Further observations on the manifestation of certain physiological disorder variants in 'Hass' and 'Maluma' avocado fruit

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ABSTRACT

During a previous presentation, certain hypotheses were formulated regarding the manifestation of a range of physiological disorders afflicting South African 'Hass' avocado fruit. One of the disorders, "storage induced internal chilling injury" was attributed to cool storage of a late fruit set that was cultivated under low nitrogen conditions. Further research has, however, refuted the late set causative component. The disorder, nevertheless, seemed to be primarily associated with malnourished fruit from under-fertilised trees. In certain cases the malnourishment was associated with the withholding of fertiliser during a recuperation period after hail damage. The second disorder to be referred to in this report is bruising. During the current 'Maluma' post-harvest project by the South African Avocado Growers' Association, it was noticed that longitudinal changes in the prevalence of bruising in concurrently ripened 'Hass' and 'Maluma' fruit exhibit very specific incidence patterns. The results infer that bruising may be initiated under mild pressure conditions, provided the fruit are within a specific firmness range when the pressure is applied. Short reference is also made to "seed coat abscission related grey pulp" in 'Maluma' fruit and a possible relationship between plant feeding practices and lenticel damage.

INTRODUCTION

In a previous article, Kruger & Lemmer (2015) reported on a number of epidemiological observations made regarding certain physiological disorder variants that afflict South African 'Hass' avocado fruit. In the present report, certain additional observations regarding one of these disorders, "storage induced internal chilling injury" (as opposed to orchard cold-damaged fruit) are reported on. Short reference is also made to two other physiological disorders ("dead seed associated grey pulp" and lenticel damage). In addition, more detailed information is presented on the causes of bruising, the results of which emanate from the 'Maluma' storage condition study presently being performed (Kruger *et al.*, 2016, 2017).

MATERIALS AND METHODS

'Storage induced internal chilling injury'

Mineral analyses

During 2015, mineral analyses were conducted on the fruit pulp of packinghouse hold-back samples that exhibited "storage induced internal chilling injury". Fruit from two producers were analysed. The one was affected by the disorder while the other was not. In the case of the affected producer, the fruit were further divided into two groups, namely fruit exhibiting symptoms and symptomless fruit.

Moisture content analyses

During April 2016, 10 round and 10 normal pear shaped fruit were sampled from each of three affected orchards. Moisture content analyses were done on individual fruit and the mean moisture contents determined.

Spatial distribution and climatic history

The spatial distribution of the different orchards, as plotted for the initial article, was revisited and the climatic history of the affected production area researched.

'Dead seed associated grey pulp'

During 2015 and 2016, a number of orchards which showed the highest incidences of "dead seed associated grey pulp" in the Tzaneen and Mooketsi areas were visited and all available climatic, horticultural and orchard management data collected. An elimination process was then followed in an attempt to establish the most possible causes of the disorder.

Lenticel damage

Certain of the current authors recently performed a study on behalf of the industry aimed at relaxing the allowable wind damage/netting regulations. An example of the netting related results that were presented to Department of Agriculture, Forestry and Fisheries for amendment purposes is shown in Figure 1. This action was followed by a similar process with lenticel damage. One of the aspects considered was the relationship between lenticel damage and the prevalence of the other physiological disorders that afflict South African export avocado fruit. To do this, fruit with different intensities of lenticel damage were sampled from a packinghouse over a one day period and stored under simulated export conditions, followed by quality analyses. The results of these trials are briefly referred to in the present report.

Bruising

The information on bruising presented in the present report was generated during the 'Maluma' postharvest upgrade study currently being performed (Kruger *et al*., 2016, 2017). Two of the aspects, namely the effects that the pre-cooling ambient period and the cool storage period had on fruit quality, are reported on here. During the first part of the study, the fruit were placed into storage after, respectively, 8, 16, 24 or 32 hours at ambient. In the second part, the avocados were stored for either 20, 25, 30 or 35 days at 6°C. This was followed by ripening at 6°C. The effects that the pre-storage ambient period and the length of storage period had on fruit quality were then measured. Bruising was one of the disorders that was scored.

RESULTS AND DISCUSSION

'Storage induced internal chilling injury'

Our initial hypothesis regarding "storage induced internal chilling injury" (Fig. 2) was that the disorder occurs in late set fruit from malnourished orchards (Kruger & Lemmer, 2015). However, moisture content analyses of the present samples showed that the round fruit and the normal pear shaped fruit were of similar maturity (Table 1). It is therefore highly unlikely that the susceptible round fruit that exhibited "storage induced internal chilling injury" were from a later set.

When comparing the mineral composition of the symptomatic fruit from the affected orchard with that of the fruit from the unaffected orchard, a number of interesting trends emerged.

Figure 1. Examples of ripened 'Lamb Hass' fruit with different incidences of netting that were submitted to DAFF as motivation to relax current regulations regarding the symptom. A similar approach was followed for lenticel damage.

Table 1. Fruit pulp moisture content of round and pear shaped 'Hass' fruit from orchards exhibiting "storage induced internal chilling injury" symptoms.

	Pulp moisture content (%)					
Orchard no	**1**		**2**		**3**	
Fruit no	**Pear shaped**	**Round shaped**	**Pear shaped**	**Round shaped**	**Pear shaped**	**Round shaped**
1	74	72	75	71	76	74
2	72	70	73	73	77	74
3	72	72	69	73	76	66
4	71	72	69	70	74	75
5	71	75	74	71	75	76
6	70	75	73	72	77	75
7	76	72	75	75	76	75
8	74	71	72	70	74	73
9	73	69	77	74	76	76
10	71	71	75	77	73	74
Mean	72,4 a	71,9 a	73,2 p	72,6 p	75,4 x	73,8 x

Figure 2. "Storage induced internal chilling injury" symptoms of 'Hass' fruit.

Figure 3. "Dead seed associated grey pulp" recorded by European importers in 'Hass' fruit during the 2015 (left) and 2016 (right) seasons.

Table 2. Pulp mineral content concentrations of symptomatic and asymptomatic 'Hass' fruit from affected and non-affected orchards.

Sample	Mineral concentration												
	N (%)	Ca (%)	Mg (%)	K (%)	Na (mg/kg)	S (%)	P (%)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Mo (mg/kg)	B (mg/kg)
Symptomatic fruit: affected orchard	0.76 a	0.097 a	0.137 a	1.85 a	64.8 a	0.090 a	0.130 a	47.3 a	33.4 a	8.0 a	18.2 a	0.765 a	56.1 a
Asymptomatic fruit: Affected orchard	0.96 b	0.076 a	0.136 a	1.92 a	48.6 b	0.096 a	0.140 a	36.2 a	25.5 a	10.5 b	19.9 a	0.931 a	60.2 a
Asymptomatic fruit: Unaffected orchard	1.32 c	0.058 b	0.137 a	2.90 b	56.4 a	0.151 b	0.239 b	43.1 a	12.2 b	15.3 c	27.3 b	0.910 a	37.4 b

Table 3. Pulp mineral concentrations of symptomatic 'Hass' fruit relative to asymptomatic fruit from affected and non-affected orchards, expressed as percentages.

Relative concentrations of mineral elements		
Element	**Symptomatic fruit in relation to asymptomatic fruit from an affected orchard (%)**	**Symptomatic fruit from the affected orchard in relation to the fruit from the unaffected orchard (%)**
N	-21	-42
Ca		67
K		-36
Na	33	
P		-46
Mn		174
Cu	-24	-48
Zn		-33
B		50

It would appear that the symptomatic fruit had lower concentrations of not just (as to be expected) Zn, but a range of other elements as well (N, K, P & Cu). Interestingly, a number of other (immobile) elements were present in higher concentrations in the symptomatic fruit from the affected orchard than in the fruit from the unaffected orchard (Tables 2 & 3). When comparing the symptomatic fruit from the affected orchard with asymptomatic fruit from the same orchard, it was noticed that the symptomatic fruit have lower N and Cu levels and higher Na levels. The higher Na level readings concur with observations made by the current authors (and others) regarding the placement of the trees that bore the highest numbers of round fruit. These trees were found to be located in the lower lying areas of the affected orchards that are more susceptible to orchard cold damage. These areas may possibly be more saline than the higher lying areas.

The higher levels of immobile elements in the symptomatic fruit from the affected orchard in comparison with the asymptomatic fruit from the unaffected orchard may possibly be indicative of less dense trees with higher sunlight penetration. A large proportion of the severe symptoms occurred in a linear track of orchards through which a hailstorm passed in 2011. The producers did not prune back their trees after the hailstorm and they also cut back on their fertiliser applications. The damaged branches subsequently turned a yellow colour. On these farms, the round shaped fruit were primarily (but not exclusively) borne in these damaged trees during subsequent seasons.

At this stage it is recommended that producers ensure that their fertiliser and irrigation programmes are up to scratch at all times. Also, remove all branches that are damaged by hail, orchard cold and sun burn, or prune back the whole tree while relying on professional assistance regarding the fertilising of these trees.

'Dead seed associated grey pulp'

Reports from overseas clients revealed that this type of grey pulp primarily occurs in fruit with dead seeds, usually in the count 20-24 range. The incidence of dead seed associated grey pulp (Fig. 3) started to increase during the 2015 season when it became prevalent in fruit from certain orchards planted in well drained, sandy soils that suffered a temporary water deficiency spell during the last two months of 2014 (Fig. 4).

During the 2016 season, the incidence of the disorder significantly increased. In general, the sizes of 'Hass' and 'Maluma' fruit were also drastically reduced during the 2016 season. This was because of the drought conditions that prevailed during the 2015/16 season and the exceptionally hot November-December period (Table 4). Orchards with large numbers of small no-count fruit had a lower incidence of the disorder in packed fruit because it was most prevalent in the no-count fruit. In orchards that bore a higher percentage of larger counts, it was most prevalent in the 20-24 size range (Table 5).

At this stage we hypothesise that one possible reason the disorder is higher in 'Maluma' than in 'Hass' during a hot and dry season, is because 'Maluma' fruit have thicker pedicels and more robust vascular bundles (Fig. 5), resulting in more fruit with dead seeds not being shed by the tree. However, it is more likely that because 'Maluma' is larger than 'Hass', fruit of the latter cultivar with dead seeds fall in the no-count category and are thus not recognised as such.

At this stage we recommend that packinghouses cut an appropriate number of fruit of all sizes prior to packing so as to establish which counts exceed the PPECB dead seed tolerance limit. These counts must then be locally marketed. Another effective dead seed exclusion tool is to ensure that fruit that

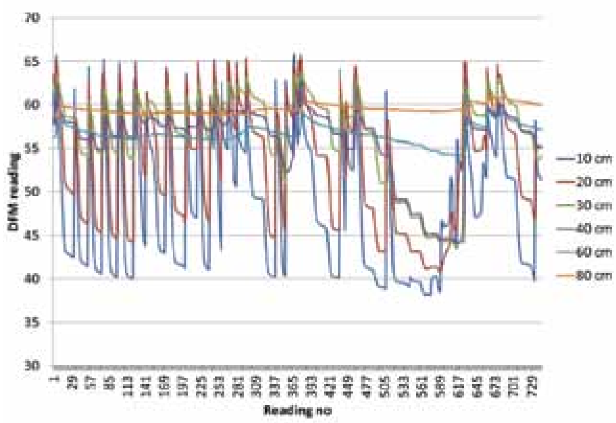

Figure 4. DFM probe readings taken during December 2014 in a 'Maluma' orchard that exhibited "dead seed associated grey pulp" symptoms during the 2015 season.

Figure 5. The pedicel attachment of 'Maluma' fruit (bottom) compared to that of 'Hass' (top).

Table 4. Maximum temperatures recorded during December 2015 at a weather station in the Mooketsi area in relation to those recorded during other years.

Period and reading	Temperature (°C)
Mean maximum: December 2011-2016 (exl. 2015)	31.3
Mean maximum: December 2015	35.5
Highest: December 2015	42.4

Table 5. Incidence of dead seeds in 'Maluma' fruit of different sizes, recorded at a packinghouse in the Tzaneen area during the 2016 season.

Producer no	Orchard no	Dead stones per count (%)			
		Count 18	Count 20	Count 22	Count 24
1	1	3	8	23	46
	2	3	18	18	33
	3	6	0	11	31
2	1	0	8	16	17
	2	0	10	9	31
3	1	0	0	2	2
	2	0	0	0	6

have started to develop colour on the tree are not exported. These fruit have a considerably higher percentage of dead seeds (Fig. 6).

Lenticel damage

During the study it was found that fruit with lenticel damage have considerably higher incidences of anthracnose and bruising (Fig. 7). This obviously precludes the relaxation of the current lenticel damage regulations in a similar way as was the case with netting.

During the 'Pinkerton' studies conducted at the turn of the century, it was noticed that fruit from over-fertilised orchards had higher incidences of physiological and pathological disorders. The present fruit originated from orchards with a high nitrogen status and the results serve as a point of departure to refine the current fruit pulp nitrogen norms, which will contribute towards addressing the lenticel damage problem.

Bruising

Three graphs depicting the incidences of bruising are shown in Figures 8-10. Figure 8 shows the

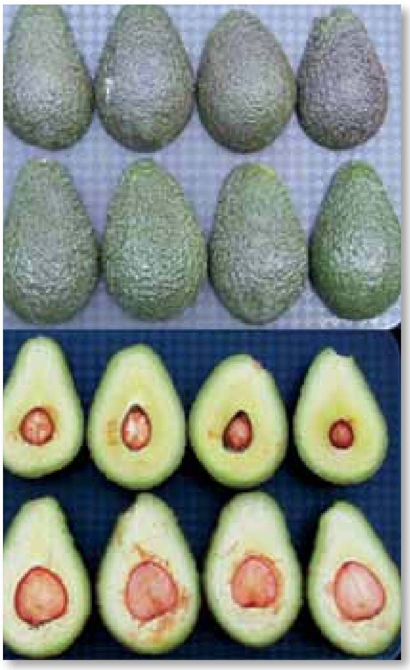

Figure 6. Advanced pre-harvest external colour of 'Maluma' fruit with dead seeds (top row in both photographs) compared to the green colour of fruit with live seeds (bottom row in both photographs).

Figure 7. Internal quality of 'Hass' avocado fruit without lenticel damage (left) and with lenticel damage (right).

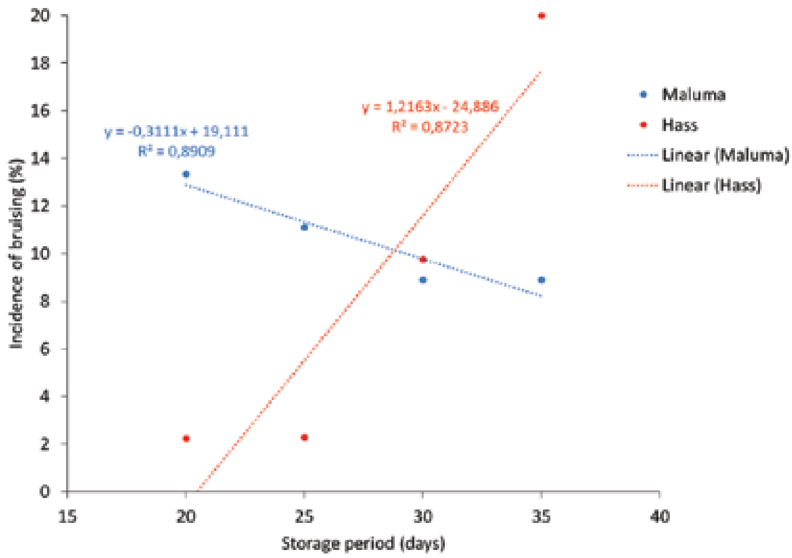

Figure 8. Example of a case where the incidence of bruising increased in 'Hass' and decreased in 'Maluma' as the storage period lengthened.

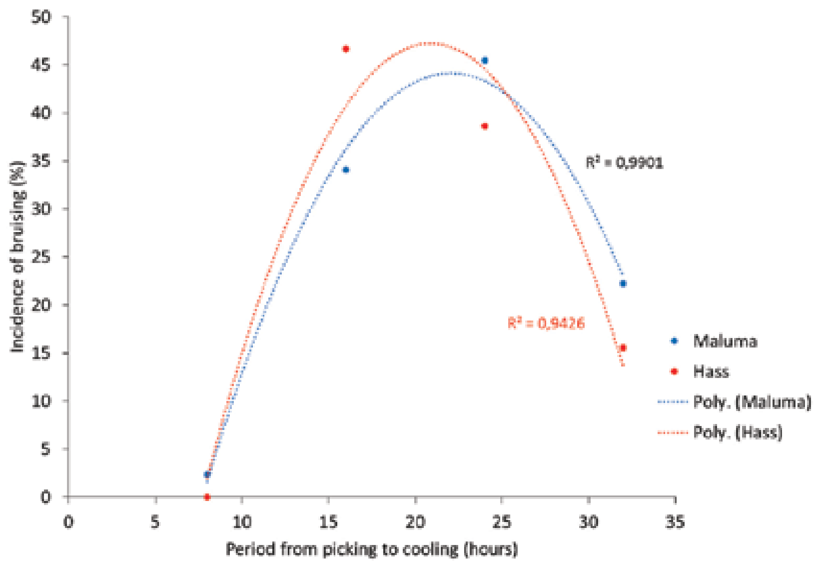

Figure 9. Example of a case where the incidence of bruising increased and then decreased in both 'Hass' and 'Maluma' as the period from harvest to cooling lengthened.

effect that the storage period had on bruising, while Figures 9 and 10 depicts the effect of the pre-cooling period. In Figure 8 the incidence of bruising is shown to increase in 'Hass' as the storage period lengthens, while it decreases in 'Maluma'. In Figure 9 the incidence of the disorder follows a hyperbolic trend in both cultivars. In Figure 10 'Maluma' exhibits a hyperbolic curve, while bruising in 'Hass' increases linearly.

In order to interpret the data, it is necessary to first revisit the results generated by the present authors for the PHI-1 programme during the last decade. During the various studies it was found that the respiration rate of cool stored avocado fruit only starts to increase after about three weeks of storage (Fig. 11). In contrast, the firmness of the fruit declined in a linear fashion as from the first day of storage (Fig. 11). It was further established that the rate of firmness loss was related to storage temperature. It was also found that 'Maluma' was of lower firmness than 'Hass' as from the start of storage (Fig. 12). However, the rate of firmness loss was similar in both cultivars.

The above information aids the interpretation of the effect that storage period has on firmness. It does not assist the interpretation of the effect that the pre-cooling period may have had. However, the PHI-1 study contained a comparable variable, namely the effect that a temperature break on day 5 had on firmness. It was shown that the firmness of fruit that were subjected to such a break decreased at a faster rate than those that were not (Fig. 13).

Keeping the above in mind, a hypothesis was developed regarding the effect that the storage period and the period between harvest and cooling may have on bruising (Figs. 14 and 15). It would appear that avocado fruit are extremely sensitive to bruising when handled within a very specific firmness range. Under experimental conditions, this handling probably occurs when the cartons are taken out of the cold storage and stacked in the ripening room. In the case of Figure 14, the fruit represented by the red line were too hard to bruise on day 20. They then entered the sensitive range and remained there on days 25 and 30. By day 35 the fruit were starting

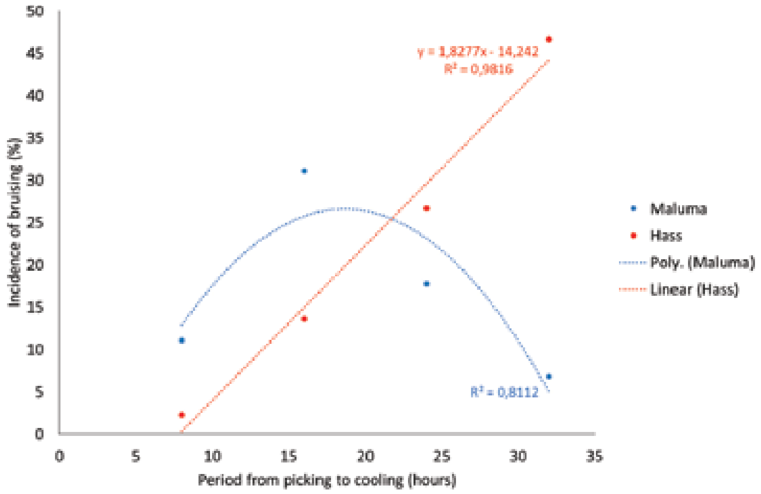

Figure 10. Example of a case where the incidence of bruising increased in 'Hass' as the period from harvest to cooling lengthened while that of 'Maluma' exhibited a hyperbolic pattern.

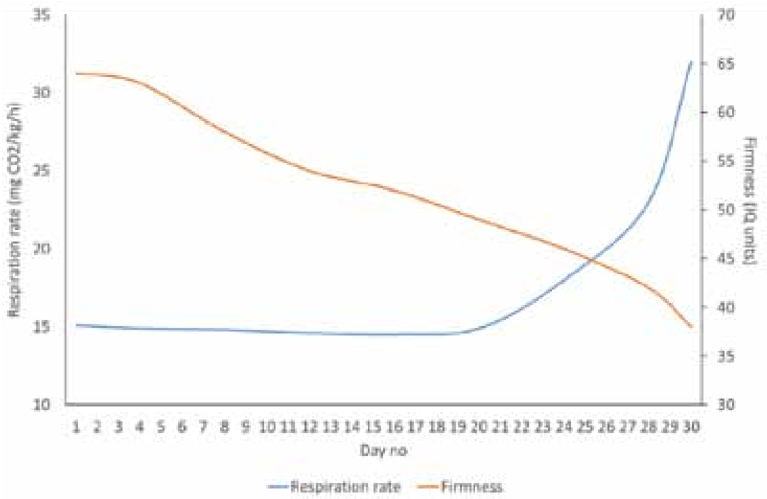

Figure 11. Example of the relationship between the respiration rate and firmness reduction rates of avocado fruit over a one month storage period.

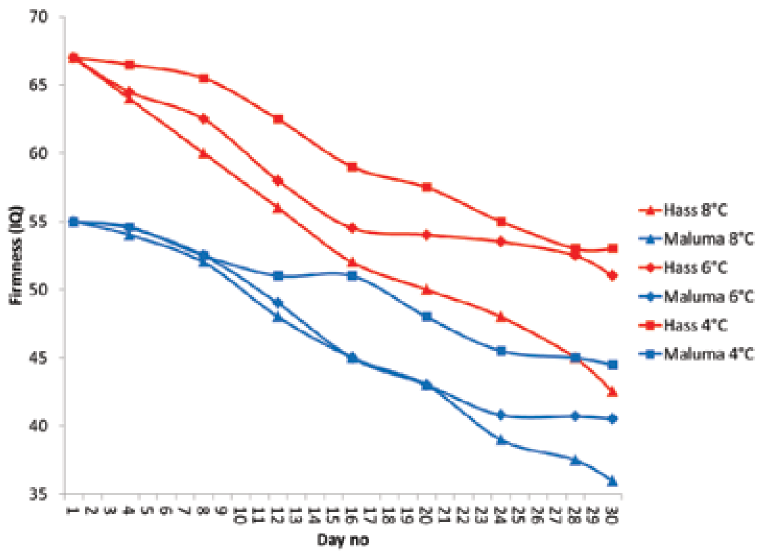

Figure 12. Firmness reduction rates of 'Hass' and 'Maluma' avocado fruit stored for one month at three temperatures.

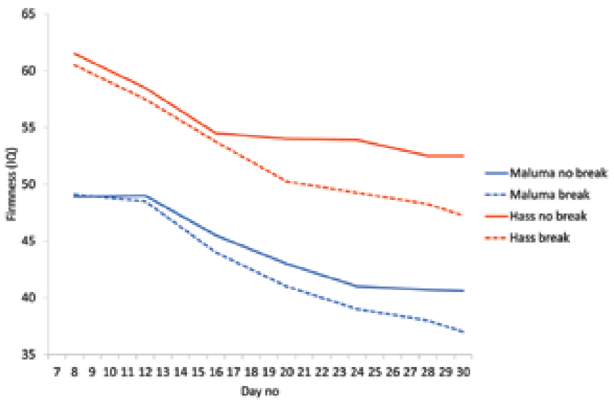

Figure 13. Firmness reduction rates of 'Hass' and 'Maluma' avocado fruit that were subjected to a cold chain break on day 5 of a 30 day storage period.

to become too soft to contract bruising. In a similar way, the fruit represented by the blue line entered the sensitive firmness range while the green fruit exited the sensitive firmness range during the same period.

In so far as the harvest-to-cooling periods are concerned (Fig. 15), a parabolic trend indicated that the fruit that were placed into cool storage after 8 hours at ambient, were still hard when taken out of storage. On the other hand, the 16- and 24-hour samples were within the sensitive zone while the 32-hour sample was already too soft to contract bruising when taken out of cool storage.

The current results emphasise the importance of landing rock hard fruit. It also infers that bruising can occur when the fruit are only gently bumped during the susceptible firmness phase. The pallets should therefore only be moved when the ready-to-eat stage has been reached.

Acknowledgements

The authors would like to acknowledge SAAGA, PHI, ZZ2, Afrupro and all other institutions and individuals who have contributed towards the study. We would also like to thank Mark Penter of the ARC-TSC for proofreading the manuscript.

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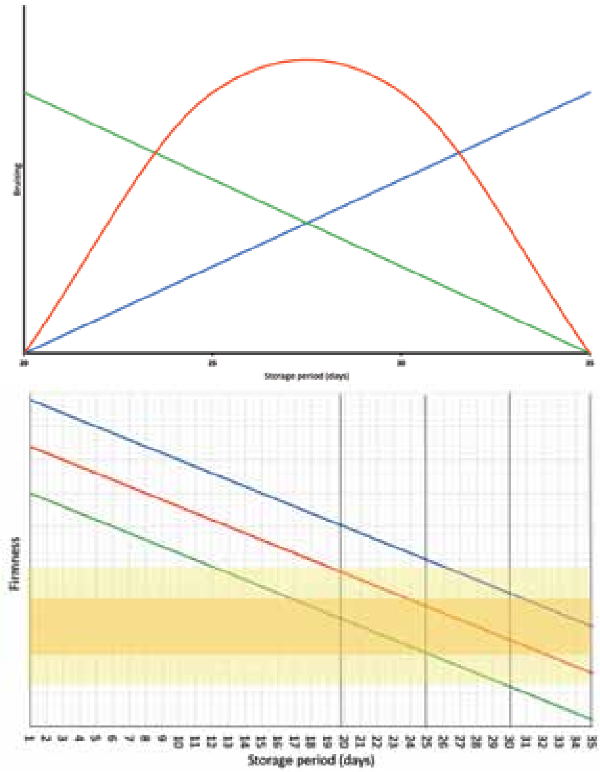

Figure 14. Graphic representation regarding the suggested interrelationship between storage period, fruit firmness and bruising incidence/intensity in avocado fruit as explained in the text.

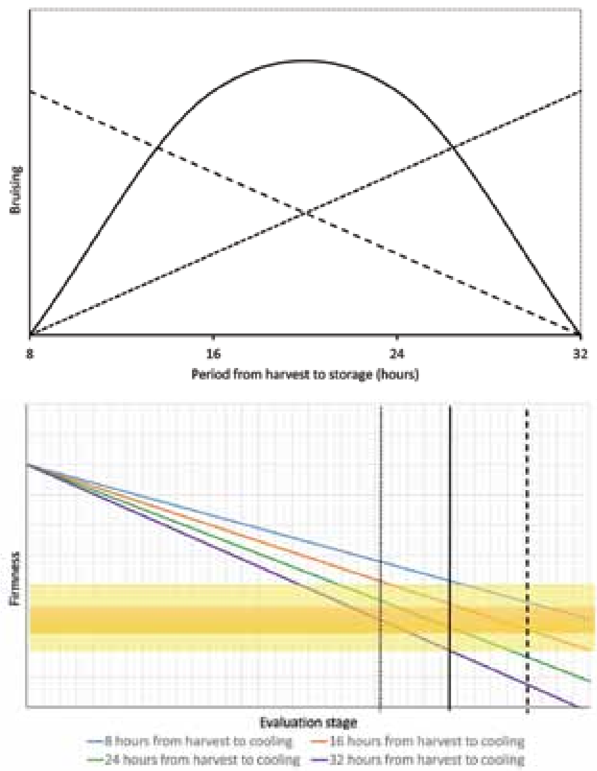

Figure 15. Graphic representation regarding the suggested interrelationship between the harvest to cooling period, fruit firmness and bruising incidence/intensity in avocado fruit as explained in the text.