Semi-commercial trials to determine the risk of shipping South African 'Hass' at 1ºC

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INTRODUCTION

The South African avocado industry is engaged in the process of applying for access to new markets such as the USA, which require disinfestation treatments to be applied before fruit can enter their country. In 2007 the South African Avocado Growers' Association (SAAGA) started initiating trials to evaluate 1) the effect a cold sterilisation treatment would have on potential quarantine pest mortality, and 2) the effect the treatment would have on South African 'Hass' fruit quality. A period of 21 consecutive days during which time fruit were kept at a pulp temperature below 2ºC was identified as being a possible requirement to attain a probit 9 level of quarantine treatment efficacy. Understandably severe chilling damage was expected on avocado fruit stored at such low temperatures, as standard South African shipping temperatures rarely fall below 4ºC (delivery air temperature, DAT). Nevertheless, during semi-commercial trials conducted during 2008 it was found that external chilling injury damage fell within an acceptable range throughout the 'Hass' avocado season (Van Rooyen, 2009) and that the internal quality of the fruit was unaffected. Another year's data was needed to confirm these results. This paper reports on the second year's results.

MATERIALS AND METHODS

Fruit source and numbers

As during the 2008 season (Van Rooyen, 2009), 'Hass' fruit were obtained from Westfalia Fruit Estates at three dates in the 2009 avocado season, thought to represent "Early" (02/06/09), "Mid" (02/07/09) and "Late" (17/08/09) season fruit. For each date two pallets of export-quality fruit, count 14, were sourced from the Westfalia packhouse after fruit had passed over the packline (i.e. after the standard washing, waxing, grading and palletising). Each "export quality" pallet was made up of fruit picked from between three and five different orchards. The orchard codes were recorded and the moisture content of the fruit from each orchard determined. Eighteen pallets of factory grade fruit were packed into cartons used for export and used to fill up the remainder of the container in order to simulate commercial airflow conditions.

The two "export quality" pallets were divided up between three pallets, as reported during 2008 (Van Rooyen, 2009). During 2008 the fruit were randomly assigned to the three pallets. However, in 2009, to minimise variation, cartons from different orchards were separated and placed in the same position on each pallet so that the effect (if any) of pallet position in the container could be more accurately ascertained. Fruit were conditioned for the cold sterilisation treatment before the storage temperature was dropped to 1ºC (DAT) for a minimum of 22 days, making the total storage period 28 days. During 2009 a sub-sample of the "export quality" fruit were also stored at 5.5ºC for a comparison of standard shipping temperatures, and another sub-sample was directly ripened at ambient temperature (±24ºC).

Storage container

In order to improve the temperature uniformity of the standard "regular atmosphere" container used, a few small structural modifications were made within the container. These modifications are still in the experimental phase; however, the container is generally referred to as a "modified airflow" (MAF) or "directed airflow" container.

Parameters recorded

Temperature monitoring

Data loggers were used to monitor both the air and fruit pulp temperature and the relative humidity at various layers and positions in the container.

Fruit quality

Immediately after removal from the storage container, the severity of the following external quality parameters were rated on all the "export quality" fruit: chilling injury, lenticel damage and discolouration. Fruit were rated on a scale of 0 to 3, where ratings of 0 represented clean fruit. Fruit were considered to be "severely" damaged / affected if ratings were above 2. Generally, at a rating of 1, the consumer will notice the damage but will in all likelihood consider it "acceptable". To determine fruit quality at ripening, cartons from each "export-quality" layer (**Figure 1**) were taken and left at ambient room temperature (±24ºC) until "eating ripeness" was attained. "Eating ripeness" was determined using a hand-held densimeter (Bareiss, Oberdischingen, Germany) using a scale of 0 (soft) to 100 (hard) where a reading of 55 to 60 was deemed to indicate

(a)

(b)

Figure 1. Photos taken immediately after storage of "early" season 'Hass' (harvested 02/06/09) stored at either (a) 5.5ºC or (b) 1ºC (DAT), showing brown chilling damage on fruit stored at 5.5ºC.

"eating ripeness" (Köhne *et al.*, 1998). At "eating ripeness" the following was determined: exocarp colour, shrivelling, appearance, internal disorders (grey pulp, pulp spot), pathological infections, vascular browning, taste and days to ripening.

RESULTS AND DISCUSSION

Fruit maturity

The average moisture content of fruit from the various orchards used to make up the experimental pallets was obtained from the packhouse records. The average moisture content of the fruit was found to decrease with each consecutive trial date (**Table 1**).

Table 1. Average moisture content of fruit, from various orchards, used to determine the sensitivity of 'Hass' fruit to storage at 1ºC (DAT) throughout the 2009 season.

	Early season	Mid-season	Late-season
Average moisture content (%)	74	70	65

Temperature and relative humidity

Temperature variation within the container was fairly uniform and temperatures remained within the required range for a cold sterilisation treatment, except for the "mid"-season trial where the low night temperatures resulted in the cooling unit malfunctioning and pulp temperatures increasing to 4ºC for three days in the third week of storage. According to the APHIS treatment manual, the air temperature of produce receiving a cold sterilisation treatment may increase slightly above the set / required temperature (for example during a defrost cycle), however pulp temperature may not increase more than 0.28ºC above the treatment temperature. This container would therefore have been rejected at the port of entry. In citrus the following is required where temperatures increase above the set temperature: the fruit are required to stay an

Table 2. Percentage 'Hass' fruit (count 14) rated as having "severe" chilling injury after storage at 1ºC (DAT) or 5.5ºC (DAT) in the static containers for the various trial dates in 2009.

% Fruit rated as "severe"			Front	Middle	Back	*Mean*
Early season	1ºC	Top	1.0 (0.4)*	3.1 (0.7)	0.6 (0.4)	*1.6 (0.5)*
		Middle	0.6 (0.3)	0.7 (0.4)	0.4 (0.2)	*0.6 (0.3)*
		Bottom	0.8 (0.4)	2.0 (0.2)	0.6 (0.3)	*1.1 (0.3)*
		Mean	*0.8 (0.4)*	*1.4 (0.5)*	*0.6 (0.3)*	*1.1 (0.4)*
	5.5ºC	All				*0.0 (0.0)*
Mid-season	1ºC	Top	3.3 (0.9)	1.5 (0.6)	1.4 (0.5)	*2.1 (0.7)*
		Middle	1.8 (0.6)	0.4 (0.2)	1.0 (0.4)	*1.1 (0.4)*
		Bottom	0.8 (0.4)	0.7 (0.4)	1.2 (0.5)	*0.9 (0.4)*
		Mean	*2.0 (0.7)*	*0.9 (0.5)*	*1.2 (0.5)*	*1.4 (0.5)*
	5.5ºC	All				*1.2 (0.4)*
Late-season	1ºC	Top	1.1 (0.1)	0.0 (0.0)	0.0 (0.0)	*0.4 (0.0)*
		Middle	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	*0.0 (0.0)*
		Bottom	0.4 (0.2)	0.1 (0.1)	0.4 (0.2)	*0.3 (0.2)*
		Mean	*0.2 (0.2)*	*0.0 (0.1)*	*0.1 (0.1)*	*0.2 (0.1)*
	5.5ºC	All				0.0 (0.0)
Number of fruit/date	1ºC	Total				7062
Number of fruit/date	5.5ºC	Total				168

*Figures in brackets denote the standard error

additional eight hours for every temperature spike, or where temperature spikes are longer than eight hours another eight hours per eight hour period above the treatment temperature.

In terms of pallet position in the static container used for the 2009 trials, the middle pallet, on average, logged slightly higher pulp temperatures for all three dates (±0.30ºC). When comparing the average temperature for the three "export" pallets, the top layers in the pallets were found to be slightly warmer (±0.35ºC) than the middle and bottom layers (which were virtually similar). The relative humidity was fairly constant for all three dates and averaged at about 90% (±1.5%).

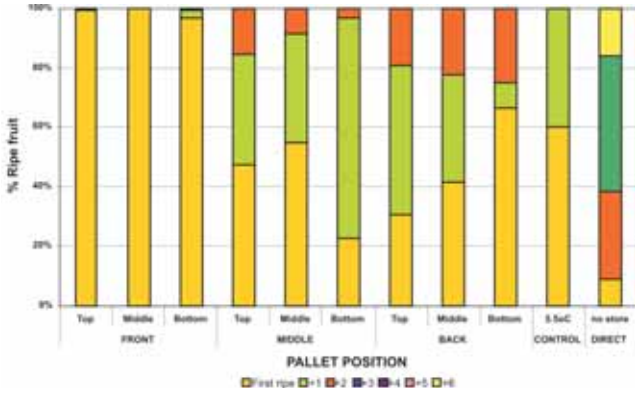

Figure 2. Ripening uniformity of 'Hass' fruit harvested in June 2009 and stored at 1ºC or 5.5ºC (DAT), compared to fruit directly ripened (no store). Data depicts percentage fruit ripe when first fruit reached "eating ripeness" (Densimeter reading 55 to 60) and each consecutive day thereafter. The x-axis shows the position of the carton in the pallet (first line of axis heading), and then the position of the pallet in the container (second line of axis heading).

External chilling injury

For all three trial dates very little "severe" black chilling injury was recorded in fruit stored at 1ºC (DAT) (<4% on average, **Table 2**). The fruit in the top layers of the respective pallets had marginally more fruit with "severe" chilling injury than fruit stored at other positions in the container. In fact, the black chilling damage severity between fruit stored at 1ºC or 5.5ºC was fairly similar during the "mid"-season trial, if fruit from the top layers of pallets were excluded. Furthermore, during the "early" season trial, fruit stored at 5.5ºC, while not developing black chilling lesions, did display a form of "brown" chilling injury (**Figure 1**). The "late"-season fruit harvested in August showed the least chilling damage (**Table 2**).

Lenticel damage

Generally lenticel damage was very high throughout 2009 (**Table 3**), however more so during the early part of the season. Harvest date had a greater effect on lenticel damage than position of fruit in the pallet or container. Lenticel damage in fruit stored at 1ºC (DAT) was only marginally higher than unstored fruit stored at 5.5ºC (DAT).

Grey pulp

Throughout the 2009 season the percentage fruit affected by grey pulp was higher in fruit stored at 5.5ºC than 1ºC (DAT) (**Table 4**).

Fruit ripening

Fruit stored at 1ºC generally took three days longer to start ripening than fruit stored at 5.5ºC (DAT). No significant difference between fruit stored at 1ºC and

Table 3. Percentage 'Hass' fruit (count 14) rated as having "severe" lenticel damage after storage at the respective temperatures during the 2009 'Hass' season.

% Fruit rated as "severe"			Front	Middle	Back	*Mean*
Early season	1ºC	Top	48.0 (2.4)*	63.5 (2.0)	35.5 (2.4)	*49.0 (2.3)*
		Middle	29.2 (2.5)	49.0 (2.4)	29.5 (2.1)	*35.9 (2.3)*
		Bottom	41.9 (2.5)	40.7 (1.8)	30.7 (2.0)	*37.8 (2.1)*
		Mean	*40.4 (2.6)*	*51.8 (2.5)*	*32.1 (2.2)*	*40.9 (2.2)*
	5.5ºC	All				*14.9 (1.4)*
	Direct	All				*35.7 (1.6)*
Mid-season	1ºC	Top	33.2 (2.6)	24.0 (2.1)	47.9 (2.1)	*35.0 (2.3)*
		Middle	24.9 (1.9)	17.3 (1.8)	29.6 (1.7)	*23.9 (1.8)*
		Bottom	48.5 (2.9)	33.8 (2.3)	46.4 (2.0)	*42.9 (2.4)*
		Mean	*36.3 (2.9)*	*25.6 (2.3)*	*42.1 (2.2)*	*33.9 (2.2)*
	5.5ºC	All				*30.4 (2.0)*
	Direct	All				*36.3 (3.7)*
Late-season	1ºC	Top	14.8 (1.6)	8.1 (1.7)	21.0 (2.2)	*14.6 (1.8)*
		Middle	6.7 (1.3)	4.0 (1.1)	19.6 (1.3)	*10.1 (1.2)*
		Bottom	13.1 (1.3)	6.9 (1.2)	16.1 (1.2)	*12.0 (1.2)*
		Mean	*11.9 (1.5)*	*6.6 (1.4)*	*18.8 (1.7)*	*12.2 (1.4)*
	5.5ºC	All				8.9 (0.4)
	Direct	All				11.3 (0.4)
Number of fruit/date	1ºC	Total				7062
Number of fruit/date	5.5ºC	Total				168
Number of fruit/date	Direct	Total				168

*Figures in brackets denote the standard error

5.5ºC was noted during "early" (**Figure 2**) and "late"-season trials (**Figure 4**) in terms of ripening uniformity. However, during the "mid"-season trial fruit stored at 1ºC ripened more uniformly (**Figure 3**). During all trials unstored fruit took longer to ripen, and ripened less uniformly, than stored fruit (**Figure 1-3**). Pallet (or carton) position appeared to have no effect on ripening uniformly, except during the "early" season trial when the ripening uniformity was best in the pallet situated at the front of the container (closest to the cooling unit), although only by one day. Fruit taste was not affected by storage temperature and fruit peeled just as easily between the two temperatures. Colour development was generally good throughout the season, although fruit stored at 5.5ºC (vs 1ºC) developed less colour on ripening during the "early" season trial (**Figure 5**).

CONCLUSION

Cold sterilisation does not appear to render 'Hass' of an unacceptable quality, with consistent results being achieved over two seasons when using MAF containers. However, before this treatment can be implemented as a disinfestation treatment, a lot of work still needs to be done to get the modifications to the container approved, by example USDA-APHIS and / or shipping lines. Should the modifications be difficult to approve, the use of other containers will need to be investigated

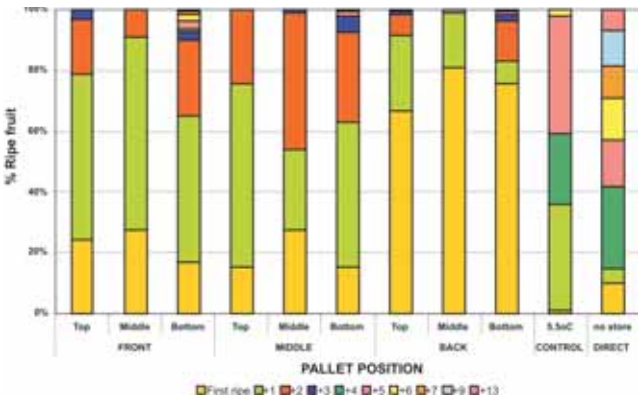

Figure 3. Ripening uniformity of 'Hass' fruit harvested in July 2009 and stored at 1ºC or 5.5ºC (DAT), compared to fruit directly ripened (no store). Data depicts percentage fruit ripe when first fruit reached "eating ripeness" (Densimeter reading 55 to 60) and each consecutive day thereafter. The x-axis shows the position of the carton in the pallet (first line of axis heading), and then the position of the pallet in the container (second line of axis heading).

Figure 4. Ripening uniformity of 'Hass' fruit harvested in August 2009 and stored at 1ºC or 5.5ºC (DAT), compared to fruit directly ripened (no store). Data depicts percentage fruit ripe when first fruit reached "eating ripeness" (Densimeter reading 55 to 60) and each consecutive day thereafter. The x-axis shows the position of the carton in the pallet (first line of axis heading), and then the position of the pallet in the container (second line of axis heading).

Table 4. Percentage 'Hass' fruit (count 14) rated as having "severe" grey pulp after storage at the respective temperatures during the 2009 'Hass' season.

% Fruit rated as "severe"			Front	Middle	Back	*Mean*
Early season	1ºC	Top	0.0 (0.2)*	0.0 (0.2)	0.0 (0.1)	*0.0 (0.2)*
		Middle	1.3 (0.3)	0.7 (0.1)	0.0 (0.2)	*0.7 (0.2)*
		Bottom	0.0 (0.2)	0.6 (0.0)	0.0 (0.2)	*0.2 (0.1)*
		Mean	*0.4 (0.2)*	*0.4 (0.2)*	*0.4 (0.2)*	*0.4 (0.2)*
	5.5ºC	All				*16.1 (0.8)*
	Direct	All				*0.0 (0.1)*
Mid-season	1ºC	Top	1.2 (0.3)	3.4 (0.5)	0.0 (0.0)	*1.5 (0.3)*
		Middle	1.2 (0.3)	6.0 (0.2)	0.0 (0.1)	*2.4 (0.2)*
		Bottom	0.0 (0.1)	1.2 (0.2)	0.0 (0.1)	*0.4 (0.1)*
		Mean	*0.8 (0.3)*	*3.6 (0.5)*	*0.0 (0.1)*	*1.5 (0.3)*
	5.5ºC	All				*21.4 (1.0)*
	Direct	All				*0.0 (0.0)*
Late-season	1ºC	Top	0.0 (0.0)	0.6 (0.2)	0.0 (0.2)	*0.2 (0.1)*
		Middle	0.0 (0.0)	0.6 (0.0)	0.0 (0.0)	*0.2 (0.0)*
		Bottom	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	*0.0 (0.0)*
		Mean	*0.0 (0.0)*	*0.4 (0.0)*	*0.0 (0.1)*	*0.1 (0.0)*
	5.5ºC	All				16.7 (0.8)
	Direct	All				0.0 (0.0)
Number of fruit/date	1ºC	Total				1512
Number of fruit/date	5.5ºC	Total				168
Number of fruit/date	Direct	Total				168

*Figures in brackets denote the standard error

(a)   (b)

Figure 5. Photos taken of early season 'Hass' (harvested 02/06/09) on attaining "eating ripeness"; (a) fruit stored at 5.5ºC for 28 days and (b) fruit stored at 1ºC (DAT).

(for example, those used by the South African citrus exporters). Further, the logistics of how or where to apply the preconditioning treatment still needs further investigation.

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