South African Avocado Growers' Association Yearbook 1993. 16:14-15

INVASION OF ORCHARDS BY THE AVOCADO BEETLE *MONOLEPTA* APICALIS (SAHLBERG) (COLEOPTERA:CHRYSOMELIDAE): ASSESSMENT OF DAMAGE TO LEAVES AND FRUIT

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ABSTRACT

Avocado orchards in the Kiepersol region were invaded by the avocado beetle Monolepta apicalis *(Sahlberg). Damage to leaves and fruit was assessed. The percentage of fruit damaged per tree reached levels of over 90% within four days of the appearance of the beetle swarm. Smaller fruits (≤80g) were attacked to a greater extent than larger fruits. Leaves were not damaged extensively. Over 90% of the leaves sampled had ≤10% of their surface area damaged. However, the percentage of leaves damaged on each tree was high. The biology of* M. apicalis *is compared to that of* M. australis *(Jacoby), a pest of avocados in Australia.*

INTRODUCTION

A severe outbreak of *Monolepta apicalis* (Sahlberg) in a mixed Hass/Fuerte orchard was observed on Lulu Farm (A.P. Vos & Seuns) in the Kiepersol region during the first week of January 1993. Further investigation showed the beetle to be present on numerous farms in the area, with varying reports on severity of attack. Damage by beetles to avocado fruits of five cultivars in the Nelspruit/Hazyview region has previously been reported (Erichsen & Schoeman, 1992), but this was the first recording of beetle populations of this magnitude in avocado orchards in South Africa (Erichsen & Schoeman, 1993).

Monolepta species have also been recorded as pests of avocados in Australia, Israel, and the Philippines (Ebeling, 1959; Wysoki & Izhar, 1978; Sarooshi *et al.,* 1979; Erichsen & Schoeman, 1993). Although chrysomelids have previously been reported as pests of a number of cultivated crops in South Africa, their importance in this regard has received very little attention (Erichsen & Schoeman, 1993).

The outbreak of beetles was investigated on Lulu Farm and the neighbouring Danroc Farm. An assessment of damage to leaves and fruit was conducted and the outbreak is discussed with reference to the biology of a similar beetle species.

MATERIALS AND METHODS

Damage to fruit

Sampling of fruit

Sampling of fruit took place on Lulu Farm. Due to the seriousness of the avocado beetle infestation, control measures were a priority (C. Partridge, personal communication) and it was considered necessary to begin sampling fruit in the part of the orchard where the infestation was first noted (i.e. Tree-set A). This was also "assumed" to be the region of highest infestation (i.e. border of the orchard). Control measures were implemented within six days after initial sampling began. As a result, further sampling of fruit took place in another part of the orchard where beetles were not as abundant and control measures were not required (i.e. Tree-set B).

Tree-set A

Ten 16 year old Hass trees were randomly selected within the orchard belt of highest beetle infestation and stripped of their fruit. Fruit was picked separately from the upper and lower halves (=aspects) of the tree.

Tree-set B

Seven 16 year old Mass trees were randomly selected from the same orchard, but in a belt of much lower beetle infestation. Fruit was picked in the manner described above (see "Tree-set A").

Fruit-damage assessment

Fruit damage per tree

The percentage of fruit damaged per tree in Tree-set A and B was determined. An analysis of variance (ANOVA) was conducted between sets on arc-sine transformed data. The median and range of the percentage of fruit damaged per tree in each Tree-set was determined.

Fruit damage per aspect

The percentage of fruit damaged in the upper and lower aspect of the trees in Tree-set A and B was determined. An ANOVA between aspects was conducted on arc-sine transformed data. The median and range of the percentage of fruit damaged in each tree aspect was determined.

Damage in each fruit size category

Fruit from the upper and lower aspects of the trees in both Tree-set A and B were weighed into four size categories *viz.* ≤50 g; 51-80 g; 81-110 g; ≥111 g. Each fruit was weighed on an electronic balance and placed into the appropriate category. The fruit from each size category was inspected for beetle damage and scored from one to 10 corresponding to the percentage fruit surface area damaged (1, 1-10% of the fruit surface area damaged; 2, 11-20% of the fruit surface area damaged; etc). An ANOVA was conducted to determine differences in the amount of fruit damaged in each size category. The data from Tree-set A and B required an arc-sine and a square root transformation respectively. A Chi-square test was performed to determine any differences in percentage damage recorded per fruit in each size category. The median and range of the percentage of fruit damaged in each size category was established.

Damage to leaves

Sampling of leaves

Leaves were sampled from the same sets of trees (see "Sampling of Fruit") (i.e. Leaf-set A & B). In addition, leaves were sampled from a set of seven three year old trees from the neighbouring Dan roc Farm which had also been heavily infested by beetles (Leaf-set C). The trees of Leaf-set B and C were in full flush (80-100%/tree) as opposed those of leaf-set A (<10%/ tree).

Leaf-set A

Leaves were picked randomly from the same 10 trees in Tree-set A. Twenty mature leaves (as there was very little flush) were picked from each of the upper and lower aspects of each tree in a similar manner to the fruit (see "Tree-set A"),

Leaf-set B

Forty flush leaves were picked at random from each of the seven trees in Tree-set B but were not differentiated into upper and lower aspects as with the fruit.

Leaf-set C

Flush leaves picked from Danroc Farm were not differentiated into upper and lower tree aspects. Firstly, 40 leaves were collected at random on all levels around each tree. Secondly, another 20 leaves were picked from all levels around the same seven trees, but were deliberately selected with beetle damage. These trees were not bearing sufficiently for fruit samples to be taken.

Leaf-damage assessment

Leaf damage per tree

The percentage of leaves damaged by beetles was calculated for each of the Leaf-sets A, B, & C. An ANOVA was performed between sets on reciprocal (for Leaf-sets A & C) and square-root (for Leaf-set B) transformed data.

Leaf damage per aspect

The percentage of leaves damaged in the upper and lower aspects of the trees in Leaf-set A was determined (trees in Leaf sets B & C were not partitioned into aspects). An ANOVA was conducted on square-root transformed data. The median and range of the percentage of leaves damaged per tree aspect was determined.

Damage per leaf

Leaves from Leaf-sets A, B and C were inspected for beetle damage. The percentage of the leaf area damaged was calculated using a transparent grid with 2.5 square centimeter blocks. The numbers of blocks representing the area of the leaf and the area damaged were counted and the percentage of leaf surface area damaged was calculated. An ANOVA was conducted to measure differences in the extent of damage per leaf between leaves in each tree for each of the leaf-sets. The data for Leaf-sets A and B required a reciprocal square-root and Leaf-set C a square-root transformation. In addition, the extent of damage per leaf in Leaf-set A was calculated for the upper and lower tree aspects. The data required a reciprocal square-root transformation. The percentage surface area damaged of the leaves in Leaf-set A and Leaf-set B was plotted. The median and range of the extent of damage per leaf was established.

Damage per leaf area

Correlation and regression analyses were conducted between the leaf area and corresponding area damaged (as calculated using the transparent grid, see "Damage per leaf") of 140 leaves from Tree-set C. Associations between leaf area and percentage damage were established.

RESULTS

Damage to fruit

Fruit damage per tree

There was a significant difference in the percentage of fruit damaged in Tree-set A and B ($F=28.757$, $df=16$, $P<0.001$) (Table 1). The median and range of the percentage of fruit damaged is tabulated (Table 1)

Fruit damage per aspect

There was no significant difference in the percentage of fruit damaged by the avocado beetle between the upper and lower aspects of the trees In Tree-set A or B alone, as a result of which both sets of trees were combined for the statistical test ($F=0.003$, $df=33$, P<0.958) (Table 2).

Damage in each fruit size category

There was no significant difference in the percentage of fruit damaged between the four fruit size categories in Tree-set A (F=0.935, df=39, P<0.434) or Tree-set B (F=1.617, df=26, P<0.213) (Table 3). The mean number of fruit damaged in size category 1 was, however, consistently higher than those of the remaining classes in both sets of trees (Table 3). Results of the Chi-square showed that there was a significant difference in the percentage surface area damaged per fruit between size categories one and two and between these and three and four, but not between categories three and four (X^2=476.20, P<0.001) (Table4). The median and range of the percentage fruit damaged per size category is tabulated (Table 4).

Damage to leaves

Leaf damage per tree

There was a significant difference in the percentage of leaves damaged between Leaf-sets A & B and Leaf-set C (P<0.0001) (Table 5).

Leaf damage per aspect

There was a significant difference in the percentage of leaves damaged between the upper and lower aspects of the trees (F=7.205, df=19, P<0.01) (Table 6). The median and range are tabulated (Table 6).

Damage per leaf

There was no significant difference in the extent of damage to leaves between trees in Leaf-set A (F=2.99, df=117, P>0.003) and C (F=1.228, df=139, P<0.300) (Table 7). A significant difference in the extent of damage to the leaves was evident in Leaf set B (F=8.295, df=157, P<0.001) (Table 7). Leaf-sets A, B, and C had 100%, 98.1%, and 92.86% of their leaves with between 0-10% of their surface area damaged respectively. There was a significant difference in the extent of damage to leaves between the upper and lower aspects (F=10.395, df=116, P<0.001) (Table 8). There was no significant difference in the percentage of the surface area damaged of leaves between trees in Leaf-set A. Trees in Leaf-set B exhibited a significant difference. The median and range of the extent of damage is tabulated for each leaf-set (table 9)

TABLE 1 Percentage of fruit damaged in the two parts of the orchard sampled, i.e. tree sets A and B, and median and range of fruit damaged per tree, n = number of trees.

TREE SET	n	% FRUIT DAMAGED	MEDIAN (%)	RANGE (%)
Tree-set A	10	73.00%	80	35-93
Tree-set B	7	27.17%	34	10-40

TABLE 2 Percentage of fruit damaged and 95% Tukey HSD intervals for fruit in the upper and lower tree aspects. Non significant difference between aspects denoted by similar lower case letters, n = number of trees.

TREE ASPECT	n	% FRUIT DAMAGED	HSD INTERVALS
Upper aspect	17	62.49%	0.4903-0.7595 a
Lower aspect	17	63.20%	0.4974-0.7665 a

TABLE 3 Mean percentage fruit damaged and 95% Tukey HSD intervals for each of the four fruit size categories in tree sets A and B, with significant differences between sets denoted by dissimilar lower case letters, n = number of trees.

FRUIT SIZE CAT.	n	MEAN % FRUIT DAMAGED	HSD INTERVALS
Tree-set A			
≤50g	10	98.56%	0.7929-1.1783 a
51-80g	10	87.49%	0.6822-1.0676 a
81-110g	10	74.78%	0.5551-0.9405 a
≥111g	10	89.23%	0.6996-1.0850 a
Tree-set B			
≤50g	10	66.32%	0.5389-0.7874 b
51-80g	10	49.39%	0.3697-0.6182 b
81-110g	10	50.37%	0.3795-0.6280 b
≥111g	10	50.62%	0.3720-0.6404 b

TABLE 4 Median percentage and range of surface area damaged per fruit in each fruit size category in tree sets A and B, with significant differences between size categories denoted by dissimilar lower case letters.

TREE SET	MEDIAN (%)	RANGE (%)
Tree-set A		
≤50g	74	13-100 a
51-80g	49	11-95 b
81-110g	47	9-95 c
≥111g	54	7-100 c
Tree-set B		
≤50g	50	13-100 a
51-80g	30	11-38 b
81-110g	23	9-47 c
≥111g	35	7-40 c

TABLE 5 Percentage of leaves damaged in tree sets A, B and C, with significant differences between sets denoted by dissimilar lower case letters.

TREE-SET	% LEAVES DAMAGED
Tree-set A	59.0% a
Tree-set B	56.4% a
Tree-set C	79.1% b

Damage per leaf area

There was a significant negative correlation between leaf area and area of the leaf damaged by the avocado beetle (r= 0.585, P<0.0001). There was a multiplicative increase in damage with decreasing leaf area (c = -0.585, R^2 = 34.24%, P<0.0001) by a factor of 0.758, i.e. a fourfold increase in damage with every fivefold decrease in leaf area.

DISCUSSION

This is the first record in South Africa of *M. apicalis* invading avocado orchards to such a severe extent (Erichsen & Schoeman, 1993). There have been reports of damage by chrysomelids from other avocado-growing countries; the most recent report being that of *M. australis* (Jacoby) on avocados in Australia (Fay & DeFaveri, 1990). Fay & DeFaveri (1990) report differences in the behaviour of *M. australis during* phase two (spring, flowering and vegetative growth) and phase three (summer, vegetative growth and rapid increase in fruit size) of the phenological growth cycle (Kotzé, 1979). During phase two, the beetle disperses within a tree on arrival, or after feeding has begun. In contrast, during phase three, the beetles swarm and flight activity is reduced. During flowering (September-October 1992) no significant *M. apicalis* population levels were noticed in the Kiepersol region. However, the sudden appearance of an invasive population in January 1993 suggests that the behaviour of *M. apicalis* during phase two and three of the phenological growth cycle is not unlike that of *M. australis.* Murray (1982) pointed out, however, that *M. australis* may swarm at any time of the year. He concluded that there were possibly three generations per year, including an over wintering generation.

At first inspection of the avocado orchard (i.e. Tree-set A) on Lulu Farm, it was apparent that the beetle infestation was heaviest on the edge of the orchard bordering the natural vegetation. In Russia, Kulikova (1983) found natural vegetation harboured a dominant pest of soybean, *Monolepta quadriguttata* (Motsch.). Avocado fruits of all sizes were attacked, but the surface area damaged on small fruit was significantly greater than that of larger fruits (Tables 3 & 4). This may be related to the stage of fruit development. The fruit would be growing rapidly and the nutrient value of the fruit subsequently increasing. *M. australis* was reported to invade avocado orchards during Phase 2 of the phenological growth cycle (Fay & DeFaveri, 1990). Although the beetles damaged the flowers, conclusions were that it had no significant effect on overall fruitset. However, the potential of *M. australis to* inflict severe damage to avocado fruit was acknowledged. Sarooshi *et al.,* (1979) reported that an entire avocado crop on a tree can be rendered unmarketable within hours.

Field observation of the behaviour of the avocado beetle support the finding that there was no significant difference in the amount of fruit damaged in each aspect of the tree (Table 2). The beetles were found to restrict their movements to within the shaded areas of the tree between early morning and late afternoon. Thereafter, movements of the beetles were less restricted and flying within and between trees were more frequent. Fruits of large trees would be shaded most of the day and such an environment would enhance feeding on the fruits. Swarming behaviour would also lend to an increase in the percentage of fruit damaged and/or to the extent of damage per fruit.

There was a significant difference in the percentage of leaves damaged between Leaf-sets A & B and Leaf-set C (Table 5). Although sample sets are not directly comparable, differences between sets are noted. The significant difference in the percentage of leaves damaged between the upper and lower aspects of the trees in Leaf-set A (Table 6) may possibly be due to light. *M. apicalis* was observed to feed during early morning or late afternoon. During this period, the lower regions of the avocado tree would be dark and lit feeding regions in the tree more attractive.

The extent of damage to leaves between trees in Leaf-set A & C was not significantly different although the leaves in Leaf-set A were old spring vegetative growth (Table 7). The beetle population was large (=swarm) and capable of inflicting damage very quickly. Samples of leaves and fruit were taken from the site of Leaf-set A within four days of the first report of the beetle invasion. The even distribution of beetle damage throughout Leaf-sets A & C suggests that the beetle population was well established and only a short time was required for extensive damage to be inflicted. This is in agreement with Fay & DeFaveri (1990) and Sarooshi *et al.,* (1979).

TABLE 6 Percentage, median and range of leaves damaged in the upper and lower tree aspects, with the significant difference between aspects denoted by dissimilar lower case letters, n = number of trees.

TREE ASPECT	n	% LEAVES DAMAGED	MEDIAN (%)	RANGE (%)
Upper aspect	10	37% a	35	15-70
Lower aspect	10	22% b	20	5-40

TABLE 7 Mean percentage leaf surface area damaged in each of tree sets A, B and C, with significant differences between tree sets denoted by dissimilar lower case letters, n = number of leaves.

TREE-SET	n	EXTENT OF DAMAGE TO LEAVES
Tree-set A	118	3.08% a
Tree-set B	158	4.33% b
Tree-set C	140	3.60% a

TABLE 8 Mean leaf surface area damaged (mm^2) in the upper and lower aspects of tree set A, n = number of leaves.

TREE SET A	n	EXTENT OF DAMAGE TO LEAVES (mm^2)
upper aspect	73	225
lower aspect	44	114

TABLE 9 Median and range of percentage leaf surface area damaged in leaf sets A, B and C.

LEAF SET	MEDIAN	RANGE
A	2.80%	2.40 - 3.20
B	3.60%	2.80 - 5.70
C	4.35%	1.50 - 4.00

The significant difference in the extent of damage to leaves per tree (=uneven distribution) in Leaf-set B (Table 7) is a reflection of the beetle population not having established in that part of the orchard. However, the mean percentage damage to leaves in Leaf-set B is higher than that of Leaf-set A (Table 7). In addition, the percentage of fruit damaged in

Tree-set B is lower than that of Tree-set A (Table 1). Although the latter can be argued to be a function of the low beetle population levels in that part of the orchard, the higher extent of the damage to the leaves suggests that new vegetative growth is preferred over fruits. In other words, trees with extensive flush would exhibit, if not a smaller percentage of fruit damaged per tree, a smaller percentage of damage to the surface area of each fruit. More fruit would then be suitable at least for the local market. *Monolepta* species have previously been reported to be serious crop pests as a result of injuriousness to leaves (Kumar *et al.,* 1979; Butani &Verma, 1981).

The relationships between vegetative growth, levels of nitrogen, and herbivorous insect feeding have been well documented. Koo & Young (1977) found that nitrogen levels were higher in the second avocado flush leaves (phase three) than those in phase two. In addition, Bar *et al.,* (1987) found that nitrogen levels in leaves of fertilized trees were always higher than in poorly fertilized or unfertilized trees. In addition, phase three is also the optimal period for the application of fertilizer to stimulate leaf growth (Robertson, 1969; Kotzé, 1979). Insect herbivores will eat the highest quality foliage they can find (Mauricio & Bowers, 1990) and will be constrained by their preference for the new vegetative growth (Stamp & Bowers, 1990). Hence, *M. apicalis* swarms would attack the new flush leaves for as long as they remain available.

Fertilization to stimulate leaf growth benefits the size of the fruits and "the efficiency of the leaves will be reflected in the quality and size of the fruits" (Kotzé, 1979). Damage by the avocado beetle to leaves, however, may seriously impair the photosynthetic efficiency of the leaves and, hence, fruit quality and size. This is probably more important in young trees as shown by the significantly greater percentage of leaves damaged in Leaf-set C (Tables).

The high percentage of leaves in Leaf sets A, B, and C exhibiting ≤10% of their leaf surface area damaged may, firstly, be a result of wound-induced chemical changes in leaf quality (Edwards & Wratten, 1983). Herbivory can alter the quality of the host plant (Mauricio & Bowers, 1990 & various cited authors) which in turn induces changes in the foraging patterns of the herbivore. If this is the case in *M. apicalis,* it would further explain why a level in the extent of damage per leaf between trees becomes constant in a short period of time. Secondly, foraging patterns may be a result of predator avoidance. *M. apicalis* feeds primarily on the adaxial surface of the leaves (C. Erichsen, personal observation) and would therefore be less exposed to predators.

Leaves with an area ≤2500 mm^2 had ≥10% of the leaf area damaged. This may be as a result of the high nitrogen levels (Bar *et al.,* 1987) coupled with low fibre and epidermal toughness of the leaves. Beetle populations, appearing simultaneously with the beginning of new summer vegetative growth flush, may significantly reduce the photosynthetic ability of the developing leaves.

Although *M. apicalis* may not significantly affect fruit set (the beetles were not observed to be a problem in the spring of 1992, and when compared to the study of *M. australis),* the results of this paper show that the beetles are capable of invading avocado orchards and inflicting severe damage to leaves and fruit in a very short period of time. Why did a severe outbreak of *M, apicalis* occur; is this pest one of seasonal importance or restricted to sporadic outbreaks only; and can this pest be effectively controlled using parasitoids and/or predators (see Erichsen & Schoeman, 1993), are questions that demand urgent attention. Careful monitoring of this pest is warranted.

ACKNOWLEDGEMENTS

The authors thank Prof. J.M. Kotzé for his support; C.J. Partridge (Director-South African Avocado Growers Association (SAAGA)) and N.J. F. Claassens (SAAGA) for valuable discussions; E. Ciuchini (Eastfarm-Kiepersol), S.G. Hearne (Danroc-Kiepersol), R. Porritt (Koeltehof Kiepersol), and W. Vos (Lulu Farm Kiepersol) for permitting access to avocado orchards and sampling of produce; and the South African Avocado Growers' Association for financial support.

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