Acta Phytopathologica et Entomologica Hungarica 55 (1), pp. 89–102 (2020)
DOI: 10.1556/038.55.2020.006

Susceptibility of Avocado Fruit to *Scirtothrips aurantii* Faure (Thysanoptera: Thripidae) and Wind Scarring Damage in Limpopo and KwaZulu-Natal Provinces of South Africa

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(Received: 20 January 2020; accepted: 1 February 2020)

In South Africa, the avocado (*Persea americana*) is an important fruit, grown primarily for export and contributing ZAR 1.75 billion to the gross domestic product of the country. As an export driven industry, optimising exportable avocado fruit volume is a primary concern. Wind induced abrasion and damage by thrips (Thysanoptera: Thripidae), through their feeding on avocado fruit results in corky tissue development (scarring) and making the fruit unsuitable for export. The study aimed to determine the economic losses caused by these agents as well as assess different cultivar responses to scarring damage. Across cultivars, the 1.49% revenue annually due to *Scirtothrips aurantii* downgrading (3.86% loss factor), translating to ZAR 34.90 million (US$2.39 million). Packhouse study results showed that both thrips and wind abrasion damage accounted for 30% scarring damage, a loss factor of 13.72% and a combined revenue loss of 5.57%. The cultivar 'Pinkerton' showed the greatest susceptibility to scarring damage by both wind and *S. aurantii* whilst the cultivar 'Carmen®-Hass' showed a natural predisposition to higher levels of thrips damage. The presence of macadamia trees near avocado trees predisposes avocado fruit to *S. aurantii* damage.

Keywords: South Africa, avocado, fruit scarring, thrips, wind abrasion.

Grown mainly in the humid, subtropical areas of South Africa, avocado (*Persea americana* Miller, fam. Lauraceae) is an economically important tropical fruit, contributing ZAR 1.75 billion to the gross domestic product of the country (http://www.worldstopexports.com/avocados-exports-by-country/). Globally, avocado production was estimated to be in excess 3.5 million tonnes annually, 20% of which was traded amongst countries (Schaffer et al., 2013). The world's largest producer of avocados is Mexico, followed by Indonesia, Dominican Republic and USA (FAOSTAT, 2019). In 2014, avocado world production stood at 5 million tons, with Mexico accounting for 30% (1.52 million tons) of the total production (FAOSTAT, 2019). Approximately 76% of avocados are produced in the Americas, 11% in Africa, 9% in Asia and 2% in Europe and in the South Pacific. South Africa is the 12th largest producer of avocados and is among the top ten exporters of avocados globally (FAOSTAT, 2019). In Africa, Kenya is the largest avocado exporter, followed closely by South Africa. Other African countries that produce avocados include

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Rwanda, Democratic Republic of Congo, Cameroon, Tanzania and Zimbabwe. As an export oriented industry, South Africa primarily targets the European market (The Netherlands, UK, France and Spain) and in 2016, exported 57 867 tons of avocados with a total value of ZAR 1,061 million, accounting for approximately 1.7% of international market share (DAFF, 2017).

The worldwide demand for avocado has seen the area under avocados in South Africa increase rapidly from 2,000 ha in the 1970's (DAFF, 2017) to 17,500 ha in 2018, with forecasts of a further increase of 1,500 ha plantings to be planted annually for the next five years (Donkin, 2019). Commercial avocado production is mainly concentrated in the subtropical areas of Limpopo (60%), Mpumalanga (29%), KwaZulu-Natal (9%) and parts of the Cape Province (2%) (Donkin, 2019). Approximately 70% of the trees grown in South African avocado nurseries are 'Hass' and the remaining 30% is comprised mostly of 'Fuerte', 'Ryan' and 'Pinkerton' (Blakey and Wolstenholme, 2014).

Of the 170,000 tons produced in 2018, approximately 51% (86,000 tons) were exported, mainly to Europe, approximately 10-15% were processed (oil and purée) and the rest were sold at fresh produce markets (Donkin, 2019). The value of 2018 South African avocado export fruit was estimated at US$116.7 million (ZAR 1.75 billion), approximately 2.1% of total income from exported avocados globally (http://www.worldstopexports.com/avocados-exports-by-country/).

As an export driven industry, optimising the volumes of exportable avocado fruit is a primary concern. The presence of poor quality fruit plagues the industry, and with several global competitors vying for the same market, the need to improve quality is paramount (Nelson, 2014). Several pests and diseases work to constrain production and export. Diseases such as Phytophthora root rot caused by *Phytophthora cinnamomi* Rands (Zentmyer, 1979), anthracnose (*Colletotrichum gloeosporioides* (Penz.) Penz. et Sacc.) and cercospora spot (*Pseudocercospora purpurea* (Cooke) Deighton) (Darvas and Kotze, 1987) cause major economic losses. Insect pests such as thrips, sucking bugs, false codling moth, fruit flies, avocado scale (*Fiorinia fioriniae* (Targioni-Tozzetti)) (Erichsen and Schoeman, 1992), and the heart shaped scale (*Protopulvinaria pyriformis* (Cockerell)) (Du Toit et al., 1991) are among some of the pests which commonly reduce the quality of avocado fruit in South Africa.

With a continuously expanding market and changes in the production and market systems, thrips pose a constant threat to avocado production. Feeding by both adults and larvae on the fruit epidermis causes permanent superficial scarring of the fruit that appears as corky (alligator) tissue. As Stevens et al. (1999) noted, minimal thrips scarring can be tolerated but damage in excess of 2 cm^2 area will result in the fruit being unacceptable for premium export grade (downgraded to local market or processing grade).

Thrips are minute, fringe-winged insects in the order Thysanoptera, suborder Terebrantia or Tubulifera. With a few exceptions of thrips species belong to the suborder Tubulifera (*Haplothrips*, *Liothrips*, *Gynaikothrips*), most pest species of thrips belong to the suborder Terebrantia. Important thrips pests belong to the family Thripidae that contains a number of widespread, polyphagous and multivoltine species.

A study carried out by Bara and Laing (2019) established that *Scirtothrips aurantii* Faure (Thysanoptera: Thripidae) (South African citrus thrips) was a major economic pest of avocado fruit (Fig. 1). Damage to avocado in the USA by a related thrips species *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) (avocado thrips) has been estimated to cost that industry US$8.65 million annually (Hoddle et al., 2003). Feeding by low densities of *Scirtothrips perseae*, approximately three larvae on young avocado fruit (< 5 cm in length) was determined to scar the entire fruit surface, with the localized feeding starting as discrete brown scars that elongate as fruit matures (Hoddle et al., 2002) (Fig. 1).

Scirtothrips aurantii is an established pest of citrus (Gilbert and Bedford, 1998) and mango (Grové et al., 2000). Bean-shaped, minute eggs (less than 0.2 mm) are laid separately in soft green fruit tissue, tender leaves and shoots (Bedford, 1943) by means of a serrated ovipositor. The two feeding larval stages that follow the egg stage are yellow to orange and cigar-shaped. These are followed by two non-feeding pupal stages, the prepupa and the pupa. The average duration of the larval stages is about 7.6 days whilst that of the pupal stages is 4.0 days, depending on the temperature (Bedford, 1943). Adult thrips are yellowish-orange. All stages are less than 1 mm in length and are barely visible to the unaided eye. In citrus, the duration of the life cycle varies from 44 days in winter to 18.4 days in summer, with 9.4 generations being possible every year (Bedford, 1943). The species is not known to undergo diapause owing to the mild climatic conditions of the main citrus-producing areas in South Africa (Gilbert and Bedford, 1998). This means that, subject to the availability of suitable feeding conditions, larvae and adults can be found throughout the year.

Young avocado fruit are especially vulnerable to *S. aurantii* feeding damage (Bara and Laing, 2019). As young foliage from the spring growth hardens during the time of fruit set, adult female thrips move from the foliage to feed and oviposit into young fruit. Feeding by the emerged larvae and adults results in damage to the skin of developing fruit (Hoddle et al., 2002).

Carapace skin first described by Horne (1929) is a type of abrasion (mechanical) injury on avocado fruit caused by wind induced rubbing of tender young fruit on leaves or stems. Chronic recurring wind damage on young fruit causes russet type blemishes (angular netting), which may grow to cover significant portions of the fruits as the fruit mature. The scar tissue is rigid and as the fruit grows, it fractures along lines of force, resulting in the scars showing angular netting (Fig. 1). In mature fruit, the damage exhibits itself as external corky, cracked tissue with regular, angular divisions resembling a turtle's back. The flesh underneath the scar is undamaged but the external appearance of the fruit results in downgrading of the fruit at packhouses (Dreistadt, 2007).

The objectives of this study were to quantify losses incurred and describe the susceptibility of different avocado cultivars to damage by wind abrasion and *Scirtothrips aurantii* in Limpopo and KwaZulu-Natal Provinces of South Africa.

Materials and Methods

Study sites

This study was carried out at in the province of KwaZulu-Natal at Conlink Trust Farm (–29.453415, 30.683398) Wartburg; Everdon Estate (–29.452322, 30.266425), Howick; and at Baynesfield Estate (–29.756873, 30.314269), Richmond. In the province of Limpopo, the study was carried out at Lombard Avocado (–23.923729, 30.136581) and at three Westfalia farms – Macnoon (–23.719230, 30.131611); Waterval (–23.754705, 30.123056); and Fowey (–23.812237, 30.120610).

Fruit infestation

In May and June 2019, 515 'Carmen®-Hass' fruitlets 15-20 mm long were randomly collected from fruiting trees at Macnoon (Limpopo) and Everdon (KZN) and brought to the University of KwaZulu-Natal laboratory for incubation or 'rearing', as described by Bara and Laing (2019). The fruit infestation index was calculated as the ratio of the number of larvae and adults per fruit collected (Cowley et al., 1992).

Scarring damage assessment

From June 2018 to September 2019, 27,800 fruits from 'Hass', 'Pinkerton', 'Fuerte' and 'Rinton' were randomly sampled from in field assessments from the two provinces. Each fruit was examined for thrips and wind scarring damage. Limpopo field assessments were conducted in May 2019, in which 60 trees per cultivar were randomly selected from blocks of 'Hass', 'Fuerte' and 'Pinkerton'. From these 60 trees, 15 mature fruit per cardinal direction giving a sample size of 3,600 per block. In KwaZulu-Natal, 45 trees per cultivar ('Hass', 'Fuerte', 'Rinton' and 'Pinkerton') per block were randomly selected in June to July 2019 and from these trees two mature (ready to harvest) fruit per cardinal direction were selected giving a sample size of 360 per cultivar.

Fig. 1. Scarring damage on avocado fruit:
a) blemish free fruit; b) Scirtothrips aurantii damage; and c) wind induced abrasion damage

The packhouse study was done at Conlink Trust farm, KZN during the August to September 2018 fruit packing period. Ten lugs (= crates) of freshly picked, unsorted avocado fruit were randomly selected from fruit being packed at the time. A total of 100 fruit were sampled per cultivar per sampling period and the sampling was done twice giving a sample size of 800 fruit.

The percentage fruit damage and damage severity was evaluated for each cultivar (Phillips et al., 1995), and expressed as Class 1 and Class 2 grade (for export), % local grade (downgraded), % reject, to quantify damage and assess susceptibility of the cultivars to wind and thrips damage. Percent damage was calculated as % damage = 100 (a/b):

where:

a = the number of fruit with scarring damage; and b = the total number of fruit assessed.

The amount of scarring covering the surface of fruit was visually rated using ranks modified from Phillips et al. (1995): 1, no scar; 2, < 2 cm^2 scarring damage; 3, 2 cm^2 –

half of the fruit scarred; 4, greater than half of the fruit scarred; 5, completely scarred. To eliminate biases in assessing scarring damage, a fixed team of evaluators scored fruit.

A fixed exchange rate of 1 EUR = ZAR 16.55 (https://www.exchange-rates.org/Rate/EUR/ZAR/10-10-2019) was assumed for all financial calculations to cater for fluctuations in the exchange rates. Due to currency fluctuations, seasons and the impact of competition from other exporting countries, sometimes the revenue earned from local sales exceeds that of exports but for purposes of this study, it was assumed that exports significantly earn more than local sales. Potential revenue export is the revenue that potentially accrues to the industry when avocado fruit are exported and this can be approximated using the equation:

Export revenue = a × b

where:

a = % Class 1 and 2 (export) fruit; and b = potential total revenue.

Potential revenue from local sales (downgraded fruit) is the revenue that growers gain per ton when Class 3 and Class 4 fruits are sold on the local market. This is represented by the equation:

$$\textit{Revenue from downgraded fruit} = \frac{a+b}{100} \times 1000 \times c$$

where:

a = % Class 3; and b = % Class 4; c = market price

Potential revenue loss is the estimated loss in revenue when fruit are downgraded, *i.e.,* the difference between potential revenue and revenue gained from downgraded fruit sales and estimated using the equation:

Potential revenue loss = $a - (b + c)$

where:

a = potential revenue; b = revenue gained from Class 1 and 2 export sales; and c = revenue from local, downgraded fruit sales.

The percent loss is the potential loss expressed as a percent of potential revenue and is calculated as % loss = 100 (a/b):

where:

a = potential revenue loss; and b = potential revenue.

Statistical analysis

Scoring data was analysed using non-parametric Kruskal–Wallis rank sum test and pairwise comparisons done using Wilcoxon rank-sum test in R (v. 3.6.1., R Foundation for Statistical Computing, Vienna, Austria).

Results

The damage scores of ‘Fuerte’, ‘Rinton’, ‘Hass’ and ‘Pinkerton’ were determined by visual assessment. The damage scores were not normally distributed and the non-parametric Kruskal–Wallis rank sum test was therefore used for data analysis. Wind damage across all the cultivars investigated accounted for 25.33% downgrading (loss factor %) in Pietermaritzburg (KwaZulu-Natal), which was significantly different from the 3.92% recorded for Tzaneen (Limpopo) (Kruskal–Wallis $\chi^2 = 3591.6$, df = 1, $P < 0.001$). More fruits suffered from wind induced abrasion in KZN (55.06%) than in Limpopo (8.27%) (Tables 1 and 2).

Table 1

Summary of wind induced damage on avocado fruits in Limpopo and KZN

Site	N	Export	% Scarring	Loss factor %	Mean ± se
Limpopo	25200	96.08	8.27	3.92	1.13 ± 0.003^{a}
KZN	1800	74.67	55.06	25.33	1.81 ± 0.02^{b}
Pooled	27000	94.66	11.39	5.34	1.18 ± 0.003

Note: Periods sharing a letter in superscript are not significantly different at the 0.05 level according to Benjamini-Hochberg (BH) procedure, $P < 0.05$. Kruskal–Wallis $\chi^2 = 3591.6$, df = 1, $P < 0.001$.

Table 2

Wind induced damage in Limpopo and KZN

	Limpopo		KwaZulu-Natal	
Cardinal Direction	N	Mean ± se	N	Mean ± se
North	6300	1.143 ± 0.006^{b}	450	1.742 ± 0.038^{b}
East	6300	1.117 ± 0.001^{a}	450	1.627 ± 0.036^{a}
West	6300	1.152 ± 0.001^{b}	450	1.947 ± 0.041^{c}
South	6300	1.110 ± 0.005^{a}	450	1.940 ± 0.041^{c}

Note: Periods sharing a letter in superscript are not significantly different at the 0.05 level according to Benjamini-Hochberg (BH) procedure, $P < 0.05$. Kruskal–Wallis $\chi^2 = 3591.6$, df = 1, $P < 0.001$.

Table 3

Summary of fruit scarring damage caused by wind induced abrasion and *S. aurantii*

Cultivar	N	Scarring %	Mean ± se	Loss factor %	% Export	Revenue lost %
'Fuerte'	200	31.50	1.39 ± 0.04^{b}	7.00	93.00	2.65
'Hass'	200	11.00	1.16 ± 0.03^{a}	4.50	95.50	2.77
'Pinkerton'	200	44.00	1.80 ± 0.07^{c}	33.50	66.50	12.69
'Rinton'	200	33.50	1.49 ± 0.05^{b}	15.50	84.50	5.87
Pooled	800	30.00	1.46 ± 0.03	13.72	86.28	5.57

Note: Treatments sharing a letter in their superscript are not significantly different at the 0.05 level according to Benjamini-Hochberg (*BH*) procedure, $P < 0.05$. Damage score: 1, no scar; 2, < 2 cm^2 scarring damage; 3, 2 cm^2 – half of the fruit scarred; 4, greater than half of the fruit scarred; 5, completely scarred.

In Tzaneen, the greatest wind induced damage was recorded on fruits in the North-West direction and the least in the East-South direction (Kruskal–Wallis $\chi^2 = 27.749$, df = 3, $P < 0.001$). In Pietermaritzburg, the greatest wind damage was recorded in the South-West direction whilst the least damage was recorded in the East direction (Kruskal–Wallis $\chi^2 = 27.749$, df = 3, $P < 0.001$) A packhouse study of 800 mature, fruit harvested from four cultivars in Wartburg, Pietermaritzburg was done in August and September 2018. For this study, where scarring from thrips and wind damaged were pooled, 30% of the fruits showed some form of scarring damage, a loss factor of 13.72%, and combined revenue loss of 5.57% was recorded (Table 3). The data was not normally distributed and the Kruskal–Wallis non-parametric test was performed to analyse the data. 'Hass' showed the least scarring (1.16 ± 0.03), followed by 'Fuerte' (1.39 ± 0.04), 'Rinton' (1.49 ± 0.05) and 'Pinkerton' (1.80 ± 0.07). 'Rinton' and 'Fuerte' scarring was not significantly different from each other (Kruskal–Wallis $\chi^2 = 63.822$, df = 3, $P < 0.001$). In terms of revenue lost, a pooled 5.57% can be across the cultivars, with 'Fuerte' showing the least revenue lost (2.65%), while 'Pinkerton' had the highest at 12.69 % When pooled, thrips damage was highest on 'Pinkerton' with a mean damage score of 1.265, and the least thrips damage was recorded on 'Fuerte' (1.008 ± 0.001) (Table 4) (Fig. 2). The damage on the cultivars differed significantly from each other (Kruskal–Wallis $\chi^2 = 1172$, df = 3, $P < 0.001$). The mean damage score was between 1 and 2, implying that in most cases, the damage scar was ≤ 2 cm^2. In Limpopo Province, 'Fuerte' was the least thrips scarred avocado cultivar (1.004 ± 0.001), followed by 'Hass' (1.121 ± 0.004) and then 'Pinkerton' (1.272 ± 0.008). Very little 'Rinton' is grown in Limpopo Province, and no data for scarring damage was recorded. In KwaZulu-Natal, 'Rinton' had the least thrips scarring, with a damage score of 1.044 ± 0.016. 'Fuerte' (1.097 ± 0.018) scar damage was significantly different to 'Rinton' (1.044 ± 0.016), but was not significantly different to 'Hass' (1.122 ± 0.021). The highest damage score was recorded for 'Pinkerton' at 1.193 ± 0.019. However, this was not significantly different to 'Hass's (1.122 ± 0.021) (Kruskal–Wallis $\chi^2 = 37.733$, df = 3, $P < 0.001$)).

The summary of the financial impact of damage caused by *S. aurantii* is summarised in 'Pinkerton' consistently showed greater thrips scarring, downgraded percent and revenue loss. The revenue lost was higher in Limpopo (ZAR2418.06 across the three cultivars) than in KZN (ZAR1955.63 for the four cultivars).

Site differences were clearly illustrated at Westfalia, Tzaneen when blocks of 'Hass' and 'Carmen®-Hass'- a "Hass-type" cultivar. Thrips damage at Macnoon farm, where blocks Macnoon 5C, Macnoon 4B and Macnoon 'Carmen®-Hass' were close to a macadamia (*Macadamia integrifolia* Maiden et Betche) orchard of the 695 ('Beaumont') cultivar were significantly different to block Fowey 'Hass' Z2A, which was about 10 km away from the macadamia orchard (Kruskal–Wallis $\chi^2 = 854.4$, df = 3, $P < 0.001$). In particular, block Macnoon 4B recorded the highest level of thrips damage (1.272 ± 0.010) and was adjacent to the macadamia orchard, whereas the least scarred was block Fowey 'Hass' at 1.0023 ± 0.001 (Fig. 3). The higher damage scores recorded at Macnoon was further supported by thrips infestation studies carried out in May and June 2019, which revealed a fruit infestation index of 53.33 % compared to Everdon's 17.6%. The 'Carmen®-Hass' at Macnoon is planted very close to a macadamia block while the 'Carmen®-Hass' at Ever-

Table 4

Scirtothrips aurantii scarring damage scores in Limpopo and KwaZulu-Natal Provinces

	Overall		Limpopo		KwaZulu-Natal	
Cultivar	N	Mean ± se	N	Mean ± se	N	Mean ± se
'Pinkerton'	7920	1.265 ± 0.008^{d}	7200	1.272 ± 0.008^{c}	720	1.193 ± 0.019^{c}
'Hass'	11160	1.121 ± 0.004^{c}	10800	1.121 ± 0.004^{b}	360	$1.122 \pm 0.021^{b,c}$
'Fuerte'	7560	1.008 ± 0.001^{a}	7200	1.004 ± 0.001^{a}	360	1.097 ± 0.018^{b}
'Rinton'	360	1.044 ± 0.016^{b}			360	1.044 ± 0.016^{a}

Note: Periods sharing a letter in superscript are not significantly different at the 0.05 level according to Benjamini-Hochberg (BH) procedure, $P < 0.05$.

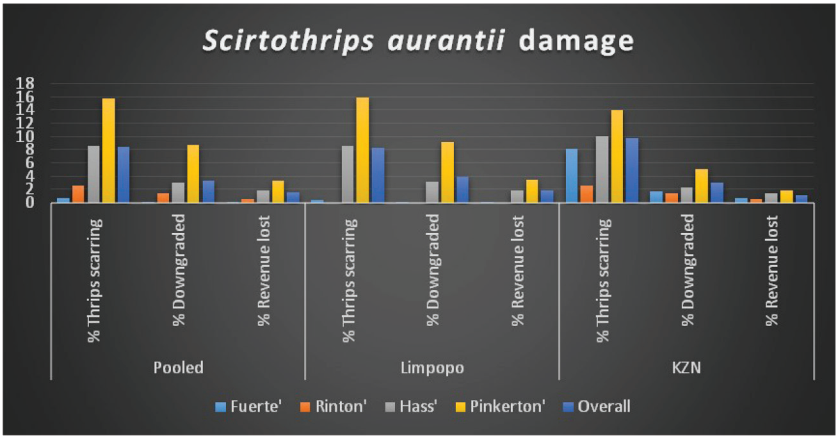

Fig. 2. The impact of *Scirtothrips aurantii* damage on revenue

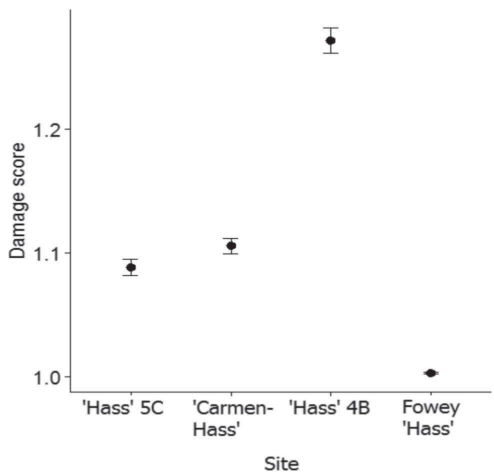

Fig. 3. Errorplot of damage scores of "Hass-type" cultivars at Westfalia Estates, Tzaneen

Table 5

Scirtothrips aurantii fruit infestation indices (mean ± se) in Tzaneen and Pietermaritzburg

Site	Province	Cultivar	Total No. of fruitlets	No. of infested fruitlets	% fruit infestation	Mean No. of emerging larva/ fruit
Macnoon	Limpopo	'Carmen®-Hass'	330	176	53.33	2.60 ± 0.18
Everdon	KZN	'Carmen®-Hass'	125	22	17.6	2.64 ± 0.19
Pooled		'Carmen®-Hass'	515	198	38.45	2.60 ± 0.175

don was not near macadamias. When pooled, *S. aurantii* fruit infestation was 38.45% with a mean number of 2.60 ± 0.175 larva emerging per fruitlet (Table 5).

Economic impact of scarring damage

Due to pricing fluctuations, we assumed a price of EUR 7.00-15.00 per 4 kg carton export price resulting in gross revenue of ZAR 37,237.50 to ZAR 59,993.75 per ton (price dependant on cultivar). 'Pinkerton', 'Fuerte', 'Hass' and 'Rinton' all have different yield potentials and different market prices and consequently different levels of revenue. Potential revenue from 'Hass' was highest at ZAR59,993.75 whilst the other cultivars peaked at ZAR37,237.50 per ton (Table 6). 'Pinkerton' had the highest potential revenue loss of ZAR1,227.28 per ton, representing a 3.296% revenue loss from *S. aurantii* scarring damage, followed by 'Hass' at 1.878%. 'Fuerte' showed the least thrips scarring at 0.035%. In ZAR terms, *S. aurantii* potentially costs the industry ZAR1,227.28 per tonne of 'Pinkerton' harvested, marginally followed by 'Hass' with a potential loss of ZAR1,126.39. 'Rinton' and 'Fuerte' showed the least thrips scarring losses at ZAR195.94 and ZAR13.06 per ton harvested respectively.

Table 6

Potential revenue gained from sales and lost through downgrading of *S. aurantii* scarred fruit

		South African Rand (ZAR)						
Cultivar	EUR/ 4 kg	Mean ZAR/kg	Potential revenue/ton	Export class/ ton	Local sales	Total revenue earned	Potential Revenue loss	Potential revenue lost %
'Fuerte'	7-11	37.24	37237.50	37203.02	21.42	37224.44	13.06	0.035
'Hass'	14-15	59.99	59993.75	58160.61	706.75	58867.36	1126.39	1.878
'Pinkerton'	7-11	37.24	37237.50	33998.03	2012.19	36010.22	1227.28	3.296
'Rinton'	7-11	37.24	37237.50	36720.31	321.25	37041.56	195.94	0.526

The fruit in Limpopo had a higher thrips damage incidence of 8.27%, Export % 96.08% and downgrading % of 3.92% compared to KZN's thrips damage incidence of 9.72%, an export % of 96.94% and downgrading of 3.06%. The potential revenue lost percent was lowest in 'Fuerte' at 1.96% and highest in 'Pinkerton' at 3.44%. No 'Rinton' fruits were assessed in Limpopo (Table 7).

Table 7

Effect of *S. aurantii* scarring on revenue accrued per ton harvested in Tzaneen, Limpopo

		South African Rand (ZAR)						
Cultivar	EUR/ 4 kg	Mean ZAR/kg	Potential revenue/ton	Export class/ ton	Local sales	Total revenue earned	Potential Revenue lost	Potential revenue lost %
'Fuerte'	7-11	37.24	37237.50	37232.33	3.21	37235.54	1.96	0.005
'Hass'	14-15	59.99	59993.75	58143.94	713.18	58857.12	1136.63	1.89
'Pinkerton'	7-11	37.24	37237.50	33860.27	2097.76	35958.03	1279.47	3.44

In KwaZulu-Natal, the lowest *S. aurantii* scarring induced revenue loss was recorded in 'Rinton' at 0.53%, whilst the highest potential revenue loss was in 'Pinker-

Table 8

Effect of *S. aurantii* scarring on revenue accrued per ton harvested in Pietermaritzburg, KZN

Cultivar	EUR/ 4 kg	South African Rand (ZAR)						
		Mean ZAR/kg	Potential revenue/ton	Export class/ ton	Local sales	Total revenue earned	Potential Revenue loss	Potential revenue lost %
'Fuerte'	7-11	37.24	37237.50	36616.88	385.50	37002.38	235.13	0.63
'Hass'	14-15	59.99	59993.75	58660.56	514.00	59174.56	819.19	1.37
'Pinkerton'	7-11	37.24	37237.50	35375.63	1156.50	36532.13	705.38	1.89
'Rinton'	7-11	37.24	37237.50	36720.31	321.25	37041.56	195.94	0.53

ton' at 1.89% (Table 8). However, the potential revenue loss per tonne of harvested fruit was highest in 'Hass' at ZAR819.19 followed by 'Pinkerton's ZAR705.38, 'Fuerte's ZAR235.13 and 'Rinton's ZAR195.94

Discussion

Adverse biotic (pests and diseases) and abiotic factors (wind, temperature, humidity) act to limit the exportable percent of avocado. In this study, wind damage accounted for 25.33, 3.92 and 5.34% downgrading of avocado fruit in Pietermaritzburg (KZN), Tzaneen (Limpopo) and pooled, respectively (Table 1). Significant differences in wind damage were observed between these sites, with fruit in KZN showing a greater mean damage score due to greater wind damage of 1.81 ± 0.02 compared to Tzaneen's 1.13 ± 0.003. Traditionally, wind induced abrasion damage has been managed by using wind breaks. However, considering the "hilly" terrain in which avocados are often planted, they are not always effective. In some cases, tree species such as *Casuarina cunninghamiana* Miq. (beefwood) though, which is reported to reduce wind damage by 26% in 'Hass', has been shown to also compete with the avocado trees for water, sunlight and nutrients (Holmes and Farrell, 1993), and this therefore presents production challenges, especially in a water-scarce environments such as South Africa. Other tree species commonly used as windbreak in citrus such as *Grevillea robusta* A. Cunn. ex R. Br. have been found to also harbour *S. aurantii* (Grout and Richard, 1990), making the selection of tree species to be used as windbreak important.

From July 2018 to October 2018 predominately, predominately North-easterly winds of an average speed of 1.54 m s^{-1} were recorded in Tzaneen https://www.windfinder.com/windstatistics/tzaneen-grenshoek). This period was chosen because, the early fruiting stage is the most susceptible to scarring damage, and assessments of fruit in May 2019 was of fruit exposed to these winds during development. The greatest damage on fruit was observed on fruits facing the West and North cardinal directions (1.152 ± 0.001 and 1.143 ± 0.006 respectively) (Table 2). In KZN, the highest wind damage was recorded on West and South facing fruit (1.947 ± 0.041 and 1.940 ± 0.041, respectively). The apparent susceptibility of 'Pinkerton' to wind damage may have to do with its early fruiting, which coincides with periods when the weather is windy (August, September, October) (https://weatherspark.com/y/96783/Average-Weather-in-Durban-South-Africa-Year-Round).

In addition, 'Pinkerton' has short internodes and crowded branches against which young developing fruit can bruise in windy conditions. The predominant winds experienced in Pietermaritzburg from July to October 2019 were South easterlies of average speed 2.44 m s^{-1} (https://www.windfinder.com/windstatistics/pietermaritzburg). There appears to be a relationship between wind direction and the damage observed.

When pooled, all the cultivars had significantly different scar damage scores (Kruskal–Wallis $\chi^2 = 1172$, df = 3, $P < 0.001$). 'Pinkerton' had the highest level of scar damage (1.265 ± 0.008), followed by 'Hass' (1.121 ± 0.004), 'Rinton' (1.044 ± 0.016) and 'Fuerte' (1.008 ± 0.001). This trend was observed both in Limpopo (Kruskal–Wallis $\chi^2 = 1165.8$, df = 2, $P < 0.001$) and KZN. However in KZN, damage to 'Hass' was not significantly different to 'Pinkerton' (Kruskal–Wallis $\chi^2 = 37.733$, df = 3, $P < 0.001$). Dennill and Erasmus (1992) noted that in the 1990s' *Heliothrips haemorrhoidalis* (Bouché) and *Selenothrips rubrocinctus* (Giard) were the thrips of economic concern in South African avocado, and that at the time, farmers were complaining that 'Hass' was the most susceptible cultivar. In this study, these two thrips species were not collected, only *S. aurantii*, as in Bara and Laing (2019). However, thrips damage to 'Hass' featured prominently with damage to the cultivar second only to 'Pinkerton', and in KZN this was not significantly different to 'Pinkerton'. *Scirtothrips aurantii* damage in 'Fuerte' was consistently lower than that of 'Pinkerton' and 'Hass' in both provinces.

'Pinkerton' appears to be highly susceptible to scarring damage. Susceptibility of 'Pinkerton' to thrips maybe related to the degree of compatibility between the seasonal phenology of the trees and the environment. 'Pinkerton' may be susceptible to thrips feeding in spring due to its early development when the temperatures are low and when it develops young fruit that present fresh growing tissue favourable to thrips attack. According to Scholefield et al. (1985), floral initiation occurs in autumn followed by flowering in late winter/ early spring with fruit maturation occurring the following winter. A spring vegetative flush coincides with the end of flowering and early fruit development. This is the time when the greatest scarring damage occurs.

'Pinkerton' is a high yielding cultivar that does well under South African conditions. However, the cultivar is plagued by problems associated with its early flowering and extended flowering period (June to December) (Sippel et al., 1994). This extended flowering period causes the tree to have various sized fruit at differing maturity levels, and this predisposes fruits to thrips feeding over a longer period.

The level of damage caused by *S. aurantii* to avocado fruit of the four cultivars is a function of a range of biotic and abiotic factors. The presence of macadamia trees near avocado orchards appears to modify the avocado-thrips population dynamics. This was demonstrated when comparing the 'Hass' cultivars near and distant from macadamia orchards. Fruitlets collected from 'Carmen®-Hass' blocks near macadamias showed higher thrips incidence (53.33%) than the 'Carmen®-Hass' at Everdon Estate where there are no macadamia's (17.60%) (Table 5). The blocks near the macadamia orchard also exhibited high *S. aurantii* damage. This is supported by work down by Schoeman (2019) who also concurred that thrips damage was significantly greater in orchards near macadamias'. Macadamia's are well known hosts of *S. aurantii* (Rafter et al., 2013). The proximity of macadamia's to avocados allows for host switching when conditions are unfavourable in one crop, for example, after chemical spray application, thrips may disperse to untreated crops/ blocks, and return when the environment is favourable. This means that within these farms, there will usually always be a resident population on one of the tree crops that forms the base population for subsequent outbreaks.

In South Africa, 'Carmen®-Hass' is unique in its ability to flush continuously through-out the year, predisposing it to *S. aurantii* damage because there is a constant supply of young tissue in the trees that can support *S. aurantii* populations throughout the year. This was probably why there was a high thrips incidence in 3 week old 'Carmen®-Hass' fruitlets at both Macnoon 53.33% (near Macadamia orchards) and at Everdon, Pietermaritzburg (17.60%). These infestation levels differ from those obtained in Pietermaritzburg (4.82%), as determined in an earlier study (Bara and Laing, 2019).

'Hass' earns more money per unit volume exported to the EU (potentially up-to ZAR59,993.75 per ton) (Table 7), probably due to the European market's preference for the cultivar (DAFF, 2017). However, it is susceptible to *S. aurantii* feeding damage and was second to 'Pinkerton' in potential revenue loss (Table 8). The potentially losses of 'Pinkerton' of ZAR1,227.281 per ton of fruit harvested was closely followed by 'Hass' at ZAR1,126.392 (Table 6). The 2018 season was an 'on' year for avocados, producing 170,000 tons of avocado fruit. Of this, 86,000 tons were exported (Donkin, 2019), with an estimated value of ZAR 1.75 billion (US$116.7 million) (http://www.worldstopexports.com/avocados-exports-by-country/). South Africa's five-year annual average production stands at 118,000 tons (Donkin, 2018).

Across cultivars, the industry loses is 1.49% revenue annually due to *S. aurantii* downgrading (3.86% loss factor), translating to ZAR34.90 million (US$2.39 million). In Ventura (USA), a related thrips species *S. perseae*, was reported to cause an economic damage of at least 15% through fruit being downgraded at packinghouses in 1997-98 (Phillips et al., 1999). Faber et al. (2000) noted that the losses could be higher, given that the reported economic loss did not include fruit that dropped off trees and never made it to the packinghouses.

It was also noted that more thrips damaged fruit was observed in the lower canopy area than the higher canopy fruit, probably because these fruit are the first to be encountered by newly emerged adults from weeds and from the ground pupation sites (Ascención-Betanzos et al., 1999).

Conclusion

The industry loses 1.49% revenue annually due to *S. aurantii* downgrading (3.86% loss factor), translating to ZAR34.90 million (US$2.39 million). In our study, *S. aurantii* caused scarring damage on 'Pinkerton' of 3.296% per ton of fruit harvested, followed by 'Hass' (1.878%), 'Rinton' (0.526%) and 'Fuerte' (0.035%).

The presence of macadamia trees near avocado trees appeared to expose the avocados to greater frequencies of *S. aurantii* feeding damage. 'Carmen®-Hass' in South Africa, is naturally predisposed to higher levels of thrips damage owing to its continuous flush phenology.

The loss to russet netting (wind abrasion damage) was higher in Pietermaritzburg (25.33%) than in Tzaneen (3.92%). Growers are advised to consider site, locality and the presence/absence of macadamia's in the area when selecting cultivars to grow. In wind prone areas, growers can take cultural management measures such as planting windbreaks and planting on the leeward side of slopes to minimise wind induce abrasion damage.

Acknowledgements

We gratefully acknowledge Elsje Joubert and Zelda Van Rooyen for reviewing this article. Special thanks also to Baynesfield Estate, Westfalia Estate, Everdon Estate and Conlink Trust Farm for financial and logistic assistance with this work. The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at are those of the authors and are not attributed to the NRF.

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