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Effects of self-incompatibility control substance and blossom thinner on fruit set and quality of apple (*Malus domestica*)

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Abstract: Effects of calcium nitrate (CN) and sodium sulfate (SS) blossom thinning agents applied after self-incompatibility control substance (SICS) treatment on the fruit set rate and quality of apple were investigated for 2 cropping seasons. CN and SS at 0.1% and 0.2% concentrations were applied once (3 or 4 days after SICS treatment) or twice (3 and 5 or 4 and 6 days after SICS treatment). Commercial Japanese flower thinning agent (FTA: Ekoruki) treated and untreated apple trees were used as treated and untreated controls. SICS was sprayed 7 days before full bloom. Both agents showed a fertilizing effect in 'Hongno', improving its fruit yield and quality. SS obtained 29.8% and 36.3% thinning rates in the central floret of 'Fuji'. Both CN and SS were effective in 'Gala', which induced a lower fruit set than SICS treated plants. Earlier and double applications of CN and SS at 0.2% concentration resulted in a higher thinning rate and improved fruit quality in 'Gala'. Results also showed similar thinning efficacies in Ekoruki, CN, and SS.

Key words: Blossom thinning, fruit set, self-incompatibility

Introduction

Self-incompatibility in apple coupled with unstable weather conditions and low insect activity or an inadequate number of pollinators can severely decrease the fruit yield of apple trees. Hand or managed-bee pollination is employed to increase fertilization and fruit set in apple. These methods are often impractical and not effective due to high costs and the unpredictable behavior of bees, especially given the recent phenomenon of bee colony collapsed disorder (Gautam et al. 2004).

Crop load is another factor affecting apple production; too many blossoms or fruits often result in low marketable fruit quality (Giuliani et al. 1997; Stopar 2006). To improve fruit quality and size, which are important criteria for high marketability of apples (Schotzko 1985), chemical or hand thinning of blossoms and fruitlets is practiced (Williams 1985;

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Wertheim 1998). Several chemicals used in fruit thinning are being tested such as ammonium thiosulfate (ATS), 1-naphthaleneacetic acid, ethephon, cytokinin 6-benzyladenine, endothall, and pelargonic acid (Basak 2000; Dennis 2000).

SICS is a mixture of chemicals that suppress self-incompatibility in apples, allowing self-fertilization to occur (Son and Chung 2006). New possible alternative chemical blossom thinners with calcium nitrate tetrahydrate and sodium sulfate as active ingredients were tested for their blossom thinning efficacy. These caustic agents desiccate the pistil opening, thereby making it useless for pollination. These chemicals are different from the currently existing thinners, whose sites of action are the leaf, seed, or fruit (Dennis 2000).

Nothing has been published yet on the application of calcium nitrate tetrahydrate and sodium sulfate for apple, especially in conjunction with SICS. Thus, the objective of this study was to investigate the successive application of self-incompatibility control substance and blossom thinners on the fruit set rate and quality of 'Hongno' and 'Gala' apples.

Materials and methods

Site description

The experiment was conducted in Youngju, Cheongsong, and Andong, Gyeongbuk, Korea, different geographical regions with different environmental and meteorological conditions. The meteorological data during the 2005 experiment are presented in Table 1. In 2006, the experiment was only done in Andong, where the meteorological data recorded were similar to those of 2005.

Treatment

SICS, commercially known as "Apple Plus" (ISTECH, Inc., Korea), contains 0.05% boron and 0.10% manganese. It was applied 7 days before full bloom at a rate of 1235 L of solution per hectare in either 0.1% or 0.2% concentrations using machine sprayed SS. SICS was applied prior to the blossom thinning agent treatment. CN and SS at 0.1% and 0.2% concentrations were applied once (3 or 4 days after SICS treatment: 3DAST, 4DAST) or twice (3 and 5, or 4 and 6 days after SICS treatment: 3,5DAST, 4,6DAST). The commercial Japanese flower thinning agent (FTA: Ekoruki) was sprayed according to the manufacturer's recommended application rate. Ekoruki treated and untreated trees were used as treated and untreated controls.

Measurement

Fruit set was measured as the ratio of total number of fruit to the total number of flowers. Fruit weight was measured using 50 pieces of randomly picked fruits per tree while seed number was determined by counting seeds in 10 randomly picked fruits (Son and Chung 2006). The L/D ratio was measured using Mitutoyo Calipers. For the measurement of soluble

Table 1. Meteorological data in the experimental fields (2005) [a].

	Mean precipitation level (mm)	Mean highest temperature (°C)	Mean lowest temperature (°C)
Cheongsong			
Cropping season [b]	109.4	26.0	13.0
Annual	70.7	18.4	4.6
Andong			
Cropping season	115.5	24.9	13.9
Annual	73.5	17.4	5.9
Youngju			
Cropping season	175.7	25.0	13.9
Annual	108.6	17.0	6.0

[a] Source: Korean Metrological Administration, 2005
[b] Cropping season is from April to October.

solids, fruit extract samples prepared from crushing and filtering the apple fruit were used. The brix measurement of juice was done using a PAL-1 (Atago) machine.

Experimental design and statistical analysis

The experiment was done in the open field with 3 replicates using 1 tree per replicate. All apple trees used were 7-year-old M.9 stocks. In 2005, blossom thinners were screened using 'Fuji' apple in Youngju, Cheongsong, and Andong, Gyeongbuk, Korea. In 2006, a repeat experiment was done using 'Hongno' and 'Gala' apple in Andong, Gyeongbuk, Korea.

The data were statistically analyzed for significance using the General Linear Model (GLM) procedure of the SAS program. Duncan's multiple range test was used to compare treatment means when ANOVA showed significant level of differences among means.

Results

Effects on fruit set

SS at 0.1% and 0.2% reduced fruit set in 'Fuji' while CN at 0.2% caused a decrease in the fruit set of the side floret only (Table 2). SS at 0.1% and 0.2% treatments resulted in a fruit set in the central floret that was lower than those of the control by 29.8% and 36.3%, respectively. The same treatments resulted in a fruit set in the side floret that was lower than those of the control by 41.7% and 18.4%, respectively. In terms of quality, only CN at 0.1% obtained fruit weight higher than the control.

CN and SS were retested on 'Hongno' and 'Gala' at varying application times (Table 3). In 'Hongno', all thinning agents resulted in a fruit set in the central floret higher than that obtained with SICS and the control. Only Ekoruki reduced the fruit set in the side floret, by 52.5% and 60% compared to SICS and the control, respectively. In 'Gala', CN at 0.2% applied 3,5DAST and SS at 0.1% applied 3DAST obtained the lowest fruit set (14.1%) among their respective treatments. Both CN and SS resulted in a fruit set in the side florets lower than that of the control, except for SS at 0.2% applied 4DAST, which recorded an abnormally high fruit set (7.8%).

Effect on fruit quality

The effects of CN and SS on the fruit quality of apples are presented in Table 4. All treatments that obtained a low fruit set in the side floret of 'Hongno', namely CN at 0.1% applied 4,6DAST, SS at 0.1% applied 3DAST, SS at 0.1% applied 4 or 4,6DAST, and SS at 0.2% applied 4 or 4,6DAST, gave higher fruit weight except for SS at 0.1% applied 3DAST. SS at 0.1% applied 3DAST in 'Hongno' had the lowest fruit set, but gave lower fruit weight (218 g), L/D ratio

Table 2. Fruit set rate and quality of 'Fuji' apple treated with self-incompatibility control substance followed by blossom thinning agent in different experimental fields (2005).

Area	Treatment[a]	Concentration	Fruit set (%)[b]		Weight (g)	L/D ratio	No. of seeds	Sugar content (°Brix)
			central	side				
Youngju	Control	-	77.4b[c]	53.5b	278b	0.90a	8.9	13.6a
	CN	0.1%	87.3a	64.6a	286a	0.89a	8.6	14.4a
Cheongsong	Control	-	14.7b	20.3a	232a	0.86a	3.9	14.1a
	CN	0.2%	18.0a	13.5b	233a	0.85a	3.8	14.6a
Andong	Control		51.3a	22.3a	276a	0.86a	6.4	12.8b
	SS	0.1%	36.0b	13.0b	280a	0.80b	5.6	12.8b
	SS	0.2%	32.7b	18.2b	281a	0.81b	5.9	13.6a

[a] Control - untreated plants; SS - sodium sulfate-based blossom thinning agent; CN - calcium nitrate-based tetrahydrate blossom thinning agent applied 4 days after SICS treatment.
[b] Ratio of total fruit harvested to number of central floret and side floret
[c] Different letters within a column indicate significant differences by Duncan's multiple range test, $P < 0.05$.

Table 3. Fruit set rate of different apple varieties in 2006 treated with self-incompatibility control substance followed by flower-thinning agent in Andong.

Treatment[a]	Concentration	Day of treatment[b]	Fruit set rate (%)[c]			
			Hongno		Gala	
			central	side	central	side
Control	-	-	23.3c[d]	39.7ab	28.3ab	4.5ab
SICS	0.1%	-	38.3bc	33.3ab	39.4ab	1.8b
Ekoruki	0.1%	3	48.3ab	15.8b	20.2ab	1.8b
CN	0.1%	3	51.7ab	40.8ab	16.2ab	1.8b
		3, 5	60.0ab	36.7ab	19.2ab	1.0b
		4	33.3abc	20.0ab	20.2ab	3.0b
		4, 6	46.7ab	27.1ab	19.2ab	2.0b
	0.2%	3	43.3ab	21.3ab	20.2ab	2.8b
		3, 5	35.0bc	35.0ab	14.1b	1.3b
		4	50.0ab	40.4ab	18.2ab	1.5b
		4, 6	51.7ab	36.3ab	20.2ab	1.3b
SS	0.1%	3	31.7bc	23.3ab	14.1b	2.8b
		3, 5	51.7ab	43.3a	16.2ab	1.0b
		4	50.0ab	22.1ab	32.3ab	2.0b
		4, 6	43.3bc	28.3ab	32.3ab	2.0b
	0.2%	3	68.3a	39.2ab	19.2b	2.0b
		3, 5	35.3bc	35.6ab	23.2ab	1.0b
		4	45.0ab	21.7ab	44.4a	7.8a
		4, 6	38.3bc	15.8b	31.3ab	1.0b

[a] Control - untreated; SICS - fertilization stimulant treatment; SS - sodium sulfate-based blossom thinning agent; CN - calcium nitrate-based tetrahydrate blossom thinning agent; Ekoruki - Japanese flower thinning agent.
[b] Number of days after treatment of self-incompatibility control substance.
[c] Ratio of total fruit harvested to number of central floret and side floret.
[d] Different letters within a column indicate significant differences by Duncan's multiple range test, $P < 0.05$.

(0.80), number of seeds (3.3 pieces), and sugar content (12.2 °Bx) than the control. Compared with the control, treatments with lower fruit set in the side floret had a lower L/D ratio and higher number of seeds and sugar content, except for SS at 0.2% applied 4 or 4,6DAST in the number of seeds.

In the case of 'Gala', CN at 0.2% applied 3,5DAST recorded the lowest fruit set among the CN treatments. It did not obtain high fruit weight but gave higher values in other fruit quality parameters. SS at 0.2% applied 3 or 3,5DAST obtained high fruit quality values consistent with the results of blossom thinning, but SS at 0.1% applied 3 or 3,5DAST did not show the same results.

Discussion

SS was effective in fruit thinning of 'Fuji' while CN was not. Neither blossom thinner was effective in the 'Hongno' variety. CN and SS treatments in 'Hongno' resulted in a high fruit set compared to the untreated

Table 4. Fruit quality of different apple varieties in 2006 treated with self-incompatibility control substance followed by flower-thinning agent in Andong.

Treatment[a]	Concentration	Day of treatment[b]	Hongno				Gala			
			Weight (g)	L/D ratio	No. of seeds	Sugar content (°Brix)	Weight (g)	L/D ratio	No. of seeds	Sugar content (°Brix)
Control	-	-	239abcde[c]	0.85ab	4.9ab	12.2d	196cd	0.91abc	4.6bcd	12.3bc
SICS	0.1%	-	215cde	0.87a	4.0ab	13.0abcd	282a	0.90abc	4.2bcd	11.6bc
Ekoruki	0.1%	3	227abcde	0.80bc	4.2ab	13.1abcd	227bcd	0.90abc	3.3d	12.1bc
CN	0.1%	3	228abcde	0.82abc	4.0ab	12.6cd	212bcd	0.89abc	2.7d	11.6bc
		3, 5	238abcde	0.80bc	4.3ab	13.0abcd	216bcd	0.90abc	4.8bcd	11.5bc
		4	241abcd	0.81abc	6.3a	13.9abc	232bcd	0.94a	3.7d	12.0bc
		4, 6	261abcd	0.84abc	5.0ab	12.8bcd	225bcd	0.92abc	3.4d	12.1bc
	0.2%	3	261abcd	0.83abc	5.9a	14.3ab	237abc	0.87c	4.6bcd	11.8bc
		3, 5	214de	0.84abc	5.5ab	14.6a	223bcd	0.94abc	4.7bcd	12.3bc
		4	243abcde	0.79c	6.3a	13.2abcd	258ab	0.95a	3.8cd	11.6bc
		4, 6	243abcde	0.81bc	5.3ab	13.4abcd	185d	0.90abc	3.5d	13.8a
SS	0.1%	3	218bcde	0.80bc	3.3b	12.5cd	218bcd	0.94a	2.9d	12.8ab
		3, 5	189e	0.80bc	4.4ab	13.2abcd	243abc	0.93abc	4.1bcd	11.8bc
		4	279a	0.81bc	5.6ab	14.1abc	216bcd	0.91abc	4.2bcd	11.1c
		4, 6	268abc	0.83abc	5.6ab	12.9bcd	221bcd	0.94ab	5.8abc	11.0c
	0.2%	3	250abcd	0.83abc	6.1a	13.5abcd	225bcd	0.89abc	4.6bcd	12.2bc
		3, 5	265abcd	0.83abc	4.2ab	13.4abcd	256ab	0.93abc	6.1ab	11.6bc
		4	263abcd	0.84abc	3.3b	13.5abcd	257ab	0.88bc	4.7bcd	11.5bc
		4, 6	272ab	0.84abc	4.4ab	12.6cd	217bcd	0.89abc	7.0a	12.0bc

[a] Control - untreated; SICS, fertilization stimulant treatment; SS - sodium sulfate-based blossom thinning agent; CN - calcium nitrate-based tetrahydrate blossom thinning agent; Ekoruki - Japanese flower thinning agent.

[b] Number of days after treatment of self-incompatibility control substance.

[c] Different letters within a column indicate significant differences by Duncan's multiple range test, $P < 0.05$.

and SICS treated plants. Even Ekoruki, which is an established commercial blossom thinner, did not obtain a lower fruit set. In 'Gala', CN treatments resulted in a blossom thinning rate comparable with that of the commercial blossom thinner Ekoruki.

'Hongno' is not a difficult to thin variety, indicating that the increase in its fruit set is probably be due to the fertilizing effect of the chemical blossom thinner (Ouma 2007). It could also be that SICS induced early fertilization in flowers. Reports showed that flowers that have been fertilized already may be less susceptible to the effect of blossom thinners (Jonoudi and Flore 2005). The fertilizing effect of CN and SS on SICS treated plants deserved more in-depth studies. The results also showed that the efficacy of the blossom thinners were crop or variety dependent, which is in agreement with previous studies (Byers and Lyons 1985; Irving et al. 1989; Schupp and Greene 2002).

In terms of fruit quality, earlier and double application of a higher concentration of blossom thinner in 'Gala' resulted in higher thinning efficacy and improved fruit quality. This result was consistent with other studies (Dennis 2000; Stopar and Lokar 2003) wherein multiple applications were used to adjust the fruit load when the initial rate did not remove enough fruit. Furthermore, Schupp and Greene (2002) reported a higher thinning rate when blossom thinning agents were applied early. The opposite was observed in 'Hongno', which had a higher thinning efficacy in one application at a lower concentration of blossom thinner than in double application at higher concentration.

Some blossom thinners like 1-naphthaleneacetic acid and ethephon tested caused physiological stress and russeting of the fruit (Link, 2000). However, these signs of physiological stress were not observed on the plants treated with calcium nitrate tetrahydrate and sodium sulfate (data not shown).

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