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# Thinning and Subsequent Lateral Flowering of 'Hayward' Kiwifruit Vines

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***Abstract.*** **Manual fruit thinning is a common practice to enhance the quality of kiwifruit, yet information on its effects regarding subsequent lateral blooming remains limited. We investigated the impact of floral and fruit thinning on fruit size, dry matter, and carbohydrate accumulation. Effects on lateral blooming in the following season were also assessed. Thinning was conducted at full bloom, and 53 and 103 days after full bloom (DAFB), removing 50% of flowers or fruits. Thinning flowers or fruit at 53 or 103 DAFB resulted in increased fruit fresh and dry weights. The percentage of dry matter also rose with flower or fruit thinning at 53 DAFB. Fruit firmness, total soluble solids, and fruit shape at harvest were not affected significantly by thinning. Floral thinning boosted the fruit content of fructose, sucrose, starch, soluble, and total carbohydrates. All treatments led to an increase in the total carbohydrate content in the fruit, but floral thinning produced the highest values for starch and total carbohydrates. In the following season, floral thinning yielded a marked increase in inflorescences with double and triple lateral flowers, significantly enhancing the reproductive capacity of the vines. Additionally, fruit thinning at 53 DAFB also resulted in a rise in inflorescences featuring triple flowers and an increase in reproductive capacity, though to a lesser extent.**

The high-quality standard of 'Hayward' kiwifruit (*Actinidia chinensis* var. *deliciosa*) is important for international marketability and profitability of kiwifruit cultivation in Italy. A few years ago, fruit size and shape were the primary indicators of quality. Today, additional factors such as taste and aroma have gained prominence, with soluble sugar content and the sugar-to-organic acid ratio playing a critical role in the sensory appeal of ripe berries (Jaeger et al. 2003; Marsh et al. 2004).

The dry matter content at harvest correlates with starch levels at harvest and soluble solids content in mature fruit (Jordan et al. 2000; Richardson et al. 1997; Velemis et al. 1997). Consequently, kiwifruit prices, especially in New Zealand, are based not only on size, but also on dry matter content, and dry matter is influenced by agronomic practices in the orchard (Currie et al. 2018).

Crop load affects fruit growth and dry matter accumulation inversely (Famiani et al. 2012), and thinning practices improve fruit size significantly, but provide limited insight into effects on dry matter and carbohydrate content (Pescie and Strik 2004). Moreover, appropriate leaf-to-fruit ratios (Akbaş and Özcan 2020) are crucial to support fruit growth and dry matter accumulation (Cruz-Castillo et al. 2010; Snelgar et al. 1986). Low leaf-to-fruit ratios result in reduced fruit dry matter (Famiani et al. 1997). Thinning at 1 week after full bloom increased the number of flowers during the subsequent season (Burge et al. 1987). However, the effects of source–sink modifications, such as floral or fruit thinning, on kiwifruit dry matter and carbohydrate content remain unclear, including their impact on a subsequent year's yield potential (Antognozzi et al. 1996; Burge et al. 1987). We investigated the effects of floral and fruit thinning on fruit size, dry matter, and carbohydrate accumulation. During the subsequent season, the lateral blooming was also evaluated.

## Materials and Methods

The experiment was carried out in a commercial orchard of 'Hayward' kiwifruit [*A. chinensis* var. *deliciosa* (A. Chev.)], in Montefiascone, Vitervo, Italy, in 2021 and 2022. Eight-year-old vines grafted on 'Bruno' seedlings were trained to the T-bar system, with 2.5 m between vines within the row and 5 m between rows. 'Matua' pollinizers were present with a male-to-female ratio of 1:5.

A thinning treatment on whole vines was established in late May, with 50% of the flowers removed at full bloom. This was repeated 53 or 103 d after full bloom (DAFB), removing fruitlets. The control vines were not thinned. Each treatment was applied to 10 different vines in a completely random design. All the fruit per vine were counted, and fresh weight was determined at harvest in late October. A sample of 30 fruit, selected randomly per vine, was used to determine flesh firmness, which was evaluated with a handheld penetrometer with an 8-mm plunger (Effe.gi, Ravenna, Italy), after removing ~1 $cm^2$ of skin. The total soluble solids content (degrees Brix) from the equatorial part of each fruit was measured with a handheld refractometer (Atago®, Japan). Fruit dry matter content was determined by drying the fruit at 105 °C in a forced-air oven to constant weight (Famiani et al. 2012). Fruit shape was measured with a digital caliper (Steren). Length; minimum, medium, and maximum diameters; and length-to-diameter and minimum-to-maximum diameter ratios were recorded. The carbohydrate and starch content determination was performed on four pulp samples (one per plant), each composed of 10 subsamples taken from different fruit. Freshly extracted pulp was frozen immediately in liquid nitrogen, homogenized in liquid nitrogen with a mortar and pestle into powder, and stored at –80 °C until analysis. Sugars were extracted by adding 1.5 mL of an 80% ethanol/20% water solution containing 100 mM 4-(2-hydroxyethyl)piperazine-1-ethanesulfonic acid–potassium hydroxide (HEPES-KOH; pH 7.1) and 20 mM magnesium chloride ($MgCl_2$) to 50 mg of frozen powder. The samples were incubated in a water bath at 80 °C for ~60 min to enhance extraction, followed by centrifugation at 12,000 $g_n$ for 5 min. The supernatant was recovered, treated with 150 μL of a charcoal suspension (100 mg·$mL^{-1}$), mixed, and centrifuged again at 12,000 $g_n$ for 5 min. The supernatant was stored at –20 °C for metabolite analysis. The sugar contents (glucose, fructose, and sucrose) were determined enzymatically using a spectrophotometric assay (Jones et al. 1977). The assay mixture contained 100 mM HEPES-KOH (pH 7.0), 5 mM $MgCl_2$, 0.5 mM dithiothreitol, 0.02% (w/v) bovine serum albumin, 100 mM adenosine triphosphate, and 40 mM nicotinamide adenine dinucleotide. The glucose measurement was initiated by adding 3 U of hexokinase (from yeast) and 1 U of glucose-6-phosphate dehydrogenase. Fructose and sucrose were analyzed sequentially, adding 1 U of phosphoglucose isomerase for fructose and 100 U of invertase for sucrose. Measurements were based on absorbance changes at 340 nm. Starch was determined on the pellet obtained after soluble sugar extraction (Moscatello et al. 2011).

In April of the following year, the percentage of blind buds (buds without burst); percentage of floral budburst (buds that originated shoots with flowers with respect to total buds that originated shoots); percentage of

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Table 1. Effect of thinning flowers or fruitlets at different times after full bloom on fruit quality of 'Hayward' kiwifruit.

| Thinning | Thinning period | Yield (kg/vine) | No. of fruit | Fruit fresh wt (g) | Fruit dry fruit wt (g) | Dry matter (%) | TSS (°Brix) | Fruit firmness (kg) |
|---|---|---|---|---|---|---|---|---|
| Control | 0 | 74.8 a[1] | 985 a | 70.7 b | 12.0 b | 16.93 b | 7.6 ab | 9.0 b |
| Flower | Full bloom | 44.6 b | 532 b | 84.3 a | 15.2 a | 18.01 a | 8.0 a | 9.9 ab |
| Fruitlet | 53 DAFB | 47.8 b | 597 b | 82.3 a | 14.3 a | 17.34 ab | 7.3 ab | 11.3 a |
| Fruitlet | 103 DAFB | 51.2 b | 580 b | 88.2 a | 15.0 a | 16.95 b | 6.7 b | 10.7 ab |

[1]Means followed by the same letter are not significantly different by the Student–Newman–Keuls test ($P \geq 0.05$).

DAFB = days after full bloom; TSS = total soluble solids.

vegetative buds (buds that did not produce flowers with respect to total buds); number of flowers per inflorescence; percentage of inflorescences with one, two, or three lateral flowers; number of inflorescence/floral bud; and a floral index calculated by multiplying the percentage of fertile buds by the number of flowers per fertile bud were determined on six canes per treatment on each of the 10 plants evaluated. All data were evaluated by analysis of variance using SAS software (v. 8e; SAS Institute, Cary, NC, USA). The mean differences were determined using the Student–Newman–Keuls test at the 5% level.

## Results and Discussion

The control fruit had a medium commercial fresh mass determined as class I at ∼71 g (Table 1) (Codex Alimentarius International Food Standards 2020). The thinning treatments increased the mean fresh and dry fruit weight in vines with similar yields and numbers of fruit per vine (Table 1). The percentage of dry matter increased significantly when the thinning was performed at full bloom. The increase in the percentage of dry matter when the thinning was conducted 53 DAFB indicates that thinning close to full bloom may be more effective for increasing the percentage dry matter in the fruit (Table 1). Compared with the control, the increase in fruit weight in the flower-thinning and fruit-thinning treatments performed 53 and 103 DAFB ranged from 15% to 25% for fresh weight and from 19% to 27% for dry weight. The comparison between the increase in fresh weight (20%) and dry weight (25%) clearly indicates that thinning had a greater effect on the accumulation of dry matter than on fresh weight. A reduction of 50% in the number of flowers and fruit led to a production reduction of ∼30% (Table 1). Thus, the increased leaf area available for each fruit allowed for greater berry growth, and the increase in fresh and dry fruit weight resulting from flower or fruit thinning was ∼20% and ∼25%, respectively (Table 1). The kiwifruit was unable to exploit fully the greater supply of assimilates resulting from the larger leaf area. Other studies on source–sink relationships in kiwifruit have also highlighted an inherent weakness in the fruit's sink strength (Famiani et al. 1997; Mowat and Maguire 2007), and cytokinins may play a role in the lack of stimulation of cell expansion for carbon allocation into the fruit (Nardozza et al. 2020).

All thinning treatments achieved fruit with greater fructose, sucrose, starch, soluble solid, and total carbohydrate values with respect to the control (Table 2). The flower-thinning treatment resulted in fruit with the greatest starch and total carbohydrate contents (Table 2). The carbohydrates in the fruit show that the timing of thinning influenced the dynamics of soluble carbohydrate and starch accumulation. In particular, flower thinning, increased soluble sugars, starch and total carbohydrates. Late thinning performed 103 DAFB demonstrated a fructose, sucrose, and total soluble sugar accumulation similar to the control, but starch content was significantly different (Table 2). This difference can be associated with the dynamics of metabolite accumulation in kiwifruit development where the starch accumulates, and later is degraded into soluble sugars during the final period of fruit ripening. During this period, the carbohydrates continue to be transported from the leaves, contributing to the increase of these metabolites in the fruit before harvest (Moscatello et al. 2011). Therefore, when thinning is performed early, the increased leaf area per fruit allows greater carbon accumulation in the fruit. The greater accumulation of dry matter and sugars correlates to the organoleptic quality of the fruit (Burdon et al. 2004; Crisosto et al. 2012; Currie et al. 2018). Therefore, thinning, by increasing both dry matter and sugars, improves the quality of the fruit, especially when is done early. Thinning is usual in kiwifruit vine management and is effective in increasing fruit size and dry weight (Boyd and Barnett 2011; Patterson and Currie 2011). Total soluble solids and fruit firmness were not clearly affected by the thinning treatments at harvest (Table 1). Fruit shape (length and maximum/minimum diameters and their ratios) was unaffected significantly ($P \leq 0.05$) by the thinning treatments (data not shown).

During the subsequent season, flower and fruit thinning influenced flower bud differentiation and bud fertility (Table 3) in a burst that was similar for all treatments (Table 3). The thinning at full bloom and 53 DAFB provoked a significant increase in inflorescences with laterals of three or two flowers, and a decrease in those with a single flower (Table 3). Moreover, these treatments increased the number of inflorescences per floral bud, the number of flowers per fertile bud, the number of flowers per inflorescence, and the floral or fertility index (Table 3). The increased availability of assimilates caused by thinning resulted in improved bud fertility, especially in the flower-thinning and fruit-thinning treatments performed 53 DAFB (Table 3). There was an increase in fertile buds of 15% to 20%, in inflorescences per fertile bud of ∼15%, and in flowers per fertile bud of 24% to 35%. The fertility index summarized the results on fertility considering both the percentage of fertile buds and the number of flowers per fertile bud. Compared with the control, the increase in this index as a result of early thinning was ∼50%. The greater increase in flowers per fertile bud influenced an increased availability of assimilates that promoted the formation of inflorescences with two or three flowers rather than those with only one flower (Table 3). Thus, practices manipulating the increase of carbohydrates in the fruit would increase return bloom and the occurrence of lateral flowers. Burge et al. (1987) showed that thinning 50% of flowers in 'Hayward' kiwifruit unaffected significantly the number of nodes with laterals. However, their differences in the percentage of nodes with laterals (20%) with respect to the control (10%) was of 50%. 'Hayward' kiwifruit produces inflorescences as a compound dichasium, with a terminal and two lateral flowers. Then, 'Hayward' kiwifruit inflorescences potentially have three flowers, but in general, one or both lateral flowers abort, resulting in inflorescences with two flowers or just one flower (Richardson et al. 2022). The effects of assimilate availability on bud fertility contribute to understanding the mechanisms behind flower differentiation in kiwifruit. It

Table 2. Effect of thinning flowers or fruitlets days after full bloom on the carbohydrate content of 'Hayward' kiwifruit.

| Thinning | Thinning period | Glucose (μmol·g$^{-1}$ FW) | Fructose (μmol·g$^{-1}$ FW) | Sucrose (μmol·g$^{-1}$ FW) | Starch (μmol·g$^{-1}$ FW) | Total soluble carbohydrates (μmol·g$^{-1}$ FW) | Total carbohydrates (μmol·g$^{-1}$ FW) |
|---|---|---|---|---|---|---|---|
| Control | 0 | 71.6 ab[1] | 74.5 b | 26.9 b | 244.9 c | 173.0 b | 417.8 c |
| Flower | Full bloom | 73.1 ab | 85.8 a | 37.8 a | 305.3 a | 196.6 a | 501.9 |
| Fruitlet | 53 DAFB | 71.8 ab | 80.7 a | 37.6 a | 272.5 b | 190.1 a | 462.6 b |
| Fruitlet | 103 DAFB | 67.7 a | 72.9 b | 28.7 b | 283.4 b | 169.3 b | 452.7 b |

[1]Means followed by the same letter are not significantly different by the Student–Newman–Keuls test ($P \geq 0.05$).

DAFB = days after full bloom; FW = fresh weight.

Table 3. Effect of thinning flowers or fruitlets at different days after full bloom on return bloom of 'Hayward' kiwifruit.

| Thinning | Thinning period | Blind bud (%) | Vegetative bud (%) | Floral buds (%) | Infl. with triple flowers (%) | Infl. with double flowers (%) | Infl. with single flowers (%) | No. of Infl./floral bud | No. of flowers/ fertile bud | No. of flowers/ Infl. | Floral index (no. of flowers/ 100 buds) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | 0 | 38.9 ab[1] | 16.0 ab | 44.5 b | 2.7 c | 3.1 b | 94.3 a | 3.1 b | 3.4 b | 1.09 c | 151.3 b |
| Flower | Full bloom | 40.0 a | 8.5 b | 51.5 a | 9.2 a | 9.7 a | 81.1 b | 3.6 a | 4.6 a | 1.28 a | 236.9 a |
| Fruitlet | 53 DAFB | 34.5 b | 12.2 ab | 53.4 a | 5.8 b | 7.8 a | 86.4 b | 3.5 a | 4.2 a | 1.19 b | 224.3 a |
| Fruitlet | 103 DAFB | 38.0 ab | 17.9 a | 43.3 b | 2.2 c | 2.9 b | 94.9 a | 3.1 b | 3.3 b | 1.07 c | 142.9 b |

[1]Means followed by the same letter are not significantly different by the Student–Newman–Keuls test ($P \geq 0.05$).
DAFB = days after full bloom; Infl. = inflorescences.

seems that with increased assimilate availability, *MADS*-box (Varkonyi-Gasic et al. 2011) or *AcFT* genes (Moss et al. 2018) may have a role in lateral floral specification. There was an increase in fertile buds (15%–20%), which produced inflorescences, and especially an increase in inflorescences with three and two flowers, and thus more flowers. An increased abortion of lateral flowers results in king or single flowers. Fruit yield was not studied the second year of our study. In kiwifruit production, the number of fruit left on the plant after thinning corresponds to the final yield under normal conditions (Burge et al. 1987).

It seems a self-regulation mechanism exists in response to assimilate availability for the formation of a certain number of flowers through greater or less floral abortion, and the *AcKNOXs* genes would be involved (Jia et al. 2024). Overall, our results indicate that thinning from late May (full bloom) to August (fruit cell division) would improve return bloom, affecting floral differentiation, and that buds have an important sensitivity/capacity to use increased carbon assimilates.

Thinning before bloom has increased kiwifruit size (Pescie and Strik 2004), but effects on subsequent flowering are unknown. Thinning girdling trunk or branches increases budburst and single flowers per cane (Currie et al. 2018); defoliation reduces the number of lateral flowers (Cruz-Castillo et al. 2010). An excessive number of lateral flowers provoked by thinning is a disadvantage because growers focus on the king or single flower. Thus, thinning effects would depend on specific vine management by growers, as occurs with girdling (Currie et al. 2018).

## Conclusion

More assimilates were available for the fruit by thinning at full bloom and 53 DAFB. Thus, the size, dry matter, and carbohydrate content of 'Hayward' kiwifruit were increased. The potential for the production of lateral flowers the following year was also enhanced with a greater number of triple and double lateral flowers. In conditions of limited carbohydrate availability, less induction/differentiation of flower buds and abortion of lateral flowers in inflorescences may occur. It seems buds, compared with fruit, have greater sensitivity/capacity to use the increased assimilate availability.

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