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Pedicel Weight and Length Do not Affect Kiwifruit Size

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Summary

The influence of pedicel dimension on 'Hayward' kiwifruit (*Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson var. *deliciosa*) size was studied. Plant growth regulators and defoliations were used to manipulate pedicel weight and length. When lateral pedicels, with fruit removed, were inserted into vials filled with Agromil-Plus® (5 µl L^{-1} CPPU (N-(2-chloro-4-pyridy)-N'-phenylurea) plus natural bioregulators), the terminal pedicel dimensions were dramatically increased but the fruit size response (122 g) was inferior to that obtained by dipping fruit in CPPU (138 g). GA_3 (100 mg L^{-1}) supplied to the pedicel reduced the fruit weight and increased the length of terminal pedicels. ABA (50 mg L^{-1}) did not significantly influence fruit weight or pedicel length. Fruit dipped in CPPU that additionally received a pedicel application of this compound had similar fruit weight (141 g) to that of dipped fruit but significantly greater pedicel weight. Cane defoliation initiated at bud burst produced pedicels of small size on fruit of similar fresh weight to untreated canes. The conclusion was reached that pedicel length and weight are not casually related to fruit size but conditions leading to large fruit may also produce large pedicels.

Key words. *Actinidia deliciosa* – Agromil-Plus – CPPU – defoliation – fruit stalks – GA_3

Introduction

Actinidia deliciosa fruit are produced on inflorescences that set one to three fruit. Generally, the terminal fruit of the inflorescence is the only one used for commercial production, and the lateral fruit are thinned in spring or early summer. The fruit are connected to the vine by pedicels or fruit stalks of 4–7 cm of length. After fruit set, an increase in vascular development occurs in the fruit stalk, existing vascular tissue enlarge and new strands differentiate (Nii 1980). Large amounts of carbohydrates and nutrients from the vine pass through the pedicel to the fruit. The pedicels of 'Hayward' kiwifruit consist of parenchymatous cortex and pith, secondary xylem, and secondary phloem (Antognozzi et al. 1991; Woolley et al. 1992).

Pedicel dimension and weight have been correlated with fruit size in several crops (Webb 1973). In mandarin (Takagi et al. 1978), *Citrus hassaku* (Nii 1980), and pepper (Setiamihardja and Knavel 1990), a large fruit stalk was correlated positively with fruit weight. Pedicel dry weight has also been positively correlated with fruit fresh weight at commercial harvest in apple (Ferree et al. 2001).

Pedicel dimension has been artificially manipulated. Apple applications of paclobutrazol at full bloom reduced pedicel length and final fruit size (Curry and Williams 1983; Greene 1991). In contrast, applications of $GA_{(4+7)}$ increased the length of the apple pedicel but reduced fruit fresh weight (Privé et al. 1989). Short or very long pedicel lengths in apples indicated poorly developed flowers with reduced fruit retention (Feucht 1976). Defoliation induces reduction of fruit retention (Mehouachi et al. 2000).

In kiwifruit, pedicel dimension has been related to fruit size in spite of the lack of specific experimentation on this regard. Heavy kiwifruit may result in large pedicels. For example, kiwifruit of large size promoted by the fruit application of CPPU or forchlorfenuron (N-(2-chloro-4-pyridy)-N'-phenylurea) usually produce pedicels with large diameters (Woolley et al. 1992). McPherson et al. (2001), studying floral quality effects on kiwifruit size over two seasons, and across several kiwifruit orchards located in different production areas in New Zealand determined that pedicel length was negatively correlated with 'Hayward' fruit fresh weight. Lai et al. (1990), linked large pedicel diameter with large fruit size at harvest, suggesting that flowers with thick pedicels might produce kiwifruit of large size. Antognozzi et al. (1991), demonstrated that large terminal fruit on kiwifruit inflorescences were associated with a large fruit stalk area. Thus, hypotheses concerning pedicel size as a limiting factor have often been made, but evidence establishing causality is very limited.

In the present work, we manipulated the size of the pedicel by applying plant growth regulators or defoliating individual canes. The objective was to study if pedicel weight and length determine a significant increase of kiwifruit fresh weight at harvest.

Materials and Methods

Comparison of plant growth regulators applied on pedicels inside vials

The experiment was conducted on five adjacent 8-year-old own-rooted 'Hayward' kiwifruit vines established in an orchard at the Fruit Crops Unit, Massey University, Palmerston North, New Zealand (175 °39 ' E, 40 °20 'S). The vines were spaced at 5 x 2.5 m and trained on T-bars. Flowers were bee pollinated from male vines 'M 51' and 'M 56'. All small and misshapen fruit were removed three days before establishing the experiment, and the vines thinned to 45 fruit m^{-2}. Twenty-four inflorescences per vine of uniform terminal fruit size, and having one or two lateral fruit, were randomly selected (Antognozzi et al. 1991) to establish experimental inflorescences having only one terminal fruit and one lateral pedicel. The lateral fruit on each of the 120 inflorescences was removed 30 days after mid point of bloom in 2001, and their pedicels inserted into empty vials partially covered with parafilm™. The vials were attached by rubber bands to the pedicel of the terminal fruit (Fig. 1). These vials were removed three weeks before fruit harvest. Each vial with the pedicel inside was filled with 2.5 ml of water, GA_3 (gibberellic acid) 100 mg L^{-1}, ABA (abscisic acid) 50 mg L^{-1} or Agromil-Plus® bioregulator compound (Agroenzymas Laboratories, Tlanepantla, Mexico). The latter contains 2000 µl L^{-1} CPPU plus natural auxins, gibberellins, cytokinins, and vitamins from plant extracts. Agromil-Plus® had a final concentration of 5 µl L^{-1} CPPU. The four different applications were repeated on the 11 and 23 Jan., 49 and 61 days after mid point of bloom, respectively. The treatments were arranged in a randomised complete block design where the vines were considered as blocks. At commercial harvest in May 2002, fruit fresh weight (g), fruit seed number, pedicel fresh weight (g), and pedicel length (mm) were determined. Seed number was counted in all fruit studied. Fruit were cut into quarters transversely, and the seed number counted on the six surfaces. A cut seed was counted as a half seed. Seed counts in this form are related to total seed number (Currie 1997). The data were analysed using the procedure ANOVA of SAS, software release 8.02 (SAS Institute, Cary, N.C., USA). Duncan's multiple range test at $P \leq 0.05$ was used for means differentiation.

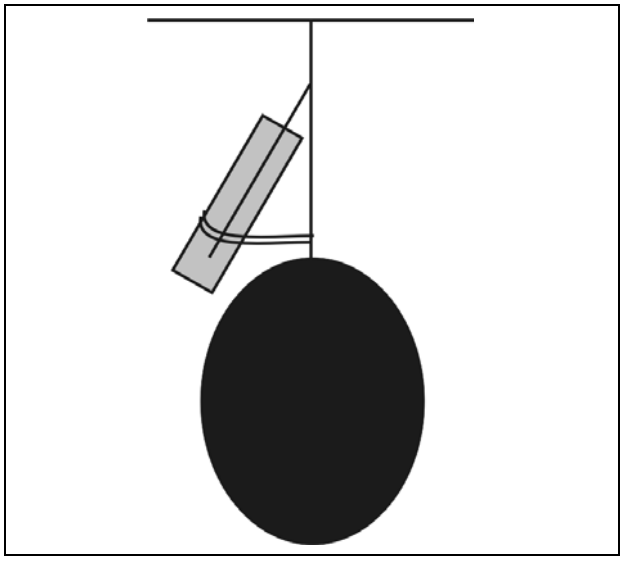


Fig. 1. Scheme for plant growth regulators application on pedicels inside vials. Lateral fruit was removed and the pedicel was inserted in a vial filled with water, ABA, GA_3 or Agromil-Plus®. Rubber bands attaching the vial on the terminal pedicel, and a fruit are shown.

CPPU application to the pedicel and/or fruit

The experiment was established in the orchard described in the last experiment. Fruit thinning per vine was as in the first experiment. Eighty shoots each with three similarly sized fruit was randomly distributed over eight 'Hayward' vines growing in the same row in December 2001. The bioregulators applied to every three fruit per shoot were: 1. Untreated; 2. Fruit dipped in CPPU 10 µl L^{-1}; 3. CPPU 10 µl L^{-1} applied to the pedicel; 4. Fruit dip + pedicel application. The treatments were established 35 days after mid point of bloom. The pedicels were finger rubbed with CPPU using latex gloves and taking great care to avoid any contact with the fruit pericarp. Five days after establishing the treatments a second application was performed to ensure CPPU uptake into the pedicel or fruit. Treatments were arranged in a two factor completely randomised design where fruit and pedicel were the main factors. The procedure ANOVA of SAS was used to analyse the treatments. Orthogonal contrasts were carried out for means differentiation. The measured variables were as for the last experiment. The fruit seed number evaluation was recorded on a sample of 30 fruit per treatment of average size for the treatment.

Influence of partially defoliated canes on pedicel and fruit size

Across eight adjacent vines 32 canes averaging 230 cm of length were selected in the same orchard at the end of winter dormancy. Half of the canes were partially defoliated, starting on the 2nd of October 2001, when all the sprouting buds along the canes had reached at least 2 cm of length, 5 days after bud burst or 50 days before mid point of bloom. This treatment consisted in removing two leaves every third leaf, starting from the base of the cane (Piller et al. 1998). Any further leaves that developed on the selected canes were removed when they attained 50–70 % of expansion. The defoliation periods were established every ten days until November 11th 2001. Untreated and partially defoliated canes were arranged in a randomised complete block design. Each block consisted of a defoliated cane plus an adjacent untreated cane located along one side of the vine. Percentage of fruit retention per cane was determined as the difference between flower number at full bloom and fruit number in February. Pedicel length (mm) was recorded one month before commercial harvest by using digital callipers. Fruit volume (cm^3) by water displacement was evaluated on December 10th 2001 using a volumetric cylinder. Fruit fresh weight (g) per cane was determined at commercial harvest. A random sample of

30 fruit from each of the two treatments was cut into quarters transversely, and the seed number counted on the six surfaces. The variables were analysed using the procedure TTEST of SAS (SAS Institute, Cary, N.C., USA) for independent samples. The procedure GLM of SAS was used to perform the ANOVA for fruit weight because more than 50 % of the fruit on the defoliated canes abscised. Least square means of SAS were obtained to differentiate the fruit weight treatment means.

Results

The application of Agromil-Plus® 30 days after full bloom (Fig. 1) resulted in the largest increase in fruit weight (Table 1). Pedicel weight and length were also greater than the control. In contrast, when GA_3 was applied, the fruit size was significantly reduced by more than 8 g (Table 1). This treatment also produced the longest pedicels. The ABA treatment and the control produced fruit and pedicels of similar size (Table 1).

There were treatment differences in final fruit fresh weight. Application to the pedicel alone produced fruit significantly larger than the control by 15 g but of less weight than dipped fruit and dipped fruit plus pedicel application (Table 2). CPPU applied to the fruit as a dip, and fruit and pedicel application achieved the highest fresh weight, increasing fruit weight by 34 and 37 g, respectively. These two treatments were similar by orthogonal contrast tests ($P \leq 0.05$) but their pedicel weights were significantly different. Dipped fruit also had heavier pedicels than the control. Pedicel length, and fruit seed number were not significantly affected by the treatments (Table 2).

Fruit weight at harvest on partially defoliated canes after bud burst (88.7 g) and on untreated canes (91.9 g) was not significantly different, and both treatments had fruit of similar seed number (Table 3). Fruit retention % was reduced by the partial defoliation by 47.5 % (Table 3). The fruit volume recorded in the second week of December was significantly greater on canes that were not defoliated (Table 3), because on the defoliated canes there were many small fruit that dropped soon after measurement. Pedicel length and pedicel fresh weight were significantly reduced in the fruit growing on a partially defoliated canes even though fruit fresh weights similar (Table 3).

Table 1. Fruit and pedicel average size after applying bioregulators on lateral pedicels of 'Hayward' kiwifruit[z].

Treatment	Fruit weight (g)	Pedicel fresh weight (g)	Pedicel length (cm)	Seed number
Agromil-Plus®	122.2 a	1.58 a	6.8 ab	192 a
GA_3	87.5 c	0.95 b	7.1 a	194 a
ABA	91.7 bc	0.83 bc	6.4 bc	195 a
Control	96.0 b	0.70 c	6.0 c	197 a

[z]Numbers in the same column with different letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

Table 2. Fruit and pedicel size effects after a CPPU (10 ppm) application direct to the pedicel, fruit, and fruit and pedicel in 'Hayward' kiwifruit[z]

Treatment	Fruit weight (g)	Pedicel fresh weight (g)	Pedicel length (cm)	Seed number
Control	104.2 c	0.75 c	6.1 a	186 a
Pedicel	119.7 b	1.05 a	5.9 a	180 a
Fruit	137.9 a	0.83 b	5.9 a	181 a
Pedicel + Fruit	141.5 a	1.05 a	5.9 a	189 a

[z]Numbers in the same column with different letters are significantly different by orthogonal contrasts at $P \leq 0.05$.

Table 3. Floral and fruit variables recorded after a partial defoliation on individual kiwifruit canes 5 days after bud burst.[z]

	Pedicel length (cm)	Pedicel fresh weight (g)	Fruit retention (%)	Fruit volume (cm^3)	Fruit weight (g)	Seed number
Control	5.1 a	0.70 a	78.1	5.2 a	91.9 a	181 a
Partially defoliated canes	3.8 b	0.58 b	41.0	4.4 b	88.7 a	183 a

[a]Number in the same column with different letters significantly differ by t-test at $P \leq 0.05$

Discussion

Vine crop load is a major determinant of fruit size, rather than crop load of an individual cane or fruiting lateral shoot (Lai et al. 1989, 1990). Thus in the present work comparisons between treatments were always made at similar over-all crop loads and differences in crop load at the cane or fruiting lateral level were considered unimportant (Snelgar et al. 1986).

A significant fruit weight response was observed when lateral pedicels of an inflorescence were immersed in Agromil-Plus®. This treatment achieved the largest pedicel weight. However, the increase in fruit weight was inferior to the fruit weight achieved by dipped fruit or dipped fruit plus pedicel application of CPPU (Table 2). Thus, fruit size increase was related to a direct CPPU effect rather than an increase in transport of photoassimilates due to enlarged pedicel dimensions. CPPU transport is limited when applied to leaves or directly to the fruit (Biasi et al. 1993; Neri et al. 1993; Cruz-Castillo et al. 1997) but changes in fruit weight and length of trichomes found in the present work demonstrated a movement of CPPU from the lateral pedicel to the fruit.

Application of GA_3 through the lateral pedicel did not affect seed number but produced longer and heavier pedicels and fruit of about 10 g less weight when compared to the control fruit (Table 1). Path limited translocation in terms of distance between source and sink due to an increase in length of the pedicel may be associated with the reduction in fruit growth (Canny 1973, 1975). Burge et al. (1990), also found a reduction in kiwifruit size associated with long pedicel length after spraying GA_3 to flowers before bloom. GA_3 applications enhance fruit size of seedless grapes but are ineffective unless directly applied to the fruit (Considine 1983). Since GA_3 is normally considered a promoter of fruit growth it could be suggested that the principal hormonal effect found in the present work was on the elongation of the pedicel of the terminal fruit. However, all CPPU treatments had pedicels of similar length but greater weight compared to the control treatments and the larger fruit weights may indicate that sufficient amount of carbohydrates were translocated through the pedicel (Table 2). This viewpoint is supported by the observation that fruit of large size with long pedicels are produced by the application of hydrogen cyanamide on kiwifruit vines in winter (Patterson et al. 1999). Thus, long pedicels are not always associated with fruit of small size.

The reduction of the pedicel dimension in the fruit growing on the partially defoliated canes at bud burst (Table 3) may show less translocation of gibberellins from the leaves to the pedicel because application of gibberellins to kiwifruit shoots increased the length of the kiwifruit pedicel (Burge et al. 1990). McPherson et al. (2001) showed a significant association between long pedicels and kiwifruit of small size. In the present work, fruit with short pedicels on defoliated canes were similar in fresh weight to control fruit that had longer pedicels.

With respect to fruit retention in the defoliation experiment it seems vine or fruit endogenous mechanisms on the defoliated canes regulated the pedicel length decreasing a possible path of resistance for carbohydrate translocation into the fruit (Canny 1973, 1975) to promote fruit retention. Likewise, defoliation may reduce fruit retention by limiting the capacity of vascularisation in the pedicel (Jacobs 1970). However these possible effects of the developing pedicel on the retention of fruitlets would appear to be separate phenomena from the effect of the vascularized pedicel on final fruit size.

Fruit weight was increased applying CPPU to the pedicel but larger ($P \leq 0.05$) fruit sizing effects were recorded on fruit dipped in CPPU, plus or minus pedicel application (Table 2). This additive fruit sizing effect applying CPPU on pedicel plus fruit did not significantly influenced pedicel size with respect to the pedicel application. However, CPPU dipped fruit resulted in smaller pedicel size but larger fruit size compared to fruit pedicel only treated with CPPU (Table 2). Applications of 2,4-D and naphthyl-1-acetic acid have increased the vascularization of cherry pedicels (Tukey and Hammer 1949). In the present work, we did not evaluate the anatomy of pedicels treated with CPPU but previous work (Woolley et al. 1992) indicated that CPPU treatments increased the area of vascular tissue compared to untreated pedicels.

The increased pedicel weight found in fruit treated with CPPU (Table 2) could possibly be related to CPPU transport from the fruit to the pedicel rather than an effect of high fruit sink activity. These increases in pedicel dimensions could be responsible for increased fruit size if transport of carbohydrates were limiting growth. However, application of CPPU to both fruit and pedicel increased pedicel size but had no significant effect on fruit size compared to fruit treatment alone. Thus, large pedicel dimension with an increased cross-sectional area of vascular tissue (Woolley 1992) did not improve the unloading of assimilates into CPPU treated fruit.

There is good evidence to believe that the phloem transport pathway has spare capacity (Wardlaw 1990). Never-the-less many workers have found that there is a positive relationship between fruit size and pedicel/peduncle size and have implied that is casually related to improved carbohydrate translocation to the fruit. Thus, Lai et al. (1990) studying flower quality effects in kiwifruit development found a positive significant correlation between pedicel diameter and kiwifruit fresh weight at harvest. Similarly, Antognozzi et al. (1991) indicated that the pedicel diameter is important determining large fruit size while McPherson (2001) found a negative correlation between pedicel length and fruit size. Large fruit size has also been related to large dimensions of the peduncle in strawberry (Webb 1973), pepper (Setiamihardja and Knavel 1990), citrus (Nii 1980), and apple (Ferree et al. 2001).

In the present work, although there was a dramatic increase in pedicel diameter, there was not a commensurate increase in fruit size that would be expected if pedicel diameter were limiting photoassimilate import into the fruit. Therefore, we would contend that thick pedicels are a result of high sink activity producing a large fruit.

In kiwifruit vines, the size of the pedicel may be a response of the fruit to natural conditions or cultural practices that promote fruit sink strength. For example, pedicel length and flower size were enlarged by increasing the duration of the period of chilling in sweet cherry (Mahmood et al. 2000). Aloni (1987) suggested that plants grown under favourable conditions have larger pedicel vascular elements, and thick diameter of vessels indicated efficiency in water conduction. Thus, kiwifruit canes treated with hydrogen cyanamide (Patterson et al. 1999), shoots with a favourable leaf:fruit ratio (Lai et al.

1990), kiwifruit applications of CPPU (Table 2; WOOLLEY et al. 1992), and terminal fruit in a kiwifruit inflorescence (ANTOGNOZZI et al. 1991) produce large fruit with a pedicel of large dimension. The evaluation of pedicel dimensions of fruit under these circumstances could confirm that sink strength determines pedicel size and phloem transport into the fruit, and that the size of the pedicel do not significantly limit kiwifruit size as indicated by the results presented here. A useful approach to further investigating the relationship between pedicel dimensions and fruit growth would be resistance analysis of the pathway, which would involve determining carbohydrate fluxes along the pedicel in response to differing sink strengths (the driving force) combined with further anatomical investigations of pedicels of different dimensions.

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