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ORIGINAL ARTICLE

Crop Load Management with Blossom Thinners in 'Redchief' Apple and Their Effects on Fruit Mineral Composition

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Abstract

The aim of this study was to determine the effect of ammonium thiosulphate (ATS) and potassium thiosulphate (KTS) on crop load, fruit quality and fruit mineral content of the eight-year-old 'Redchief'/M26 apple. Seven different treatments were performed in the study as ATS (1%, 2%, 3%), KTS (1%, 2%, 3%) and hand thinning (after June drop) except for unthinned control. Thinning treatments were carried out as single application in full bloom period. Hand thinning and 3% ATS treatments were the best practices to increase fruit quality (diameter, weight). The fruit set ratio among the applications varied between 13.20% (2% ATS) and 23.46% (1% ATS). Yield was lowest in 2% and 3% ATS. Thinning with ATS was found more effective compared to KTS. The lowest Fe, Cu and Zn elements were determined in 2% ATS application, and the difference between the applications in terms of other elements was found to be insignificant. Phytotoxic effect was not observed for any ATS or KTS doses. As a result, flower thinners can be used as an alternative to hand thinning to improve fruit quality in 'Redchief' variety.

Keywords Ammonium thiosulphate · Fruit size · Yield · *Malus x domestica* · Thinning

Fruchtbehangsregulierung durch Blütenausdünnung in Apfelanlagen der Sorte 'Redchief' und ihre Auswirkungen auf die Mineralstoffzusammensetzung in der Frucht

Schlüsselwörter Ammoniumthiosulfat · Fruchtgröße · Ertrag · *Malus x domestica* · Ausdünnung

Introduction

Fruit quality is defined as a combination of visual and sensory characteristics. It emerges as a consequence of interrelationships among genetic structure, environmental factors and growing practices such as pruning, shading and crop load management (Bound 2005).

In general, fruit trees tend to much more set fruit in optimum conditions than necessary. These fruits grow shortly after fertilization with an increase by cell division and compete with each other for the intake of nutrients in this period (Webster and Spencer 2000). Consumption of the photosynthesis products produced by leaves and the minerals from the soil for fruit development cause the decrease of the storage products required for winter period. The amount of nutrients used by each fruit also decreases with increase in the number of fruits, so fruits do not reach the desired largeness (Webster and Spencer 2000; Wertheim 2000). Lower competition in domestic and international markets due to low fruit quality cause a huge loss on production potential. Another effect of the crop load is on the preharvest fruit drop. Some apple varieties such as 'Redchief' and 'Scarlet' spur have short fruit stem and, depending on the crop load, preharvest fruit drop can occur and cause a significant reduction in marketable fruit production. Thinning applications can also affect the mineral content of fruit (Bregoli et al. 2007). Some of the physiological disorders caused by lack of calcium such as bitter bit are more common in trees with low crop load than optimum crop load. Hand fruit thinning, one of the applications in crop load management, is not economical for industrial countries because it increases labor costs and is a time-consuming practice (Bangerth and

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Quinlan 2000). Some growth regulators and caustic materials seen as an alternative to hand thinning have been tested for years in different fruit species, especially in countries with high labor costs and large operating scales.

Chemical thinners can be used in different phenological stages (bud, flower or small fruit). The mechanisms of flower and fruit thinners are different from each other. The thinners applied during the fruit period are mostly hormone-like substances, which stimulate the ethylene synthesis and cause the small fruit drop. Flower thinners, on the other hand, cause damages to flower organs due to their caustic effects, thereby prevent pollination or fertilization and reduce fruit set (Kaçal and Koyuncu 2012; Fallahi and Willemsen 2002). Ammonium thiosulphate (ATS) and potassium thiosulphate (KTS) used for flower thinning instead of chemical agents applied after flowering have high usage potential in organic fruit growing due to their have no negative effect on environment and human health. At the same time, the effects of caustic thinners vary with temperature, and thinning effects can be predicted especially in cold areas on flowering time (Bound 2005).

The effects of thinners may vary depending on weather conditions in the application period, chemical type, dose and variety. Therefore, their efficiency should be tested for each region and cultivar. The objective of this study was to evaluate the efficiency of ATS and KTS as blossom thinners on fruit quality, yield and mineral composition of fruit of 'Redchief' on M26 rootstock.

Materials and Methods

This study was carried out at Eğirdir Fruit Research Institute. Experiment area is located on between Eğirdir and Kovada lakes named Boğazova valley. The region has a transitional climate between the Mediterranean and continental climate. Eight-year-old 'Redchief'/M26 apple trees were used that planted in 2007 spaced 3.5 m × 1 m in north-south rows at Fruit Research Institute's Serpil orchard. 'Granny Smith' apple cv. were used as pollinator. The soil was loamy-clay of experimental area. It contains 10% lime and 2.8% organic matter, the soil pH is 7.9. Trees were irrigated by drip irrigation at three days intervals. During the trial, orchard management practices (irrigation, fertilization, plant protection and pruning) was carried out regularly.

Thinning Treatments

This study consists of eight different applications including, ATS (1%, 2% and 3%), KTS (1%, 2% and 3%), hand fruit thinning and control (unthinned). Experimental trees were selected within healthy and uniform trees (similar vigor and size). ATS and KTS treatments were applied at the full bloom period (when 70–80% of the blossoms were open) on the all parts of the trees as a single application. No surfactant was used. Water were sprayed to the control trees. Hand fruit thinning was done in the grower level on each tree by one fruit for each flower cluster.

Fruit Quality, Yield and Mineral Composition

Physical [fruit width (mm), fruit length (mm), fruit weight (g), fruit flesh firmness (N) and fruit color (L * a * b *)] and chemical [titratable acidity (TA) (%) and soluble solids content (SSC) (%)] analyzes were carried out on fruit samples to determine the effects of thinning applications on fruit quality attributes. Twenty fruits for each tree were used for fruit analyses. Mineral content of the fruits were also examining for determine thinning effects on it. Analyzes of P, N, K, Ca, Mg, Fe, Cu, Mn, Zn and B were done on the fruits.

All flower clusters were counted to determine fruit set ratio at pink bloom stage and the number of fruit per tree at harvest. Yield was recorded in each tree at harvest. During the winter period, the stem diameter was measured at a height of 15 cm from the graft union and the trunk cross-sectional area (TCSA) was calculated (πr^2). The fruit number per cm^2 was determined by dividing the number of fruit per tree to the trunk cross sectional area.

The trial was arranged as a randomized complete block design with three replicate and fifteen tree was selected for per treatment. The differences among applications were determined according to the "Duncan Multiple Comparison Test" in the SPSS software package program.

Results and Discussion

Flower thinners reduce the fruit competition in the early period after fertilization to allow for a higher number of cells and higher fruit quality. Although hand fruit thinning after June drop is a major crop load management practice for growers in traditional fruit growing, the demand for labor is very high and its effect on alternate bearing is low.

In our study, the effects of thinners were found to be statistically significant on fruit quality characteristics except for the fruit flesh firmness. The most effective application on important quality characteristics such as fruit width, height and weight was hand fruit thinning, and 3% ATS was close to hand fruit thinning (Table 1). While hand thinning has a positive effect on fruit weight and other quality properties, its effect is less on prevention of fluctuations in productivity (Koike et al. 1990). Other applications were in the same with control. Effects of the chemical thinning varies to the variety, rootstock, ecology, dose, tree health and phe-

Table 1 Effects of thinners on fruit quality characteristics

Treatments	Doses	Fruit diameter (mm)	Fruit lenght (mm)	Fruit weight (g)	Fruit flesh firmness (N)	SSC (%)	TA (%)
Control	–	74.44b*	66.00ab	167.0573b	78.7628 ns	11.58b	0.23ab
Hand thinning	–	78.30a	69.63a	196.03a	78.93	11.61b	0.25ab
ATS	1%	74.09b	67.10ab	167.89b	78.97	11.65b	0.23ab
	2%	75.09b	65.76ab	170.93b	80.62	12.83a	0.26a
	3%	76.75ab	67.99ab	180.79ab	78.40	11.45b	0.25ab
KTS	1%	74.28b	65.38b	163.03b	80.72	12.00ab	0.21b
	2%	74.54b	66.40ab	167.35b	79.14	11.50b	0.23ab
	3%	74.16b	66.84ab	169.26b	78.76	11.52b	0.23ab

*The difference between the averages indicated by different letters is significant ($p < 0.05$)
ns none significant

nological stage. Therefore it can be seen differences among results obtained our and other previous studies.

The effects of 3% ATS on fruit quality was better than other applications (Table 1). 2.5% ATS (Fallahi et al. 2004) in the 'Fuji' and 1.5% ATS (Webster and Spencer 2000) in the 'Queen Cox' and 'Royal Gala' varieties were determined as effective ATS doses.

A limited studies are available in literature on the use of potassium thiosulfate in crop load management studies. Bound and Wilson (2004) found that 1% and 1.5% potassium thiosulphate is sufficient to increase the fruit weight in 'Royal Gala', Milić et al. (2011) reported that KTS and ATS could be implemented in first steps of thinning programs. However, in our study, KTS doses did not cause a change on fruit quality and no significant difference was found among doses (Table 1). Higher doses of KTS can be try in 'Redchief' but we must be careful due to burning effects on flowers and leaves.

Depending on the crop load, changes in flesh firmness vary according to previous studies. Hand fruit thinning and 3% ATS treatments did not change the flesh firmness despite of increasing of weight (Table 1). Katuuramu (2012), Castro et al. (2015) and Yıldırım et al. (2016) support our findings that low, medium, and heavy crop load in the apple did not affect the flesh firmness in their experiments. Salvador et al. (2006) reported that flesh firmness was also high in the 'Golden Delicious' and 'Redchief' varieties they had high crop load. On the other hand, the increase in fruit flesh firmness on the light crop load was observed in the 'Jonagold' (Stopar et al. 2002) and 'Braeburn' (Mpelasoka 2001; Tough et al. 1998). Mpelasoka (2001) suggested that this may be due to the high cellular density of trees with excess crop load.

2% ATS increased SSC and titratable acidity compared to other applications (Table 1). In applications had higher yield than 2% ATS (Table 2), reductions in SSC may have been the result of reductions in soluble carbohydrates, increased competition for assimilate between plant organs due to increased crop load. SSC and titratable acidity are higher in trees with low crop load in 'Cox Orange Pippin', 'Cleopatra' (Martin 1954) and 'Braeburn' (Mpelasoka 2001) apples. Similar findings were found by Palmer et al. (1997), Sıham et al. (2005) and Neilsen et al. (2010). However, SSC has not changed depending on crop load in 'Liberty' (Katuuramu 2012) and 'Gala' (Radivojević et al. 2014) apples. Salvador et al. (2006), on the contrary to our findings, determined that SSC increased with crop load in 'Golden Delicious Cl. B' and 'Red Chief' apples. Bound

Table 2 Effects of applications on yield values

Treatments	Doses	Fruit set (%)	Yield (kg/tree)	Fruit/TCSA cm^2	Yield efficiency (kg/tree)/TCSA
Control	–	19.83ab*	19,806ab	1.82 ns	261.20
Hand thinning	–	16.36abc	22,155ab	1.58	276.95
ATS	1%	23.46a	24,602ab	1.36	262.50
	2%	13.20c	15,276b	1.47	200.84
	3%	15.55abc	15,919b	1.52	241.36
KTS	1%	16.23abc	17,883ab	1.93	206.31
	2%	20.20ab	24,049ab	1.85	240.82
	3%	19.13abc	27,008ab	1.76	264.86

*The difference between the averages indicated by different letters is significant ($p < 0.05$)
ns none significant

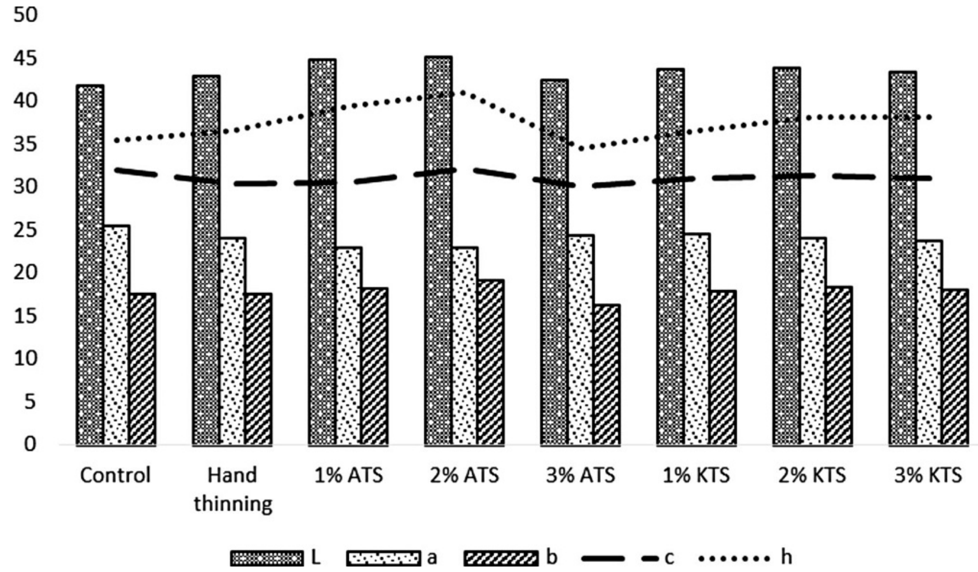

Fig. 1 Effects of thinners on fruit color (The difference between the treatments is insignificant ($p < 0.05$))

and Wilson (2007) reported that the SSC increases with increasing doses of ATS in 'Hi Early Delicious' apple.

Fruit thinning in red skin color fruits increases the intensity and area of redness (Link 2000). Although, Meland (2007) has stated that flower thinning by hand improved fruit color in the 'Elstar' apple variety, the effect of ATS and KTS on fruit color was insignificant. The same effect has been reported by Jemrić et al. (2005) and Yıldırım et al. (2016). Red color development is genetically controlled, but is also influenced by carbohydrate sources, light, temperature and nutrient factors (Jackson 2003). Medium sized trees, high temperature differences between day and night, and good horticultural practices may be shading of thinners effects on fruit color in this study (Fig. 1).

When fruit set is high, the number of fruits on the tree can affect the fruit quality at harvest. Studies indicate that there is a negative relationship among fruit number, fruit size and fruit weight (Treder 2008). The difference between thinners for yield efficiency and number of fruits to trunk cross sectional area are insignificant except for fruit set ratio and yield. The highest fruit set ratio was obtained from 1% ATS while 2% ATS was lower compared to all. The efficiencies of treatments were found to similar except for 2% and 3% ATS in the yield. While the dose increases in KTS, no yield reduction was determined (Table 2).

The number of fruits on the trunk cross-sectional area for marketable fruit is between 4 and 6 (Greene and Autio 1998). However, this number can vary depending on the variety and variety/rootstock combination. Robinson and Watkins (2003) found that fruit size, color, and taste decreased when the crop load of 'Honeycrisp' apples was higher than 10 fruits/cm^2, the amount of flowers and fruit quality in the next year is reduced in 7–8 fruits/cm^2 and were obtained at optimum fruit quality in 4–5 fruits/cm^2. Bound (2005) reported that fruit weight and size decreased when the number of fruits in the trunk cross-section area was more than 6 in 'Gala' and 'Pink Lady' varieties. In the 'Fuji', 2 fruits to the trunk cross sectional area were given the highest fruit weight. Raines (2000) obtained the optimum yield when the 2.5 fruits to the TCSA in 'Nittany'

Table 3 Effects of thinners on the fruit mineral composition

Treatments	*N*	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	0.53ns	0.08	0.85	0.05	0.05	16.96bc*	3.70de	1.13	2.96ab	15.66bc
Hand thinning	0.52	0.08	0.90	0.05	0.05	22.50abc	4.56abc	1.00	3.30ab	17.20abc
1% ATS	0.48	0.08	0.83	0.05	0.05	23.43abc	5.23a	1.23	3.43a	17.33abc
2%	0.43	0.08	0.89	0.05	0.04	12.40c	3.30e	1.15	1.90b	16.20abc
3%	0.44	0.07	0.86	0.04	0.04	26.10abc	4.90ab	1.10	3.00ab	18.70ab
1% KTS	0.43	0.07	0.90	0.05	0.04	33.13a	4.56abc	1.10	2.83ab	19.06a
2%	0.49	0.07	0.89	0.05	0.05	23.30abc	4.20bcd	1.06	3.30ab	16.70abc
3%	0.48	0.07	0.82	0.04	0.05	28.76ab	3.93cde	0.96	3.20ab	14.63c

*The difference between the averages indicated by different letters is significant ($p < 0.05$)
ns none significant

apples grafted on M9 and M26 rootstocks. In our study, the number of fruits to the TCSA varied between 1.36 and 1.93. Fruit/TCSA in hand thinning and 3% ATS were calculated as 1.5 (Table 2).

ATS and KTS are caustic chemicals originally used as fertilizer and they have similar modes of action as flower thinners. However, caustic effect of KTS was higher than ATS on ‘Redchief’ flowers, it didn’t show significant thinning effect compare to control and ATS doses. This effect may vary depending on the dose or environmental conditions.

Most of the caustic chemicals such as ATS can cause phytotoxicity on the some tree parts and russet on fruit (Greene 2002). Although the caustic effect of KTS on flowers was higher than ATS, no phytotoxic effect on leaves and branches was seen. However, Milić et al. (2011) observed that 3% ATS and 1.5% KTS in ’Braeburn’ variety had phytotoxic effects on leaves and flowers. These differences in the phytotoxic effects of the thinners are largely due to the temperature and humidity at the time of application (Janoudi and Flore 2005) and the overall physiological conditions of the tree.

The few data published about effects of thinning treatments on fruit mineral content. Thinning treatments did not effect on macro nutrients compare to unthinned trees. However, we observed different response on micro nutrients of treatments (Table 3). Volz et al. (1993) and Tough et al. (1998) found that there was no difference in the magnesium content of the fruit between light and standard crop loads at ’Cox Orange Pippin’ and ’Braeburn’ while calcium and potassium were significantly influenced by crop load. The amount of calcium in the standard crop load increased while potassium decreased. Similar findings were found by Elgar et al. (1999). Ferguson and Watkins (1992), however, have found that the amount of Ca decreased in the light crop load while the amount of potassium increased. Treatments did not affect the concentration of Mg. We haven’t seen any disorders on the fruits as bitter bit or water core depending on the mineral content of fruits.

Conclusion

The economic impact of chemical thinners for fruit growers is higher than hand fruit thinning. Our study results show that ATS can be used as an alternative to hand thinning in the ‘Redchief’ variety to improve fruit quality. 3% ATS, positively affects the fruit quality, and it can be recommended for the ‘Redchief’ variety. However, these results are for Eğirdir ecology and it would be beneficial to determine usage doses for other ecologies. But, it must be careful for in areas have the risk of late spring frost.

Conflict of interest E. Kaçal, G. Öztürk, İ. Gür, M. Aydınlı, H. Koçal, M. Altındal and A.N. Yıldırım declare that they have no competing interests.

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