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Effects of Bloom Thinning with Lime Sulfur on Fruit Set, Yield, and Fruit Quality Attributes of 'RubyS' Apples

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

NMW, DL, YSC, and JCN designed the experiment. NMW and JCN conducted the experiment. JP and YYS assisted in the experiment. YL, MYP, HJK, and IKK advised the experiment. NMW wrote the original manuscript. NMW and JCN revised the manuscript. JCN supervised the project.

Abstract

Bloom thinning is an important practice that influences the profitability of the orchard. Hence, we assessed the effect of chemical bloom thinning on thinning efficiency and fruit quality of 'RubyS' apples. Lime sulfur was applied as a bloom thinning agent at 1, 1 + 3, and 2 + 4 days after full bloom (DAFB), and non-bloom thinning trees were used as controls. Compared to the control and bloom thinning treatments at 1 DAFB and 2 + 4 DAFB, the application of bloom thinning at 1 + 3 DAFB greatly decreased the number of fruits per cluster in both terminal and lateral flowers. Although the application of bloom thinning at 2 + 4 DAFB decreased the number of fruits per cluster in the terminal flower, it did not affect the number of fruits per cluster in the lateral flower when compared to the control. At harvest, the number of fruits per tree (fruits/ tree) and yield (kg/ tree) was significantly higher in control trees than in bloom-thinned trees. However, fruit quality attributes including fruit weight and size, flesh firmness, soluble solids content, area of red-blushed surface, and *a** value in the fruit were significantly improved by bloom thinning at 1 + 3 DAFB. Therefore, this study suggested that applying bloom thinning at 1 + 3 DAFB could serve as an effective thinning treatment to manage crop load in trees and improve the quality of 'RubyS' apple fruits.

Additional key words: fruit color, fruit size, fruit weight, lateral flowers, terminal flowers

Introduction

Thinning practice of flowers (blooms) or fruits is one of the crop load management strategies used by growers in many commercial apple orchards (Dennis, 2000; Fallahi and Greene, 2010; Costa, 2016) to improve fruit size, color, and quality (Link, 2000). Thinning of flowers or fruits in apple trees is conducted using manual, chemical, or mechanical thinning methods (Guak et al., 2009; Hehnen et al., 2012; Yoo et al., 2016; Lordan et al., 2018; Allen and Sherif, 2019). In Korea, many apple growers still use the hand thinning method for removal of flowers and fruitlets in trees, which might be due to a lack of information on the use of chemical or mechanical thinning methods, leading to higher production costs (Chun et al., 2012). However, some researchers reported that the success of using post-bloom chemical fruit thinning depends on external factors, including weather conditions (Bayers and Carbaugh, 1991; Yuan, 2007). Therefore, chemical bloom thinning would be an alternative to hand thinning in apple trees.

Numerous chemical bloom thinning treatments have been used to reduce the flower density in apple trees, including lime sulfur, octyl alcohol, ammonium thiosulfate (ATS), 1-naphthaleneacetic acid (NAA), and 6-benzyladenine (BA) (Stover et al., 2001; Stopar and Lokar, 2003; Yoo et al., 2016; Yoo et al., 2019; Fruk et al., 2017; Allen et al., 2021). Among them, positive effects were reported for lime sulfur in numerous apple cultivars (Bertschinger et al., 2000; Guak et al., 2004; McArtney et al., 2004; Stopar, 2004; Yoo et al., 2016; Yoo et al., 2019). Lime sulfur inhibits pollen germination and pollen tube growth in the pistil, thereby preventing fertilization (Schupp and Kon, 2019). However, lime sulfur can cause spur leaf damage and fruit russeting when applied under high temperature or suboptimal weather conditions (Schupp and Kon, 2019). Additionally, the effect of lime sulfur on apple bloom thinning was highly dependent on the concentration, time of application, flower density, and cultivar (Chun et al., 2012; Yoo et al., 2016; Yoo et al., 2019; Allen et al., 2021).

‘RubyS’ (‘Alpsotome’ × ‘Sansa’) is a locally developed new apple cultivar (Kwon et al., 2019), which recently became popular in the apple market in Korea owing to its high sweetness. Hence, the production of increased yield with high-quality fruit is economically essential for this apple cultivar, and crop load management by chemical bloom thinning could be used to produce marketable quality fruits. However, as a new apple cultivar, the effect of bloom thinning by lime sulfur on the ‘RubyS’ apple has not yet been reported.

Therefore, this study aimed to assess the efficacy of lime sulfur as a bloom thinner on the removal of flowers in the ‘RubyS’ apple tree. We also investigated the influence of bloom thinning on the yield and quality characteristics of the apple fruits at harvest.

Materials and Methods

Plant Materials and Experimental Field Conditions

The experiment was performed in a commercial orchard located in Yeongcheon, Korea. Five-year-old ‘RubyS’ apple trees, planted in the same soil and environmental conditions, were chosen for this experiment. The apple trees were grafted to M.9 rootstock planted with 3.0 × 1.5 m spacing in the experimental field. The experimental field was managed with standard agricultural practices and an integrated pest management system. Additionally, the trees were irrigated using a drip irrigation system and mulched with coarse bark chips.

Bloom Thinning Treatments

In the experimental field, flowers fully bloomed on April 19, 2021. For bloom thinning, we used a solution of lime sulfur (120-fold dilution, 8.33 mL/L) (Be' 22, Hwangbuja, Enbio Co., Jecheon, Korea). We randomly selected a total of 20 uniform trees. Then, the trees were divided into four groups, and five trees were included in one group. For the first group, the bloom thinning treatment was applied to trees only one time at 1 day after full bloom (DAFB) (April 20, 2021). For the second group, bloom thinning treatment was applied twice at 1 and 3 DAFB (1 + 3 DAFB; April 20 and 22, 2021).

For the third group, bloom thinning treatment was applied twice at 2 and 4 DAFB (2 + 4 DAFB; April 21 and 23, 2021). The fourth group was used as a non-bloom-thinning (control) group. All bloom thinning treatments were applied using a hand sprayer in the morning (around 9:00 a.m.).

Assessments of the Fruit Set Rate in Terminal and Lateral Flowers, Number of Fruits per Tree, and Yield

For the fruit set rate, the number of fruits per cluster in the terminal and lateral flower cluster was counted before and after the application (fruitlet stage) of lime sulfur. On August 18, 2021, fruits were harvested and immediately sent to the laboratory of the Apple Research Institute, Gunwi, Korea. The number of fruits per tree was counted at harvest time. After recording the number of fruits and yield, 10 uniform fruits per tree were randomly selected for evaluation of fruit quality attributes.

Assessments of Fruit Quality Attributes

Fruit weight was measured using a digital weight balance (AND Co., Daejeon, Korea), and the unit was expressed as grams. Fruit size (length and diameter) was measured using a digital caliper (CD-15APX, Mitutoyo Corp., Japan) and expressed in millimeters. For fruit coloration, the development of red-blushed surface area in each fruit peel was recorded as reported in Serra et al. (2016), and expressed as a percentage. Fruit peel color parameters (L^*, a^*, and b^*) were measured at the reddest cheek area of individual fruit using a chromameter (CR-200, Konica Monilta, Japan). Flesh firmness (11-mm plunger) was measured at three places in the equatorial regions of each fruit using a digital penetrometer (Fruit firmness tester, TR Co., Italy), and expressed as newton (N). Soluble solids content (SSC) was measured on a juice sample (0.5 mL) of each fruit using a digital refractometer (PR-201 α, Atago Co., Japan), and expressed as ^{o}Brix. Titratable acidity (TA) was measured by titrating the juice sample (5 mL) of each fruit using the reduction method of malic acid (pH 8.1), according to Win et al. (2019), and expressed as % of malic acid equivalent. For the starch pattern index (1–8 score), each fruit was cut horizontally at the equatorial region, and the cutting slices were dipped into iodine solution by following a Cornell starch pattern index analysis method (Blanpied and Silsby, 1992).

Statistical Analysis

The SPSS statistical software program was used for all analyzes (Version 25, IBM SPSS Corp., NY, USA). The data were subjected to analysis of variance, and the mean differences in the treatments were separated using Duncan's multiple range test at a significance level of $p < 0.05$.

Results and Discussion

Effect of Bloom Thinning on the Fruit Set Rate

In all bloom thinning treatments, the application of lime sulfur at 1 + 3 DAFB was the most effective thinning treatment for the 'RubyS' apple tree (Table 1). The number of fruits per cluster in terminal flowers was significantly decreased by

Table 1. Effect of bloom thinning on the fruit set rate of the terminal and lateral flower cluster of ‘RubyS’ apples

Thinning treatments	Terminal Fruits per cluster	Lateral Fruits per cluster
Non-bloom thinning (control)	3.07 ± 0.18[z] a[y]	1.72 ± 0.51 a
Bloom thinning (1 DAFB)	2.69 ± 0.51 ab	1.16 ± 0.07 a
Bloom thinning (1 + 3 DAFB)	1.69 ± 0.28 c	0.89 ± 0.08 b
Bloom thinning (2 + 4 DAFB)	2.48 ± 0.23 b	1.39 ± 0.11 a

[z]The data are expressed as mean ± standard error (n = 5). (*Flowers per cluster are counted in the 5 individual trees).
[y]Means within a column are separated using Duncan’s multiple range test at $p < 0.05$.
DAFB: Days after full bloom.

bloom thinning at 1 + 3 DAFB (1.69), compared to the control (3.07), bloom thinning at 1 DAFB (2.69), and bloom thinning at 2 + 4 DAFB (2.48). In lateral flowers, the number of fruits/ cluster was also decreased by bloom thinning at 1 + 3 DAFB (0.89), compared with the control (1.72), bloom thinning at 1 DAFB (1.16) and bloom thinning at 2 + 4 DAFB (1.39). However, the application of bloom thinning at 2 + 4 DAFB decreased only the number of fruits/ cluster in terminal flowers, but not in lateral flowers, compared to the control. Additionally, the number of fruits/ cluster in terminal and lateral flowers was not different between the bloom thinning treatments of 1 DAFB and 2 + 4 DAFB (Table 1).

The application timing of thinning in apple trees is important to achieve the optimum result (Jones et al., 1992; Dennis, 2000; Guak et al., 2004), and the earlier thinning time was more effective than the later thinning time (Bayers and Carbaugh, 2002; Allen et al., 2021). In general, lime sulfur thins flowers by inhibiting pollen germination, pollen tube growth, and fertilization (Peck et al., 2017; Schupp and Kon, 2019). Inconsistent bloom thinning responses may be attributed to application timing since pollen tubes can reach the base of the style within 48 hours (Yoder et al., 2009). Thus, delaying application by one or two days can result in failure of the bloom thinner treatment because the treatment would have little or no effect on fertilization and fruit set of earlier pollinated flowers (Yoder et al., 2009; Yoder et al., 2013; Peck et al., 2016; Peck et al., 2017). However, the growth rate of pollen tubes may vary by cultivar and temperature (Yoder et al., 2009; Yoder et al., 2013). Therefore, determining the optimum application timing is critical for successful bloom thinning practices. Additionally, Yoo et al., (2016) reported that two applications of lime sulfur had a greater effect on thinning in terminal flowers, lateral flowers, and reduction of the fruit set rate than a single application. A similar result was observed in the double application of lime sulfur at 1 + 3 DAFB, compared to a single application at 1 DAFB and the control. Previous studies reported that two lime sulfur applications are typically needed for apple bloom thinning (Schmidt et al., 2011; Allen and Sherif, 2019; Allen et al., 2021). However, no consistent effect was observed in various application timings with lime sulfur in ‘Hongro’ and ‘Fuji’ apples (Chun et al., 2012). The double application of lime sulfur at 2 + 4 DAFB was less effective than double application at 1 + 3 DAFB, which might be due to the timing of the application as discussed above.

Effect of Bloom Thinning on the Number of Fruits per Tree, Yield, Fruit Weight, and Fruit Size

The number of fruits per tree was significantly higher in control trees than in bloom-thinned trees at harvest (Table 2). Additionally, the yield (kg per tree) was also higher in control trees than in bloom-thinned trees. However, the number of fruits per tree and yield were not significantly different among the bloom thinning treatments. Fruit weight was significantly increased in the 1 + 3 DAFB and 2 + 4 DAFB treatments compared with the control. However, fruit weight

Table 2. Effect of bloom thinning on the number of fruits per tree, yield (kg per tree), fruit weight, and fruit size of ‘RubyS’ apples

Thinning treatments	Number of fruits per tree	Yield (kg per tree)	Fruit weight (g)	Fruit size (mm)		
				Length (L)	Diameter (D)	L/D ratio
Non-bloom thinning (control)	365.00 ± 33.00^{z} a^{x}	19.27 ± 2.77^{z} a	52.95 ± 1.69^{y} c	46.23 ± 0.66^{y} b	49.92 ± 0.84^{y} c	0.92 ± 0.01^{y} a
Bloom thinning (1 DAFB)	211.00 ± 4.00 b	11.95 ± 0.36 b	56.35 ± 2.24 bc	46.38 ± 0.86 ab	51.23 ± 0.34 bc	0.91 ± 0.01 a
Bloom thinning (1 + 3 DAFB)	190.00 ± 29.26 b	11.60 ± 1.64 b	62.42 ± 1.08 a	48.70 ± 0.35 a	52.69 ± 0.46 ab	0.92 ± 0.00 a
Bloom thinning (2 + 4 DAFB)	224.00 ± 25.54 b	13.88 ± 1.48 b	61.02 ± 1.56 ab	48.06 ± 0.80 ab	53.03 ± 0.28 a	0.91 ± 0.01 a

^{z}The data (within a column) are expressed as mean ± standard error (n = 5). (*Number of fruits per tree and yield are counted in the 5 individual trees).

^{y}The data (within a column) are expressed as mean ± standard error (n = 50). (*Fruit weight and size are measured in the 10 individual fruits per tree).

^{x}Means within a column are separated using Duncan's multiple range test at $p < 0.05$.

DAFB: Days after full bloom.

was not significantly different between the control and 1 DAFB treatment. The increase in fruit size depends on fruit length and diameter. Fruit length was highest in fruits from trees treated at 1 + 3 DAFB, and fruit diameter was highest in fruits from trees treated at 2 + 4 DAFB. However, the ratio of fruit length per diameter (L/D ratio) was not significantly different among the treatments (Table 2). The reduction of fruits per tree (crop load) in bloom-thinned trees is due to the lime sulfur-induced reduction in the number of fruits within each fruiting cluster. Similar results were also reported in previous studies (Yoder et al., 2013; Peck et al., 2017). Additionally, a recent study reported significantly larger fruit weight and size in bloom-thinned trees at harvest, along with a lower yield and number fruits per tree, compared with untreated trees (Allen et al., 2021). The increase in fruit weight in bloom-thinned trees due to reduced inter-fruit competition in each flower cluster (Shin et al., 2019; Stover et al., 2001; Kamiab et al., 2020). Additionally, a significant increase in fruit weight by lime sulfur application was also reported in ‘Gamhong’ apple (Yoo et al., 2016; Yoo et al., 2019). Similar results were also observed in this study, especially for the fruits from trees in the 1 + 3 DAFB treatment.

Effect of Bloom Thinning on the Fruit Quality

Flesh firmness was significantly higher in fruits from trees of the 1 + 3 DAFB treatment than in fruits from control trees (Table 3). However, flesh firmness was not significantly different in fruits among the bloom thinning treatments. Additionally, flesh firmness was not significantly different in fruits from control trees and fruits from trees treated at 1 DAFB and 2 + 4 DAFB. The SSC was significantly higher in fruits from trees treated at 1 DAFB and 1 + 3 DAFB, compared with fruits from control trees. However, the SSC in fruits from trees treated at 2 + 4 days DAFB was not significantly different from that in other treatments (Table 3). In fruits from all treatments, the TA, SSC/TA ratio, and starch index were not significantly different (Table 3).

Flesh firmness is an indicator of fruit hardness, and it is used to measure the stage of fruit maturity (Harker et al., 2008). Also, SSC and TA are important for taste, and contribute to the sweetness of the fruit. Additionally, Harker et al. (2008)

Table 3. Effect of bloom thinning on flesh firmness, soluble solids content (SSC), titratable acidity (TA), SSC/TA ratio, and starch index of 'RubyS' apples

Thinning treatments	Flesh firmness (N)	SSC (°Brix)	TA (%)	SSC/TA ratio	Starch index (1–8)
Non-bloom thinning (control)	90.85 ± 1.42[z] b[y]	13.66 ± 0.04 b	0.54 ± 0.03 a	25.45 ± 1.42 a	6.67 ± 0.17 a
Lime sulfur (1 DAFB)	95.80 ± 0.77 ab	14.20 ± 0.22 a	0.53 ± 0.03 a	26.81 ± 1.74 a	6.33 ± 0.17 ab
Lime sulfur (1 + 3 DAFB)	97.62 ± 2.53 a	14.42 ± 0.18 a	0.58 ± 0.01 a	24.75 ± 0.63 a	6.00 ± 0.29 b
Lime sulfur (2 + 4 DAFB)	94.42 ± 1.94 ab	14.04 ± 0.06 ab	0.63 ± 0.06 a	22.68 ± 2.50 a	6.17 ± 0.17 ab

[z]The data are expressed as mean ± standard error (n = 50).

[y]Means within a column are separated using Duncan's multiple range test at $p < 0.05$.

DAFB: Days after full bloom.

reported that SSC and firmness are economically important parameters in the marketplaces that determine the quality of fruits and consumer acceptability. Moreover, the improvement of fruit quality attributes is related to the application time of bloom thinning treatments. The bloom thinning treatment applied at nearly full bloom improved quality attributes more than bloom thinning applied at a later time (Tromp, 2000; Bayers and Carbaugh, 2002). A similar improvement of quality attributes in fruits from the 1 + 3 DAFB treatment were observed in our study. However, non-significant changes in quality attributes were observed in 'Fuji' apples treated with lime sulfur at various application times (Chun et al., 2012). Therefore, the effects of bloom thinning with lime sulfur on fruit quality attributes could vary by the cultivar used. The starch index is used to evaluate apple fruit maturity, and to estimate the harvest window (Blanpied and Silsby, 1992; Doerflinger et al., 2015). In this study, the starch index score of fruits from trees treated at 1 + 3 DAFB was significantly lower than that in fruits from control trees. Therefore, the higher starch index score in fruits from control trees indicated that starch degradation to sugar was increased in control fruit, leading to faster fruit maturity.

Effect of Bloom Thinning on the Fruit Coloration

Fruit color is important for consumer preference and poor-colored fruits have lower market value. Hence, we measured the area of the red-blushed surface and other color parameters (L^*, a^*, and b^*) in fruit at harvest (Table 4). The area of the red-blushed surface in the fruit peel was significantly enhanced by bloom thinning treatments, especially for fruits from trees treated at 1 DAFB and 1 + 3 DAFB, compared with fruits from control trees. Similar results were also observed in the fruit peel a^*. However, the area of red-blushed surface and a^* in fruits were not significantly different between the 2 + 4 DAFB treatment and the control. Interestingly, L^* and b^* were substantially higher in fruits from control trees than in fruits from trees treated at 1 DAFB and 1 + 3 DAFB. However, L^* and b^* were not significantly different between fruits from control trees and trees treated at 2 + 4 DAFB (Table 4).

In apples, fruit peel color enhancement is strongly associated with the amount of light exposure to fruit (Takos et al., 2006; He and Giusti, 2010). Robinson and Lopez (2009) reported that fruit color could decrease in fruits from trees with a high number of fruits per tree. In this study, a significantly higher number of fruits per tree was observed in control trees, which thereby affected fruit peel color. However, a^* in 'Fuji' apple was not significantly enhanced by bloom thinning with lime sulfur (Yoo et al., 2019). Additionally, the L^* and b^* values were higher in 'Fuji' but lower in 'Hongro' apple fruits from untreated trees compared with fruits from bloom-thinned trees (Chun et al., 2012). However, in this study, higher values of L^* and b^*, and lower values of a^* were observed in fruits from control trees. Therefore, the development

Table 4. Effect of bloom thinning on the red-blushed surface area and fruit peel color (L^*, a^*, and b^*) of 'RubyS' apples

Thinning treatments	Red-blushed surface (%)	Fruit peel color		
		L^*	a^*	b^*
Non-bloom thinning (control)	61.00 ± 6.24[z] b[y]	50.51 ± 3.84 a	12.21 ± 4.52 b	19.86 ± 1.61 a
Bloom thinning (1 DAFB)	74.00 ± 4.62 a	42.33 ± 1.54 b	23.55 ± 1.11 a	16.38 ± 0.63 b
Bloom thinning (1 + 3 DAFB)	75.33 ± 1.76 a	41.61 ± 1.03 b	23.02 ± 1.31 a	16.20 ± 0.49 b
Bloom thinning (2 + 4 DAFB)	69.67 ± 3.48 ab	46.57 ± 1.87 a	17.49 ± 1.72 b	18.29 ± 0.81 ab

[z]The data are expressed as mean ± standard error (n = 50).

[y]Means within a column are separated using Duncan's multiple range test at $p < 0.05$.

DAFB: Days after full bloom.

of fruit peel color could depend on the cultivar used. But, for the 'RubyS' cultivar, red pigmentation could be enhanced by bloom thinning treatment, mainly when applied at 1 + 3 DAFB.

In conclusion, bloom thinning of apple trees with lime sulfur decreased the fruit set rate of the terminal and lateral flowers in the tree. Although the application of lime sulfur reduced the number of fruits per tree and fruit yield, it produced higher quality fruits. However, the effect of lime sulfur depends on the timing of application. Among the different treatments used in this study, the application of lime sulfur at 1 + 3 DAFB was the most effective bloom thinning treatment for managing crop load in the tree and improving fruit size and weight, flesh firmness, SSC, and fruit peel color of 'RubyS' apples.

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