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A Study on Labor Force Reduction and Fruit Quality with the Use of Substances Showing Thinning Effect in 'Fuji' and 'Arisu' Apple Varieties

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Thinning is a common practice in apple production. Many thinning agents have been used to thin apples. The effectiveness of the agents depends on the apple variety and other factors such as orchard conditions or environmental ones. 'Fuji' is one of the apple varieties that is difficult to thin and has been stubborn with different chemical thinning agents. In this study we evaluate the effectiveness of the flower thinning effect agent (FTEA) on 'Fuji' (late maturing variety) and 'Arisu' (early maturing variety) apple qualities such as fruit weight, L/D, hardness, number of seeds, sugar content, and acidity. FTEA was sprayed at 70% bloom only one time. The fruit set rates of FTEA–treated ones were 34.8% for 'Fuji' and 19.9% for 'Arisu', while those of the control were 73.0% for 'Fuji' and 79.9% for 'Arisu'. Thus, the fruit set rates were 38.2–60.0% lower in FTEA–treated plot than the controls. The weight of the fruits also increased by 4.6–13.0%. However, there were no differences in acidity, coloring, seed number, russet and physiological disorders between the two groups. In addition, we noticed a significant increase in yield without any negative effects, and the results generally showed that FTEA has a significant effect on 'Fuji' and 'Arisu' apple fruits. For the stimulation effect of pollen tube elongation, the results indicated no effect of FTEA on pollen tube elongation in an in vitro experiment. FTEA treatment significantly reduced total cost and labor force of flower thinning activity in apple orchard as decreased 67.8% and 76.6%. These results showed that the effects of FTEA spray for flower thinning were significant for both 'Fuji' and 'Arisu' varieties for fruit weight, thinning cost, and labor force reduction.

Key words: apple, chemical thinning, flower thinning, fruit set, labor force reduction

INTRODUCTION

Thinning apple fruitlets by hand is often impossible because of labor costs and the limited supply of available labor (Stopar 2006). Therefore, the development of chemical thinning is needed to ensure profitable apple production.

During the reproductive process, many types of fruits trees produce more fruit than they can support to maturity, and as a consequence this affects fruit quality such as size, weight and production in general. To avoid this biennial production, many researchers have been searching for an effective thinning method. In the beginning, hand thinning was the only method to reduce the number of fruits. However, this method presents time limitations due to weather, high labor costs, and skilled labor in thinning. Therefore, this method is neither economical nor practical. All these reasons have stimulated interest in chemical thinning (Xiao *et al*., 2014; Dias *et al*., 2018).

Chemical thinning in apple cultivation uses ethephon, ammonium thiosulphate, napthylacetic acid, carbaryl, benzyladenine, ethephon, conjugates of naphthalene acetic acid and NAA, and gibberellins (Jones *et al*., 1983; Greene, 1989; Nielsen and Dennis, 1993; Jemric *et al*., 2003; Matta and Ouma 2007; Berlanga Reyes 2008). Many thinning agents such as NAA, ethephon, and 6–BA have been applied to 'Fuji' apples (Guak *et al*., 2002). Naphthaleneacetamide (NAD) has also long been in use. It acts as a synthetic auxin. NAD should be applied from the peak of the blossoming period to up to one week after the end of the blossoming period. NAD is considered to be a weak thinning agent (Westwood, 1993; Stopar 2006). NAD cannot be used on 'Delicious' trees because it induces the formation of a large number of pygmy fruit that stay on the tree until harvest time (Wertheim, 2000).

Benzyladenine (BA) thinning agent was found to be good. Besides thinning, it also accelerates cell division. Apples from trees thinned with BA are therefore larger than would be expected on the basis of the thinning effect alone (Greene, 1993; Wismer *et al*., 1995). When used to thin 'Fuji' trees, BA is most effective when applied when the fruitlets are 10 mm in diameter. BA also improves return bloom (Robinson *et al*., 1998; Sally *et al*., 1991).

In case of ethephon, which has also been used for a long time, and one of its positive effects is that it improves return blooms, and it can also be applied over a longer period. However, the thinning effect of ethephon can vary considerably depending on the temperature (Olien and Bukovac, 1982). Ethephon gives inconsistent results and can even cause overthinning (Wertheim, 2000). For these reasons, it is not approved for use in

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many countries (Link, 1986). The timing of application of chemical thinners can be affected by many factors including species or cultivars and generally the time to apply fruit thinner is generally determined either by fruit size or days after bloom (Batjer *et al*., 1968; Donohoe, 1968; Leytry, 1973; knight and Spenser, 1987). Carbaryl is a highly toxic carbamate pesticide and its use has been reduced due to its harmful effects on pollinating insects (Dennis, 2000).

Therefore, it is necessary to develop eco–friendly thinning agents that are safe for pollinating insects as well as the environment. Some were found to be effective and some had a negative effect. Chemical thinning practices give quite unpredictable results. Nevertheless, many apple farmers want them and there are many variables to use them. Apple growers in different regions need different chemical fruit thinning responses for thinning trees with different ages, culture conditions, rootstocks, climates, and amounts of fruit desired to be removed (Byers and Carbough, 1991). Recently, an eco–friendly thinning agent, Koduri (brand name), was developed by using various organic compounds and microelements, and its safety on honeybees was demonstrated (Jahan *et al*., 2014). We hypothesized that flower thinning effects can be influenced by the presence and quantity of various microelements in the formulation. The objective of this research was to identify thinning effectiveness, and fruit quality by spraying flower thinning effect agents and to determine their impact on pollen tube elongation and the degree of cost reduction due to reducing fruit sets in 'Fuji' and 'Arisu' apple.

MATERIALS AND METHODS

Area description

The trial was conducted in Hwanggan, Chungpook Province of South Korea (latitude: 36˚15'54.08", longitude:127˚55'04.42" elevation: 221 m) in 2019.

Plant materials

The apple variety used is 'Fuji' (late maturing variety) and 'Arisu' (early maturing variety) developed by the Rural Development Administration of Korea. M9 rootstock, 6–year–old 'Fuji' and 'Arisu' trees of uniform size and vigor were selected to field test the flower thinning as well as fruit quality of treatments. The planting distance was 4.0*1.5 and the vitality of tree was medium. All treatment trees were subjected to the standard orchard management practices as applied at apple cultivation.

Treatments applied

The total number of blooms on each tree was counted during the middle of April 2019 before spraying the treatments. The average number of flower clusters per tree at that time was more than 100. The flower thinning effect agent (FTEA, Koduri), containing various organic compounds and microelements were sprayed just once during 50~70% bloom. The dilution of the concentration in water was 0.1% (v:v) and sprayed on the whole tree as 2.5 ton/ha. To prevent biased results, the treatments were arranged in a randomized complete block design replicated three times with 15 trees per replication (Table 1).

Preparation of flower thinning effect agent (FTEA)

The flower thinning effect agent (FTEA) (Apple Bio Co. Ltd., Daegu, Korea) were prepared. The FTEA were registered as a micro–element complex fertilizer, and the guaranteed ingredients were 0.7% zinc and 2% boron of water solubility. Other ingredients included seaweed extract, mannitol, nitrogen, and so on.

Fruit Quality

All the fruits were harvested on November 5, and average fruit weight was measured. A random sample of 15 apples per tree from five trees for each treatment were assessed in detail for fruit quality, including number of seed, L/D, sugar content, acidity, and firmness. All harvested fruits were measured as followed by Bhusal *et al*. (2016) and Matsumoto *et al*. (2017). Russeting and Physiological disorders were investigated every two weeks until harvesting by visual evaluation.

Pollen tube elongation

The plants of apple trees were grown in the experimental orchard described above. The flowers for experiments were collected at about 9 A.M., before the dehiscence of anthers occurred and their pollen was immediately obtained for further use. The experiments were carried out in laboratory. 1/1000 ml of diluted FTEA solution was added to the MS culture medium (Murashige and Skoog 1962). Incubation was done in the sterilized, non–corrosive cavity dishes. After 60 min of incubation, the germination of pollen was measured.

RESULTS AND DISCUSSION

Table 2 shows the total thinning cost and labor force for flower thinning. The total cost of the control, lime sulfur and FTEA were 4,652.8, 3,158.9 and 1,499.6 (US$/ha), respectively, and decreased 67.8% with FTEA treat-

Table 1. Experiment details

Variety	Plot repetition	Number of trees per plot	Total number of trees tested	Area required per plot (m^2)	Total area (m^2)
Fuji (M9)	3	15	45	270.0+90 (non–treated)	720
Arisu (M9)	3	15	45	270.0+90 (non–treated)	

Table 2. Effect of saving thinning cost and labor force expenses for 'Fuji' apple cultivation

	Price of thinning agent[z] ($/ha)	Hand thinning labor force[y] (people/ha)	Hand thinning expenses[x] ($/ha)	Total cost[w] ($/ha)	Saving Rates[v] (%)
Control	0.0	64.0	4,652.8	4,652.8	0.0
Lime sulfur (two times)	250.9	40.0	2,908.0	3,158.9	32.1
FTEA	409.1	15.0	1,090.5	1,499.6	67.8

[z] Based on recommended amount per unit area, [y] Convert to base 8 hours/day, [x] Labor cost $72.7/person/day, [w] Price of thinning agent + Hand thinning labor force, [v] Total cost (control–treat) / Total cost (control) × 100.

ment. The labor force needed for the control, lime sulfur and FTEA were 64, 40 and 15 person/ha, and decreased 76.6% with FTEA treatment. Therefore, FTEA treatment significantly reduced the total cost and labor force for flower thinning activity in the apple orchard.

Fruit set rates in 'Fuji' and 'Arisu' varieties were compared between the untreated control and FTEA–treated plots (Table 3). In 'Fuji' variety, the fruit set rate of FTEA–treated one was 34.8% with 33.0% of terminal flowers and 36.6% of axillary flowers, while that of the control was 73.0% with 77.7% of terminal flowers and 68.3% of axillary flowers. Thus, the fruit set rate was 38.2% higher in untreated plot. In 'Arisu' variety, the fruit set rate of FTEA–treated one was 19.9% with 18.8% of terminal flowers and 21.0% of axillary flowers, while that of the control was 79.9% with 82.9% of terminal flowers and 76.9% of axillary flowers. Thus, the fruit set rate was 60.0% higher in the untreated plot. These results showed that the effect of FTEA spray was significant for both 'Fuji' and 'Arisu' varieties.

The apple fruit quality of 'Fuji' and 'Arisu' varieties were compared between the untreated control and FTEA–treated plots (Table 4). For the 'Fuji' variety, the weights of the control and FTEA–treated fruit were 310.6 g and 351.0 g, respectively, and was 11.3% higher for the FTEA–treated fruit. L/D, hardness, and sugar content of the control and FTEA–treated apples were 0.84 and 0.89, 1.33 and 1.36, and 13.8 and 14.2, respectively. However, there were no differences in acidity, coloring, seed number, russeting and physiological disorders between the two groups. The 'Fiji' variety did not show any symptoms of physiological disorders, russeting or morphological changes, while the 'Arisu' variety showed slight russet symptoms, but this was observed in both groups, which indicated that this was not an effect of FTEA treatment. These are similar to results by Byers *et al.* (1991) who reported that shading reduced viable seed numbers by about 50% for 'Golden Delicious' apples in fruit remaining at harvest, but chemical thinning agents did not affect viable seed number and increased fruit size (Stopar 2006). Manual and chemical thinning of blossoms or fruits to enhance fruit size are practiced for a number of fruit crops (Kon *et al.*, 2018).

Figure 1 showed the results of an in vitro experi-

Table 3. Fruit set rate after the application of FTEA to 'Fuji' and 'Arisu' apples

Variety	Fruit set rate (%)		
	Terminal flower	Axillary flower	Terminal flower + Axillary flower
Fuji	33.0 ± 3.8	36.6 ± 3.7	34.8
Control (Fuji)	77.7 ± 2.9	68.3 ± 3.2	73.0
Arisu	18.8 ± 3.6	21.0 ± 4.1	19.9
Control (Arisu)	82.9 ± 2.8	76.9 ± 3.0	79.9

Table 4. Fruit quality by treatment of 'Fuji' and 'Arisu' apples with FTEA

Variety	Weight (g)	Length (mm)	Diameter (mm)	L/D	Hardness (kg · 3mm)	Sugar content (°BX)	Acidity (%)	Coloring (0~9)	Number of seeds (ea)	Russet[z]	Physiological disorder[z]
Fuji	351.0±9.0	80.4	90.3	0.89±0.01	1.36±0.10	14.2±0.5	0.36±0.03	6.5	9.2±0.1	0	0
Control (Fuji)	310.6±8.3	74.0	88.0	0.84±0.01	1.33±0.15	13.8±0.8	0.37±0.04	6.5	9.0±0.2	0	0
Arisu	285.8±7.4	75.5	82.8	0.95±0.07	1.17±0.10	14.1±0.4	0.33±0.02	8.0	9.1±0.2	2	0
Control (Arisu)	273.3±7.3	73.3	76.7	0.91±0.08	1.19±0.07	14.0±0.4	0.33±0.01	8.0	9.1±0.3	2	0

[z] Visual evaluation 0: no physiological disorder, 9: severe physiological disorder.

ment on the stimulation effect of pollen tube elongation when of FTEA was added to pollen culture medium. The rates of pollen tube elongation of untreated, 500– and 1000–times dilutions were observed under a microscope 1 h after treatment. Their germination rates were about 83% in all three groups. This result indicated no effect of FTEA on pollen tube elongation. Therefore, FTEA is an eco–friendly flower thinning agent without any effects on apple fruition. In the other flower thinning, Liquid lime sulfur + stylet–oil and ammonium thiosulfate (ATS) reduced the number of pollen tubes that entered the style for 'Golden Delicious' by 75% and 63%, respectively. Endothall and naphthaleneacetamide (NAD) did not affect the number of pollen tubes that entered the style (Kon *et al.*, 2018).

Figure 2 shows the weather conditions before and after when FTEA was treated in April~May 2019. FTEA was treated one time into 'Fuji' and 'Arisu' varieties on April 27, which showed mean temperature 10.5°C with minimum 3.9°C and max 16.8°C. In general, 'Arisu' variety bloom faster a few days than 'Fuji'. But 2019 was similar. Fruit set rate was determined on May 15, which was 18 days after spraying. There were some rains on April 23, 24, 26 and 29, but no significant effect on FTEA activity was assumed.

CONCLUSION

The major labor force required for apple cultivation is for flower thinning, pruning, management of pests, diseases, and weeds, and harvesting. Among them, thinning and harvesting require the biggest labor force. The season for apple thinning is busy and requires intensive labor in many other agricultural fields. Therefore, it is necessary to reduce labor force requirements by developing labor–saving types of mechanized thinning techniques. Although many studies have been conducted on developing such techniques, farmers in the field have not been very satisfied with them. This study showed the development possibilities of a flower thinning product that can save labor in agricultural fields and is beneficial for the efficient use of labor forces in the active

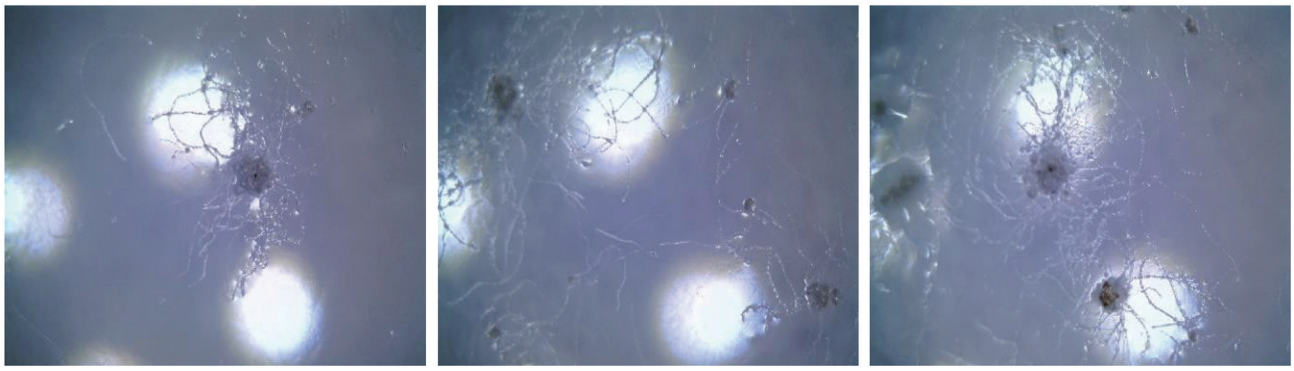

Fig. 1. In vitro investigation of pollen tube elongation by FTEA treated. (left: control; middle: thinning agent contained (500 X); right: thinning agent (1,000 X)).

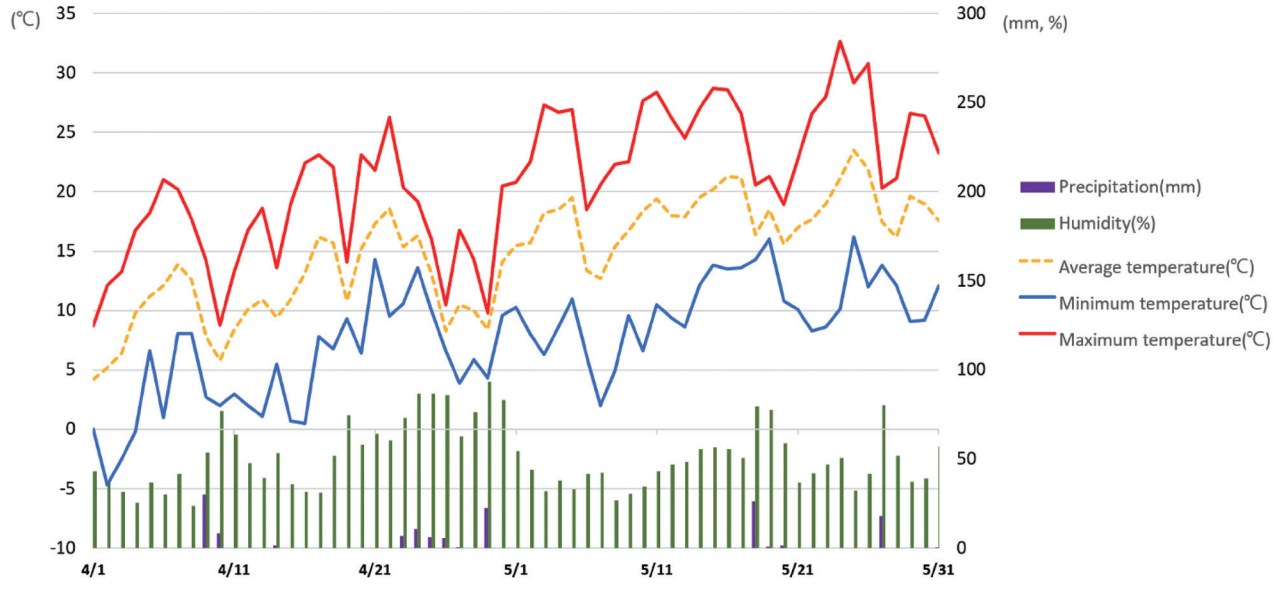

Fig. 2. Weather conditions. Full blooming: May 01, Application date: April 27.

season. In addition, the use of flower thinning products has a positive effect on the prevention of biennial fruiting phenomenon and high–quality apple production. This study showed that this flower thinning product is not harmful to pollinating insects in the orchards. Therefore, this is an environmentally friendly product that can contribute to the development of agriculture in the future.

The timing of application of chemical thinners can be affected by many factors including species or cultivars. Apple growers in different regions need different chemical fruit thinning responses for thinning trees of different ages, culture conditions, rootstocks, climates, and amounts of fruit desired to be removed. Blossom thinning has the greatest potential to increase fruit size (Lakso *et al*., 1996), and can promote return blooms in the following season (Batjer, 1965; Bobb and Blake, 1938). According to the observations of our research for many years, it seems that the return bloom is more affected in the late maturing variety than in the early maturing variety.

There was a thinning effect in two apple varieties using FTEA. Fruit from FTEA treatment had a higher weight. However, in the other parameters, L/D, hardness, number of seeds, sugar content and acidity shown no differences compared to a non–treated plot.

One of the primary difficulties in the development of flower thinning agents is the consistency that can be applied to various orchards without any variations in thinning effects. The variation in thinning effects in each orchard may depend on tree vigor. The flower thinning effect was higher in weaker trees than healthy trees. The flower thinning rate can be increased to 80%, but some orchards that have a low thinning rate show a high fruit setting rate. To improve commercialization, it is important to increase the fidelity of the thinning effect in various orchards. Further development is necessary to improve the consistency of flower thinning effects in various conditions of orchards and environments.

AUTHOR CONTRIBUTIONS

Tae–Kwon Son was responsible for the study design and preparation of experimental materials and performed the experiments. Kyeong–Yeoll Lee analyzed the data and drafted the paper and Yukio Ozaki verified the data and reviewed the manuscript.

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