Summer Applications of NAA and Ethephon Show Little Effect on Return Bloom, Yield, Tree Growth, and Juice Quality of Cider Apple Cultivars

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Abstract

For commonly grown dessert apple cultivars, chemical thinning or the removal of some fruit each season helps maintain fruit size, quality, and annual bearing characteristics. Chemical thinning is often achieved with applications of carbaryl at petal fall alone or in combination with other plant growth regulators (PGRs). This traditional thinning program used for dessert fruit does not adequately thin European-origin cider apples resulting in insufficient return bloom or inconsistent cropping from year to year. On dessert apple cultivars with biennial bearing tendencies, midsummer applications of PGRs are used to enhance fruit bud development for the following year. In 2019, experiments were conducted in two apple orchards in Vermont, U.S. The primary objective was to evaluate the effects of naphthaleneacetic acid (NAA) and ethephon alone and in combination with carbaryl on return bloom, crop yield, and fruit and juice quality. During the two years of the study, 'Harry Masters Jersey' and 'Kingston Black' both demonstrated strong biennial production habits producing few flowers and fruit in 2020. Ethephon applications alone and in combination with carbaryl showed advanced ripening and fruit softening in 'Somerset Redstreak' during the year of treatment. 'Kingston Black' had increased fruit softening with ethephon only applications. Growth regulator treatments did not consistently affect juice quality between cultivars. During the treatment year, 2019, all Ethephon treated 'Somerset Redstreak' had a higher pH, and juice from trees treated with Ethephon and carbaryl had a lower titratable acidity. 'Kingston Black' juice was unaffected by PGR applications.

Keywords: crop load, plant growth regulators, 'Harry Masters Jersey', 'Somerset Redstreak', 'Kingston Black'

INTRODUCTION

Hard cider, made by fermenting apple (*Malus x domestica* Borkh) juice, was at one time the most popular alcoholic beverage in North America (Miles et al., 2020). Largely abandoned in the early 20th century after the temperance movement and Prohibition, fermented cider has only recently been rediscovered as an alternative to wine and beer (Watkins, 2003). In recent years, U.S. cider production saw annual growth in production of up to 50%, with total revenue over $ 2.2 billion in 2018 (Becot et al., 2016; Miles et al., 2020). Cider producers seek juice with adequate sugar, balanced acid, and high levels of phenolic compounds that enhance "mouth feel" to make unique, high-quality cider (Moulton, 2010). Currently, finding specialty cider apples that contribute to those qualities in finished cider is a significant challenge for U.S. producers. Increased demand for specialty cider apple cultivars has brought new market opportunities for fruit producers. While Vermont apple growers have expressed interest in growing and selling specialty apples for the cider industry, they have been apprehensive about planting cider cultivars as the horticultural characteristics, including crop yield, biennial tendency, cold hardiness, and disease susceptibility, of many cider apples is unknown (Becot et al., 2018). Cider cultivars have been selected for their juice qualities, not for their yield or ease of production (Miles et al., 2020). Many specialty cultivars originated in Europe in regions with a maritime climate, having warm summers, mild winters, and abundant

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precipitation. A maritime climate is dissimilar to the continental climate of most major fruit production regions of North America, which have lower winter temperatures and summer rainfall and higher summer temperatures (Merwin, 2008). Research to assess how specific cider apple cultivars grow in North America is currently growing but is limited compared to accumulated knowledge on producing dessert apple cultivars. Some growers have reported that cider cultivars are challenging to grow due to disease susceptibility, biennial bearing, premature fruit drop, and excessive vegetative growth (Moulton, 2010). The lack of strong history or experience in producing and using cider apples poses a significant challenge to growers, making the need for research on the horticultural and juice characteristics of cider cultivars necessary.

In the northeastern U.S., application of carbaryl with or without other plant growth regulators (PGRs) at petal fall (post-bloom) and soon thereafter is traditionally used for thinning dessert cultivars. A successful chemical thinning program will normally result in increased fruit size and consistent annual cropping (McArtney et al., 2007). However, some European bittersweet cultivars exhibit a poor thinning response to traditional chemical thinning programs making crop load management difficult (Merwin, 2008). Inconsistent flowering and cropping can reduce farm profitability. Various growth regulators have been shown to promote flower bud formation in apple. Recent research suggests that an increase in floral bud formation in biennial cultivars may be achieved with biweekly midsummer applications of NAA and/or ethephon beginning five to six weeks after bloom (McArtney et al., 2007; Duyvelshoff and Cline, 2013; McArtney et al., 2013).

NAA has been reported to stimulate flower bud formation independently of crop load (Harley et al., 1958). Post-bloom applications of ethephon have been shown to increase return bloom in 'Wellspur Delicious' apple trees without reducing fruit set (Harley et al., 1958; Williams, 1972). Ethrel (Bayer CropScience; Calgary, AB, Canada), a brand of the PGR ethephon, is registered in the United States to enhance flowering in apple trees. The product label recommends one or more application(s) at 1.75 to 3.50 L ha^{-1} of Ethrel but does not provide specific cultivar recommendations. PGRs used for thinning can affect fruit quality and harvest characteristics when applied closer to harvest. Ethephon has been shown to advance fruit maturity and lead to pre-harvest drop (McArtney et al., 2007; Stover et al., 2003), while naphthalene acetic acid (NAA) can delay maturity and reduce pre-harvest drop (Guo et al., 2019; Marini et al., 1993). Ethephon has also been shown to inhibit tree growth by reducing vegetative growth in apple when applied during the period of shoot growth (Byers, 1993)

While the success of bloom enhancement spray programs for dessert cultivars is promising, research on hard cider cultivars is limited, and further investigation is warranted. Controlling the year-to-year crop variation or biennial bearing of cider cultivars is important to the overall profitability of an orchard, and growers require new methods and information to understand how to maintain adequate crop yields and improve return bloom. The primary objective of this research was to evaluate the potential for NAA or ethephon applications alone and in combination with carbaryl in the heavy cropping year of a biennial bearing cycle to promote return bloom of cider cultivar 'Somerset Redstreak', 'Kingston Black', and 'Harry Masters Jersey'. Other objectives included evaluating their effects on fruit quality, tree growth, and juice quality in the year of treatment and the following year.

MATERIALS AND METHODS

Three plant growth regulators were evaluated alone and in combination for their effects on return bloom and fruit and juice quality. Plant growth regulators evaluated included: carbaryl 4 L applied at 2.3 L ha^{-1} (Drexel Chemical Company, Memphis, TN); NAA at 147 g ha^{-1} (1-naphthaleneacetic acid, sodium salt, AMVAC Chemical Corp, Los Angeles, CA); and Ethephon at 3.5 L ha^{-1} (2-chloroethylphosphonic acid, Ethrel, Bayer Crop Science, Calgary, AB) (Table 1). Treatments were applied in 2019 to single tree replicates in a randomized complete block design during the "on" year when trees were expected to crop heavily. Guard trees were located between each treated tree to minimize the chance of spray drift. Treatments evaluated were carbaryl at petal fall, midsummer applications of PGRs at 6, 8, and 10 weeks after petal fall, and combinations of the two (Table 1).

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Table 1. Experimental treatments applied in 2019.

Treatment [a]	Concentration (per liter)	Application Schedule [b]			
		Petal Fall	6WAPF	8WAPF	10WAPF
NTC	-	-	-	-	-
Carb	2.5 ml	+	-	-	-
NAA	0.16 g	-	+	+	+
NAA and	2.5 ml	+	-	-	-
Carb	0.16 g	-	+	+	+
ETH	0.62 ml	-	+	+	+
Carb & Ethephon	2.5 ml	+	-	-	-
	0.62 ml	-	+	+	+
Application Dates: 2019		7-Jun	18-Jul	2-Aug	14-Aug

[a] NTC=Non treated control, Carb= carbaryl, ETH= ethephon, NAA= naphthaleneacetic acid, [b]WAPF= weeks after petal fall, "+"= treatment applied, "-" = no treatment application

Replicated field trials were performed at two orchards in the Champlain Valley of Vermont. In South Burlington, VT, thirty 'Kingston Black' trees grafted onto 'G41' rootstocks were selected for the study. Planted in 2016, trees were tall spindle trained and spaced at 0.9 x 4.5m (2,390 trees ha^{-1}) in Windsor Adams loamy sand with supplemental irrigation. The second location was a commercial orchard in Cornwall, VT. Thirty-six trees of both 'Somerset Redstreak' and 'Harry Masters Jersey' grafted on 'M.9-Nic29'® rootstock were assessed. Established in 2016, trees were planted at 0.9 x 4.5 m (2,390 trees/ha) spacing in Nellis clay loam soil with supplemental irrigation. At both sites, orchard floor management consisted of mowing of the drive rows with a 1-m herbicide strip maintained under the canopies. Each planting followed standard commercial practices for irrigation, pest, and fertilization management. No other PGRs were applied to the orchards during the study.

Project personnel applied treatments using an electric backpack sprayer (Solo 4.5 gal. Li-ion battery backpack sprayer, SOLO Inc, Newport News, VA). Plant growth regulators were applied to entire trees as dilute sprays to the point of runoff using 2L $tree^{-1}$. Each treatment chemical had its own spray tank to eliminate chemical cross-contamination. No surfactants or additives were incorporated into the sprays. Applications were made on days when wind speeds were between 0-3mph to reduce risk of drift, and maximum daytime temperatures were between 75-84°F.

'Somerset Redstreak' was recorded at full bloom on 21 May 2019 and 2020 and 6 May 2021. Fruit were harvested according to the grower's schedule on 16 Sept 2019 and 8 Sept 2020. 'Harry Masters Jersey' full bloom was recorded on 27 May 2019, 29 May 2020, and 7 May 2021. Fruit were harvested on 30 Sept 2019 and 25 Sept 2020. 'Kingston Black' came into full bloom on 26 May 2019, 23 May 2020, and 8 May 2021 and was harvested on 10 Oct. 2019 and 5 Oct 2020.

Data collection

At full bloom for each treatment replicate, the total number of flower clusters on each tree was counted and recorded. Each fall, the vegetative growth parameters: tree height and spread (m), trunk circumference (cm), and the length of five terminal branches per tree were measured. At harvest, total crop yield (kg $tree^{-1}$) was measured, and the number of fruit per tree was recorded. Yield efficiency was calculated by dividing the total kg of fruit harvested by each tree's trunk cross sectional area (TCSA). The number of recently dropped fruits were recorded separately and assumed to be of average fruit weight as calculated from the other yield data. A randomly selected sample of five fruit per treatment-replicate (tree) was collected from harvested fruit and assessed for fruit weight (g), scored for red color, general defects, and USDA grade distribution (Bradshaw et al., 2018). After external evaluation, internal fruit qualities were assessed. Fruit firmness was measured using an 11-mm probe penetrometer (Wagner, Greenwich, CT), and ripeness was evaluated using the starch iodine

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index (Blanpied and Silsby, 1992). Fruit samples were then analyzed for juice quality parameters, including pH, titratable acidity, total phenolics, and soluble solids using standard protocols (Bradshaw et al., 2018). In 2019, due to a logistical error at the participating orchard, research fruit were collected by orchard picking crews, and harvest and juice data for 'Harry Masters Jersey' was unable to be collected.

Table 2. Total flower clusters counted annually on 'Somerset Redstreak', 'Kingston Black', and 'Harry Masters Jersey'. Collected in 2019, 2020, and 2021.

Cultivar and Location[a] Treatment	No. of flower clusters per tree								
	SSR : CWVT			KB : SBVT			HMJ: CWVT		
	2019	2020	2021	2019	2020	2021	2019	2020	2021
NTC	81.2	112.0	180.7	153.4	7.4	61.8	84.3	19.2	191.0
Carb	97.5	69.0	228.5	190.0	4.2	37.6	94.5	0.0	210.7
NAA	68.8	84.3	130.2	144.2	28.0	45.0	83.5	0.0	186.8
ETH	75.8	109.3	210.0	152.0	19.8	54.2	75.5	24.5	198.0
NAA+Carb	121.8	42.8	288.3	157.4	21.8	55.8	86.0	0.0	203.2
ETH+Carb	163.0	0.0	380.2	181.8	10.6	50.8	96.7	0.0	273.5
P-value [c]	0.287	0.454	0.261	0.897	0.727	0.971	0.838	0.554	0.392

[a] NTC=Non treated control, Carb= carbaryl, ETH= ethephon, NAA= naphthaleneacetic acid, SSR=' Somerset Redstreak', CWVT=Cornwall, Vermont, KB=' Kingston Black', SBVT= South Burlington, VT [a, b] from table one. [c] P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

Data analysis

Data were subject to analysis of variance (ANOVA) procedures by PGRs treatment separately for each orchard location and year (JMP®, Version *15,* SAS Institute Inc., Cary, NC, 1989-2019). If overall variances were found at α=0.05, post-hoc multiple comparisons were made using Tukey's adjustment.

RESULTS AND DISCUSSION

'Kingston Black' exhibited strong biennial bearing tendencies with substantially greater yields in 2019 compared to little yield in 2020. In 2020, many trees produced no fruit, and the very low crop load in that year likely affected all subsequent fruit and juice quality measurements because of smaller aggregate samples used to calculate mean values. Although a logistical error prevented crop yield collection of 'Harry Masters Jersey' in 2019, flower cluster counts (Table 2) indicate a strong biennial bearing tendency. In 2020, so few trees flowered that adequate sample sizes could not be collected for yield, fruit, and juice analysis. 'Somerset Redstreak' bore adequate flowers and fruit in 2020, with the exception of the carbaryl and ethephon treatment, which did not flower at all.

Crop load reduction during the year of treatment was inconsistent across the two cultivars (Table 3). No effects were observed for both 'Kingston Black' and 'Somerset Redstreak', but the carbaryl only treatments maintained a higher crop load than the non-treated control for both cultivars. This indicates that carbaryl alone may be an ineffective fruit thinner on both 'Kingston Black' and 'Somerset Redstreak'. For annual cropping, crop load recommendations for biennial prone 'Honeycrisp' suggest maintaining a crop load of 5 or 6 fruits cm^{-2} of TCSA, while other studies suggest up to 6 to 8 fruits cm^{-2} of TCSA (Robinson et al., 2010; Anthony et al., 2019). Despite having a large crop load 11 fruits cm^{-2} of TCSA in 2019, the NAA treatment did increase the return bloom of 'Somerset Redstreak'. Ethephon and carbaryl applied together resulted in no result bloom for 'Somerset Redstreak'. The increased crop load on 'Somerset Redstreak' may have contributed to reducing fruit weight in 2019. Crop load for Kingston Black ranged between 4-7 fruit cm^{-2} of TCSA in 2019, falling within the suggested crop load for biennial cultivars, but very few trees bloomed in 2020. This may suggest that 'Kingston Black' requires a lighter crop load than dessert cultivars in order to

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flower annually. A specific study to evaluate the optimal crop load density for 'Kingston Black' is warranted. Hand thinning to ensure crop loads of 2, 4, 6, and 8 fruits cm^{-2} of trunk cross-sectional area could lead to determining an optimal crop load on 'Kingston Black'.

Table 3. Crop yield for 'Somerset Redstreak' and 'Kingston Black' in Vermont (2019 and 2020).

Cultivar: Location Treatment [a]		TCSA[b] (cm^2)		Crop load (No. fruit/ TCSA)		Yield efficiency (kg fruit/ TCSA)		Fruit drop %	
		2019	2020	2019	2020	2019	2020	2019	2020
	NTC	13.6	15.8	7.4	8.0	0.38	0.42	0.56	0.08
	Carb	11.0	14.9	8.1	4.8	0.43	0.28	0.47	0.13
SSR	NAA	9.7	12.1	10.9	7.5	0.32	0.42	0.63	0.15
CWVT	ETH	11.3	13.5	4.5	7.9	0.09	0.42	0.79	0.12
	NAA+Carb	12.3	15.7	7.3	3.2	0.45	0.14	0.36	0.16
	ETH+Carb	11.4	14.3	6.3	0.0	0.13	0.00	0.68	0.0
	P-value	0.067	0.249	0.589	0.388	0.110	0.334	0.283	0.922
	NTC	10.1	15.0	4.8	0.0	0.06 AB	0.00	0.85	-
	Carb	9.3	12.4	6.5	0.1	0.06 AB	0.01	0.80	0.38
KB	NAA	11.2	15.7	3.9	0.2	0.11 AB	0.02	0.66	0.17
SBVT	ETH	11.3	15.3	4.1	0.1	0.05 AB	0.01	0.84	0.50
	NAA+Carb	11.9	16.2	6.4	0.4	0.14 A	0.04	0.69	0.32
	ETH+Carb	9.6	11.5	5	0.1	0.04 B	0.01	0.92	0.50
	P-value	0.345	0.347	0.650	0.394	0.025	0.521	0.211	0.211

[a] SSR= 'Somerset Redstreak', CWVT=Cornwall, Vermont, KB= 'Kingston Black', SBVT= South Burlington, VT, NTC=Non treated control, Carb= carbaryl, ETH= ethephon, NAA= naphthaleneacetic acid. Treatments from table one. [b] Trunk cross sectional area measured 30 cm above the soil line. [d] P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

There was little effect on fruit drops attributable to the treatments. Although on both cultivars ethephon alone and in combination with carbaryl exhibited a greater drop than both NAA and carbaryl, alone or in combination with each other. Drops in 2019 were high for both 'Somerset Redstreak' (36-79%) and 'Kingston Black' (66-92%) compared to 2020, where Somerset Redstreak' only 8-15% and Kingston Black' 17-35% dropped. This shows that cider cultivars do have a predisposition for pre-harvest drop. The reduction in pre-harvest drops in 2020 may be partly due to harvesting fruit at a lower starch index or before they mature. This may have some effect on the juice quality from 2020.

There was no difference among cultivars within each study year for tree growth parameters which includes include canopy volume, shoot length, and TCSA. In 2019, 'Somerset Redstreak' showed signs of advanced maturation using ethephon and carbaryl as measured by softer fruit firmness and a higher starch index. The use of NAA and carbaryl together showed a delay in fruit ripening. These results are is consistent with previous studies and knowledge of ethylene as a ripening hormone. 'Kingston Black' in 2019, no differences were observed among treatments after applying multiple comparisons adjustments for α=0.05. However, all treatments with ethephon trended toward having softer fruit than other treatment groups.

Growth regulator treatments did not consistently affect juice quality between cultivars. During the treatment year, 2019, all ethephon treatments on 'Somerset Redstreak' had a higher pH, and juice from trees treated with ethephon and carbaryl had lower titrable acidity. 'Kingston Black' juice was unaffected by PGRs applications. Due to all juice quality values falling within expected ranges for the cultivars (Valois et al., 2006; Alexander et al., 2016; Bradshaw et al., 2018;)

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Table 4. Fruit quality at harvest for 'Somerset Redstreak' and 'Kingston Black' in Vermont. Sampled autumn 2019 and 2020.

Cultivar: Location	Treatment [a]	Fruit wt. (g)		Fruit Firmness (kg * cm^{-2})		Starch Pattern Index	
		2019	2020	2019	2020	2019	2020
	NTC	82.73 ab	58.02	7.4 a	9.2 ab	4.5 ab	3.3
	Carb	95.48 ab	83.21	7.5 a	7.9 b	4.2 ab	3.7
SSR	NAA	75.51 b	62.71	7.3 a	8.5 a	5.6 ab	5.0
CWVT	ETH	82.15 ab	63.22	7.4 a	9.0 ab	5.0 ab	3.6
	NAA+Carb	94.56 a	53.58	7.4 a	10.0 a	4.1 b	5.0
	ETH+Carb	95.52 a	-	5.5 b	-	5.9 a	-
	P-value	0.0065	0.4098	0.0012	0.014	0.0094	0.1071
	NTC	70.17	-	9.0	-	4.2	-
	Carb	56.96	83.66 ab	9.6	8.1	5.2	5.3
KB	NAA	71.52	96.89 ab	8.4	7.5	3.4	5.6
SBVT	ETH	72.23	48.15 b	6.2	10.9	4.8	3.3
	NAA+Carb	74.39	81.89 ab	8.9	8.7	4.1	5.5
	ETH+Carb	50.27	119.18 a	8.1	6.5	3.5	5.0
	P-value	0.6777	0.0378	0.0452	0.6627	0.3217	0.8456

[a] SSR= 'Somerset Redstreak', CWVT=Cornwall, Vermont, KB= 'Kingston Black', SBVT= South Burlington, VT, NTC=Non treated control, Carb= carbaryl, ETH= ethephon, NAA= naphthaleneacetic acid. Treatments from table one [d] P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

Table 5. Juice quality at harvest for 'Somerset Redstreak' and 'Kingston Black' in Vermont. Sampled autumn 2019 and 2020.[a]

Cultivar and Location [b]	Treatment [c]	Soluble solids (° Brix)		pH		Titratable acidity (g malic L^{-1})		Total polyphenols (mg L^{-1})	
		2019	2020	2019	2020	2019	2020	2019	2020
	NTC	10.8	10.5	4.12 b	3.81	1.71	1.72	2283.6	2649.3
	Carb	12.4	11.2	4.03 b	3.92	1.73	2.75	2708.7	2835.4
SSR	NAA	8.8	10.7	4.06 b	3.89	1.88	1.96	2588.9	2711.3
CWVT	ETH	11.6	11.2	4.30 a	3.78	1.93	1.68	2239.3	2734.3
	NAA+Carb	10.3	13.1	4.05 b	4.05	1.84	2.40	2823.6	3465.2
	ETH+Carb	11.0	-	4.46 a	-	1.30	-	2303.4	-
	P-value[d]	0.106	0.666	0.0005	0.230	0.054	0.309	0.243	0.637
	NTC	9.5	-	3.55	-	6.08	-	2074.6	-
	Carb	9.7	16.6	3.54	3.47	6.49	8.03	1650.1	1170.1
KB	NAA	12.2	14.3	3.55	3.46	5.74	6.94	1578.6	876.0
SBVT	ETH	10.3	13.8	3.81	3.30	4.21	6.14	1594.8	2779.2
	NAA+Carb	7.8	15.4	3.62	3.51	5.41	6.93	1677.2	1516.5
	ETH+Carb	11.8	17.9	3.76	3.50	5.95	9.33	2331.6	1143.4
	P-value	0.435	0.729	0.092	0.919	0.213	0.757	0.710	0.506

[a] Juice analysis methods (Valois et al., 2006) [b] SSR=' Somerset Redstreak', CWVT=Cornwall, Vermont, KB=' Kingston Black', SBVT= South Burlington, VT. [c] from table one. [d] P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

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CONCLUSIONS

Given the limited time frame of this experiment, caution should be used in interpreting broad conclusions from the data and resulting observations. The traditional cider apple cultivars 'Harry Masters Jersey', 'Kingston Black', and 'Somerset Redstreak' exhibited biennial tendencies, which is concurrent with other studies and industry observations. The PGRs applied in this trial did not substantially affect biennial bearing to any degree likely to affect the inconsistent crop production associated with these cultivars. Slight effects of NAA on yield efficiency on 'Kingston Black', and no effects, negative or positive, on juice quality of any cultivar associated with PGR applications overall suggest that continued work may be warranted on specific cultivars to better improve annual bearing on high value cider apple cultivars. Non-PGR methods for managing production, including horticultural (e.g. spur pruning, blossom thinning, etc.) and supply chain (e.g., juice concentration in heavy-bearing years, storage and blending across multiple seasons) management are other important components of cider and cider apple production systems that must be considered in addition to the methods explored in this paper.

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