Blossom and Fruitlet Thinners Affect Crop Load, Fruit Weight, Seed Number, and Return Bloom of ‘Northern Spy’ Apple

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Abstract. To determine the effect of blossom and fruitlet thinners on crop load, fruit weight, seed development during the year of treatment, and the subsequent year effect on return bloom, fruit weight and yield, a field trial using the biennial apple cultivar ‘Northern Spy’ (*Malus × domestica* Borkh.) was established. Treatments applied at full bloom included ATS (ammonium thiosulphate) [12% (w/v) nitrogen, 26% (w/v) S]; TD [15.9% (w/v) diacarboxylic acid, 5.5% (w/v) dimethylalkylamine salt (Endothal)] and SCY [57% (w/v) pelargonic acid (Scythe)]. At 18 days after full bloom (DAFB), oil treatments [98% (w/v) mineral oil (Superior “70” oil)] were applied with S [480 g·L⁻¹ a.i. carbaryl (Sevin XLR)] and without as a means of increasing the efficacy of S. BA [19 g·L⁻¹ a.i. 6-benzyladenine /1.9 g·L⁻¹ a.i. gibberellins 4+7 (Accel)]; S; and/or SA [100% (w/w) 2-hydroxybenzoic acid (salicylic acid)], were also applied in a factorial arrangement on the same day. Fruit abscission was significantly increased the year of treatment with BA, S, BA + S, BA + SA, S + SA, BA + S + SA, oil, and S + oil. Average fruit weight was enhanced by S, BA + S, BA + SA, S + SA, BA + S + SA, and S + oil although in the latter treatment the crop load was very low. Only treatments that included BA reduced the number of fully developed seeds per fruit and seed number per trunk cross-sectional area (TCA) and increased return bloom. Defining the number of fully developed seeds per tree coupled with crop load is proposed as a predictor of return bloom in ‘Northern Spy’.

To secure markets and remain economically viable, ‘Northern Spy’ apple producers in Nova Scotia are required to grow uniform crops of large sized fruit annually. This is difficult to achieve because ‘Northern Spy’ is a strong biennially bearing cultivar that does not respond readily to chemical thinners (Dennis, 1998). Although many experiments have been performed to test the effectiveness of thinning agents for improving fruit size and reducing crop load, annual cropping continues to be difficult to achieve (Greene, 2000), prompting the search for more effective thinning products.

It has been established that blossom thinners are more effective than fruitlet thinners for increasing annual bearing (Abbott, 1984). In Canada, no blossom thinners are currently registered for apple, although ATS (a liquid fertilizer) is effective. SCY and TD have also shown promising results recently (Fallahi, 1997). Fruitlet thinner S is commonly used in commercial orchards to reduce fruit set. Oil can remove fruitlets or, as an additive, can reduce the rate of S required to thin fruit (Byers et al., 1990). BA is an effective fruitlet thinning alternative that can enhance fruit size (McLaughlin and Greene, 1984). BA is considered a moderate thinner for some cultivars (Embree, 2001; Ferree, 1996). Although S is a reliable and extensively used fruitlet thinner it has not completely solved the biennial production pattern. In an effort to increase crop performance in the field, researchers have evaluated novel bioregulators like SA (Gutierrez-Coronado et al., 1998), which has not been tested in apple to date. Thermogenic activity, pathogenesis, antisenesescence activity and the inhibition of ethylene production are all reported responses that can occur when there is an increase in the SA level in plant tissue

(Lada and Blake, 2000; Sano et al., 1994). Endogenous cytokinins are thought to be a prerequisite for the biosynthesis of SA in plant tissue (Hare et al., 1997). The highest levels of cytokinins are reported to occur during the bloom period (Luckwill, 1970) thus, an enhanced growth response to the exogenous SA treatments would be likely during early fruit cell division. Adding to the urgency to find new thinning agents is the anticipated loss of S, which has come under increased constraint from environmental regulators (Webster and Spencer, 1999).

Previous studies indicate that seed formation affects subsequent flowering in apple (Chan and Cain, 1967). A reduction in seed development resulted in increased flower bud development. McLaughlin and Greene (1984) reported that BA applied as a fruitlet thinning product suppressed apple seed development. Benzyladenine, the primary active ingredient of BA, has a mode of action similar to endogenous cytokinins which in conjunction with other phytohormones may strongly govern flower bud development. It has also been found that the effectiveness of BA increased when combined with S (Greene and Autio, 1994). Effects of fruit thinning chemicals on the following year flowering and fruiting response make a two year study essential. The complexity of plant growth regulator interactions with phytohormones that cause shifts of apple tree assimilate allocation may explain why year following treatment effects for products, which increase return bloom, has not been studied extensively (Tromp, 2000).

The objective of this study was to measure the effect of plant growth regulators on fruit set, yield, fruit weight and seed development of ‘Northern Spy’ apple and document subsequent-year blossom development, fruit set, fruit weight, and yield.

Materials and Methods

The 3-ha commercially managed orchard of ‘Northern Spy’ selected for this study was established on M.9, rootstock. It was located on a north 15% slope, in Berwick, Nova Scotia, Canada, (“45°03’00N–64°46’00W”). Each tree was individually supported by a wooden stake attached to a double wire trellis. Trees were planted 1.5 m apart and 4.5 m between rows.

The experimental design was a randomized complete block with an incomplete factorial arrangement of treatments. Trees of uniform size and bloom were selected and tree trunk circumferences were measured at 30 cm above the soil surface. The blossom density per tree was calculated by dividing the blossom number by the TCA resulting in trees being assigned to one of four blossom density blocks. All treatments (Table 1) were randomly assigned within each of the four blocks. The blossom thinning treatments ATS, TD, and SCY were applied at full bloom (FB) after approximately 10 h of favourable pollination conditions. All postbloom treatments of oil, BA, S, and SA alone and combinations were applied at mid-day in sunny weather, 18 d after full bloom

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Table 1. List of chemical thinning treatments applied and time of application.

No.	Treatment	Product trade name	Rate a.i./L water	Application time (DAFB)
1	ATS	Ammonium thiosulphate	¹ 1.25% (v/v)	0
2	TD	Endothal	² 0.09% (v/v)	0
3	SCY	Scythex	³ 0.31% (v/v)	0
4	S + Oil		624 mg·L ⁻¹ /0.25% (v/v)	18
5	Oil	Superior "70" oil	⁴ 0.25% (v/v)	18
6	Control			
7	BA	Accel	⁵ 38 mg·L ⁻¹	18
8	S	Sevin XLR	⁶ 624 mg·L ⁻¹	18
9	SA	Salicylic acid	⁷ 1400 mg·L ⁻¹	18
10	BA + S		38/624 mg·L ⁻¹	18
11	BA + SA		38/1400 mg·L ⁻¹	18
12	S + SA		624/1400 mg·L ⁻¹	18
13	BA + S + SA		38/624/1400 mg·L ⁻¹	18

¹12% w/v nitrogen, 26% w/v sulphur, Oligo Ltd. Canada.²15.9% w/v diacarbonylic acid, 5.5% w/v dimethylalkylamine salt, Elf Atochem Inc.³57% w/v pelargonic acid, Dow Agro Science LLC.⁴98% w/v mineral oil, N.M. Bartlett Inc. Canada.⁵19 g·L⁻¹ 6-benzyladenine /1.9 g·L⁻¹ gibberellins A₄₊₇, Valent Bioscience Corp. Canada.⁶480 g·L⁻¹ 1-naphthyl methylcarbamate, Rhone-Poulenc Inc. Canada.⁷100% w/w 2-hydroxybenzoic acid, Sigma Chemical Co.

(DAFB) when the fruit size was 9 mm in diameter (Table 1). A 300-kW diesel engine was used to power a Hypro pump with a liquid delivery rate of 87 L·min⁻¹. Sprayer pump pressure was fixed at 2000 kPa and a hand gun was used to apply each of the 12 treatments to the 4 preassigned treatment trees to the point of run off (based on full tree-row canopy that would require water delivery of 3370 L·ha⁻¹). No adjuncts were included in any of the experimental treatments.

Initial fruit set was determined by counting all developing fruitlets on each tree at 25 DAFB. Visual assessments of percent leaf drop were carried out at 40 DAFB and the estimates were averaged. Following natural fruit abscission (early July), the remaining fruits on each tree were counted at 53 DAFB (final fruit set) and at 144 DAFB fruit was harvested. The fruit was placed in cold storage (2 °C), and subsequently removed and graded into four size categories; <60 mm in diameter, 60 to 63 mm, 63 to 70 mm, and >70 mm. Fruit from each of the four size categories were counted and weighed to calculate the mean weight in each size category. Average fruit weight was calculated by dividing the number of fruit from each tree by the total weight of fruit harvested from that tree.

To determine the seed development in the carpel and ascertain the effect of whole tree seed production on return bloom, a representative sample of 25 apples was selected from each tree's production. For each apple; weight, length, width, and the number of seeds was recorded. The seeds of each apple were classified as plump (developed), as flat (undeveloped) endosperm or as seed initials (undeveloped residual embryo) (Chong et al., 2002). The number of developed seeds/cm² of TCA was calculated by multiplying the number of fruit/cm² of TCA by the mean number of developed seeds per apple.

In May 2001, the trunk circumference at 30 cm above the soil surface was measured on each tree to determine growth during the previous season. Blossom clusters for the whole tree were counted again in 2001 to establish treatment effects on return bloom. No plant growth

regulators were applied during the 2001 season. Fruit abscission and final fruit set was recorded during the summer. Following harvest fruit was graded as in the 2000 season.

Statistical tests were conducted using analysis of variance (ANOVA) and orthogonal contrasts. Significant differences were declared at $P \leq 0.05$ unless otherwise stated (Genstat, 1993).

Results

Fruit retention was significantly greater for only one treatment BA + S + SA, and was not sustained past 25 DAFB (Table 2). The

BA × S × SA contrast confirms a significantly greater fruit set occurred with treatments BA, S, SA and BA + S + SA. At 40 DAFB the oil treatments caused premature leaf drop that reached and estimated 20% (data not shown). The application of S + oil removed the greatest number of fruit giving a density to 0.8 fruit/cm² TCA at 53 DAFB (Table 2). BA and S reduced the number of fruit by 43% and 46% (7.1 and 6.7 fruit/cm² TCA) respectively at 53 DAFB compared to the untreated control. When combined they were even more effective. A significant reduction at this stage of development also occurred with BA + S, S + SA and BA + S + SA. Contrast comparisons that

Table 2. Whole-tree blossom density and treatment effects on 2000 fruit set per TCA of 'Northern Spy' apple on M9 rootstock.

No.	Treatment	Bloom density (no./cm ² TCA)	Fruit (no./cm ² TCA)		
			DAFB ^z		
			25	53	144
1	ATS	57	19.7	8.0	8.0
2	TD	62	18.7	8.8	8.1
3	SCY	66	21.2	13.6	12.5
4	S + oil	62	26.7	0.8*	0.7*
5	Oil	61	24.2	6.3*	5.6*
6	Control	62	26.4	13.6	12.3
7	BA	62	35.2	7.1*	7.1*
8	S	60	34.1	6.7*	6.6*
9	BA + S	59	27.6	4.9*	4.3*
10	SA	62	26.8	14.4	13.5
11	BA + SA	56	31.4	7.6	7.1*
12	S + SA	62	26.4	6.3*	5.5*
13	BA + S + SA	63	42.1*	4.7*	4.3*
SE ^y (N = 4, 12 df)		2.3	4.42	1.75	1.58
LSD _{0.05}		6.9	13.26	5.25	3.84
Contrasts (<i>P</i> values)					
Treated vs. control		0.32	0.03	<0.001	<0.001
BA		0.30	0.09	0.002	0.002
S		0.77	0.46	<0.001	<0.001
BA × S0.34		0.67	0.06	0.07	
SA		0.99	0.73	0.89	0.97
BA × SA		0.66	0.14	1.00	0.98
S × SA		0.05	0.38	0.69	0.63
BA × S × SA		0.25	0.04	0.95	0.61
Other treatments (4 df)		0.27	0.02	<0.001	<0.001

^zDAFB = days after full bloom.^ySE = standard error.*Significant at $P \leq 0.05$.

Table 3. Whole-tree treatment effects on percent of fruit >70 mm, average fruit weight, yield, and number of developed seeds [per fruit and TCA (cm²)] in 2000. Following year (2001) effects on bloom density, average fruit weight, and yield of 'Northern Spy' apple on M 9 rootstock.

No.	Treatment	2000					2001		
		Size (%)	Fruit	Yield	Seed		Blooms	Fruit	Yield
		>70 mm)	wt (g)	(kg·cm ⁻² TCA)	(no./fruit)	(no./cm ² TCA)	(no./cm ² TCA)	wt (g)	(kg·cm ⁻² TCA)
1	ATS	77	163	1.25	7.4	21.9	29	200	0.56
2	TD	82	160	1.21	6.9	22.1	45	124*	0.44
3	SCY	60	134	1.56	7.2	34.5	22	177	0.40
4	S + oil	94*	241*	0.16*	8.0	1.9*	56	82*	0.72
5	Oil	72	177	0.61*	8.0	15.7*	13*	139	0.45
6	Control	54	130	1.47	8.2	35.1	46	174	0.67
7	BA	90*	173	1.20	3.3*	13.1*	72	104*	0.94
8	S	91*	205*	1.23	9.3	20.0	38	118*	0.78
9	BA + S	99*	255*	1.01*	1.7*	6.0*	41	138	0.71
10	SA	44	119	1.53	7.5	37.6	26	165	0.40
11	BA + SA	92*	214*	1.34	4.4	13.6*	67	134	0.75
12	S + SA	97*	219*	1.18	4.9	12.4*	48	14*	0.72
13	BA + S + SA	99*	243*	1.03*	2.3*	5.9*	75*	97*	0.89
SE ^y (N = 4, 12 df)		11.7	22.4	0.13	0.33	5.11	9.84	15.9	0.17
LSD _{0.05}		35.1	67.2	0.4	0.99	15.33	29.52	47.7	0.51
Contrasts (<i>P</i> values)									
Treated vs. control		0.02	<0.001	<0.001	0.008	<0.001	0.003	<0.001	0.40
BA		0.007	0.002	0.04	<0.001	<0.001	0.002	0.04	0.16
S		0.003	<0.001	0.006	0.14	<0.001	0.80	0.03	0.50
BA × S		0.03	0.31	0.77	0.42	0.09	0.20	0.03	0.31
SA		0.96	0.58	0.65	0.66	0.74	0.50	0.60	0.49
BA × SA		0.85	0.70	0.70	0.13	0.70	0.18	0.97	0.50
S × SA		0.66	0.64	0.55	0.42	0.47	0.02	0.16	0.25
BA × S × SA		0.59	0.24	1.00	0.50	0.52	0.76	0.11	0.75
Other treatments (4 df)		0.37	0.02	<0.001	0.24	0.004	0.005	<0.001	0.25

^yStandard error (SE) values are adjusted for S + oil (SE × 1.52) and oil (SE × 1.15) to reflect reduced number of apples in sample.

*Significant at *P* ≤ 0.05.

included BA and S confirmed the significant reduction in fruit set for these two compounds. At harvest (144 DAFB) fruit set was similar to 53 DAFB for all treatments except BA + SA that was now significantly lower than the control (Table 2).

Trees treated with S + oil produced a significant increase in fruit size, with 94% of fruit >70 mm compared to untreated control at 54% (Table 3). For treatments BA + S and BA + S + SA, 99% of the fruit was greater than 70 mm in diameter. All treatments including BA and S alone or in combination consistently increased fruit size as confirmed by orthogonal contrasts (Table 3). The contrast comparison for BA × S indicates, percent fruit size >70 mm increases when either BA or S are used and no additive effect was significant when these products were combined. Fruit weight was highest for the BA + S treatment. The treatments S, BA + SA, S + SA, BA + S + SA, and S + oil also significantly increased fruit weight (Table 3). The BA and S contrast was also significant indicating either chemical effectively increased fruit weight. The two oil treatments reduced the crop load substantially (Table 3). The S + oil treatment almost defruited these Northern Spy trees and resulted in the smallest crop load among all treatments (Table 3). Treatments with BA + S and BA + S + SA significantly reduced crop load. In the contrast comparisons crop load was also significantly reduced by treatments that included BA and S.

The BA, BA + S, and BA + S + SA treatments significantly reduced the number of developed seeds per fruit. Treatments that include BA except when combined with SA reduced the number of developed seeds per fruit at *P* < 0.001 significance level and was

confirmed by the contrast comparison (Table 3). Treatments BA, BA + S, BA + SA, S + BA, BA + S + SA, S + oil, and S all significantly reduced the developed seed number/cm TCA of tree compared to the control. Contrasts for BA and S confirmed this result (Table 3). The low number of developed seeds/cm TCA for the S, S + oil, and the oil treatments, was however a result of the low number of fruit/cm² TCA not normal seeds per fruit (Tables 2 and 3). In this experiment there was no indication of a relationship between seed number and fruit weight (Table 3).

Only the oil-alone treatment resulted in a significantly lower blossom density in 2001 (Table 3). Given the low crop load and seed number/cm² TCA in 2000 an increase in 2001 bloom was expected. Blossom density in 2001 for BA + S + SA was significantly greater than control (Table 3). Contrasts for treatments which included BA the previous season showed significantly higher return bloom than those without (Table 3). The contrast comparison S × SA showed S and SA had a negative impact on return bloom. In 2001 significantly lower fruit weight was found for BA, S, S + SA, BA + S + SA, TD, and S + oil. Significant lower fruit weight was also evident for contrasts BA, S and BA × S in 2001. Fruit weight was significantly reduced on trees that had been treated with S + oil in 2001 (Table 3).

Discussion

Finding the optimum range in crop load that promotes both a full crop with highly marketable fruit size and a strong return bloom continues to be the goal of any tree fruit crop load management program. The theoretical

goal of blossom thinning is the early reduction of the crop load thereby releasing more metabolites for current season fruit growth and fruit bud development for the following year. Even though blossom thinners in this experiment were applied when the king blossom was fully open and the stigma of the lateral flowers were visible adequate thinning was not achieved. Climatic conditions as well as application timing are critical for successful blossom thinning (Embree and Foster, 1999). Bound (2001) found TD was an effective blossom thinner, that also reduced seed number and length/diameter ratio in 'Red Delicious'. Our results suggest an earlier application or two applications at different stages of bloom development may be necessary to achieve an optimum crop load.

An increase in fruit retention with the BA + S + SA treatment at 25 DAFB was identified (Table 2). It was not sustained throughout the season therefore the physiological basis for this temporary fruit retention effect may be worthy of further study. McLaughlin and Greene (1984) reported that BA is an effective fruit thinning product. Enhanced thinning has been reported when BA is combined with S (Greene and Autio, 1994; Wertheim et al., 1996). Our results at 53 DAFB supports these findings. At harvest (144 DAFB) the combined treatment gave a 26% increase in fruit weight over the mean for the individual products (Table 3). BA also influenced seed development in Northern Spy more than any other treatment in this study (Table 3), which supports earlier reports of a BA induced reduction in the number of developed seeds, an increase in the number of nondeveloped seeds yet no influence on the total number of seeds per McIntosh fruit

(Greene and Autio, 1994; Yuan and Greene, 2000). Although no relationship between seed number and fruit weight was found in this study others, like Ward et al. (2001), contend that 25% to 30% of the variability in fruit weight can be explained by seed number.

Stover et al., (2001), points out that reduced crop load is the principal variable influencing return bloom. This work shows that the number of developed seed and healthy foliage are also very important. It is not enough to reduce seed number per fruit, seed number per tree is also critical. Return bloom was significantly improved when seed number/cm² TCA was reduced by a treatment of BA + S + SA yet dramatically reduced for trees that had been given the oil treatment. Leaf abscission resulted from the oil treatment, which also induced leaf drop and could have caused the poor return bloom in 2001. It was likely a direct result of inadequate metabolite supply from remaining foliage. It is recognized that the extensive leaf drop may have been exacerbated by previously applied fungicides. Stress on the trees following the oil treatment may have promoted ethylene biosynthesis, which in turn promoted leaf and fruitlet abscission (Taylor and Whitelaw, 2001). Interestingly 'Northern Spy' was reported by Walsh et al. (1979) to be more responsive than 'Golden Delicious' to thinning treatments that included ethephon. Both oil treatments reduced the seed count/cm² TCA. The S + oil treatment drastically reduced yield and subsequent seed count to 1.9 cm² TCA and increased flower bud initiation and development. Leaf abscission was similar for both treatments. This supports the findings by Schneider and Lasheen (1973) who propose that adequate metabolite supply can be controlled by factors other than seed development including a specific leaf to fruit ratio.

The BA + S + SA treatment suggest a crop load of $\approx 1 \text{ kg} \cdot \text{cm}^{-2}$ TCA a seed load of 5.5 to 6 fully developed seed/cm² TCA will support sufficient metabolite supply in the crop year to support a return bloom of 75 blossoms/cm² TCA. High crop load per tree of 1.56, 1.47, and 1.53 kg·cm⁻² TCA for the treatments SCY, Control and SA respectively coupled with seed levels of 35/cm² TCA exhausted the metabolite supply during 2000 and led to low boom levels in 2001 (Table 3). These treatments are also examples of how high seed number/cm² TCA may have altered the plant hormone balance which in turn reduced fruit bud initiation and impede fruit bud development. These findings also imply conversely that the trees crop load can increase to a higher level without affecting repeat bloom, if the seed load is reduced (Table 3).

Clearly the effectiveness of BA to improve return bloom is evident (Table 3). BA did not

have the same impact on return bloom when combined with S, unless SA was a component of the spray mixture. Even though measuring the return bloom in crop load management field studies takes extra time the potential for the tree fruit industry is far reaching. There is also need for basic studies on the mechanism by which the plants endogenous hormone complex is influenced by seed numbers. Increasing our understanding of whole tree physiology should lead to production recommendations that would assure a consistent level of bloom annually. Forshey (1982) stated that distinctly different flowering and fruiting patterns are inversely related to the previous crop. This work supports this conclusion and identifies other influences such as metabolite supply and seed number/cm² TCA as important contributors to annual flowering as well. Until more is known producers should consider the previous seasons: crop load, thinning practices, tree health, fertility, pruning and all other inputs prior to planning and executing the current-year crop load management strategy.

Literature Cited

- Abbott, D.L. 1984. The apple tree: Physiology and management, p. 51–89. Grower Books, London.
- Bound, S.A. 2001. The influence of endothal and 6-benzyladenine on crop load and fruit quality of red 'Delicious' apple. J. Hort. Sci. Biotechnol. 76:691–699.
- Byers, R.E., J.A. Barden, R.F. Polomski, R.W. Young, and D.H. Carbaugh. 1990. Apple thinning by photosynthetic inhibition. J. Amer. Soc. Hort. Sci. 115:14–19.
- Chan, B.C. and J.C. Cain. 1967. The effect of seed formation on subsequent flowering in apple. Proc. Amer. Soc. Hort. Sci. 91:63–67.
- Chong, C., B.B. Bible, and H.-Y. Ju. 2002. Germination and emergence, p. 57–115. In: M. Pessarakli, (ed.). Handbook of plant and crop physiology. 2nd ed. Marcel Dekker, New York.
- Dennis, Jr., F.G. 1998. The 'Northern Spy' apple. Fruit. Var. J. 52:66–71.
- Embree, C.G. 2001. Effect of fruitlet thinners on 'McIntosh', p. 18–22. In: Fruitlet thinning trials–2001 report. Atlantic Food Hort. Res. Ctr., Kentville, N. S. Can.
- Embree, C.G., and A. Foster, Jr. 1999. Effects of coating and pollenicides on pollen tube growth through the stigma and style of 'McIntosh' apple blossoms. J. Tree Fruit Prod. 2:19–32.
- Fallahi, E. 1997. Applications of endothalic acid, pelargonic acid and hydrogen cyanamide for blossom thinning in apple and peach. Hort-Technology 7:395–399.
- Ferree, D.C. 1996. Performance of benzyladenine as a chemical thinner on eight apple cultivars. J. Tree Fruit Prod. 1:33–50.
- Forshey, C.G. 1982. Branching responses of young apple trees to applications of 6-benzylaminopurine and gibberellin A₄₊₇. J. Amer. Soc. Hort. Sci. 107:538–541.
- Genstat 5 Committee. 1993. Genstat 5. version 3. AFRC Inst. Arable Crops Res., Rothamsted Expt. Sta., Harpenden, Hertfordshire, U. K. AL5 2JQ. Oxford Univ. Press, New York.
- Greene, D.W. 2000. Reducing floral initiation and return bloom in pome fruit trees-applications and implications. HortTechnology 10:740–743.
- Greene, D.W. and W.R. Autio. 1994. Combination sprays with benzyladenine to chemically thin spur-type 'Delicious' apples. HortScience 29:887–890.
- Gutierrez-Coronado, M.A., C. Trejo-Lopez, and A. Larque-Saavedra. 1998. Effects of salicylic acid on the growth of roots and shoots in soybean. Plant Physiol. Biochem. 36:563–565.
- Hare, P.D., W.A. Cress, and J. Van-Staden. 1997. The involvement of cytokinins in plant environmental stress. Plant Growth Regulat. 23:79–103.
- Lada, R.R. and T.J. Blake. 2000. Early growth invigoration of jack pine seedlings by natural plant growth regulators. Trees 12:420–423.
- Luckwill, L.C. 1970. The control of growth and fruitfulness in apple trees, p. 237–253. In: L.C. Luckwill and C.V. Cutting (eds.). Physiology of tree crops. Academic Press, New York.
- McLaughlin, J.M. and D.W. Greene. 1984. Effects of BA, GA₄₊₇ and daminozide on fruit set, fruit quality, vegetative growth, flower initiation and flower quality of 'Golden Delicious' apples. J. Amer. Soc. Hort. Sci. 109:34–39.
- Sano, H., S. Seo., E. Orudjev, S. Youssefian, K. Ishizuka, and Y. Ohashi. 1994. Expression of the gene for small GTP binding protein in transgenic tobacco elevates endogenous cytokinin level, abnormally induces salicylic acid response to wounding, and increase resistance to tobacco mosaic virus infection. Proc. Natl. Acad. Sci. 91:10556–10560.
- Schneider, G.W., and A.M. Lasheen. 1973. NAA and Sevin on composition, development, and abscission of apple fruit. HortScience 8:103–103.
- Stover, E., F. Wirth, and T. Robinson. 2001. A method for assessing the relationship between crop load and crop-value following fruit thinning. HortScience 36:157–161.
- Taylor, J.E. and C.A. Whitelaw. 2001. Signals in abscission New Phytol. 151:323–339.
- Tromp, J. 2000. Flower-bud formation in pome fruits as affected by fruit thinning. Plant Growth Regulat. 31:27–34.
- Walsh, S.C., H.J. Swartz, and L.J. Edgerton. 1979. Ethylene evolution in apple following postbloom thinning sprays. HortScience 14:704–706.
- Ward, D.L., R.P. Marini, and R.E. Byers. 2001. Relationships among day of year of drop, seed number, and weight of mature apple fruit. Hort-Science 36:45–48.
- Webster, A.D. and J.E. Spencer. 1999. New strategies for the chemical thinning of apple (*Malus domestica* Borkh L.) cultivar 'Queen Cox' and 'Royal Gala'. J. Hort. Sci. 74:337–346.
- Wertheim, S.J., J. M.T. Balkhoven-Baart, and J.H. Bootsma. 1996. Chemical thinning, p. 31–38. Annu. Rpt. Fruit Res. Sta., Brugstraat 51, 4475 AN Wilhelminadorp, The Neth.
- Yuan, R. and D.W. Greene. 2000. 'McIntosh' apple fruit thinning by benzyladenine in relation to seed number and endogenous cytokinin levels in fruit and leaves. Scientia Hort. 86: 127–134