IMPACT OF RAINFALL PRIOR TO HARVEST ON RIPE FRUIT QUALITY OF 'HASS' AVOCADOS IN NEW ZEALAND

H.A. PAK, J. DIXON, D.B. SMITH, T.A. ELMSLY AND J.G.M. CUTTING

Avocado Industry Council Ltd, P.O. Box 16004, Bethlehem, Tauranga
E-mail: HenryPak@nzavocado.co.nz

ABSTRACT

Three field trials (October 2002, December 2002 and February 2003) were conducted to determine the impact of different amounts of rain in the 24 hours preceding harvest on both susceptibility to handling damage and ripe fruit quality. In each trial a control sample of 200 fruit were harvested prior to the forecast rain event. Half of the fruit were picked directly into trays, while the remainder was jostled to simulate handling during the harvesting process. Further samples were then harvested after various periods of rain, and a final sample at least 24 hours after rain ceased. Fruit were coolstored for 28 days at 4-5ºC, then ripened at 20ºC and fruit quality assessed at eating ripeness. As little as 5mm of rain was sufficient to impact negatively on ripe fruit quality. Rain increased the susceptibility of fruit to handling damage, and facilitated the development of body rots. Jostling of fruit had a greater effect on development of body rots than on stem-end rots. During prolonged periods of rain fruit quality may revert to that prevailing prior to the start of the rain event. Analysis of the industry library tray database confirmed that rainfall prior to harvest increased the incidence of stem-end rots and severity of body rots.

Keywords: handling damage, body rots, stem-end rots, lenticel

INTRODUCTION

In order to optimise export quality of New Zealand (NZ) avocados the Avocado Industry Council sets guidelines for harvest conditions, which include rainfall. The guidelines currently specify that fruit should not be harvested if more than 5mm of rain has fallen within the previous 24 hours, as this level of rainfall should be sufficient to increase fruit turgor. High fruit turgidity has been shown through *in vivo* experiments to increase the susceptibility of lenticels to handling damage (Everett *et al.*, 2001). Mechanical pressure applied to a lenticel in a turgid state may lead to rupture of the underlying cells. Browning of the tissues beneath the lenticel may result (Figure 1A), with a characteristic translucent appearance in recently damaged tissue (Figure 1B). Symptoms of peel handling damage may appear as little as two hours after turgid fruit are subject to handling. Everett *et al.* (2001) also showed that as fruit lose water and the lenticels return to their normal state, they are less susceptible to handling damage.

***) An abbreviated version of this paper was first published in the Proceedings of the Vth World Avocado Congress**

A)

B)

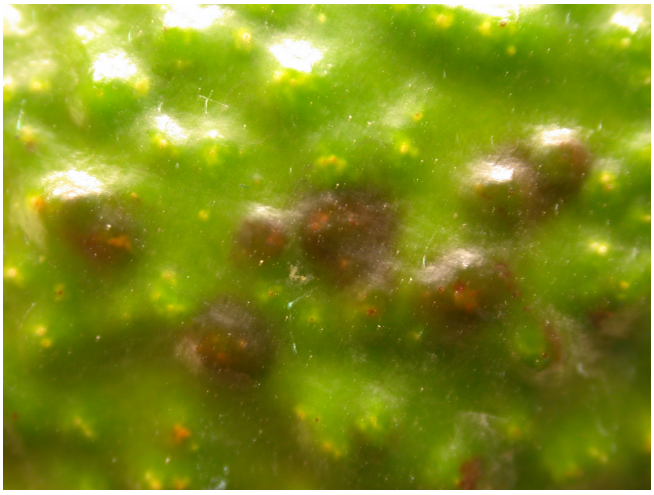

Figure 1. A) Fruit showing symptoms of peel handling damage within 24 hours of being subjected to jostling treatment. B) Close up of damaged lenticels exhibiting characteristic translucency.

While it has been generally accepted that fruit harvested while wet are more prone to develop post-harvest rots, the extent to which peel handling damage contributes to an increased level of post-harvest rots is uncertain. Similarly, the level of rainfall required to impact on susceptibility to handling damage and ripe fruit quality under field conditions has not been determined. Field experiments were conducted in the 2002/3 harvest season to determine the impact of different amounts of rain in the 24 hours preceding harvest on both susceptibility to handling damage and ripe fruit quality. In addition, the industry library tray database was interrogated to determine the impact of rainfall in the 24 hours prior to harvest on ripe fruit quality in commercially harvested fruit.

MATERIAL AND METHODS

Each trial was timed to coincide with a rain forecast that followed a 2-3 week dry period. There were 3 trials carried out in October 2002 (Trial A), December 2002 (Trial B) and February 2003 (Trial C). All fruit were harvested from a single orchard block in the Bay of Plenty region (37°S, 176°E), North Island of NZ. In each trial a control sample of 200 fruit were harvested prior to the forecast rain event. Half of these fruit were placed into trays and the remainder jostled in plastic bins using the method of Everett *et al.* (2001) to simulate handling during the harvesting process. Further samples were then harvested after various periods of rainfall, recorded daily at 9.30 am, and a final sample at least 24 hours after it had ceased raining. Fruit were coolstored for 28 days at 4-5ºC, then ripened at 20ºC and fruit quality assessed at eating ripeness. Ripeness was determined by firmometer when the fruit reached a softness reading of 85 using a 300g weight or by hand feel after calibration to a firmometer. Fruit were assessed for disorders according to the Avocado Industry Council Fruit Assessment Manual (2001). Disorders were rated by assessing the percentage (scale 0 to 100) of the cut surface of the fruit or skin surface area that was affected by disorders. Green fruit were rated for peel damage (skin abrasions) and peel handling damage (diffuse grey patches spreading beyond individual nodules; Figure 1). Ripe fruit were cut longitudinally into quarters where the cut surface of ripe fruit was rated for stem-end rot (discoloured flesh from the stem button down) and vascular browning. The under side of the peeled skin was rated for brown patches (body rot as circular brown coloured patches).

The results of each individual trial were analysed using a nested ANOVA design in Minitab. The relationship between handling damage and body rot incidence was determined using a multiple regression model in Minitab.

Rainfall prior to harvest was recorded for 26% of the 1110 lines entered in the industry database for the 2002/2003 season. Lines were grouped according to rainfall (0, 0.1-5mm, 5.1-10mm, 10.1-15mm, 15.1-20mm and >20mm. The corresponding rot incidence and severity was calculated and the results analysed using an unbalanced ANOVA in Minitab.

RESULTS AND DISCUSSION

Trial A

A light rainfall of 12mm in the 24 hours prior to harvest on the 17/10/02 increased both the incidence ($p<0.05$) and severity ($p<0.05$) of peel handling damage despite the minimal handling of the fruit (Table 1, Figure 2A). After a further 24 hours even though there was no more rain, the incidence of unsound fruit increased in the control due to an increase in the incidence of body rots (Figure 2C).

Jostling of fruit on the 11/10/02 prior to the rain event increased the incidence of unsound fruit relative to the control by 17%, mainly due to an increase in the incidence of body rots (Table 1, Figure 2C). Although jostling significantly increased both incidence ($p<0.001$) and severity ($p<0.001$) of peel handling damage, jostling fruit either during or 24 hours after the rain event did not impact on ripe fruit quality. This may be related to the reduction in peel handling damage and severity.

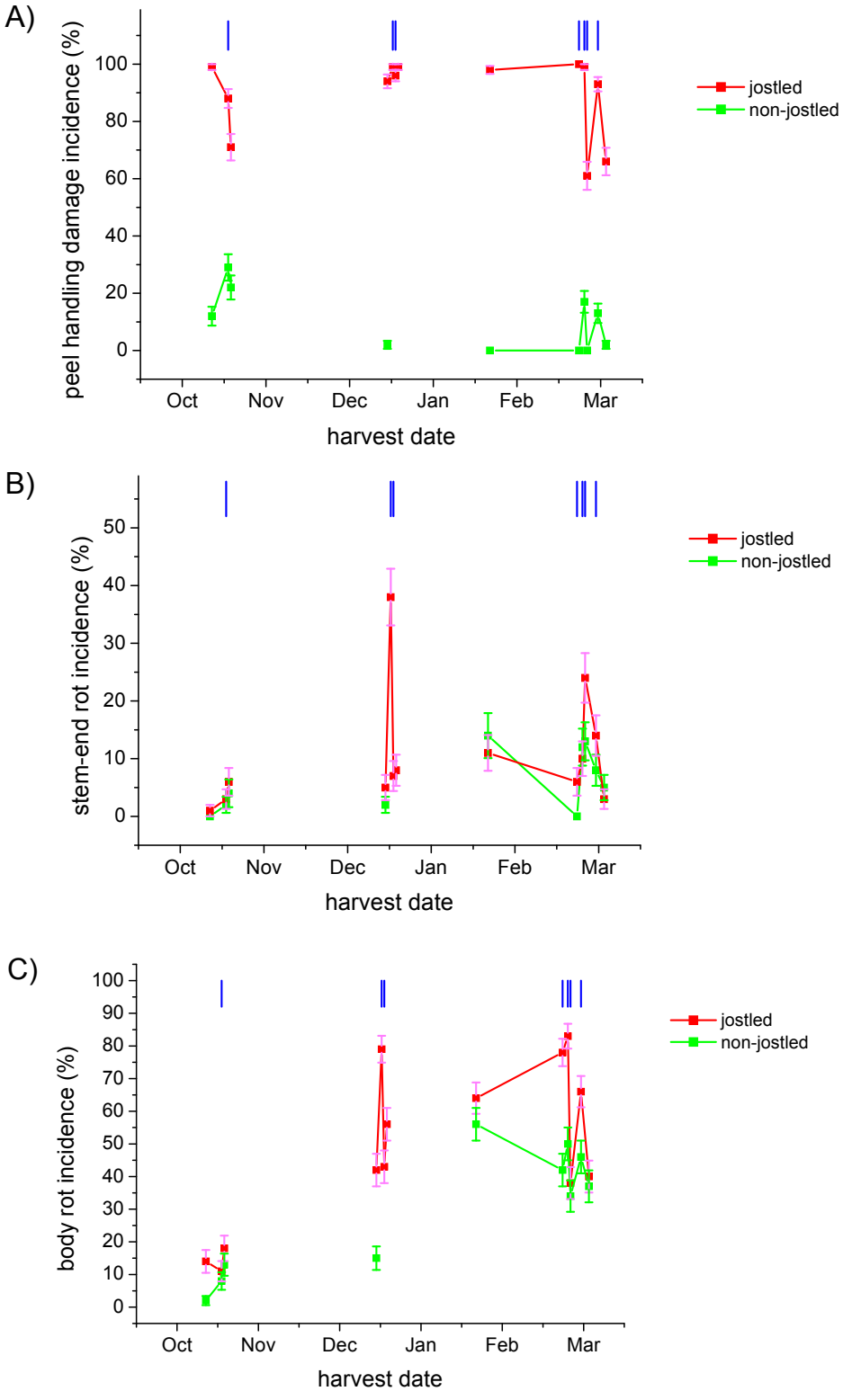

Figure 2. Combined results of Trials A-C comparing jostled and non-jostled fruit at each harvest date (± s.e.) for incidence of peel handling damage (A), incidence of stem-end rots (B) and incidence of body rots (C). Solid blue bars indicate the timing of rain events within each trail.

Trial B

Jostling of fruit on 16/10/02 prior to the rain event increased the incidence and severity of peel handling damage and body rots relative to the control (Table 2, Figure 2A,C). The proportion of unsound fruit increased by 27% as a result of jostling due to an increase in body rots. There was no effect of jostling on either stem-end rot incidence or severity.

Table 1. Trial A: Effect of harvest date, rainfall (mm) in the 24 hours prior to harvest and handling treatment on severity and incidence of stem-end rots (SER), brown patches (BP), peel handling damage (PHD) and incidence of unsound fruit (incidence of ripe fruit with any disorders exceeding 5%). ANOVA table for effect of date and of handling treatment (control vs jostled) by date.

			Severity			Incidence			
Date	Rain	Handling	SER	BP	PHD	SER	BP	PHD	Unsound
11/10/02	0	Control	0	0.10	0.14 a	0	2 a	12 a	2 a
17/10/02	12	Control	0.02	0.12	0.48 b	2	8 a,b	29 b	9 a,b
18/10/02	0	Control	0.04	0.19	0.29 a,b	4	13 b	22 a,b	16 b
ANOVA		**Date**	**ns**	**ns**	**p=0.003**	**ns**	**p=0.014**	**p=0.012**	**p=0.002**
11/10/02	0	Jostled	0.01	0.29	4.12 a	1	14	99 a	19
17/10/02	12	Jostled	0.03	0.18	2.48 b	3	11	88 a,b	14
18/10/02	0	Jostled	0.11	0.31	2.84 b	6	18	71 b	24
ANOVA		**Date**	**ns**	**ns**	**p=0.002**	**ns**	**ns**	*******	**ns**
ANOVA		**handling*date**							
		11/10/02	ns	ns	***	ns	p=0.002	***	***
		17/10/02	ns	ns	***	ns	ns	***	ns
		18/10/02	ns	ns	***	ns	ns	***	ns

*** p<0.001, ns not significant. Values within the same section of column (jostled/control) with the same letter are not significant at p=0.05 according to the Tukeys' HSD test.

In terms of rainfall, 5mm of rain falling in the 24 hours prior to harvest on 18/12/02 resulted in an increase in incidence and severity of both stem-end and body rots in jostled fruit as well as severity of peel handling damage (Table 2, Figure 2B,C). The proportion of unsound fruit was increased more than 40%. However, a further 21mm rain in the following 24 hours resulted in an improvement in fruit quality and decrease in the severity of peel handling damage, with a return to the incidence of unsound fruit prior to the rain on 17/12/02. After a further 24 hours of no rain fruit harvested on the 20/12/02 differed significantly from the fruit harvested prior to the initial rain event on 17/12/02 only in a higher incidence of body rots.

Table 2 Trial B: Effect of harvest date, rainfall (mm) in the 24 hours prior to harvest and handling treatment on severity and incidence of stem-end rots (SER), brown patches (BP), peel handling damage (PHD) and incidence of unsound fruit (incidence of ripe fruit with any disorders exceeding 5%). ANOVA table for effect of date and of handling treatment (control vs jostled) by date.

			Severity			Incidence			
Date	Rainfall	Handling	SER	BP	PHD	SER	BP	PHD	Unsound
16/12/02	0	Control	0.03	0.07	0.1	2	15	2	16
16/12/02	0	Jostled	0.09 a	1.32 a	3.0 a	5 a	42 a	94	43 a
18/12/02	5	Jostled	1.15 b	3.07 b	4.9 b	38 b	79 b	99	86 c
19/10/02	21	Jostled	0.20 a	0.78 a	3.2 a	7 a	43 a	96	47 a,b
20/12/02	0	Jostled	0.20 a	1.73 a	3.3 a	8 a	56 a	99	61 b
ANOVA		**Date**	***	***	***	***	***	**ns**	***
ANOVA		**Handling by date**							
		16/12/02	ns	***	***	ns	***	***	***

*** $p<0.001$, ns not significant. Values within the same section of column (jostled/control) with the same letter are not significant at $p=0.05$ according to the Tukeys' HSD test.

Trial C

This trial captured a prolonged rain period that was preceded by at least 4 weeks with no significant rainfall. The initial rain event of 10mm preceding harvest on 24/2/03 lead to a reduction in both incidence of stem-end rots and unsound fruit relative to the control fruit harvested one month earlier under dry conditions (Table 3). While the interval between these two harvest dates is greater than desirable the observed reduction in stem-end rot runs counter to an observed trend for incidence and severity of both stem-end rots and body rots to increase over this time of year (Pak, 2001).

Table 3 Trial C: Effect of harvest date, rainfall (mm) in the 24 hours prior to harvest and handling treatment on severity and incidence of stem-end rots (SER), brown patches (BP), peel handling damage (PHD) and incidence of unsound fruit (incidence of ripe fruit with any disorders exceeding 5%). ANOVA table for effect of date and of handling treatment (control vs jostled) by date.

			Severity			Incidence			
Date	Rain	Handling	SER	BP	PHD	SER	BP	PHD	Unsound
22/1/03	0	Control	0.25 a,b	2.0 a	0 a	14 a	56 a	0 a	60 a
24/02/03	10	Control	0 a	1.0 a,b	0 a	0 b	42 a,b	0 a	42 b
26/02/03	17.5	Control	0.24 a,b	1.2 a,b	0.2 b	12 a	50 a,b	17 b	54 a,b
27/02/03	23	Control	0.31 b	0.3 b	0 a	13 a	34 b	0 a	43 b
3/03/03	77	Control	0.14 a,b	1.5 a,b	0.2 b	8 a,b	46 a,b	13 b	47 a,b
7/03/03	0	Control	0.10 a,b	1.4 a,b	0 a	5 a,b	37 b	2 a	38 b
ANOVA		**Date**	**p=0.04**	**p=0.005**	***	**p=0.002**	**p=0.018**	***	**p=0.018**
22/1/03	0	Jostled	0.31a,b	4.6 a	3.6 a	11 a	64 a	98 a	66 a
24/02/03	10	Jostled	0.10 b	2.3 b	4.7 a,b	6 a	78 a,b	100 a	79 a,b
26/02/03	17.5	Jostled	0.20 a,b	3.2 a,b	5.1 b	10 a	83 b	99 a	84 b
27/02/03	23	Jostled	0.50 a	0.5 c	1.4 c	24 b	38 c	61 b	48 c
3/03/03	77	Jostled	0.28 a,b	3.5 a,b	3.5 a	14 a,b	66 a	93 a	68 a
7/03/03	0	Jostled	0.05 b	0.6 c	1.1 c	3 a	40 c	66 b	43 c
ANOVA		**Date**	**p=0.002**	***	***	***	***	***	***
ANOVA		**handling by date**							
		22/1/03	ns	p=0.004	***	ns	ns	***	ns
		24/02/03	p=0.017	***	***	p=0.013	***	***	***
		26/02/03	ns	***	***	ns	***	***	***
		27/02/03	ns	p=0.024	***	p=0.045	ns	***	ns
		3/03/03	ns	p=0.002	***	ns	p=0.004	***	p=0.003
		7/03/03	ns	ns	***	ns	ns	***	ns

*** p<0.001, ns not significant. Values within the same section of column (jostled/control) with the same letter are not significant at p=0.05 according to the Tukeys' HSD test.

Prolonged heavy rain had a limited impact on quality of the control fruit with no increase in the severity of brown patches or stem-end rots, or in the incidence of unsound fruit or body rots, despite over 127 mm of rain falling over a two week period (Table 3). Quality of fruit harvested four days after the rain event on 7/3/2003 was better than that of fruit harvested on 22/1/2003 with a lower incidence of body rots (Figure 2C) and unsound fruit (Table 3). Incidence and severity of peel handling damage followed a cyclic pattern with peaks on the 26/2/2003 and 3/3/2003 (Figure 2A).

Fruit that had been subjected to jostling also showed a cyclical pattern in peel handling damage. Low incidences and severities were observed for fruit harvested on the 27/2/2003 and 7/3/2003, which complemented the peaks observed in the control fruit (Table 3, Figure 2A). The decreased incidence of unsound fruit on 27/2/2003 and 7/3/2003 is due to a decline in the incidence and severity of body rots. While body rots tended to reflect changes in peel handling damage, stem-end rots

were greatest in jostled fruit on 27/2/2003, when body rots were lowest. (Figure 2A-C)

Fruit harvested prior to rain on the 22/1/2003 and subjected to jostling had greater peel handling damage severity and incidence and a higher severity of body rots than the control (Table 3). Fruit harvested after the start of rain on the 24/2/2003 that were jostled had increased severity and incidence of stem-end rots, body rots and peel handling damage with an increase of 27% unsound fruit. Continued rain prior to harvest on 26/2/2003 combined with jostling increased severity and incidence of body rots relative to the control, although there was no impact on stem-end rots. Fruit harvested on the 27/2/2003 were less prone to deterioration of quality as a result of jostling, despite the continued rain, with no significant difference in incidence of body rots or unsound fruit relative to the control. The reduced impact of jostling on fruit harvested on the 27/2/2003 coincides with low levels of peel handling damage observed on this date (Figure 2A). Ripe fruit quality was not significantly impacted by jostling four days after the end of the rain event on 7/3/2003. The combined results from Trial C suggest that harvesting fruit while wet increases susceptibility to handling damage and reduces ripe fruit quality but minimal handling of fruit limits the impact of prolonged rainfall on fruit quality.

The combined results of all these trials indicate that rainfall in the 24 hour period prior to harvest can have a detrimental impact on ripe fruit quality. The results of all three trails were combined to further elucidate the relationship between peel handling damage and ripe fruit quality. Using multiple regression a significant relationship (r^2=76.9%, $p<0.001$) was observed between the severity of peel damage, the amount of rainfall in the 24 hours preceeding harvest, harvest date and the incidence of body rots (Figure 3).

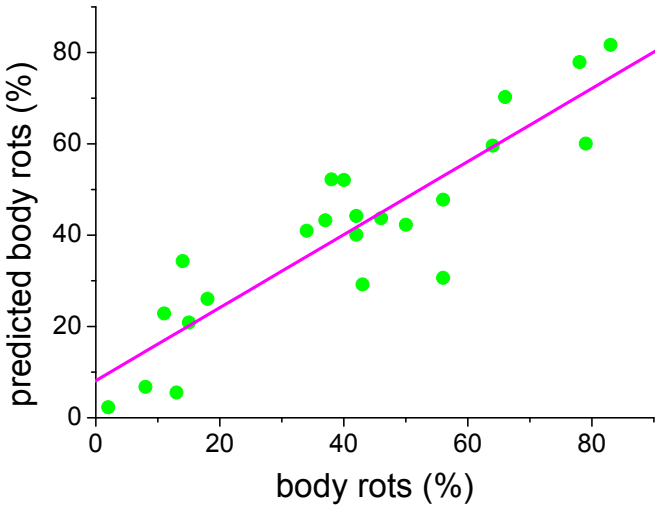

Figure 3. Relationship between observed incidence of body rots and those predicted using the model Y=10.8 + 8.1*PS + 0.29*Date – 0.02*Rain where PS = peel handling damage severity, date = harvest date, Rain = rainfall (mm) in the 24 hours preceeding harvest (r^2=76.9%, $p<0.001$).

Rainfall within the first 24 hours of the commencement of a rain event appears to have the greatest impact on quality, since any negative effects appear to be ameliorated with continued rain. This may reflect the role of inoculum level in the development of opportunistic infections on fruit with increased susceptibility as a result of handling damage. Continued rainfall may deplete the reserve of inoculum available to infect fruit, hence the perceived improvement in quality. The base level of rots to which the fruit reverts following prolonged periods of rain or following a rain event may reflect the level of latent infections as opposed to opportunistic infections that occur at harvest.

Susceptibility of fruit to handling damage increases during a rain event, but the fruit recover within 24 to 72 hours. Rainfall sufficient to wet the soil makes fruit more susceptible to peel handling damage. This is probably the result of increased turgidity of cells beneath the lenticular cavity (Everett *et al.,* 2001). The level of body rots that developed tended to reflect the susceptibility of fruit to peel handling damage (Figure 3), suggesting that peel handling damage may facilitate opportunistic infection.

Industry library trays

The database of fruit quality obtained from the industry library trays was interrogated to determine if there was any relationship between pre-harvest rainfall and ripe fruit quality. Where more than 10 mm of rainfall occurred in the 24 hours prior to harvest, there was a significant increase ($p<0.05$) in the incidence of stem-end rots in commercially harvested fruit with a further increase as the rainfall amount increased (Figure 4). Body rot severity increased significantly ($p<0.05$) in commercially harvested fruit when more than 15 mm of rainfall occurred prior to harvest (Figure 5). These results confirm the findings from the experimental trials indicating that rainfall prior to harvest impacts negatively on ripe fruit quality.

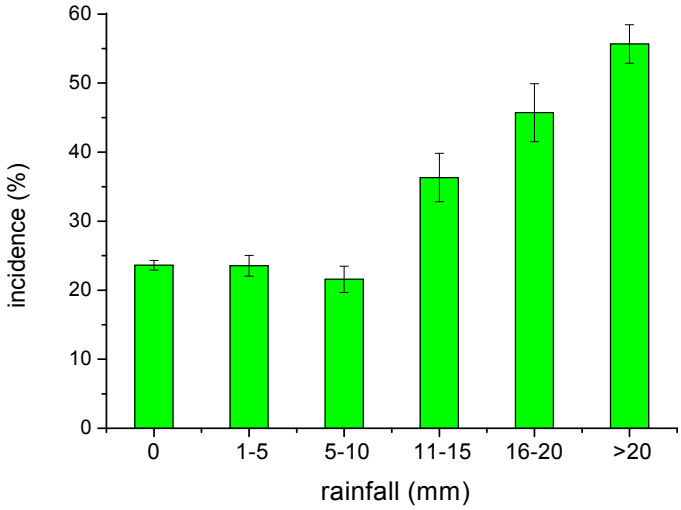

Figure 4. Impact of rainfall (mm) in the 24 hours prior to harvest on incidence of stem-end rots (± standard error). Data obtained from the industry library tray database (n=284 lines).

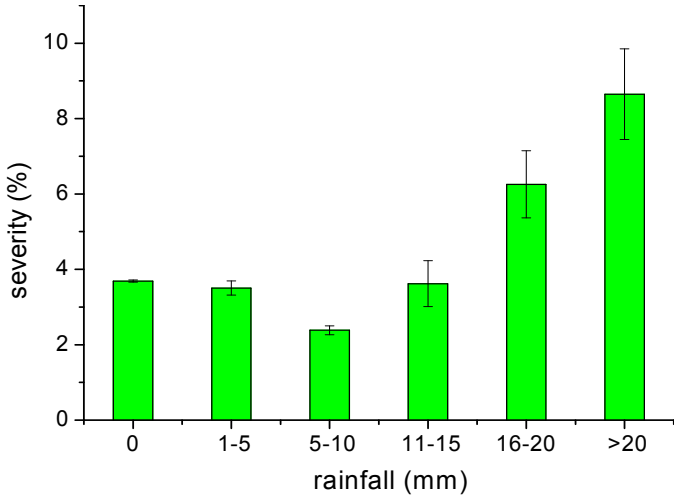

Figure 5. Impact of rainfall (mm) in the 24 hours prior to harvest on severity of body rots (± standard error). Data obtained from the industry library tray database (n=284 lines).

CONCLUSIONS

As little as 5mm rain in the 24 hours preceding harvest is sufficient to negatively impact on ripe fruit quality. Susceptibility of fruit to handling damage increases during a rain event but fruit recover with 24 to 72 hours. Peel handling damage appears to facilitate the development of body rots. Jostling of fruit had a greater effect on the development of body rots than on stem-end rots. Rainfall over a 48 hour period or longer may ameliorate the negative effects of shorter rainfall events, possibly by depleting the level of inoculum available for fruit infection. The experimental findings were confirmed in commercially harvested fruit, as indicated by the library tray results.

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