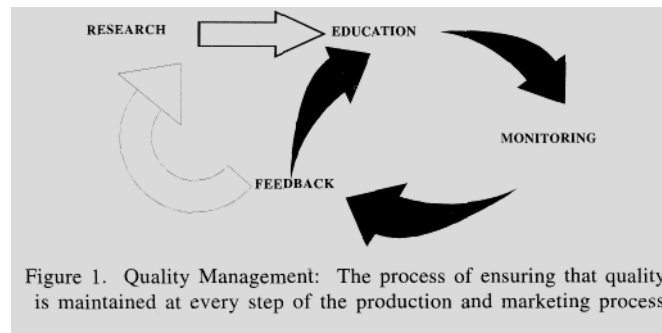
•Who is accountable?

The important thing to remember is that ultimately it is the **grower** who is accountable

for quality losses. He cannot abdicate his accountability by blaming it on others. Alistair Young of 'Team Avocado' in New Zealand is quoted as saying 'We have learned the hard way to keep control of our product until it reaches the retailer' (Smith, 1996).

•The Solution

The process of achieving quality at all stages, can be summarised in figure 1. A total quality management process is required.



• Definitions

The basics of quality include cultivar choice, shape, external colour, freedom from blemishes and freedom from disease. Internally the fruit should be free of physiological disorders, bruising and disease symptoms and should be of reliable and excellent eating quality.

Quality certainly means different things to different people (Combrinck, 1996). To the **grower** it is perceived as the standard laid down by the industry, prescribed by the packer and export agent, and in some cases by marketing boards. In the case of the avocado, this will usually mean fruit of a specific cultivar, of the correct size, properly mature but rock hard, free of disease and free of blemishes. The **wholesaler**, whether local or overseas, will probably have similar requirements and will expect fruit to be hard and to have sufficient shelf-life to allow time for distribution and sale at the best price. The **retailers'** needs vary, depending on whether they are selling firm, triggered, or ready-to-eat fruit. They will want the fruit to be free of blemishes with dependable internal quality and sufficient shelf-life to avoid spoilage losses.

The **consumer** has two moments of quality assessment, firstly at purchase and secondly during consumption. At purchase their eyes must tell them that this is a sound fruit, of the kind he or she is familiar with and preferably with a predictable waiting period before being ready to eat. It must also represent good value for money, with the **consistent assurance** that 'what you buy you can eat'.

At the time of use, the consumer must enjoy the even colour, smooth texture and delicious subtle flavour of a mature and properly ripe avocado. They should at the same time, be aware of the health value of the avocado.

THE LIVE AVOCADO

Education is a major factor required in the quality management process, particularly when it comes to understanding the nature of the avocado fruit. The avocado must be recognised by all those handling it as a **living entity**.

• Respiration

The picked avocado fruit respire. In other words, it utilises oxygen and produces carbon dioxide. The respiration process consists of the metabolism of carbohydrates in the presence of oxygen, leading to the production of water, carbon dioxide and heat energy (Combrinck, 1996). The avocado has a high respiration rate, compared to apples, citrus, grapes.

The avocado is a climacteric fruit, meaning that its physiology is characterised by an increase in respiration with time, reaching a peak, after which the ripening and softening process occurs (Bower and Cutting, 1988). Whereas fruit continue to mature on the tree, they will not soften until picked.

Cellulase is the main enzyme involved in the softening process (Pesis *et al.* 1978). Early in the season cellulase activity is low in freshly picked fruit, however levels are higher in more mature fruit (Fuchs and Zaubermann, 1987). These authors concluded that cellulase activity and softening of fruit at 20°C are not triggered by ethylene production but rather precede it.

Ethylene plays a vital role in the avocado ripening process. It is generally recognised as one of the triggers which induce the enzyme ripening process (Tucker *et al.* 1985; Starrett and Laties, 1993). However, Zauberman *et al.* (1988) have shown that the ripening process of avocado fruit requires the continuous presence of ethylene. Gazit and Blumenfeld (1970) and Köhne (1985) have shown that immediately after harvest, fruit will not readily respond to ethylene induced ripening. They explained this response as being due to an endogenous ripening inhibitor present in fruit while still on the tree, and remaining functional for a limited time after harvest. Ethylene induces an enhancement of tissue permeability, respiration and ripening (Bangerth, 1979). Ethylene production by fruit can be increased due to mechanical injuries, disease incidence and increased temperatures (Kader *et al.*, 1985)

Tingwa and Young (1974) showed that infiltration of avocado fruit with calcium in the form of CaSO₄ or CaCl₂, depressed and delayed the peak of ethylene production if applied prior to the climacteric.

Hofmann *et al.* (1997) showed that the respiration rate of Fuerte fruit can be increased by levels as low as 0.01 µl⁻¹ of ethylene during storage at temperatures of 10-14°C. Reduction of ethylene levels during long-term storage is therefore vitally important. Sufficient air exchanges are essential in container vessels, while under CA conditions, scrubbers will be required.

The commercial use of ethylene for ripening fruit for the consumer is discussed later in this paper.

Transpiration is the process of water loss by the fruit and is an important factor in

determining fruit quality. The evaporation of water will be affected by temperature, relative humidity, air velocity, surface coatings such as waxes or wrappers and packaging. Rind moisture loss has been shown to have a significant effect on fruit quality and the degree of cold injury in Fuerte fruit stored at 5.5°C (Bower and Cutting, 1987; Donkin and Cutting, 1994)

Water loss is certainly one of the important factors leading to overseas fruit deterioration. Increased moisture loss resulting in stress during storage, not only enhances polyphenol oxidase (PPO) activity and visual symptoms of physiological disorders, but also increases the prevalence of pathological disorders (Bower and Cutting, 1987). The relative humidity in the storage atmosphere therefore plays a vital role. Cutting *et al.* (1992) have shown that more mature fruit are less subject to moisture loss than relatively immature fruit.

A basic rule in heat dynamics is that the greater the temperature gradient (T) and the less the volume of air in the system, the higher the moisture loss will be from the fruit. By decreasing the volume of air (i.e. by using a cooling system with a bigger capacity) and restricting T , moisture loss can be limited. The design of the cooling system in a packhouse therefore plays a major role in preventing water loss from fruit and in final fruit quality (Vorster *et al.*, 1990).

• Temperature

Temperature is the most vital factor when planning long term storage of avocados. However, it is not just temperature *per se*, it is the maintenance of the cold chain, right through to the consumer, that is of equal importance. The impact of a break in the cold chain was clearly shown by Swarts (1981) who demonstrated that the later in the cold chain such a break in cooling occurred, the greater the increase in softening.

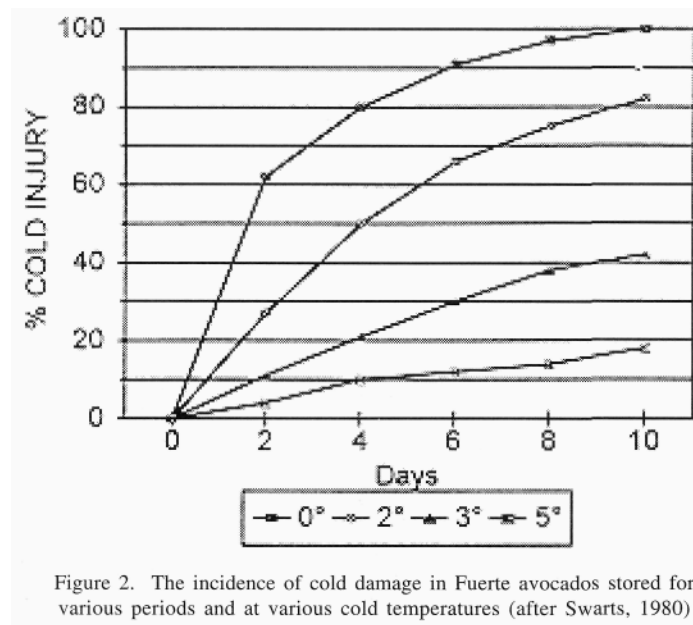
It is therefore clear that a total management strategy in which time and temperature are both controlled is necessary if a good outturn of fruit quality is to be achieved.

After problems were experienced in South African fruit arriving soft in Europe, a detailed analysis of seasonal data was made by Bezuidenhout (1992). He showed that a deviation in holding temperature 1°C higher than recommended, for a 22-day transit time, increased the softness of fruit from a firmometer reading of 25 to 35. Furthermore, a similar increase (1°C) over a total transit period of 28 days, caused an increase in softness from 32 to 46 on the firmometer (table 1).

Table 1. The influence of fruit age and temperature deviations on fruit firmness on arrival in Europe (after Bezuidenhout, 1992)

FRUIT AGE DAYS	TEMPERATURE DEVIATION	FIRMOMETER READING
22	NIL	25 (hard)
22	1°C	35 ('breaking' to soft)
28	NIL	32 (firm to 'breaking')
28	1°C	46 (soft)

The rate of development of external cold injury of Fuerte avocados at various temperatures below 5°C, over time, was clearly demonstrated by Swarts (1980). See figure 2.



The relationship between ethylene production, the climacteric, and ripening of Hass avocados at various temperatures, was shown by Eaks (1983). Bezuidenhout (1983) drew up a climacteric model for Fuerte fruit and was able to establish that excessive cold prior to the climacteric is favourable for chilling injury and pulp-spot to develop. Once the climacteric has passed, temperatures can be lowered. He also found that large Fuerte fruits are more susceptible to physiological disorders than small fruits. Pulpspot susceptibility drops later in the season, whereas grey pulp increases steadily, especially if high temperatures occur in the post-climacteric phase (Bezuidenhout, 1983).

Vorster *et al.* (1987) carried out trials in which the schedules proposed by Toerien (1986) were evaluated on various cultivars. Early season Fuerte fruit were found to be

very sensitive to external cold injury, and the use of 7.5°C as storage temperature for the first week, followed by 5.5°C for two weeks and 3.5°C for one week, was found to reduce the incidence of early cold injury during the first half of the season, when compared with the standard of 5.5°C for four weeks. The step-down temperature also resulted in a significant reduction in pulp-spot symptoms. These authors proposed a step-down temperature programme, not only during the storage period, but also throughout the season (Vorster *et al.*, 1987; Eksteen and Bester, 1987). By 1990 a more sophisticated schedule of shipping temperatures, based on the oil content of fruit had been developed (Vorster, *et al.* 1990) (table 2).

Table 2. Temperature guidelines for export of avocados from South Africa (after Vorster, <i>et al.</i> , 1990)					
% MOISTURE	COLD ROOM °C	ROAD TRANS- PORT °C	PORT STOR- AGE °C	VESSEL 1ST WEEK °C	LAST WEEK °C
78.5 - 80.0	7.5	7.5	7.5	7.5	5.5
77.5 - 78.4	7.5	7.5	7.5	6.5	5.5
76.5 - 77.4	7.0	7.0	7.0	6.0	5.5
75.5 - 76.4	6.5	6.5	6.5	6.0	5.5
74.5 - 75.4	6.5	6.5	6.5	5.5	5.5
73.5 - 74.4	6.0	6.0	6.0	5.5	5.5
72.5 - 73.4	6.0	6.0	6.0	5.5	5.5
71.5 - 72.4	5.5	5.5	5.5	5.5	5.5
69.5 - 71.4	5.5	5.5	5.5	5.5	4.5
69.4 & Less	5.5	5.5	5.5	5.5	3.5

NOTE: The temperatures depicted in table 2 are air delivery temperatures. The above temperature regimes are best suited to Fuerte, Hass and Ryan avocados.

Interestingly, this stepped down schedule of cooling was found to be unnecessary for Fuerte fruit grown in KwaZulu-Natal, where continuous storage at 5.5°C was found to be satisfactory in terms of external quality and internal physiological disorders (Donkin, *et al.* 1995).

Various authors (Zauberman and Jobin-Decor, 1995; Jessup, 1991) have shown the potential of storing Hass fruits at temperatures as low as 2°C. However, at 1°C severe chilling injury was found to occur (Vuthapanich and Hofman, 1997). The pre-conditioning of Hass fruit to induce tolerance to low temperatures (Woolf *et al.* 1995, 1996) is not dealt with in this paper.

Table 3. The influence of low temperatures on the development of cold injury in Fuerté avocados which were stored for various periods (after Swarts, 1979)

STORAGE TEMPERATURE	STORAGE PERIOD DAYS	% COLD INJURY
3,3°C	15	12,5
	28	66,0
	34	82,0
4,4°C	15	3,6
	28	26,0
	34	43,3
5,6°C	15	0,0
	28	10,2
	34	20,2
6,7°C	15	0,0
	28	1,9
	34	1,9
7,6°C	15	0,0
	28	0,0
	34	0,0

•Time

Swarts (1979) has shown the relationship between time and storage temperature and how chilling injury increases with reduced temperatures and longer time (table 3).

Vorster, *et al.* (1988) has also shown that dramatic increases in external cold injury in Fuerte occur if the time of storage is extended from 21 to 28 days. Similarly, grey pulp increases in both Pinkerton and Hass as the storage period is extended. Bower (1988) also found that total post-harvest disorders increased from 14% after 21 days to 30% after 30 days and to 58% after 44 days.

'Brown cold damage' is a disorder that is very seldom present when a container of South African Fuerte avocados arrives in Europe. It usually develops only after the fruit is placed at ambient temperature. It is characterised by lesions or marks that are brown to dark brown in colour (as opposed to black) and which have relatively clearly defined edges and which are very slightly sunken. Initial symptoms are faint and then darken with time. The affected area can be anywhere on the fruit surface and usually only a few fruits in a carton are affected.

'Brown cold damage' definitely appears to be correlated with age of fruit (after picking) and this, coupled with low temperature storage for long periods, appears to aggravate the problem. For example, fruit placed at ambient temperature on arrival in Europe (22 days) showed no symptoms. However, after a further 10 days of cold storage, the symptoms clearly developed after holding the fruit for two days at ambient temperature. Once again, this malady appears to be time x temperature related. Desiccation may, however, also play a role (Milne, 1994).

WHAT CAN BE DONE ABOUT QUALITY?

IN THE ORCHARD

To produce a fruit with adequate storage capacity it is essential to manage all the factors that influence the **inherent** physiological characteristics of the fruit. This is described as the pheno-physiological approach. Some seasonal factors such as low, or very high rainfall, hail, excessive winds or extremely low temperatures cannot be controlled by the grower and furthermore the area of production can have a significant impact on shelf-life and post-harvest diseases (Vuthapanich *et al*, 1995). However there are many aspects that do require grower management inputs.

Correct irrigation scheduling, with the use of tensiometers or other monitoring systems is essential in order to achieve fruit of optimum size, free of physiological disorders. In a trial carried out by van Eyk (1994) in South Africa, irrigation of Hass to field capacity (-15cb) gave superior yields of larger fruit than irrigation according to phenological demand. Similarly, in trials carried out on seven-year-old Hass trees Vuthapanich *et al*. (1997) showed that well-watered (20kPa) trees in Queensland had twice the yield of the least watered trees (70kPa) mainly due to more consistent yields and greater fruit numbers. Post-harvest characteristics of these fruits were not found to differ between irrigation treatments. However, Bower (1988) found that water stress during the first 3-4 months after fruit set in Fuerte affects the activity of abscisic acid and of the browning enzyme, polyphenol oxidase. These in turn adversely affected fruit quality during storage (Bower and Cutting, 1987). Akkaravessapong *et al*. (1997) investigated the effect of water deficit on ripening time of avocados. The fruit harvested at night between 20h00 and 05h00 had a significantly higher water potential than those harvested during the day. The fruit harvested during the day (07h00 to 15h00) were found to ripen a day earlier than those harvested at night.

• Nutrition

Nutrition plays an important role in determining fruit quality, particularly with regard to storage ability. Nutrition research of avocados was first explored in detail by Embleton and Jones (1964) and was reviewed by Bower and Cutting (1988). Whiley (1994) has recently demonstrated that the application of nitrogen before flowering, together with foliar sprays of PBZ applied at mid-anthesis, led to significant increases in Hass fruit size, total yield and shelf-life.

It is beyond the scope of this paper to review the literature on nutrition, but it is recommended that growers remain abreast of recent trends and make use of consultants or extension staff where possible.

• Mulching

Mulching was investigated by Moore-Gordon and Wolstenholme (1996) as a possible method of increasing Hass yield and fruit size through improved root activity and reduced tree stress in a field trial in KwaZulu Natal. Feeder root growth was greatly

increased throughout two seasons by the application of a coarse composted pine bark mulch beneath the tree canopy. Over two seasons, the mulch treatment resulted in a significant 11.8% increase in mean fruit mass, in spite of 16.7% more fruits per tree. The combined effect was a 30.4% greater yield. The probable explanation for this increase is that mulching ameliorates overall plant stress.

• Maturity

Maturity of the fruit prior to harvest plays a major role in fruit quality and this relates mainly to the lipid or oil-content of the fruit. Percentage dry matter in the fruit is directly related to oil content and the total oil and moisture contents are reciprocal and generally sum to a constant for each cultivar (Swarts, 1978).

It is important for the grower to monitor trends prior to the start of picking, to ensure that each cultivar has reached the required standard. Maturity will vary within a single tree, due to multiple fruit-set periods, so selective picking is recommended.

During the extremely high rainfall which occurred in 1996 in South Africa, following two years of drought, the higher soil-moisture levels were found to accelerate the production of oil in Hass fruit (Kruger and Claasens, 1997).

• Diseases

Diseases such as anthracnose, *Pseudocercospora* (black spot), sooty mould, stem-end rots and sooty-blotch, should be kept under continuous control in the orchard. Sprays of copper-oxychloride are generally used for this purpose.

• Picking

Picking is a process which can greatly affect post-harvest quality, whether mechanical pickers or pole-pickers are used. It is generally accepted that Fuerte pedicels should be manually clipped, whereas it has been found that Hass can be snap-picked without detrimental effects on fruit quality (Köhne and Kremer-Köhne, 1995).

It is essential to avoid mechanical injury in the picking and handling process. A survey has shown that 49% of the decay occurring in apples stored for long periods, could be ascribed to infections arising from mechanical injuries (Combrink, 1996).

Temperature already plays an important role during the picking process and in the potential for creating physiological disorders. Measurements made on cherries, picked into lug boxes in the United States, showed that if fruit was stored in the sun, pulp temperatures at the top of a lug could reach 38°C (with an air temperature of 27°C) while fruit at the bottom of the lug were at 16°C. However, if fruit were stored in the shade, the maximum temperature reached was 24°C (Kader *et al.*, 1985). Fruit should reach the packhouse within two hours of picking.

Although Darvas (1982) reported an increase in stem-end rot induced by *Dothiorella* and *Colletotrichum* complex when fruit were harvested wet, this was not confirmed in

later studies by Duvenhage (1993). However, the latter author found that wet picked Fuerte fruit had a significantly higher incidence of black cold damage during early picking, which may be ascribed to the low storage temperature of 5.5°C. Lenticel damage of wet picked Fuerte fruit was also significantly higher during early picking when compared to dry picked fruit. In general the incidence of lenticel damage was high for all fruit early in the season. Although pulp spot incidence in the trials was significantly higher for wet picked Fuerte fruit than for dry fruit, it occurred at an extremely low level and could not be considered a commercial problem. No significant difference occurred in the total percentage of clean fruit, when fruit was picked either wet or dry.

Although wet picked Hass fruit had a significantly higher incidence of lenticel damage during early picking, this may not pose a problem due to the darkening of Hass fruit on ripening. Incidence of vascular browning in Hass fruit picked wet during late picking dates increased significantly when compared to dry picked fruit. For this reason, wet picking of Hass late in the season, is not recommended (Duvenhage, 1993).

Late picked fruit tend to ripen much faster, particularly when grown in warmer areas (Vuthapanich *et al*, 1995).

Whether plastic lug-boxes or large wooden crates are used for picking, hygiene is important and the picking containers should be regularly washed, preferably using a fungicidal sterilant such as sodium or calcium-hypochlorite, copper sulphate or quaternary ammonium compounds.

•Transport to the packhouse

Transport to the packhouse should be by means which minimise fruit vibration. Zauberman *et al* (1969) noted that the main cause of fruit injury during transport was contact with the sides or the bottom of the bins. Therefore, the percentage of injured fruits in bulk bins (13.6%) was less than in lug boxes (33.4%) as relatively fewer fruits were in contact with the sides and bottom of the bulk bins. Injury incidence was reduced by 50% when bins were lined with canvas.

AT THE PACKHOUSE

•Sampling

The first step to be taken at the packhouse is to collect a representative sample from each grower's fruit, preferably on an individual orchard basis. This sample should be carefully evaluated for damage, including wind damage, hail damage, sunburn, the presence of diseases, insects or insect damage and mechanical damage incurred during the picking or transport process. This analysis should be reported immediately to the grower and/or picking team, so that corrective action can be taken where necessary. The presence of pathological problems on fruit on arrival at the packhouse, is usually a fair indication that orchard practices are not being well managed.

•Packhouse hygiene

Whether the packhouse is your own or not, ensure that **packhouse hygiene** is rigorously applied. This includes personal hygiene of staff as well as regular sterilising of cold rooms, packing-equipment, etc. Any fruit falling on the floor or rejected for disease should be disposed of far from packing facilities and orchards.

At Westfalia Estate, representative samples of export fruit are held back under simulated sea-shipment conditions, representing each vessel's fruit. In this way differences between **inherent** problems in the fruit and actual commercial storage, can be evaluated. Corrective action can then be taken.

•Temperature

Monitoring of temperatures in the packhouse is of vital importance. Packers and transporters should not rely solely on temperature dials and electronic devices. Conventional mercury thermometers should be used in an ice/melted-ice mixture to calibrate 0°C. Such a thermometer can then be used to evaluate measuring equipment. It is not uncommon to find equipment that reads up to 2°C off the actual temperature. Such a deviation is not acceptable in avocado storage. Note that hand-held electronic probes may give different readings when the instruments themselves are in a warm or a cold environment.

The Perishable Products Export Control Board (PPECB) in South Africa, applies a grading system to the cooling facilities in packhouses. If the minimum standards are not met, the packhouse may not pack for export. On arrival at the packhouse, if the fruit is not packed immediately, it should be pre-cooled to approximately 16°C in order to remove field heat. Lower temperatures may result in condensation during packing.

•Waxing

Waxing is commonly used for export fruit in order to improve appearance and also to increase shelf-life. Kremer-Köhne and Duvenhage (1997) have demonstrated that 'Stafresh', a natural wax emulsion containing shellac and carnauba wax, gave results equivalent to or better than polyethylene wax ("Tag") in terms of physiological disorders, external appearance and shelf-life. Boonyakiet (1997) has also had success in storing avocados under ambient conditions using edible coatings.

•Grading

Grading is carried out according to local or international standards. The Organisation for Economic Co-operation and Development (OECD) produced a booklet (Anon, 1995) giving standards according to cultivar, size, shape, colour and blemishes, including chilling injury incurred during transport.

•Packaging

Packaging used will vary according to market requirements. However, adequate ventilation is the basis of being able to hold all the fruit at the correct storage temperature. Ventilation holes should register, i.e. be continuous throughout a pallet stack, and should comprise approximately 8 to 9% of the vertical surface area (Boelema, 1987). Where link-sheets are used to stabilise pallet loads, these must also register with the ventilation holes in the cartons. Boelema (1987) also concludes that a space of 5mm between the fruit and the lid of the carton is desirable. However, the trend today is towards open-top cartons.

Carton markings have now become international practice, where cultivar, class, exporter, country of origin and average fruit mass must be recorded on the carton. Most exporting countries now also use grower codes (in order to monitor potential problems arising from specific producers), packer codes (in order to monitor productivity and accuracy) and date codes. Packing dates or date codes are essential in monitoring the time x temperature chain involved in export of fruit. When sea transport is used, the date of packing should be used for setting cut-off dates after which fruit cannot successfully be exported. Date codes are also of vital importance in monitoring the movement of fruit through the marketing chain (see Overseas Technical Officer).

•Fruit Storage Temperature

After packing, fruit temperatures should be reduced to the final storage temperature as soon as possible, especially if long term storage is required. This is often achieved by placing the cartons in a standard cold room. The refrigeration capacity required in a cold room for cooling of fruit is influenced by the temperature of the fruit entering storage, the throughput of fruit, the ambient temperature and the desired rate of cooling (Hardy *et al*, 1995).

Rapid and uniform cooling can be achieved with forced-air or pressure cooling. An air pressure difference is produced between opposite faces of the pallets, which forces air through the packaging and carries heat away. Watkins and Ledger (1990) report that avocados can be forced-air cooled to storage or transport temperatures in 8 to -12 hours with air flows of 1.0 and 0.5 litres sec⁻¹kg⁻¹, respectively. Faster cooling times are not practical as the pressure drop across the pallet required for higher air flows is very high, and when low temperatures are used early in the season, chilling injury can occur. It should be remembered that the air velocity needed for cooling is greater than that needed for storage, therefore fruit in the cooling room will tend to lose water faster than under storage (Anon, 1997).

• Vapour pressure

The rate of moisture loss from avocados is primarily controlled by the difference in vapour pressure between the air in the intercellular spaces of the fruit and the air surrounding it. Vapour pressure increases as the air moisture content and air temperature increase. The air in the fruit is nearly saturated or, in other words, is close to 100 percent relative humidity. Therefore, the humidity ratio of this air is determined

solely by the temperature of the fruit. From a psychrometric chart it can be shown that low temperatures result in low humidity ratios and high temperatures cause high humidity ratios (Kader *et al.*, 1985).

The difference in humidity ratio between the air in the fruit and the storage air is significantly more when the fruit is not pre-cooled than when it is cooled and put in unsaturated storage air.

Desiccation of fruit in refrigerated storage can be reduced by decreasing the difference in humidity ratio between the air in the fruit and the air surrounding it. Both temperature of the fruit and humidity ratio in the surrounding air must therefore be controlled (Kader *et al.*, 1985).

Fruit respiration patterns were monitored in response to rates of water loss in Hass avocados by Akkaravessapong *et al.*, (1995) who demonstrated that the lower the relative humidity the greater the percentage weight loss and the faster the fruit ripened.

All fruit destined for export are inspected at packhouses in South Africa, using PPECB inspectors. It is their duty to reject consignments of fruit that do not meet the industry-established standards of quality or that have not reached the correct temperature for transport. Fruit destined for export are currently required to have a pulp temperature not exceeding 13°C at the time of packhouse inspection.

Temperature recorders are seen as an essential part of the process of monitoring the cold chain. In South Africa, 'Ryan' recorder instruments are positioned in one pallet out of every ten during palletisation. It is necessary to enter the name of the packer, the vessel for which the consignment is destined and the pallet number on the chart at the outset. The position of the recorder must also be clearly marked in the pallet, for ease of recovery. The Ryan recorder will reflect the air temperature surrounding the fruit at a particular point, and has been found to provide valuable information in cases where the cold chain has been broken. This applies whether the consignment has been sent by sea or air. "Squirrel data loggers" may also be used, the advantage being that they electronically record fruit pulp temperatures at various points in a consignment. Miniaturised data loggers are now also available for this purpose.

Rapid feedback to the Grower/Packer/Exporter of temperature data is essential so that adjustments can be made where necessary.

DURING ROAD TRANSPORT TO THE PORT OR MARKET

The following advice is given to ensure adequate cooling, especially over long distances using refrigerated motor transport (RMT) (Eksteen and Robinson, 1996):

Temperature control thermostats must be operating correctly and recording instruments must be functioning accurately. The RMT must be set at the correct temperature and be pre-cooled to that temperature for three hours prior to loading the fruit. The temperature-control thermostat should be set to measure delivery air temperature. In the case of top-down cooling, sufficient space should be allowed above the load to allow for adequate air circulation. All fruit should be pre-cooled to the required carrying temperature prior to loading and at least one pulp temperature per pallet must be

recorded during loading. This data should be retained by the transporter for delivery to the receiving depot at the port (Eksteen and Robinson, 1996).

Only RMT's with well-insulated and well-sealed compartments should be used. Road temperatures can reach more than 80°C and this radiated heat can cause heat build-up in palletised fruit. It is also essential that pallets are aligned in such a way as to allow adequate air-flow through the load.

The Grower should know how his fruit is being handled and has the right to request feedback of temperature data.

AT THE DOCKS

Road transport loads must be monitored for temperature deviations at the docks or container-depot. This is generally done by using probe thermometers. However, thermocouples placed in fruit in the centre of pallets at the time of palletisation can be used specifically to monitor pulp temperature at possible 'hot-spots' deep within the pallet. Depending on the process involved at the specific harbour, fruit can generally be held.

In addition to accurate monitoring of arrival temperatures at the docks, it is essential to record the age of fruit (i.e. from the date of packing, based on the date-code). The South African industry has a cut-off date under effective cooling in a holding store or container terminal prior to loading aboard a vessel. It should be noted however, that breaks in the cold chain can and do occur during this process. The 'Ryan' or other recorders should facilitate pinpointing of problems of this nature, which can be followed up with the relevant authority. Fruit should not be loaded aboard the vessel unless it is within 0.5°C of the required carrying temperature, of 12 days after packing. Older fruit will not be allowed for export and must be disposed of on the local market.

It is important for growers to be aware of the time taken for the exporter or agent to get their fruit to the port, as this can significantly affect outturn quality.

DURING SEA TRANSPORT

Eksteen (1995) has summarised South African recommendations for controlling time and temperature during sea export to Europe. In porthole container vessels it is essential to maintain a continuous record of delivery air temperatures (DAT) and return air temperatures (RAT). DAT's are adjusted according to the differential between DAT's and RAT's. If the RAT is more than 1.5°C higher than the DAT, it is an indication that the cooling process is not coping with the heat generated by the fruit. A downward adjustment of DAT is therefore made. This decision, based on reliable facts, is taken by the Industry Temperature Committee, which responds rapidly to data radioed to shore by the ship's engineer on a regular basis. In the case of integral and CA containers, temperature data is not normally available on a day-to-day basis and correct loading temperatures therefore become even more critical.

In studying shipping conditions in terms of age and temperature of fruit in relation to outturn fruit quality, Eksteen *et al.* (1995) demonstrated the following: Fruit firmness

decreased with an increase in fruit age, particularly in the case of Fuerte and Edranol avocados, which should not be stored for longer than 25 days. 'Black cold' and 'grey pulp' also increased significantly with time. Although 'black cold' has little or no effect on internal quality, it is strongly rejected by the trade. Lenticel damage also increased with fruit age but was found to correlate with specific growing areas. A deviation in temperature (higher) during loading of sea containers was found to be strongly correlated with fruit softness on arrival. Delays in re-cooling during loading also had a significant effect on fruit firmness on arrival.

Two factors are of great importance here:

- Communication and response must be extremely rapid if corrective action is to be taken.
- Any deviations from the norm must be linked to specific quality outturn on arrival.

Controlled atmosphere containers have less cooling capacity than porthole containers and loading temperature is therefore even more critical (Eksteen, 1997). However, because respiration rates are reduced by CA, and therefore heat of respiration is less, less cooling is required in such containers. The South African industry made extensive use of CA containers during the 1997 season, partly due to prior knowledge on the sensitivity of the fruit following excess rains. CA was found to give up to three days longer shelf life and a reduction in cold damage and internal physiological disorders (R. Nelson, personal communications).

• **Controlled Atmosphere (CA)**

Truter and Eksteen (1982) showed that a mixture of 10% CO₂ and 2% O₂ extended the shelf life of Fuerte, Edranol, and Hass avocados while reducing grey pulp and virtually eliminating pulp-spot. However, an increase in anthracnose was observed. This work was followed up by Truter and Eksteen (1987) who found that a 25% CO₂ shock treatment applied one day after harvest also gave very good results in reducing physiological disorders, without the concomitant increase in anthracnose.

Faubion, *et al.* (1992) indicated that Hass avocados could be stored successfully for up to 60 days, using a CA of 5% CO₂ and 2% O₂. Similar results have been obtained with Hass avocados by McLauchlan *et al.* (1992); Jordan & Barker (1992) and Meir *et al.* (1995).

During the 1996 and 1997 seasons, South African exporters resorted to CA export of many containers of avocados to Europe due to the inherent vulnerability of fruit resulting from excessive rains. The results were monitored by shipping CA and conventional containers from the same sources at the same time, and evaluating them overseas. It was found that in general, both Hass and Fuerte fruit arrived much firmer under CA, with up to a week of extra shelf life. In addition CA fruit had a lower incidence of post-harvest diseases such as anthracnose and stem-end rots (*Dothiorella/Colletotrichum* complex.) In some cases external cold injury of Fuerte was higher under CA and, as expected, CA was not a cure-all for age related symptoms such as grey-pulp. Nor did CA have any impact on uneven colouring of Hass (R. Nelson, personal communication, 1997).

• Modified Atmosphere Packaging (MA)

Passive atmosphere modification uses the respiration rates of fruits and vegetables to consume the oxygen and produce carbon dioxide and water vapour in the pack. If the respiration characteristics of the commodity can be accurately matched to the permeability of the film used for packaging, a favourable modified atmosphere can be created passively within the package when an equilibrium concentration between the oxygen and carbon dioxide is reached. (Combrink *et al.* 1996)

In a preliminary study, Boon-Long and Achariyaviriya (1994) prepared a mathematical model for determining film-permeability characteristics for the MA storage of tropical fruit.

Mission Produce from California has expanded its ability to precondition fruit through a modified atmosphere programme. The programme allows avocados to remain in storage for an additional two weeks. The process requires an extra refrigeration step after fruit is hydro-cooled and ripened with ethylene gas. The remaining gases are removed from an airtight carton, which is then kept at a constant temperature of 4.5°C (Anon, 1995).

ON ARRIVAL AT THE DISCHARGE PORT

It is the responsibility of the exporter to ensure that his agent applies the correct procedures at the discharge port. Recooling (using clip-ons, a cold-wall or cold store) must be applied within two hours of unloading, using the same delivery air temperature as that applied by the vessel prior to discharge. Air vents of ducted containers must be kept open during transit to prevent build-up of heat and carbon dioxide (Eksteen and Robinson, 1996).

Ryan recorders or other recording equipment should be retrieved by the importer and the charts returned to the exporter and/or packer as soon as possible. This data should then be correlated with fruit quality in the same consignment.

The South African industry makes use of an Overseas Technical Officer (OTO) who is stationed in Europe during the avocado season (April to September). His task is to monitor fruit arrivals and to give feedback on all quality parameters to the exporter/packer. Fruit is evaluated first on arrival and is then held for ripening, when a second evaluation is carried out. The following parameters are evaluated on a rating system:

Exporter	Firmness (using Densimeter, Köhne <i>et al.</i> , 1997)
Packer	Black cold
Grower	Brown cold
Container no.	Dusky cold
Vessel no.	Lenticel damage
Ryan recorder(s)	Mechanical damage
Pallet no.	Stem-end rot
Cultivar and count	Anthrachnose
Date code	Sooty-mould
Age of fruit	<i>Cercospora</i> spot

On ripening, shelf-life (days to ripen) and internal disorders such as pulp-spot, grey pulp and vascular browning are also recorded. (The colour of Hass skin does not necessarily correspond to its ripeness and fully coloured, rock-hard fruit can sometimes be found on the tree). Ledger and Barker (1995) showed that fruit firmness is a much better indicator of Hass ripeness. If fruit are only sold at the completely black stage, many of the fruit may be overripe and post-harvest diseases will consequently increase significantly.

COLD INJURY DEFINITIONS (B SUTER, 1997)

•Black cold

A severe early cold injury resulting in shiny, black, sunken lesions with clearly defined edges. It does not penetrate below the skin. This symptom is almost always seen immediately upon arrival of fruit overseas, and is normally associated with a severe cold shock early in the cold chain, eg. in the packhouse cold stores. Such cold injury may also result from the application of too low delivery temperatures on the vessel. Black cold may also continue to develop in cold storage after fruit arrival overseas, although this is rare. All cultivars are affected, in particular Fuerte, Pinkerton and Edranol. Black cold on Pinkerton often results in internal grey pulp development.

•Brown cold

A symptom which can be described as a severe, light brown discolouration on the skin of Fuerte (with defined, but not sunken edges), the lenticels remain green and healthy in the midst of a rapidly spreading discolouration. This symptom is rarely seen immediately upon arrival of fruit overseas, although old and soft fruit are more likely to display brown cold. It usually manifests itself as a result of prolonged cold storage after arrival. It may be absent on fruit just removed from cold storage, but can develop extremely rapidly (within less than one hour) once exposed to ambient temperatures. Brown cold is more common on old fruit and excessive moisture loss during transit and cold storage are thought to play a major role in the development of this symptom.

•Lenticel- or lenti-damage

This symptom is usually seen immediately on arrival of the fruit overseas. It involves severe injury and browning or blackening of the lenticels due to either rough handling of the fruit or too low cold storage temperatures. Fruit is also more likely to develop lenti-damage when picked during and immediately after significant rain. Hass is particularly prone to lenti-damage due to the exposed nature of the lenticels. However, the greenskin cultivars are also affected, particularly during the early part of the season. Prolonged exposure to too low storage temperatures may ultimately result in lenti-damage developing into 'black-cold'.

•Dusky cold

A faint sooty-brown or black discolourations, associated with cold storage of senescent

fruit, especially Fuerte and Edranol. It is often correlated with internal grey pulp symptoms.

The Overseas Technical Officer's data from each consignment is faxed back to the industry office, which in turn distributes the information rapidly to exporters and packers.

These records are of vital importance to all concerned in the export process. If properly evaluated and collated they will show up orchard problems, area deviations, packer problems, shipping problems and seasonal variations. The speed of this feedback can do much to prevent recurrence of specific quality problems.

AT THE PRE-PACKERS/RIPENING FACILITIES

The average consumer does not want to wait a week before eating avocados they have bought. There is therefore a major trend in the United States, Australia, the UK, South Africa, and other countries, to pre-ripen or 'trigger' fruit prior to sale. This process is generally carried out by pre-packers or retailers and has become an important part of the marketing chain. However, it is also a potential disaster area where the grower may be penalised with heavy losses due to incorrect handling procedures. Because of increasing softness, pre-ripened fruit will be extremely susceptible to bruising (Arpaia *et al.*, 1987)

The role of ethylene in the natural ripening process has already been discussed in this paper. However, the commercial use of ethylene together with heat, to initiate ripening is now common. Hofman *et al* (1997) demonstrated that respiration in Fuerte fruit can be increased by ethylene levels as low as $0.01\mu\text{l}^{-1}$ during storage at 10°C . However higher levels ($1.0\mu\text{l}^{-1}$) were required to boost respiration rates in Hass fruit held at 8°C , implying a lower level of ethylene sensitivity in this cultivar. In commercial trials carried out at Westfalia Estate, waxed fruit were found to respond less evenly to ethylene triggering of fruit, indicating that the wax may serve as a partial barrier to entry of ethylene.

Treatment of commercial consignments with $100\mu\text{l}^{-1}$ of ethylene at 20°C for 24 hours is generally regarded as sufficient to trigger fruit for marketing of ready-to-eat fruit (Kader, 1985). The use of non-destructive firmness testers is an important part of this process, to ensure uniformity of ripening, for the benefit of the retailer and consumer (Snaddon, 1997; Mizrach *et al.*, 1996; Köhne, 1997).

It is essential for the grower to ensure that monitoring of the pre-ripening process occurs and that he is given feedback on losses occurring at this stage of the marketing chain. Where necessary, corrective measures can then be taken.

IN SUPERMARKETS/RETAIL STORES

Education of the persons selling to the consumer is of great importance, particularly where ready-to-eat fruit is being sold. Correct handling of sensitive fruit, an understanding of the effects of time and temperature on the fruit and the use of "best-before" or "sell-by" dates, are all part of the education process to ensure that losses do not occur at this penultimate stage of the marketing process.

FOR THE CONSUMER

Just as is the case for the seller, the consumer must be educated on the correct storage procedure for the fruit they buy, whether rock-hard or ready-to-eat at the time of purchase. However, all the education and promotion in the world will be valueless if the inherent quality and reliability of the product is absent.

THE ROLE OF RESEARCH

Research should be aimed at three main facets:

- Production Research
- The Commercial Process from Grower to Consumer
- Market Research

Production Research

In a recent review of Production Research funded by the South African Avocado Growers' Association, Toerien (1997) showed that for a grower investment of R1, the return due to implementation of research findings is R60.

The Commercial Process from Grower to Consumer

The Commercial Process from Grower to Consumer includes virtually all the aspects dealt with in this paper. It is the entire process of monitoring, evaluating and reporting on the quality control chain and carrying out the necessary research to solve the problems that are found to occur. This research can be of enormous financial benefit to the grower.

Market Research

Market Research is obviously of vital importance. However it is beyond the confines of this paper to deal with this topic.

ISO 9000 and HACCP

This paper covers many of the principles expounded in ISO 9000 and HACCP (Hazard Analysis and Critical Control Points). ISO 9000 can be seen as an internationally accepted, overall quality control system dependent on acceptance of **management responsibility**, effective documentation, entrenchment of quality control systems and regular auditing by accredited auditors, followed by appropriate and documented corrective action.

HACCP is divided into two facets, HA (Hazard Analysis) in which a total flow diagramme is produced, identifying the type of hazards (whether physical, chemical or biological) which may impact on the end product; and CCP (Critical Control Points) which includes

identification of the critical points in the flow chart at which quality aspects must be monitored to ensure a safe and dependable end-product. Appropriate preventative measures are then documented, applied, monitored and regularly reviewed. The HACCP process is basically the one followed in this paper.

THE ROLE OF THE GROWER ORGANIZATIONS

It is you, the grower who can and should have the greatest impact in ensuring that you grow a good product and that a good product arrives at the consumer. That is what this paper is about. In the end it is you who must ensure that your production remains profitable now, and in the future.

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