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Influence Of Summer Hedging And Plant Growth Regulators On Apple Trees Grown For Hard Cider. An Evaluation Of Return Bloom, Tree Growth, And Juice Quality.

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INFLUENCE OF SUMMER HEDGING AND PLANT GROWTH REGULATORS ON APPLE TREES GROWN FOR HARD CIDER. AN EVALUATION OF RETURN BLOOM, TREE GROWTH, AND JUICE QUALITY.

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ABSTRACT

Fermented cider production has rapidly increased in the US over the last decade with an annualized growth rate of 50% between 2009 and 2014, and revenues totaling $ 2.2 billion in 2018 (Becot et al., 2016; Miles et al., 2020). Cider producers seek juice with high sugar, high acid, and phenolics that enhance ‘‘mouth feel’’ to make unique, high-quality cider. Specialty cider cultivars are selected for their juice qualities, not for their yield or ease of production. Growers have found many cider cultivars are challenging to grow due to disease susceptibility, biennial bearing, premature fruit drop, and excessive vegetative growth. Cider cultivars of European origin respond poorly to traditional crop load thinning methods, leading to fluctuating crop yields from year-to-year. Controlling the year-to-year crop variation or biennial bearing of cider cultivars is important to the overall profitability of an orchard. Growers are in need of new methods and information to understand how to maintain adequate crop yields and improve return bloom. The objective of this project has been to explore the use of hedge pruning and summer applied plant growth regulators as methods to improve return bloom.

Chapter 2: In this study, tall spindle trained cider apples ‘Somerset Redstreak’ and ‘Harry Masters Jersey’ and traditional dessert apples ‘McIntosh’ and ‘Empire’ trained to a tall spindle system were hedged during the summer to evaluate their response of return bloom, yield, tree growth, and juice quality. Treatments consisted of 1) normal winter dormant pruning with hand tools as a control; 2) mechanical winter dormant pruning with a hedger; 3) mechanical pruning at pink (prebloom) bud stage with a hedger, and; 4) mechanical pruning at the 12-14 leaf stage, in mid-June. ‘Harry Master Jersey’ exhibited a strong biennial tendency, with no return bloom in 2020. There was a noteworthy difference in canopy size for all cultivars the first season, with most hedging treatments being reduced nearly by half. Juice quality was unaffected by hedging treatment for soluble solid content, pH, titratable acidity, and total phenolics.

Chapter 3: Three plant growth regulators were evaluated alone and in combination for their effects on return bloom and fruit and juice quality on hard cider trees when applied at different times throughout the growing season. Plant growth regulators evaluated included: Carbaryl 4L at 0.58 L ha-1, naphthalene acetic acid (NAA) at 210 g ha-1, and Ethephon at 0.29 L ha-1. Growth regulator treatments did not have a consistent effect across cultivars. ‘Somerset Redstreak’ adequately flowered and cropped in 2020 with no differences seen between treatments. ‘Kingston Black’ and ‘Harry Masters Jersey’ had little to no return bloom in 2020. In 2019, ‘Kingston Black’ treated with NAA had higher yields than those treated with ethephon. Ethephon caused increased fruit softening in both ‘Kingston Black’ and ‘Somerset Redstreak’ in 2019. Juice from ‘Somerset Redstreak’ treated with ethephon had higher pH at harvest. Naphthaleneacetic acid or ethephon treatments during the bloom year of a biennial bearing cycle did not promote return bloom for two out of three hard cider cultivars tested.

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1.1. Introduction

The purpose of this review is to give background information on domesticated apple (*Malus domestica*; Rosaceae) flowering: morphology, factors affecting initiation and induction, and plant hormones involved in the process.

1.2. Origin and History of Apples

The modern apple originated from forests of the Tien Shan mountain range of Kyrgyzstan and Kazakhstan in central Asia (Ferree and Warrington, 2003; Harris et al., 2002). *Malus sieversii*, the wild ancestor to today's apple, still grows widespread across the mountains of central Asia. Archeological remains in Anatolia dating back to 6500 BC show that humans have been selecting, cultivating, and using apples for thousands of years (Ferree and Warrington, 2003). Travelers from the west along the Silk Road, gradually spread trees and fruit throughout western Europe and Asia. In Europe *M. sieversii* hybridized with the native European crab apples *M. sylvestris* (Ferree and Warrington, 2003). In the 13th century, Europeans used apples in cooking and for making cider. Hard cider or fermented apple juice was safer to drink than the local water supply, which at the time was often contaminated (Moulton, 2010) . Apples with moderate acid and high tannic were favored for cider production in Europe at the time.

European colonists brought apples to the Americas in the 1700's (Moulton, 2010). Settlers planted seeds, which established well in New England and along the Mid Atlantic. Apples became an important stable in colonial life, providing sugar and a safe drinking source. John Chapman better known as Johnny Appleseed helped plant thousands of trees across the United States (Ferree and Warrington, 2003). From the diversity of fruit planted, farmers began to select and graft the best apples for cider making. Cider was a popular drink in the United States until the temperance movement and Prohibition in 1919 nearly wiped it from the national consciousness (Moulton, 2010). The ban on alcohol led to the selection and breeding of aromatic and fresh dessert cultivars available today.

Presently apples are the number one consumed fruit in the United States. Grown in 32 states commercially, the United States produces an average of 240 million bushels of apples each year (US Apple Association, 2020). 67% of apples grown in the US are consumed fresh; the other 33% are processed into juice and food products (US Apple Association, 2020). The US is the 2nd largest apple producers in the world, second only to China (Ferree and Warrington, 2003).

1.3 Taxonomy and Morphology of Apples

1.3.1. Taxonomy

The genus *Malus* comprises deciduous trees and contains 78 primary species from Asia, Europe, and the Americas that encompasses eating apples, crabapples, and wild apples (Ferree and Warrington, 2003). Mature trees produce pome fruit that range in size from 1–4 cm in wild species to 8 cm or more in *M. domestica. M. domestica* contains over 7,500 known cultivars and are genetically diverse allowing them to be planted in a wide range of climatic conditions. Apples are diploid, sometimes triploid, containing 17 chromosomes (Velasco et al., 2010). Genome sequencing estimates that apples contain between 42-57,000 protein coding genes (Velasco et al., 2010). Typical for a temperate-zone fruit, apples naturally thrive when grown between 30-50 degrees latitude (Westwood, 1993). They require between 1000-1600 chilling hours to break dormancy and flower, and do not grow well in warmer climates (Westwood, 1993). Full ripening of apple fruits requires a growing season between 70-180 days before harvest (Westwood, 1993).

1.3.2. Morphology

Apple buds are mixed, containing both vegetative and reproductive parts. Buds are ovoid, with overlapping scales, producing a cyme inflorescence, in which the terminal flower is the most advanced (Westwood, 1993). Flowers are white, pink, or red with suborbicular petals with lateral vegetative buds at the base made of serrated leaves (Westwood, 1993). The flowers contain 15-20 stamens with yellow anthers, and 2-5 styles. The inferior ovary of the flower is surrounded by a fused base of sepals, petals, and stamens that remain attached at harvest giving rise to an accessory fruit, called a pome (Westwood, 1993). Most cultivars cannot self-pollinate due to multi-allelic S-locus (S-RNase)-mediated gametophytic self-incompatibility Sassa et al. (1994). Because of this self-incompatibility, the majority of cultivars display high levels of allelic heterozygosity and when propagated from seed, are not true-to-type, producing fruit that is extremely variable in size, appearance, and quality (Ferree and Warrington, 2003).

Apple flowers grow from both terminal and auxiliary buds of two year old shoots and fruiting spurs (Dennis, 2003); (Ferree and Warrington, 2003). Fruiting spurs are short shoots that arise from branches. They grow less than 6-inches long and have a rosette of leaves behind a large terminal bud at the tip of the shoot. The terminal bud usually develops into a flower bud (Marini, 2019).

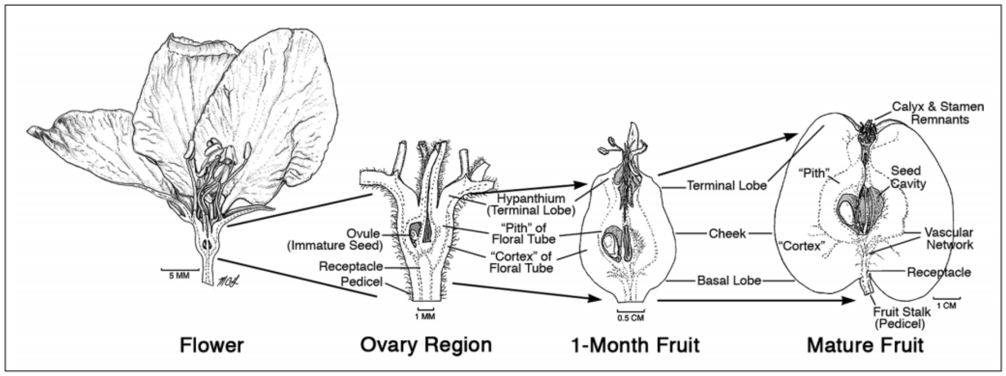

Figure 1: Diagram of an apple flower and how it develops into a fruit. Drawing by M. Goffinet (Lakso and Goffinet, 2013).

1.4 Flower Bud Formation

Apple begins to initiate flowers after shoot growth ceases and leaves mature, approximately six weeks after petal fall (Koutinas et al., 2010). If adequately pollinated, these flowers will become the following year's crop. Flower bud formation in apples happens in series of three stages: 1) induction, 2) initiation, and 3) differentiation.

Flower induction refers to the transition from the vegetative to reproductive growth phase. (Ferree and Warrington, 2003). At this stage, no visible macroscopic or microscopic changes have yet occurred in the bud (Dennis, 2003). Induction occurs in the early summer but can extend to the fall (Dennis, 2003). The transcription factor *FLO/LFY* (*FLORICAULA/LEAFY*) is involved in the transition but much is still to be understood (Wada et al., 2002).

Flower initiation is a series of cellular rearrangement and changes. The apex of a vegetative bud receives a signal for differentiating to a flower bud. The mitotic activity in the bud increases, causing the central meristem to unfold (Bubân, 1981). Once a bud undergoes this rearrangement, it will irreversibly undergo the process of floral organ development, regardless of the internal/external conditions that could affect flower induction (Miller, 1982a).

Flower initiation is followed by differentiation, or changes in the morphological structure of the bud. Floral primordia appear in the bud , as the bud apex grows, a ‘King’ flower forms in its center surrounded by four or more lateral flowers (Hirst and Ferree, 1995), then sepals, petals, stamens and carpels differentiate in succession (Koutinas et al., 2010). The first signs of flower differentiation is the visible appearance of dome-shaped swelling of the bud apex, about 12 weeks after full bloom (Abbott, 1977). Flower development continues until the following spring, when anthesis occurs (Verheij, 1996). The rate of development of flower buds during the different phases is not constant. Under unfavorable environmental conditions growth can stall making it difficult to establish how long a given phase lasts (Huang, 1996).

Factors that influence flower bud formation include cultivar, rootstock, shoot growth, depressing influences of seeds and fruit, hormones, environmental conditions, and horticultural practices.

1.5 Factors Affecting Flower Induction

1.5.1. Cultivars and Rootstocks

Apple cultivars have different flowering habits. When it comes to flower induction, cultivars differ in their timing of induction, the duration, concentration and location of floral buds, and response to flowering signals (McLaughlin and Greene, 1991). Some cultivars flower primarily on terminal buds on shoots, while other cultivars tend to flower primarily on terminal buds of spurs. Some rarely or never flower on lateral buds, while others do (Ferree and Warrington, 2003).

Due to its effects on flowering, genotype is probably the dominant reason for alternate bearing in fruit trees (Li et al., 1995). Biennial or alternate bearing refers to a large crop one year (the "on" year), followed by a small or no crop the following ("off") year. Annual bearing cultivars flower and crop consistently year to year. For example, 'Gala' is generally an annually flowering cultivar (Hirst and Ferree, 1994) while 'Fuji' tends to be very biennial bearing cultivar (Li et al., 1995).

Rootstocks have been found to have variable effects on apple flowering (Lordan et al.) Several rootstock evaluations studied the effects of rootstocks on flower density of 'Gala' and 'Triple Red Delicious' apples were found to be insignificant (Hirst and Ferree, 1995). Lordan et al (2017) evaluated 'Honeycrisp' on a selection of 'Malling', 'Budagovsky' and 'Geneva' rootstocks to test how the rootstock might impact hormone concentration and biennial bearing patterns. They found that there was a difference between rootstocks observing a high return bloom on G.935, M.9T337, and G.814, whereas B.72020 was the rootstock with the lowest value. In addition to being biennial, B.72020 showed the most upright growth pattern. The high levels of endogenous abscisic acid (ABA) found in xylem sap, was found in rootstocks that were more drought tolerant.

1.5.2. Environmental Factors

There is evidence showing the impact of environmental factors including light, temperature and water supply on flower induction and initiation of apple trees.

Light

Unlike most temperate woody species, apples are insensitive to photoperiod. Photoperiodism in many species triggers flowering based on day length (Heide and Prestrud, 2005). While photoperiod plays no role in apple flowering, solar radiation is important, but not well understood. Shaded canopies receiving reduced lighting have long been known to have reduced flowering (Auchter, 1927; Jackson and Palmer, 1977; Paddock and Charles, 1928; Tromp, 1983). Artificial shade experiments have shown shading to 37% of full sunlight reduced flowering to 44% of the control (Cain, 1973), and reduction to 30% of full sunlight was reported as the threshold level for flower bud formation (Jackson and Palmer, 1977).

Low photosynthetic active radiation (PAR) in the visible range has been correlated with a number of negative effects in apples. These include poor flower bud differentiation, reduced fruit set, and poor fruit quality. (Ferree and Warrington, 2003).

Temperature

Overall temperature experiments on flower initiation and induction have been conflicting. Tromp, 1976 showed that in a controlled environment high heat (25-27°C) can deter flowering. Zhu et al. (1997) reported improved flower formation by increasing air temperature from 13°C to 20°C, conflicting with Tromp's (1993) experiment at the same temperature range. Verheij (1996) suggests that flowering response to temperature may be cultivar dependent.

Heide and Prestrud (2005) demonstrated that the end of the vegetative growth cycle and dormancy induction were unaffected by photoperiod in apple, but rather controlled by low temperatures. If chilling requirements are not met, buds may be underdeveloped come spring (Heide and Prestrud, 2005).

1.5.3. Cultural Practices

Greene and Lord (1978) found that scoring, making a shallow cut around the trunk or branches, 12 days after bloom increases the return bloom of 'Richards Delicious'. Other horticultural practices such as bending and girdling of shoots are have been shown to have significant effects both on vegetative growth of treated shoots as well as on the retention of fruit growing on these shoots (Greene and Lord, 1978; Mika, 1969).

Mild drought conditions can favor flower bud formation, but it is not well studied (Zeng et al., 1987). Tromp (1983) documented the increase of flower induction when 'Cox's Orange Pippin' apple trees were treated with air humidity of 40%-50% instead of 80%-100%. Slight water stress may increase apple flower indirectly by changing the balance of the stress hormone ABA and regulating the balance between vegetative and reproductive growth.

1.6 Interaction of Flower Induction and Other Organs

1.6.1. Leaves

Leaves play a unique role in the formation of flowers. The effects of leaves in flower induction come from three aspects 1) leaves provide the carbohydrates needed for flower induction. 2) They help regulate the hormonal balance needed for flower induction. 3) Leaves are receptors of environmental signals related to flower induction. Flower induction in apple requires a certain number of healthy leaves. Defoliation, or leaf removal, can effectively inhibit apple flower formation. (Huet, 1972; Li et al., 1995).

1.6.2. Fruit

An excessive crop load will inhibit flower initiation and are known to induce alternate bearing (S.P. Monselise, 1982). Harley et al. (Harley et al., 1942; Harley et al., 1935b) demonstrated that flower initiation declined as fruit thinning was delayed, and this decline was more rapid in a biennial-bearing (‘Yellow Newtown’) than in an annual-bearing (‘Jonathan’) cultivar. In apple trees, the development of the current year’s fruits coincides with the time of flower induction for next year’s crop. Developing fruit are strong sinks for assimilates and were thought to suppress flower induction by competing for carbohydrates with developing buds, based on the nutrient diversion theory developed by Kraus and Kraybill (1918). While this correlates with the finding that a certain leaf/fruit ratio is a prerequisite for flower induction (Huet, 1974), Chan and Cain (1967) showed this is not the case pointing to the seeds as being the reason why fruits inhibit flowering.

1.6.3. Seeds

Chan & Cain (1967) demonstrated that the presence of seeds is the crucial element in fruit inhibition of apple flower induction. Using the apple cultivar ‘Spencer

Seedless', a facultative parthenocarpic cultivar, they found seeded fruits inhibit flowering unless they are removed within three weeks after pollination, while seedless fruits had little effect. This experiment, along with similar information on pear (*Pyrus communis L.)* (Huet, 1974), indicates the role of plant hormones in the regulation of flowering. Since Dennis and Nitsch (1966) identified GA_4 and GA_7 in apple seeds many other reports showed the inhibitory effects of exogenous GAs (Dennis and L.J.Edgerton, 1962), much research effort was expended studying gibberellic activity in apple seeds.

1.7 Nutrients and Flower Induction

Before plant hormones were identified, the dominant hypothesis about apple flowering centered on control by nutrients. This reflects the influence of the C/N ratio hypothesis proposed by Kraus and Kraybill (1918). Although, it has been observed that a high C/N ratio favors flower formation and excessive N application inhibits it, nutritional status is not the rate-limiting factor when nutrient supply reaches a threshold level. With discovery of hormone signaling in the 1970's, the C/N hypothesis was gradually abandoned. However carbohydrates and nutrients are still critical for flower formation.

1.7.1. Carbohydrates

Flower induction consumes a lot of carbohydrates and proteins (Dietz and Held, 1974). The C/N ratio hypothesis states that flower bud formation requires a high level of carbohydrates. A heavy crop load in the "on" year of biennial bearing of apple trees can lead to the depletion of the tree's carbohydrate reserve; consequently, flower formation for the following year can be inhibited by the lack of sufficient carbohydrates. Grochowska (1973) was able to concluded that hormones supplied by developing seeds lowered the starch content in spurs. As a result, finding that sufficient carbohydrates alone, do not act as the signal to trigger the transition of buds from vegetative growth to reproductive growth (Grochowska, 1973).

An adequate carbohydrate supply is needed to perform physiological processes such as respiration, fruit enlargement, bud formation, and growth of shoots, leaves, branches, and roots. (Kozlowski, 1992). Carbohydrates can be translocated and used across the tree to several competing locations. Tree growth and resource allocation is dependent upon carbon availability and the demand strength of carbons sinks and processes within the tree that require carbohydrates . These processes and sinks demand resources at different concentrations and change their needs throughout the growing season (Beattie and Folley, 1977). Kozolowski (1992) proposed a prioritized ranking in apple of “sink” strengths in the following order from strongest to weakest: fruits and seeds, new leaves and stems, mature leaves, vascular tissues, roots, and carbon reserves.

Two to four weeks after bloom fruitlets are in their cell division phase. Growing exponentially, many fruitlets become strong competing “sinks” for carbon. (Koutinas et al., 2010). Apple fruit thinning ideally should take place during this phase to reduce the number of sinks dependent on a limited carbon supply. The removal of competing fruit at this phase encourages large fruit, as fruit size is more dependent upon cell number than cell volume (Anthony et al., 2019).

1.7.2. Nitrogen and other nutrients

Nitrogen plays a critical role in plant metabolic processes because it constitutes amino acids, proteins, nucleic acids, and other compounds (Neilsen and Neilsen, 2003). As the other component of the C/N ratio hypothesis, it is generally accepted that excess nitrogen inhibits flower induction. Excess nitrogen indirectly affects flower induction by increasing the vigor and vegetative growth of the whole tree (Faust, 1989). Conversely, N deficiency may reduce flower induction by stunting tree growth (Stiles, 1999).

The nitrogen requirement of apple trees is high compared to its other nutritional requirements. A tree's N requirements can vary from 2 g N per tree at planting for a dwarfed tree in a high density system to up to 890 g N per tree for a standard 30-year-old tree (Neilsen and Neilsen, 2003). The average high-density production system requires around 30 g N per tree by its sixth year (Neilsen and Neilsen, 2003).

The form of nitrogen applied can influence tree growth. Ammonia (NH_4^+) may favor flower induction while nitrate (NO_3^-) may not. A 2016 study in Norway found no differences in the return bloom or tree growth of soil applied NO_3^- and NH_4^+ on 'Summerred' apples (Meland et al., 2016). Other studies have found NH_4^+ application gives rise to shorter shoots and increased rate of flower induction by increasing the activity of plant hormones (Verheij, 1996). One study found that after NH_4^+ application there was an increase of cytokinin detected in xylem sap, which is thought to help promote apple flowering (Gao et al., 1992). Tami et al. (1986) found 'Starkspur Golden

Delicious' trees fertilized with soil applications of urea, had a positive relationship between leaf N content and percentage of floral buds. Their study helped demonstrate that similar to carbohydrates, nitrogen is also required for flower induction.

Soil application of phosphorus (P) is reported to increase apple flowering (Neilsen et al., 1990). Benson and Covey (1979) showed that when grown in a phosphorus deficient solution 'Golden Delicious' had delayed bud break and reduced flowering. Foliar analysis is needed to determine P deficiency, as few deficiency symptoms are reportedly seen in apple (Neilsen and Neilsen, 2003).

Contradictory data has been published on the roles of many mineral elements, and the part they have in flower induction is not very clear. One important element to flowering in general is Boron. Boron (B) is a micronutrient required in low levels (p.p.m) to help maintain meristems, cells walls, and act as coenzyme. If trees suffer from B deficiency, they can have 'blossom blast', producing flowers that are shriveled, dry and unable to fruit due to an underdeveloped pollen tube (Neilsen and Neilsen, 2003).

1.8 Plant Hormones Involved in Flower Induction

Plant hormones are signaling molecules synthesized within the tree that control and direct all of the plants physiological processes (L.Taiz and Zeiger, 1991). The environment, orchard management activities, pest and disease pressure, and applications of synthetic plant growth regulators influence hormone activity and concentration (Greene, 2003 358). There are five classes of plant hormones: auxins, gibberellins (GA), ethylene, cytokinins, and abscisic acid (ABA). Many studies have shown the wide range of effects different plant hormones can have on flowering, with no one being solely responsible for flower induction. Observations have shown that hormones interact and counter balance each other to influence flowering (Koutinas et al., 2010).

1.8.1. Auxin

Auxins are a class of plant hormones synthesized in apical buds, young leaves, and root tips. Auxin has many different roles in plant development including regulating cell division, elongation, and rooting (L.Taiz and Zeiger, 1991). Auxins can delay leaf senescence, inhibit or promote (via ethylene) leaf and fruit abscission, promote flowering and growth of flower parts, induce fruit setting and growth, and delay fruit ripening (Yahia et al., 2019). Auxin can both stimulate (Grochowska, 1973) and inhibit (Bangerth, 2000; Ramirez and Hoad, 1981) growth and development, depending on the concentration and location within the plant. For example, when synthesized in the apical buds of shoots auxin promotes root growth and development, but inhibits lateral bud growth to maintain apical dominance, of upright shoot growth (L.Taiz and Zeiger, 1991).

In apples, auxins have a favorable effect on the initiation of fruit buds at the beginning of the growing season. Present in fruit seeds younger than four weeks, auxin attracts nutrients into fruiting spurs (Koutinas et al., 2010). Three to four weeks after bloom, gibberellins (GA) begin to translocate from seeds, counteracting auxin's favorable affect and inhibiting flower bud formation (Grochowska, 1973).

Harley et al. (1958) was the first to reported that flowering in apple was increased after a thinning application of synthetic auxin, naphthalene acetic acid (NAA). They found direct evidence that NAA stimulated flower bud formation independently of crop load. McArtney (2007) applied at 5ppm NAA on Delicious', 'Golden Delicious', 'Cameo', and 'Mutsu' trees between 1998-2006 and saw an increased return bloom in six of 10 experiments. Another study used weekly bud dissections to determine that NAA applied biweekly between 7-14 or 15 -20 weeks after bloom each had increased return bloom of 'Golden Delicious'(McArtney et al., 2013). This study indicated that NAA can trigger floral development, outside the generally accepted time period of 6-10 weeks when NAA was believed to have the most influence over flower bud formation.

Auxins are found in natural and synthetic forms. Indolylacetic acid (IAA) is the naturally occurring auxin used commercially for greenhouse rooting and tissue culture. Naphthalene acetic acid (NAA) is used for thinning blossoms in apples. 2,4-dichlorophenoxyacetic acid (2,4-D) ,2,4,5-trichlorophenoxyacetic acid, and chlorophenoxy acetic acid are auxin based systemic herbicides.

1.8.2. Ethylene

Ethylene is a gaseous multipurpose plant hormone that promotes or inhibits plant growth and senescence processes depending on its concentration and timing of application (Greene, 2003). Auxin induces ethylene production, and the application of auxins can elicit ethylene responses (Iqbal et al., 2017). Ethylene is known to play a role in plant aging, including fruit ripening, and flower and leaf senescence. Ethylene and auxins are tightly related during fruit senescence (Iqbal et al., 2017). Free auxin increases during senescence stimulating ethylene synthesis. Ethylene regulates fruit firmness and color changes by breaking down cell walls, reducing chlorophyll, increasing carotenoids and anthocyanins, and increasing sugars (Iqbal et al., 2017).

Apples are climacteric fruit, they generate ethylene as they mature, which stimulates ripening, and when translocated to the abscission zone of the fruit pedicel, it initiates a biochemical change that leads to the breakdown of cells in the abscission zone (Greene, 2003).

It has been well documented that ethylene and ethylene inducing compounds when applied during the period of flower induction can increase the return bloom of apple trees (S.P. Monselise, 1982);(Buban, 1967);(Williams, 1972);(McArtney et al., 2013; McArtney et al., 2007)). Ethephon (Ethrel, Bayer CropScience; Calgary, AB, Canada) is a registered plant growth regulator used to stimulate the trees natural ethylene response. Current recommendations to promote flowering on bearing trees suggest using multiple doses of ethephon at 100-200 mg/ l be applied starting six to eight weeks after full bloom (Greene, 2003). Byer (1993) showed increased flowering on 'Starkrimson Delicious' by applying either 12 weekly or six biweekly sprays of either 100 or 200 mg/l ethephon.

McArtney's (2007) researched using ethephon application(s) in the heavy cropping year of a biennial bearing cycle to promote return bloom of apple under commercial conditions and found that 'Golden Delicious' trees sprayed five weeks after bloom with 444 ppm ethephon (48 fl oz/acre Ethrel) had an increased return bloom compared to control trees. The study also found that combining four early summer sprays of 316 ppm ethephon (24 fl oz/acre Ethrel) with 15 ppm gibberellin A4 + A7 (GA4+7) increased return bloom of 'Cameo' but had no effect on return bloom of 'Mutsu' or 'Golden Delicious'. McArtney's (2013) study using combinations of NAA, ethephon, and an ethylene inhibitor aminoethoxyvinylglycine (AVG) helped show that ethylene is involved in the florigenic activity of NAA.

Ethylene acts as an effective growth retardant, as well as a fruit thinner (Greene, 2003). In some of the studies mentioned, the promotion of flower induction induced by ethylene was accompanied by reduced shoot growth. Greene and Lord (1978) found that ethephon applied 12 days after bloom at 500 and 1000 mg/1 to terminal shoots 10-15 cms long stunted growth and increased return bloom the following season in 'Richards's Delicious'.

1.8.3. Gibberellins

Gibberellins (GA) are developmental plant hormones involved in stem elongation, germination, dormancy, flowering, flower development, and leaf and fruit senescence. (Dilworth et al., 2017) GAs are given trivial names ($GA_{1,2,3\ldots n}$) based on their discovered order rather than chemical structure (Tu, 2000). There are currently 136 different GAs recognized by the International Plant Growth Substances Association (IPGSA) (Hedden, 2017)

As mentioned before, newly set fruits contain immature seeds that begin to generate gibberellins about two to four weeks after bloom, which inhibit the formation of new fruit buds (Luckwill, 1974). Using bioassays Luckwill (Luckwill, 1969, 1974) found that the GA content in seeds is 15-500 times greater than leaves and shoots up until nine weeks after bloom, about when flower induction would occur. Seeds of biennial bearing apple cultivars have been found to diffuse significantly more gibberellins than seeds of annually bearing cultivars (Grochowska and Karaszewska, 1976).

The inhibitory effect of individual GAs are not identical. A tree's response to GAs will differ depending on cultivar and the particular GAs used. Looney et al. (Looney et al.) found that application of GA_4 to 'Golden Delicious' in the heavy cropping year of a biennial bearing cycle increased flowering the following year. Tromp (1982) demonstrated the inhibiting effect of GA_4 plus GA_7 when mixed was the same as spraying GA_7 alone when applied on 'Cox's Orange Pippin'. 'Spencer Seedless' an annual producing cultivar was found to produce mostly GA_4 while biennial cultivar 'Elstar' produced primarily GA_3 (Dennis and Neilsen, 1999). Substances that interfere with GA biosynthesis such as diaminozide and paclobutrazol can improve flowering but negatively impact other aspects of tree growth (Greene, 1989).

1.8.4. Cytokinins

Cytokinins are plant hormones that regulate a wide range of growth and developmental processes including seed germination, leaf expansion, induction of flowering, as well as flowering and seed development (Iqbal et al., 2017). They also promote cell division and increase tolerance to drought stress. Cytokinins are concentrated in root tips, the apical meristem, and in immature leaves and seeds.(Dilworth et al., 2017) Cytokinins are utilized in tissue culture to stimulate cell division, adventitious shoot formation, and embryogenesiss (Dilworth et al., 2017).There are a few commercial products that have been tested on apples: forchlorfenuor (CPPU), benzyladenine (BA), and thidiazuron (TDZ).

CPPU when applied to ‘Delicious’ and ‘Empire’ reduced return bloom but had a positive increase on packed fruit size (Curry and Greene, 1993). When applied to McIntosh fruit become asymmetrical, reduced red color, and provide some return bloom (Greene et al., 2011) (Bangerth, 2000).

Benzyladenine (BA) has a mode of action similar to endogenous cytokinins and can be used to suppress apple seed development, therefore inhibiting gibberellin production. Applied as a fruitlet thinning product anywhere from 50 -100 mg/l it is used to thin hard to thin cultivars like ‘Golden Delicious’ and ‘Idared’ (Turk and Stopar, 2010). Return bloom and yield in treated trees had inconsistent results across studies (Turk and Stopar, 2010); (Buban and Lakatos, 1998); (Nichols et al., 2004).

Thidiazuron (TDZ) (N-phenyl-N'-1,2,3-thiadiazol-5-ylureia) TDZ has a negative outcome on return bloom depending on concentration, time of application, and cultivar. Greene (1993) reported a reduced return bloom on 'McIntosh' and 'Double Red Delicious' apples treated with TDZ. Amarante et al. (2002) found a reduction in bloom for both 'Gala' and 'Fuji' treated with 20 g ha^{-1} of active ingredient.

1.8.5. Abscisic Acid

Abscisic acid (ABA) is a plant hormone that plays an important role in the inhibition of seed germination and budding. It is known as the plant stress hormone because of its response of plants to weather stress, in cold or drought. ABA is also involved in embryo maturation and cell division and elongation (Dilworth et al., 2017)

The effect of ABA on apple flowering remains obscure. Attempts to relate apple flower induction to endogenous ABA concentration were inconclusive (Hoad, 1984; Ramirez & Hoad, 1981). It is possible that ABA does not play direct role in apple flowering. However, it may affect flower induction by antagonizing GA and inducing cessation of shoot elongation.

1.9 Plant Hormone Interactions

Experiments have shown that the fate of meristems is not determined by the activity of a single plant hormone. It appears auxin and GA are negative signals for flower induction. While other hormones can either, enhance or mask these negative influences there is not an obvious positive signals for flower induction even though cytokinin, ABA, each can have positive influences flower induction.

1.10 Pruning and Training

The research is variable depending on cultivar but summer pruning when applied to vigorously growing apple trees can favor flower bud formation. Not all studies conducted found increased yields, but many found increased light penetration that had a positive overall effect on fruit quality (Schupp, 1992). Summer pruning of the current season's apple shoots can cause short spurs growth of which flowers are initiated in the summer of the same year (Sadeghi, 2014). Although fruit color may be improved by summer pruning, there can be reductions in canopy photosynthesis due to removal of healthy leaves. Several studies recorded that leaf photosynthesis and transpiration changed after summer pruning (Miller, 1982b; Myers and Ferree, 1983) . Sometimes summer pruning does not have a positive influence on the initiation of flower buds. Heavy summer pruning can reduce the total number of flower buds per tree for the following year. Koutinas et al. (2010) suggests that the variation seen in pruning studies may be due to differences in pruning date, method of pruning and its severity.

Verner (1955) showed that pruning could alter a shoots normal growth pattern by altering its hormone balance. His work indicated that auxin (IAA) produced in the growing tips and leaves moves down the phloem to inhibit lateral bud growth and can influence the crotch angle between trunk and side branches. When IAA is produced by a strong terminal branch, and moves down the trunk to the base of a new side branch beneath, it results in a wide crotch angle, and limits growth of that branch by reducing synthesis and movement of the branches own IAA, resulting in a more spread tree.

Over a 10 year period Ferree (1993) mechanically pruned 'Lawspur', 'Empire','Smoothee', and 'Redchief' trees in August and reported that yield and yield per TCSA were reduced by hedging and root pruning, with the greatest reduction in yield caused by root pruning. Hedging increased cumulative yield per hectare with root-pruned trees intermediate between hedged standard-spaced trees.

Crop load management was developed to enhance fruit quality, mainly size, and to ensure consistent and profitable yields. Crop load recommendations for "Honeycrisp" in WA and Nova Scotia are maintained around 5 or 6 fruits/cm^2 of TCSA , and sometimes even 8 fruits/cm^2 of TCSA could be feasible for consistent commercial yields (Anthony et al., 2019; Robinson et al., 2010).

removal, can effectively inhibit apple flower formation. (Huet, 1972; Li et al., 1995).

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CHAPTER 2: EFFECT OF SUMMER HEDGING ON RETURN BLOOM, YIELD, TREE GROWTH, AND JUICE QUAILITY OF APPLES GROWN FOR HARD CIDER

2.1. Abstract

As growers have started planting specialty cider apples grown specifically for the production of fermented cider, new information is needed to understand how to maintain adequate annual crop yields and improve return bloom. Cider cultivars of European origin have been found to respond poorly to traditional crop load management methods using plant growth regulators and traditional return bloom sprays. In this study, tall spindle-trained cider apple cultivars 'Somerset Redstreak' and 'Harry Masters Jersey' and traditional dessert apple cultivars 'McIntosh' and 'Empire' were mechanically hedged in summer 2019 and 2020 to evaluate response on return bloom, yield, tree growth, and juice quality. Treatments consisted of 1) normal winter dormant pruning; 2) mechanical winter dormant pruning with a hedger; 3) mechanical pruning at pink (pre-bloom) bud stage with hedger, and; 4) mechanical pruning at 12-14 leaf stage, in mid-June. In 2020, dormant hand pruned 'McIntosh' had more flower clusters compared to mechanically pruned treatments. 'Harry Master Jersey' essentially did not flower in 2020, and then flowered in 2021 showing a biennial pattern with no differences among treatment groups. There was a noteworthy difference in canopy size for all cultivars the first season, with most hedging treatments being reduced nearly by half. Juice quality was unaffected by hedging treatment for soluble solid content, pH, titratable acidity, and total phenolics. Continued evaluation is needed to understand the long terms effects hedging has on return bloom.

2.2. Introduction

Biennial or alternate bearing can be a serious problem for cider apple growers. Alternate bearing refers to a large crop one year (the "on" year), followed by a small or no crop the following ("off") year (Moulton, 2010). In apples (*Malus × domestica*), the exact mechanism that leads to biennial bearing is unknown, but it is linked to the flower development cycle. A complex of factors including hormones, nutrients, and carbohydrates contribute to the biennial cycle. Gibberellins are plant hormones produced by the seeds in developing fruit that have been shown to inhibit flower production (Chan, 1967). The critical mineral elements nutrients nitrogen, phosphorus and boron are necessary for adequate flower induction (Grochowska, 1973); Wünsche and Ferguson, 2005). A heavy crop load in the on-year of biennial bearing apple trees depletes the tree's carbohydrate reserves, a lack of sufficient carbohydrates the following year leads to reduced flower formation in the off year. (Grochowska, 1973). Competitive growth processes may also inhibit flower bud formation (Koutinas et al., 2010). Crop load management through flower and fruitlet thinning are common practices and have been found beneficial on flower bud formation and return bloom in 'Honey crisp' and 'York' trees (Peck et al., 2016; Robinson et al., 2010). Growers have relied primarily on chemical thinning to adjust crop load but certain cultivars, like European-origin cider apples, do not respond effectively to chemical thinning to manage biennial cropping habit (Merwin, 2008) .

An alternative crop load management strategy is pruning. Pruning refers to the annual removal of old and/or damaged parts of trees, especially unproductive shoots and branches. Proper dormant and summer pruning can improve light penetration, airflow, and stimulate flower bud production (Lakso and Corelli Grappadelli, 1992). Hand pruning is a labor-intensive activity, and producers of cider fruit destined for processing are interested in reducing costs and labor with the use of mechanized pruning. Previous studies suggest that hedging may benefit 'McIntosh' and 'Empire' by increasing canopy volume and fruit color (Ferree and Rhodus, 1993; Schupp, 1992). Prior studies in Washington State (U.S.A.) recommend mechanical hedging during tree dormancy and the 12th leaf stage to initiate terminal bud set, and to expose fruit and potentially fruitful wood to sunlight (Lewis, 2018). Results varied across the five cultivars tested, but a decrease in return bloom was not recorded

Currently, little is published addressing how to manage cider apples or their potential for biennial bearing. Further cultivar-specific research is needed to understand the biennial tendencies of cultivars like “Somerset Redstreak” and “Harry Masters Jersey”. This project aims to provide apple growers and cider producers with a better understanding of how different crop load and canopy management strategies influence the return bloom and juice quality of four apple cultivars at harvest.

2.3 Materials and Methods

2.3.1. Field Methods

Three mechanical hedging timings were compared for their effects on return bloom in cider and dessert cultivars trained to tall spindle. Treatments consisted of 1) normal winter dormant pruning with hand tools as a control; 2) mechanical winter dormant pruning with a hedger; 3) mechanical pruning at pink (prebloom) bud stage with hedger, and; 4) mechanical pruning at 12-14 leaf stage, in mid-June. (Lewis, 2018). Treatments were applied in a randomized complete block design, with six singletree replications per treatment.

Replicated field trials were completed at two orchards in Chittenden and Addison County, Vermont. The first site located in South Burlington, VT productive eight year old, ‘Empire’ and ‘McIntosh’ trees grafted onto 'Budagovsky 9’ (BUD 9) rootstock spaced at 0.9m · 4.5m apart in Windsor Adams loamy sand with supplemental irrigation were selected for the trial. The second location, a commercial orchard in Cornwall, VT with cider cultivars ‘Somerset Redstreak’ and ‘Harry Masters Jersey’ grafted on NIC29 ® rootstock established in 2016 were planted at 0.9m · 4 m spacing in Vergennes clay 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.

Hedging was performed using a mechanical hedge trimmer (STHL model KM 56 RC-E with HL-KM attachment, STIHL Inc. Virginia Beach, VA). Trees were trimmed to a fruiting wall measuring 0.3 meter across the row using a measured guide attached to the trimmer, pruning all limbs all to an equal length from the top to the bottom of each tree. Hedging performed during the growing season was completed when no rain was forecast for two days following the procedure to limit potential for fire blight infection.

‘Somerset Redstreak’ was recorded at full bloom on May 21 in 2019 and 2020. 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 and 29 May 2020. Harvested 25 Sept 2020, 2019 harvest date unrecorded. ‘McIntosh’ came into full bloom 23 May 2019 and 21 May 2020, were harvested on 19 Sept 2019, and 24 Sept 2020. ‘Empire’ full bloom was 24 May 2019, 21 May 2020 and harvest was on 26 Sept 2019, and 28 Sept 2020.

2.3.2. Data Collection

Three mechanical hedging timings were compared for their effects on return bloom in cider and dessert cultivars trained to tall spindle. Treatments consisted of 1) normal winter dormant pruning with hand tools as a control; 2) mechanical winter dormant pruning with a hedger; 3) mechanical pruning at pink (pre-bloom) bud stage with hedger, and 4) mechanical pruning at 12-14 leaf stage, in mid-June. (Lewis, 2018). Treatments were applied in a randomized complete block design, with six single-tree replications per treatment.

Replicated field trials were completed at two orchards in Chittenden and Addison County, Vermont. At the first site located in South Burlington, VT, (SBVT) twenty-four 'Empire' and 'McIntosh' trees were selected for the trial. Established in 2011, trees were grafted onto 'Budagovsky 9' (BUD 9) rootstock, spaced at 0.9m · 4.5m apart in Windsor Adams loamy sand soil with supplemental irrigation. The second location was a commercial orchard in Cornwall, VT (CWVT). Cider cultivars 'Somerset Redstreak' and 'Harry Masters Jersey' grafted on NIC29 ® rootstock established in 2016 were planted at 0.9m · 4 m spacing in Nellis 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.

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'Somerset Redstreak' was recorded at full bloom on May 21 in 2019 and 2020. 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 and 29 May 2020. Fruit were harvested 30 Sept 2019, and 25 Sept 2020. 'McIntosh' came into full bloom 23 May 2019 and 21 May 2020, were harvested on 19 Sept 2019, and 24 Sept 2020. 'Empire' full bloom was 24 May 2019, 21 May 2020 and harvest was on 26 Sept 2019, and 28 Sept 2020.

2.3.3. Data Analysis

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

2.4. Results and Discussion

Hedging treatments applied in 2019 were expected to affect the following season's flowering. In 2020, the dormant hand pruned treatment on 'McIntosh' had an average return bloom of 238 flower clusters per tree, 83% of the prior year's total. Hedging treatments on 'McIntosh' in 2019 had a 47-54% reduction in the number of returning flower clusters from the prior year. This could be because there was less canopy volume and foliage to support flower development. There were no differences in bloom attributable to hedging treatment in 2021. In 2019 a trend toward reduced yield per tree and yield efficiency (yield per TCA) from hedging was observed for almost all cultivars, the exception being ‘McIntosh’. Dormant hand pruned ‘McIntosh’ had an average 6 kg yield increase over any hedging treatment in 2020. ‘Empire’ hedged at pink bud stage had higher crop yield than dormant hand pruned trees in 2020. After the second year of hedging ‘Somerset Redstreak’ showed an increase in cumulative yield for all hedging times. The cropping of ‘Somerset Redstreak’ in 2020 shows the potential for annual bearing tendencies for that cultivar. Previous studies on hedging ‘Empire’ suggests that hedging increases cumulative yield over a ten-year period (Ferree and Rhodus, 1993). Two years of data presented here are currently unable to fully support that statement, but hedging appears to be a promising management tool for both ‘Empire’ and ‘Somerset Redstreak’. ‘Harry Master Jersey’ exhibited biennial tendencies with very few trees flowering in 2020. This confirms the tendency for ‘Harry Master Jersey’ to be biennial and that following one-year of hedging, return bloom was not stimulated. More data are necessary to confirm this trend.

Hedging in 2019 narrowed the spread of the trees, reducing the canopy volume for each cultivar (Table 2). Hand-pruned trees were nearly twice the size of trees pruned mid-June. Hand pruned trees remained larger in 2020, but ‘McIntosh’ and ‘Somerset Redstreak’ did not show a difference among treatments. Summer hedging at pink stimulated shoot growth for ‘Somerset Redstreak’ and ‘McIntosh’ leading to a wider and denser canopy. No TCSA differences were observed in 2019 or in 2020 between trees hand pruned or hedged, across all four-cultivars surveyed.

There were no differences in juice quality for soluble solids, pH, titratable acidity, or total phenolic among treatments. Juice chemistry (Table 3) was within a normal range for all cultivars (Alexander et al., 2018; Bradshaw et al., 2018). This shows that canopy management done throughout the year and altering tree structure via hedging does not negatively affect juice quality. These results provide apple growers and hard cider producers with a better understanding of how different crop load and canopy management strategies influence juice quality at harvest. Fruit quality parameters (Table 4) for red color, firmness, and starch index rating remained unaffected by treatment. Although summer hedging opened up the canopy to allow potentially more light penetration into the tree, there were no increases in fruit color observed on hedged trees. There were no differences in fruit firmness and starch indexes at α error of 0.05. This did not agree with previous work which showed increases in fruit color, softer fruit, and higher starch indices on summer pruned 'McIntosh' trees (Schupp, 1992).

Hedging during the summer caused tissue damage to tree limbs and shoots, leaving a splintered 'broomstick' effect on the end of trimmed branches. Pruning trees mid-season can carry an increased risk of fire blight infection. Fire blight caused by the bacterium *Erwinia amylovora* is a destructive disease that causes dieback of blossoms, shoots, limbs and under ideal conditions can kill the tree. Hedging at pink and mid-June causes wounds that fire blight bacterium can enter. Infected trees can develop lesions that ooze orange bacterium filled liquid that is easily spread in moist, warm weather, by splashing rain, dew, wind and insects. The use of hedging equipment can also spread disease if not properly sanitized. Damaged branches that have dead tissue also have the potential to host a range of fungal diseases, such as black rot (*Botryosphaeria obtusa*) that can infect fruit and form cankers. Disease management for ‘McIntosh’ and ‘Empire’ is well understood, but the fire blight and disease susceptibility of ‘Harry Master Jersey’ and “Somerset Redstreak’ grown in the northeastern U.S.A. is less well-established. No fire blight damage was seen in this study, likely in part due to proper sanitation and timing hedging treatments around weather conditions. Growers would benefit from a robust disease assessment on damage caused by hedging and the incidence of disease.

Results of this study suggest that summer canopy management does not alter apple juice quality. ‘Harry Masters Jersey’ showed a tendency for biennial bearing, and summer hedging was unable to stimulate return bloom. ‘Empire’ and ‘Somerset Redstreak’ may both benefit from hedging showing signs of increased yields and annual bearing. Future studies should continue to record flowering and yield of ‘Somerset Redstreak’ and ‘Harry Masters Jersey’ to establish a biennial bearing index. Based on the two years of data presented, ‘McIntosh’ trained to tall spindle may not be suitable for hedging due to decreased yields and flower return. Both cider cultivars would benefit from a specific crop load management study that hand thins trees to specific fruiting densities based on TCSA. More research-based information is needed to understand the flowering and cropping of specialty cultivars to inform growers on how to maintain consistent annual production.

Table 1: Effects of three hedging times on bloom and crop yield of 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Sampled from 2019 & 2020.

Cultivar/ Location	Treatment [a]	No. of flower clusters tree $^{-1}$			Yield per tree (kg)		Yield efficiency (kg fruit/ TCSA)		Pre-harvest Drop (%)	
		2019	2020	2021	2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	289	238 A	217	13.99	18.58	0.99	1.25 A	2.6	4.1 AB
	D-HG	284	135 B	272	17.29	13.48	1.20	0.86 AB	1.5	8.9 A
	P-HG	262	133 B	281	12.45	12.53	0.84	0.86 AB	1.4	4.7 AB
	J-HG	339	183 AB	251	10.24	12.58	0.67	0.77 B	1.2	3.6 B
p-value[b]		0.219	0.003	0.592	0.058	0.045	0.009	0.030	0.476	0.030
'Empire' SBVT	D-HP	160	131	211	8.09	6.51	0.74 A	0.53	0.6	4.1
	D-HG	159	122	217	6.57	6.11	0.56 AB	0.47	1.0	4.5
	P-HG	164	137	198	6.91	7.96	0.58 AB	0.60	1.3	1.4
	J-HG	141	98	179	5.74	6.01	0.53 B	0.51	0.4	2.3
p-value		0.770	0.238	0.678	0.286	0.670	0.034	0.721	0.660	0.561
'Somerset Redstreak' CWVT	D-HP	112	33	195	4.72	2.75	0.43	0.23	37.8	24.4
	D-HG	75	70	116	3.94	4.38	0.34	0.39	24.0	9.4
	P-HG	50	28	214	3.12	3.97	0.28	0.32	23.5	12.7
	J-HG	59	55	159	2.74	3.09	0.24	0.28	36.2	14.1
p-value		0.534	0.670	0.711	0.718	0.934	0.687	0.932	0.702	0.574
'Harry Masters Jersey' CWVT	D-HP	100	0	200	-	-	-	-	-	-
	D-HG	94	0	200	-	-	-	-	-	-
	P-HG	80	5	162	-	-	-	-	-	-
	J-HG	98	12	189	-	-	-	-	-	-
p-value		0.770	0.534	0.810	-	-	-	-	-	-

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging
[b]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 2: Effects of three hedging timings on tree growth parameters of 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Autumn 2019 & 2020

Cultivar/ Location	Treatment [a]	TCSA (cm^2)		Canopy area (m^2)		Terminal branch length (cm)	
		2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	15.8	17.7	9.1 AB	12.7	29.1	22.8 B
	D-HG	16.5	19.8	11.0 A	10.3	23.6	20.0 B
	P-HG	17.4	19.8	5.1 B	8.5	23.8	38.5 A
	J-HG	18.5	22.1	5.7 B	8.2	25.8	20.9 B
p-value		0.714	0.683	0.003	0.230	0.708	0.005
'Empire' SBVT	D-HP	9.4	11.7	4.2	4.9 a	15.8	16.8
	D-HG	10.5	13.2	4.2	3.6 ab	18.4	26.0
	P-HG	11.0	13.8	2.6	3.6 ab	18.1	22.5
	J-HG	9.0	11.1	1.8	2.7 b	20.2	24.4
p-value		0.627	0.520	0.031	0.038	0.797	0.212
'Somerset Redstreak' CWVT	D-HP	9.8	11.8	9.1	10.7	17.4 b	36.7
	D-HG	10.1	12.1	8.7	9.1	18.7 b	27.5
	P-HG	10.5	13.6	5.9	8.9	29.5 a	35.8
	J-HG	9.3	11.9	4.4	7.3	22.7 ab	32.5
p-value		0.772	0.613	0.038	0.393	0.016	0.848
'Harry Masters Jersey' CWVT	D-HP	12.8	16.5	6.2 A	7.7 A	15.5	27.5
	D-HG	13.3	17.5	4.6 AB	4.9 B	17.8	21.5
	P-HG	12.5	15.3	3.2 B	5.0 B	18.8	29.2
	J-HG	14.9	19.0	3.3 B	4.5 B	16.3	27.6
p-value		0.280	0.145	0.0007	0.001	0.282	0.177

[a] D-HP =dormant hand pruning, D-HG= dormant hedging, P-HG= pink hedging, J-HG= June hedging

[b]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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Table 3: Juice quality at harvest for 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Sampled autumn 2019 & 2020

Cultivar /Location	Treatment[a]	SSC (°Brix)		pH		Titratable acidity (g malic L^{-1})		Total polyphenols (mg L^{-1})	
		2019	2020	2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	11.7	11.0	3.27	3.11	-	8.85	-	-
	D-HG	10.8	11.6	3.30	3.09	-	10.26	-	-
	P-HG	11.3	11.0	3.27	3.14	-	9.34	-	-
	J-HG	12.0	11.2	3.28	3.12	-	9.76	-	-
p-value		0.420	0.164	0.784	0.608	-	0.171	-	-
'Empire' SBVT	D-HP	12.3	12.6	3.35	3.22	-	8.88	-	-
	D-HG	13.1	12.7	3.31	3.22	-	8.68	-	-
	P-HG	12.8	12.5	3.32	3.24	-	8.32	-	-
	J-HG	12.7	12.8	3.34	3.22	-	8.57	-	-
p-value		0.588	0.654	0.284	0.948	-	0.481	-	-
'Somerset Redstreak' CWVT	D-HP	10.6	11.2	4.15	3.84	1.55	1.85	2719	2410
	D-HG	12.2	11.6	4.15	3.94	2.10	2.01	3061	2305
	P-HG	11.3	12.1	4.06	4.05	1.68	2.59	2205	3135
	J-HG	11.2	12.2	4.14	3.99	1.70	2.10	2556	3169
p-value		0.462	0.834	0.802	0.517	0.395	0.531	0.440	0.370

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging

[b]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 4: Fruit quality at harvest for 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Sampled autumn 2019 & 2020

Cultivar /Location	Treatment [a]	Red Color (%)		Flesh firmness (kg cm^{-2})		Starch pattern index	
		2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	85	82	7.9	7.5	5.4	5.5
	D-HG	85	78	7.7	7.3	6.0	4.8
	P-HG	92	70	7.8	7.3	5.7	5.2
	J-HG	95	80	8.0	7.2	5.1	5.2
p-value		0.1660	0.1014	0.7565	0.6717	0.0965	0.2624
'Empire' SBVT	D-HP	92	93	9.0	8.6	3.4	4.2
	D-HG	96	93	9.2	8.4	2.9	4.6
	P-HG	94	91	9.1	8.3	3.3	4.8
	J-HG	91	89	9.2	8.4	2.9	4.9
p-value		0.0921	0.2744	0.9515	0.7204	0.3115	0.0661
'Somerset Redstreak' CWVT	D-HP	73	58	7.6	8.8	4.1	3.7
	D-HG	64	57	7.8	8.2	4.2	4.4
	P-HG	75	50	7.7	8.7	3.5	5.1
	J-HG	75	58	7.5	8.5	4.3	5.1
p-value		0.6401	0.9427	0.5281	0.9714	0.7357	0.6351

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging

[b]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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CHAPTER 3: SUMMER APPLICATIONS OF NAA AND ETHEPHON ON RETURN BLOOM, YIELD, TREE GROWTH, AND JUICE QUAILITY OF CIDER APPLE CULTIVARS

3.1. Abstract

For commonly grown dessert cultivars chemical thinning or the removal of some fruit each season helps maintain fruit size, quality, and annual bearing characteristics. Chemical thinning is 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 in two apple (*Malus ·domestica*) orchards in Vermont, U.S.A with the primary objective 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. Although there were no differences among treatment groups 'Harry Masters Jersey' and 'Kingston Black' both demonstrated biennial tendencies producing few flowers and fruit in 2020, with a full return bloom in 2021. 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 have a consistent effect on 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 a lower titratable acidity. ‘Kingston Black’ juice was unaffected by PGR applications.

3.2. Introduction

Hard cider, made by fermenting apple (*Malus x domestica*) juice, was at one time the most popular alcoholic beverage in North America (Miles et al., 2020). Largely abandoned after the temperance movement and Prohibition, fermented cider has only recently been rediscovered as an alternative to wine and beer (Ferree and Warrington, 2003). In recent years, US cider production has increased at an average rate of over 50% annually, with total revenue over $ 2.2 billion in 2018 (Becot et al., 2016; Miles et al., 2020). Cider producers seek juice with high sugar, high acid, and phenolics that enhance ‘‘mouth feel’’ to make unique, high-quality cider (Moulton, 2010). Currently, finding specialty cider apples is a significant challenge for U.S. cider producers. The demand for specialty cider apples has brought increased 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 to plant 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 precipitation. A maritime climate is dissimilar to the continental climate of most major fruit productions regions of North American, which have lower winter temperatures and summer rainfall (Merwin, 2008). Currently, little research has been conducted to assess how specific cider apple cultivars grow in North America. 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 northeaster US application of carbaryl with or without other plant growth regulators (PGRs) at petal fall (post-bloom) and soon thereafter are traditionally used for fruit thinning dessert cultivars. A successful chemical thinning program will normally result in increased fruit size and consistent 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 a five to six weeks after bloom. (Duyvelshoff and Cline, 2013; McArtney et al., 2013; McArtney et al., 2007).)

NAA has been reported to stimulated flower bud formation independently of crop load (Harley et al.) and post-bloom applications of ethephon have been shown to increased return bloom in 'Wellspur Delicious' apple trees without reducing fruit set (Harley et al., 1958; Williams, 1972). Ethrel (Bayer CropScience; Calgary, AB, Canada) 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 of Ethrel per hectare 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 is also 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 are in need of 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.

3.3 Materials and Methods

3.3.1. Field 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 4L at 2.3 L ha-1 (Drexel Chemical Company, Memphis, TN); NAA at 147.0 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 tree were expected to crop heavily. 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. See table one for more detail.

Replicated field trials were performed at two orchards in the Champlain Valley of Vermont. In South Burlington, VT, thirty 'Kingston Black' trees grafted onto G.41 rootstocks were selected for the study. Planted in 2016, trees were tall spindle trained and spaced at 0.9m · 4.5m (2,390 trees/ ha) 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 NIC29 ® rootstock were assessed. Established in 2016, trees were planted at 0.9m · 4.5 m (2,390 trees/ha) spacing in Vergennes clay 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 PGRs were applied by the grower during the study.

Treatments were applied by project personnel using an electric backpack sprayer (Solo 4.5 gal. Li-ion battery backpack sprayer, SOLO Inc, Newport News, VA).a 2011). Plant growth regulators were applied to entire trees as dilute sprays to the point of runoff using 2L/tree. Each treatment chemical had its own spray tank to eliminate chemical cross contamination. No surfactants or additives were incorporated in 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 May 21 in 2019 and 2020. 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 and 29 May 2020. Fruit were harvested 30 Sept 2019, and 25 Sept 2020. 'Kingston Black' came into full bloom 26 May 2019 and 23 May 2020, harvested on 10 Oct 2019, and 5 Oct 2020.

3.3.2. 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 number of fruit per tree 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 a 11-mm probe penetrometer (Wagner, Greenwich, CT) and ripeness assigned using the starch iodine 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.

3.3.3. Data Analysis

Data were subject to analysis of variance (ANOVA) procedures by PGR 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.

3.4. 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 measurements of fruit and juice quality because of smaller aggregate samples used for calculation of 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. No effects were found for both ‘Kingston Black’ and ‘Somerset Redstreak’ but for both cultivars, the carbaryl only treatments maintained a higher crop load than the non- treated control. This indicates that carbaryl alone maybe 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/cm2 of TCSA, while other studies suggest up to 6 to 8 fruits/cm2 of TCSA (Robinson et al., 2010) (Anthony et al., 2019). Despite having a large crop load 11 fruits/cm2 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 the to the reduction in fruit weight in 2019. Crop load for Kingston Black ranged between 4-7 fruit fruits/cm2 of TCSA in 2019, falling within the suggested crop load for biennial cultivars, but very few tree bloomed in 2020. This may suggest that

‘Kingston Black’ requires a lighter crop load than dessert cultivars in order to flower annually. A specific study to evaluate the optimal crop load density for ‘Kingston Black’ is warrantied. Hand thinning to ensure crop loads of to 2, 4, 6, and 8 fruits/cm2 of trunk cross-sectional area (TCSA) could lead to determining an optimal crop load on ‘Kingston Black’.

There was little effect on fruit drops attributable to the treatments. Although on both cultivars ethephon alone and in combination with carbaryl exhibited 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 the 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 is may be partly due to harvesting fruit at a lower starch index, or before they are 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 with the use of 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 have a consistent effect on 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 PGR applications. Due to All juice quality values fell within expect ranges for the cultivars.(Alexander et al., 2016; Bradshaw et al., 2018; Valois et al., 2006)

Table 5: Experimental treatments applied in 2019

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

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

Table 6: Total flower clusters counted annually on 'Somerset Redstreak', 'Kingston Black', and 'Harry Masters Jersey'. Collected in 2019, 2020, 2021

	Number of flower clusters per tree								
Cultivar: Location	SSR: CWVT			KB : SBVT			HMJ: CWVT		
Treatment [a]	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	0.287	0.454	0.261	0.897	0.727	0.971	0.838	0.554	0.392

[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.

Table 7: Crop yield for 'Somerset Redstreak' and 'Kingston Black' in Vermont. Sampled autumn 2019 & 2020.

Cultivar: Location	Treatment [a]	TCSA[b] (cm^2)		Crop load (n fruit/ TCSA)		Efficiency (kg fruit/ TCSA)		Fruit drop % (kg kg-1)	
		2019	2020	2019	2020	2019	2020	2019	2020
SSR CWVT	NTC	13.6	15.8	7	8	0.38	0.42	0.56	0.08
	Carb	11.0	14.9	8	5	0.43	0.28	0.47	0.13
	NAA	9.7	12.1	11	8	0.32	0.42	0.63	0.15
	ETH	11.3	13.5	4	8	0.09	0.42	0.79	0.12
	NAA+Carb	12.3	15.7	7	3	0.45	0.14	0.36	0.16
	ETH+Carb	11.4	14.3	6	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
KB SBVT	NTC	10.1	15.0	5	0.0	0.06 AB	0.00	0.85	-
	Carb	9.3	12.4	7	0.1	0.06AB	0.01	0.80	0.38
	NAA	11.2	15.7	4	0.2	0.11AB	0.02	0.66	0.17
	ETH	11.3	15.3	4	0.1	0.05AB	0.01	0.84	0.50
	NAA+Carb	11.9	16.2	6	0.4	0.14A	0.04	0.69	0.32
	ETH+Carb	9.6	11.5	5	0.05	0.04B	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 $\alpha=0.05$ using Tukey's adjustment.

Table 8: Fruit quality at harvest for 'Somerset Redstreak' and 'Kingston Black' in Vermont. Sampled autumn 2019 & 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= ethphon, 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 9: Juice quality at harvest for 'Somerset Redstreak' and 'Kingston Black' in Vermont. Sampled autumn 2019 & 2020.[a]

Cultivar & 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**
SSR CWVT	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
	NAA	8.8	10.7	4.06 b	3.89	1.88	1.96	2588.9	2711.3
	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
KB SBVT	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
	NAA	12.2	14.3	3.55	3.46	5.74	6.94	1578.6	876.0
	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 $\alpha=0.05$ using Tukey’s adjustment.

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