Factors affecting 'Hass' avocado (*Persea americana*) fruit set in New Zealand

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Abstract Avocado trees typically have a low (<0.3%) fruit set. This means physiological studies on fruit development are difficult to carry out. This investigation was conducted to determine which avocado flowers are most likely to set fruit. Inflorescences at the tip of a floral shoot had significantly higher fruit set ($P < 0.05$) than inflorescences at the base. There was no significant difference in fruit set between determinate and indeterminate inflorescences. The mean fruit set on hand pollinated flowers was 5.2%, which was significantly higher than the 0.22% fruit set on open pollinated flowers. The increase in fruit set following hand pollination suggests pollination may be one factor limiting fruit set of avocados in New Zealand.

Keywords avocados, inflorescence, fruit set, pollination.

INTRODUCTION

Avocado (*Persea americana*) is an evergreen subtropical fruit tree, native to Central America and Mexico. It is grown commercially in the warmer, northern parts of New Zealand. 'Hass' is the predominant fruiting cultivar, which is usually planted with pollinisers, such as 'Bacon', 'Zutano' and 'Fuerte', or without pollinisers in block plantings with just 'Hass'.

Each mature 'Hass' tree produces approximately eight thousand compound or branched inflorescences, each comprising 100-150 flowers, located in axillary or terminal positions on flowering shoots. Each flowering shoot may contain one or several inflorescences. An inflorescence can be determinate (terminating with a flower bud) or indeterminate (terminating with a vegetative bud). Flowers are protogynous (stigma becomes receptive a day prior to pollen being released) and dianthesis (each

flower opens twice). Flowering within a tree is synchronous (Ish-AM & Eisikowitch 1993). The synchronous nature of dianthesis in the avocado flowers is sensitive to environmental conditions (Davenport 1986).

Pollination usually requires an insect vector (Ish-AM & Eisikowitch 1993). In Central America the avocado is pollinated by social bees (Meliponinae) and wasps (Vespidae). In other regions of the world honey bees (*Apis mellifera*) are the main pollinator (Ish-AM & Eisikowitch 1993). In New Zealand it is recommended that up to 10 hives of honey bees per hectare are introduced for pollination (Avocado Industry Council 2006). Bees visit avocado flowers to collect nectar and/or pollen. Only nectar foraging bees visit both pistillate and staminate flowers and contribute to pollination (Ish-AM & Eisikowitch 1993). Due to the protogynous

nature of anthesis, self pollination within a single flower cannot occur (Ish-AM & Eisikowitch 1993). Avocado flowers can be cross-pollinated (from flower to flower on different trees) or close-pollinated (from flower to flower on the same tree). Close-pollination occurs during the trees' daily bisexual phase, when pistillate flowers are closing and staminate flowers are opening (Ish-AM & Eisikowitch 1992, 1993).

Avocado trees typically produce more than one million flowers, of which less than 0.3% set fruit (Blumenfeld & Gazit 1974; Blanke & Lovatt 1993; Dixon & Sher 2002). 'Hass' avocado trees in New Zealand need to set at least 0.03% fruit to achieve an economic crop. A slight variation in percentage fruit set can lead the trees to produce either too many fruit in an 'on' year or very few fruit in an 'off' year (alternate bearing). This is a major production problem for the New Zealand industry (Dixon et al. 2006).

This study is part of a larger programme to determine the reason for the variations in avocado crop production between years. The aim was to determine the influence of inflorescence type, position of the inflorescence and pollination, on the likelihood of a particular flower setting fruit.

METHODS

The field work was carried out in an orchard near Katikati in the Western Bay of Plenty during flowering in October/November 2008. The block was planted with 'Hass', with 'Bacon' and 'Zutano' pollenizers. The trees were 2-3 m in height and managed according to industry norms (Avocado Industry Council 2008). During the trial the average daily temperature in Katikati ranged between 13-15°C. Rainfall ranged between 0-0.4 mm per day.

Effect of determinate and indeterminate inflorescences

Twenty 'Hass' trees spread throughout the orchard were selected. One floral shoot with all determinate inflorescences and one floral shoot with at least one indeterminate inflorescence, 1-2 m from the ground, were marked on each tree. All floral shoots were selected from the north-facing branches, to remove other variables, such

as light interception and shading that were not a focus in this study. The number of branched inflorescences on each floral shoot was recorded. One branched inflorescence was chosen at random from each shoot and the number of flowers/buds per inflorescence recorded. To estimate the total number of flowers on each floral shoot the mean number of flowers on a branched inflorescence was multiplied by the number of inflorescences per shoot. A paired T-test was used to assess the difference in mean percent fruit set on the different types of floral shoots.

Position of inflorescence on floral shoots

Three floral shoots with all determinate inflorescences, 1-2 m from the ground, on the north-facing side of a further 20 trees were selected. Inflorescences were removed from one shoot on each tree, leaving only the three most apical inflorescences. On the second shoot only the three most basal inflorescences were retained. The number of inflorescences removed was recorded. The third floral shoot was a control and remained untouched. The total number of flowers left on each inflorescence was estimated by multiplying the mean number of flowers per inflorescence (Mean=134), obtained in Trial 1, by the number of inflorescences within each floral shoot. A paired T-test was used to assess the difference in mean percent fruit set on inflorescences located at different positions within the floral shoots.

Effect of hand pollination

Twenty-eight inflorescences across 10 trees (same trees that were used in trial one) were hand pollinated and the type of inflorescence recorded. Approximately 20 flowers per inflorescence were pollinated, each with three dehiscent male 'Bacon' flowers. The pollen was immediately applied to the stigmas of the 'Hass' flowers by direct contact of the anthers with the stigma. The stems of the pollinated flowers were marked with water based paint. The percentage fruit set for 'hand pollinated flowers' was calculated from the total number of fruit set and the number of hand pollinated flowers. This was compared with the

mean fruit set of 'open pollinated flowers'. For the 'open pollinated flowers', the mean fruit set was the combined fruit set of all the inflorescences marked three days earlier for Trial 1. This was calculated from the total number of fruit set on the inflorescence.

Fruit set

For all of the experiments, percentage fruit set was determined on 19 February 2009, approximately 3 months after flowering.

RESULTS

Effect of determinate and indeterminate inflorescences

The number of flowers within determinate and indeterminate inflorescences did not differ significantly ($P=0.13$) nor did the percentage of fruit set ($P=0.50$) (Table 1). Most inflorescences had less than 0.5% fruit set while 32% had no fruit set (Figure 1).

Figure 1 Frequency distribution of the percent fruit set on inflorescences.

Position of inflorescence on floral shoot

Inflorescences in an apical position on the floral shoots set significantly more fruit than those located in a basal position ($P<0.01$). There was no significant difference in the number of fruit set on the treated inflorescences and on the control inflorescences ($P=0.10$) (Table 2).

Effect of hand pollination

There was no significant variation in the number of fruit produced by hand pollinated determinate and indeterminate inflorescences ($P=0.721$). The mean fruit set across all hand pollinated flowers was 5.2%, which was significantly higher ($P=0.002$) than that recorded for open pollinated flowers on the same trees of just 0.22% (Table 3).

DISCUSSION

This study showed that avocado flowers located towards the apex of floral shoots, or that were hand pollinated, were more likely to set fruit. Flowers in an apical position along a floral shoot set 4.6 times more fruit than flowers in a basal position. Flowers that were hand pollinated set 25 times more fruit than open pollinated flowers.

The higher fruit set observed at the tip of the inflorescence is consistent with work carried out by Dixon et al. (2007), who found the mean initial fruit set on inflorescences at the apex of a floral shoot to be twice as high as fruit set on inflorescences further down the floral shoot. This may be related to these flowers receiving better light, being more accessible to pollinators, or having better vascular connection, especially for inflorescences in the terminal position on the floral shoot. In other crops such as apples and kiwifruit, the central blossom in a cluster produces the 'king' fruit, which is larger than the other

Table 1 Mean percentage fruit set on floral shoots with indeterminate or determinate inflorescences. The total number of flowers was estimated by multiplying the mean number of flowers per inflorescence ($n=134$), by the number of inflorescences within each floral shoot.

Treatment	Number of floral shoots sampled	Total no. of flowers	Mean % fruit set (Total no. of fruit)
Determinate	20	29865	0.18 (56)
Indeterminate	20	23793	0.24 (40)

Table 2 Mean percentage fruit set on floral shoots with either apical or basal inflorescences remaining and also on the controls. The total number of flowers was estimated by multiplying the mean number of flowers per inflorescence ($n=134$), by the number of inflorescences within each floral shoot.

Treatment	Number of floral shoots sampled	Total no. of flowers	Mean % fruit set (Total no. of fruit)
Apical	20	8040	0.398 (32)
Basal	20	8040	0.087 (7)
Control	20	21708	0.225 (35)

Table 3 Mean percentage fruit set on floral shoots with hand pollinated and open pollinated inflorescences. The total number of flowers for the hand pollinated treatment was the total number of hand pollinated flowers. The total number of open pollinated flowers was all the flowers on the inflorescences marked for Trial 1.

Treatment	Number of floral shoots sampled	Total no. of flowers	Mean % fruit set (Total no. of fruit)
Hand pollinated	28	564	5.162 (29)
Open pollinated	40	53658	0.216 (96)

fruit (Bangerth 1993). Avocado inflorescences in terminal or subterminal positions on floral shoots are also the earliest to develop and so may have an advantage over the later developing inflorescences in terms of attracting resources (Thorp et al. 1994)

The increase in fruit set with the hand application of pollen suggests that pollination was limiting fruit set in this orchard. This result is consistent with trials conducted in Spain where hand pollination of avocado flowers using a similar method increased fruit set to 8% (LA Acro, Universida De Malaga, Spain, pers. comm.). Because fruit set over 5% has only been reported in hand pollination studies and avocado fruit set is usually less than 0.3%, pollination may be limiting in most avocado orchards.

There are two possible explanations for why pollination was limiting fruit set in this orchard. The first is that there were inadequate numbers of honey bees. Studies in Israel have shown high correlations between honey bee activity, pollination and fruit set on avocados (Ish-AM & Eisikowitch 1993). A high density of honey bees is necessary to ensure a sufficient number of pollen grains are transferred onto each stigma. 'Hass' flowers require 20-30 pollen grains per stigma

to promote fertilization. Ish-AM & Eisikowitch (1995) showed that when ≥ 20 bees were observed on a tree, only 24% of the stigmas assessed had more than 20 pollen grains per stigma.

The second possible explanation for pollination being limiting is that the planting regime in the orchard does not facilitate good honey bee pollination. The efficacy of honey bees as pollinators depends on the movement of bees between cultivars (Ish-AM & Eisikowitch 1993). In New Zealand, avocado blocks are planted with wide spaces between the trees. This would discourage cross-pollination by honey bees that typically forage in comparatively small areas, and do not move large distances between flowers (Free 1993). Close-pollination could still occur under these conditions during the time pistillate flowers are closing and the staminate flowers are opening. However, the degree to which this occurs in New Zealand has not been recorded. While this study suggests that pollination is limiting fruit set in avocados, hand pollination has not increased fruit set over 10%. This indicates that pollination is not the only reason for the low percentage fruit set in avocados.

For avocado growers, these results highlight the importance of having optimal pollination

conditions with adequate bees. For scientists, the data indicate that there is a population of flowers on a tree that are more likely to set fruit than other flowers. Identifying these successful flowers and understanding the reasons for their success should help growers achieve more consistent yields.

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