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THE EFFECT OF NAPHTHENIC ACIDS (NAs) ON THE RESPONSE OF 'GOLDEN DELICIOUS' AND 'FUJI' APPLE TREES ON CHEMICAL THINNING WITH NAA

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Abstract. NAA (α-naphthylacetic acid) thins apple fruits inconsistently regarding fruit set and weight and may cause small or misshapen fruits occurrence. Considering hormonal activity, surfactant properties and the impact of naphthenic acids (NAs) on the metabolism of auxins in plant tissue, it is assumed that thinning response and fruit size could be improved by adding NAs to NAA for chemical thinning of apple. The purpose of the research was to evaluate thinning efficacy of the mixture of NAA and NAs in two commercially grown apple cultivars, 'Golden Delicious' and 'Fuji', known to respond differently to the application of NAA. The following treatments were applied during a three-year period, from 2010 to 2012: 10 mg·L^{-1} NAA, 10 mg·L^{-1} NAA + 1.56 mg·L^{-1} NAs, 20 mg·L^{-1} NAA, 20 mg·L^{-1} NAA + 3.12 mg·L^{-1} NAs and an untreated control. The addition of NAs to NAA did not alter the effectiveness of NAA in reducing fruit set, while it significantly increased fruit weight compared to NAA applied alone in two of three years of the experiment. NAs modulated the effect of NAA on fruit weight of apple cultivar 'Fuji' by retarding fruit growth and causing a higher number of small fruits to occur compared to NAA applied alone.

Key words: α-naphthylacetic acid, fruit set, yield, fruit weight, fruit quality

INTRODUCTION

NAA (α-naphthylacetic acid) and its amide, naphthalene acetamide (NAD) were the first synthetic auxin-type chemicals used for apple fruit thinning [Wertheim 2000].

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NAA is efficient within the range of concentrations from 5 to 20 ppm. Based on the results obtained from twelve apple cultivars, Robinson [2006] calculated the optimum rate of NAA was 8.5 mg·L^{-1} to reach the largest fruit size. Thinning intensity was also the highest at the intermediate rate of NAA. According to Stover et al. [2001] the effect of thinning with NAA on fruit size improvement is the result of reduced competition among fruits within a cluster. When applied on apple cultivar Delicious at fruitlet diameter greater than 9 mm, NAA can cause fruit growth cessation and the presence of fruits smaller than 45 mm in diameter in harvest, so-called 'pigmy' fruits [Marini 1996]. The occurrence of small fruits caused by NAA application was also recorded in 'Fuji' and Braeburn [Robinson 2006]. Black et al. [1995a] counted the highest number of small fruits caused by NAA application in Redchief at 11.3 mm king fruit diameter. Considering that by-leaf uptake of NAA increased at temperature range from 16 to 26°C, Black et al. [1995b] explained that the annual variation in the number of pigmy fruits was caused by the variations in the air temperature at the time of application. In addition to the occurrence of small fruits, the negative effects of the application of NAA may be the reduced number of seeds, the irregular shape of the fruit and leaf curling [Williams 1993].

Naphthenic acids (NAs) are the complex mixture of predominately alkyl-substituted cycloaliphatic carboxylic acids (containing cyclopentane and cyclohexane rings) and small amounts of acyclic acids. They are naturally occurring compounds of crude oils at concentrations up to 3%, depending on the source of the oil [Lochte and Littman 1955]. NAs are non-volatile, chemically stable, and act as surfactants [Clemente and Fedorak 2005] by changing plant cell membrane permeability [Pavlović et al. 2015]. At high concentrations (above 50 mg·L^{-1}), they are corrosive compounds, toxic to a variety of organisms, xenobiotics and water pollutants [Clemente and Fedorak 2005, Frank at al. 2008, Thomas et al. 2009]. However, at small concentrations (up to 3 mg·L^{-1}), naphthenic acids act as plant growth stimulators [Wort and Patel 1970, Wort et al. 1973] and rooting agents [Kevrešan et al. 2007]. When used at the rate of 10^{-7} mol·L^{-1} NAs exhibited an auxin type biological activity by causing wheat coleoptiles elongation of 20% [Ćirin-Novta et al. 2002] and a very high biological activity of gibberellin type by using the endosperm test (31.6% increase in concentration of reducing sugars) [Ćirin-Novta et al. 2004]. In addition to the exhibited hormonal activity, naphthenic acids at a concentration of 0.05% stimulate the uptake and translocation of auxins in plant tissue [Ansari et al. 1989], as well as IAA synthesis [Loh 1974]. NAs were used in apple as a growth enhancing component of complex foliar nutritive fluids ('Nutrinaft' products) [Chitu et al. 2010]. 'Nutrinaft' products stimulated the growth of shoots and fruits, increased the yield and the number of fruits harvested and demonstrated fungicidal activities [Cristea et al. 2008].

Considering hormonal activity, surfactant properties and the impact of NAs on the metabolism of auxins in plant tissue, it is assumed that thinning response and fruit size could be improved by adding NAs to NAA for chemical thinning of apple, without any adverse effects on fruits quality. The purpose of the research was to evaluate thinning efficacy of the mixture of NAA and NAs in two commercially grown apple cultivars 'Golden Delicious' and 'Fuji', known to respond differently to the application of NAA.

MATERIALS AND METHODS

Experimental site. The trials were conducted during the vegetation season from 2010 to 2012 in a commercial apple orchard located in Mala Remeta, Irig, Serbia (45°05'N and 19°44'E, 215 m above sea level). The trees of cultivars 'Golden Delicious' and 'Fuji' were planted in 2007 on M.9 T337 rootstock, at a 3.2 × 0.8 m planting distance. The soil on which the field experiment was set up was degraded chernozem, medium deep form, calcareous, gleyed. The experiment was performed in conditions of drip irrigation, while standard cultural practices and pest management were followed every year, without any additional plant growth regulator application on the experimental trees.

Chemicals and treatments. In order to prepare a concentrated solution, the commercial refined naphthenic acids (Soctech, Romania) and NAA (containing 95% a.m. 1-naphthylacetic acid, Acros Organics, Belgium) were dissolved with Potassium hydroxide solution and mixed together. The concentrated solution contained 3.3% NAA and 5.4 $g \cdot L^{-1}$ NAs. Another concentrated solution was prepared containing only 3.3% NAA. Concentrated solutions were further diluted with water in the field just prior to the application obtaining the following treatments:

1. 0.3 $ml \cdot L^{-1}$ concentrated solution containing 3.3% NAA, which corresponds to the final concentration of 10 $mg \cdot L^{-1}$ NAA;
2. 0.3 $ml \cdot L^{-1}$ concentrated solution containing 3.3% NAA and 5.4 $g \cdot L^{-1}$ NAs, which corresponds to the final concentration of 10 $mg \cdot L^{-1}$ NAA and 1.62 $mg \cdot L^{-1}$ NAs;
3. 0.6 $ml \cdot L^{-1}$ concentrated solution containing 3.3% NAA, which corresponds to the final concentration of 20 $mg \cdot L^{-1}$ NAA;
4. 0.6 $ml \cdot L^{-1}$ concentrated solution containing 3.3% NAA and 5.4 $g \cdot L^{-1}$ NAs, which corresponds to the final concentration of 20 $mg \cdot L^{-1}$ NAA and 3.24 $mg \cdot L^{-1}$ NAs;
5. Untreated control.

Each treatment included six uniform trees, randomly chosen along the rows with one whole tree per replicate. The trees were sprayed with a mist blower (STIHL SR-420) until run-off, at spray volume of 1000 $L \cdot ha^{-1}$. The treatments were applied when the average king-fruit diameter ranged from 10.5 to 12.1 mm in 'Golden Delicious' (tab. 1) and from 10.6 to 12.5 mm in 'Fuji' (tab. 2).

Table 1. King fruit diameter in apple cultivar 'Golden Delicious' and the weather conditions at application

Year	King fruit diameter (mm)	Air temp. at application (°C)	Max. temp. (°C)	RH at application
2010	12.1	15.1	21.6	79.5
2011	10.5	20.6	24.0	41.5
2012	11.1	24.7	29.4	45.9

Table 2. King fruit diameter in apple cultivar 'Fuji' and the weather conditions at application

Year	King fruit diameter (mm)	Air temp. at application (°C)	Max. temp. (°C)	RH at application
2010	12.5	17.0	21.6	63.6
2011	10.8	21.4	24.0	39.2
2012	10.6	27.0	29.4	36.7

Trunk circumference was measured at the height of 5 cm above the graft union in order to calculate trunk cross-sectional area (TCSA). Two parameters that present the fruit set were calculated: the number of fruits harvested per cm^2 TCSA and per 100 flower clusters. A mean sample of 20 fruits randomly picked per each tree (120 per treatment) was used for fruit weight measurement. Fruit flesh firmness was measured using a FT 327 penetrometer (Winopal Forshchungsbedarf GmbH, Ahnsbeck, Germany), with an 11 mm probe. Two measurements were made on the opposite sides of each fruit. Starch index was evaluated using the starch iodine test [Vaysse 2002]. Total soluble solids (TSS) were determined using a hand refractometer (0–32%). Titratable acidity (TA) was measured by titration with 0.1 N NaOH to pH 8.1. The results were expressed as percentage of malic acid in fruits.

The data were analyzed using analysis of variance (ANOVA). Duncan's multiple range test was used to compare the means at $P < 0.05$ with STATISTICA 12 (StatSoft Inc, Tulsa, USA).

RESULTS

'Golden Delicious' trial. In 2010, chemical thinning treatments with NAA or NAA + NAs were not effective in reducing neither fruit set, nor the number of fruits per tree in 'Golden Delicious' (tab. 3). The average fruit weight was increased by all the treatments, while the largest fruits with the average weight of 250.8 g were obtained by the 0.3 $ml \cdot L^{-1}$ NAA + NAs application. Fruit weight was lower with higher rates of chemicals, but still higher than in the untreated control. The increase in fruit weight with unaffected fruit set did not cause a significant increase in yield. The difference between NAA and NAA + NAs treatments was significant for fruit weight only, with higher fruit weight achieved by NAA + NAs treatments compared to the NAA applied alone.

In 2011, the number of fruits per cm^2 TCSA was significantly decreased with 0.3 $ml \cdot L^{-1}$ NAA + NAs and 0.6 $ml \cdot L^{-1}$ NAA (tab. 3), while the number of fruits per 100 clusters was decreased with all the treatments, as well as the number of fruits per tree. Although a decrease in yield was recorded, it was not statistically significant. The average fruit size was increased by increasing the concentration of chemicals in all the treatments compared to the control, but the difference in effectiveness between NAA and NAA + NAs was not recorded in 2011.

In 2012, the number of fruits per cm^2 of TCSA was decreased by the application of 0.6 $ml \cdot L^{-1}$ NAA + NAs, while the number of fruits per tree was decreased in all treatments, followed by the increase in fruit weight (tab. 3). The difference in fruit weight between NAA and NAA + NAs treatments was significant. Yield was significantly reduced by the treatments as a consequence of a reduced number of fruits per tree.

There were no differences in effectiveness between NAA and NAA + NAs treatments, except for the fruit weight.

Fruits of cv. 'Golden Delicious' were softer in most treatments compared to the control (tab. 4). The significant differences were observed in the following treatments: 0.3 $ml \cdot l^{-1}$ NAA + NAs in 2010, at the higher rates of both formulations in 2011, and in all treatments in 2012. The NAA + NAs treatments had significantly lower fruit firmness compared to the NAA applied alone in 2010. A slight tendency towards an increase of starch index in NAA treatments compared to the control was observed irrespective of the chemical rate, while the effect of NAA + NAs was not different compared to NAA applied alone considering starch degradation. Chemical thinning with NAA or NAA + NAs had variable effects on TSS content and titratable acidity of 'Golden Delicious' apples, which might be due to the significant factor of the year and year × treatment interaction influencing these traits. Generally, the differences between formulations were not significant for TSS content, except for the decrease in NAA + NAs treatments compared to the NAA which was recorded in 2010. Titratable acidity was not affected by the formulations.

Table 3. Fruit set, fruit weight and yield of chemically thinned 'Golden Delicious' apple (2010–2012)

Year	Treatments	No. of fruits·cm^{-2} TCSA[a]	No. of fruits·100^{-1} clusters	No. of fruits·tree^{-1}	Fruit weight (g)	Yield (kg·tree^{-1})
2010	control	10.2 a[b]	53.7 a	90 a	214.7 a	19.3 a
	0.3 ml·L^{-1} NAA	8.7 a	59.7 a	69 a	247.4 bc	17.1 a
	0.3 ml·L^{-1} NAA + NAs	9.6 a	55.5 a	85 a	250.8 c	21.3 a
	0.6 ml·L^{-1} NAA	7.6 a	42.5 a	77 a	231.6 b	17.8 a
	0.6 ml·L^{-1} NAA + NAs	8.4 a	58.1 a	68 a	237.8 bc	16.1 a
Average for NAA		8.2 A	51.6 A	72.7 A	239.5 A	16.4 A
Average for NAA + NAs		9.0 A	56.8 A	76.5 A	244.3 B	21.0 A
2011	control	12.6 b	90.2 c	116 b	172.1 a	20.0 a
	0.3 ml·L^{-1} NAA	9.7 ab	66.3 b	84 a	197.9 b	16.6 a
	0.3 ml·L^{-1} NAA + NAs	8.1 a	58.6 b	77 a	206.1 bc	15.9 a
	0.6 ml·L^{-1} NAA	8.6 a	42.1 a	79 a	215.7 c	17.0 a
	0.6 ml·L^{-1} NAA + NAs	11.4 ab	47.3 a	87 a	207.2 bc	18.0 a
Average for NAA		9.2 A	54.2 A	81.5 A	206.8 A	16.8 A
Average for NAA + NAs		9.8 A	53.0 A	82.0 A	206.7 A	16.8 A
2012	control	13.8 b	103.1 ab	162 b	159.4 a	25.8 b
	0.3 ml·L^{-1} NAA	12.9 ab	76.0 a	99 a	180.1 b	17.8 a
	0.3 ml·L^{-1} NAA + NAs	11.6 ab	114.5 b	98 a	213.9 c	21.0 ab
	0.6 ml·L^{-1} NAA	9.8 ab	83.3 ab	101 a	186.9 b	18.9 a
	0.6 ml·L^{-1} NAA + NAs	9.5 a	87.2 ab	96 a	205.6 c	19.7 a
Average for NAA		11.4 A	79.7 A	99.8 A	183.5 A	18.4 A
Average for NAA + NAs		10.6 A	100.9 A	97 A	209.8 B	22.3 A
Statistical significance:						
	treatment	**	**	**	**	*
	year	**	**	**	**	**
	treatment × year	ns[c]	**	ns	**	ns
	formulation	ns	ns	ns	**	ns

[a] TCSA – trunk cross-sectional area
[b] Means in the column followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at P < 0.05
[c] ns – not significant at P < 0.05

Table 4. Fruit quality of chemically thinned 'Golden Delicious' apple (2010–2012)

Year	Treatments	Fruit firmness ($kg\cdot cm^{-2}$)	Starch index (1–10)	TSS[a] (%)	TA[b] (g·l)
2010	control	7.0 b[c]	9.0 a	12.4 a	0.50 a
	0.3 $ml\cdot L^{-1}$ NAA	7.0 b	8.8 a	13.3 b	0.58 ab
	0.3 $ml\cdot L^{-1}$ NAA + NAs	6.6 a	8.9 a	1 2.8 ab	0.54 ab
	0.6 $ml\cdot L^{-1}$ NAA	6.9 b	8.7 a	13.0 ab	0.60 b
	0.6 $ml\cdot L^{-1}$ NAA + NAs	6.9 b	9.0 a	12.5 ab	0.63 b
Average for NAA		7.0 B	8.8 A	13.2 B	0.59 A
Average for NAA + NAs		6.8 A	9.0 A	12.7 A	0.58 A
2011	control	8.5 c	2.5 a	9.6 a	0.43 a
	0.3 $ml\cdot L^{-1}$ NAA	8.4 c	3.2 ab	11.5 b	0.28 b
	0.3 $ml\cdot L^{-1}$ NAA + NAs	8.3 c	3.1 ab	11.5 b	0.60 b
	0.6 $ml\cdot L^{-1}$ NAA	7.5 a	3.6 b	8.9 a	0.40 a
	0.6 $ml\cdot L^{-1}$ NAA + NAs	7.9 b	3.2 ab	10.8 b	0.46 a
Average for NAA		7.9 A	3.4 A	10.2 A	0.49 A
Average for NAA + NAs		8.1 A	3.2 A	11.3 A	0.53 A
2012	control	8.7 c	3.8 a	11.5 c	0.55 c
	0.3 $ml\cdot L^{-1}$ NAA	7.7 ab	5.6 b	10.9 b	0.52 ab
	0.3 $ml\cdot L^{-1}$ NAA + NAs	7.6 a	4.8 ab	11.0 b	0.58 c
	0.6 $ml\cdot L^{-1}$ NAA	7.7 ab	4.5 a	10.6 ab	0.48 a
	0.6 $ml\cdot L^{-1}$ NAA + NAs	8.0 b	4.4 a	10.3 a	0.49 a
Average for NAA		7.7 A	5.0 A	10.8 A	0.50 A
Average for NAA + NAs		7.8 A	4.6 A	10.6 A	0.53 A
Statistical significance:					
	treatment	**	**	**	**
	year	**	*	**	**
	treatment × year	**	*	**	**
	formulation	*	ns[d]	ns	ns

[a] TSS – total soluble solids content
[b] TA – titratable acidity
[c] Means in the column followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at P < 0.05
[d] ns – not significant at P < 0.05

'Fuji' trial. Neither NAA applied alone, nor with the addition of NAs was effective in reducing fruit set of 'Fuji', except for the number of fruits per 100 clusters in 2012, while the number of fruits per tree was inconsistently decreased (tab. 5).

Fruits smaller than 45 mm in diameter were recorded at harvest in chemically treated 'Fuji' trees, while they were not found in the untreated control (tab. 5). The number of small fruits was slightly increased by the higher concentrations of chemicals and by the addition of NAs, and was the highest with 0.6 $ml\cdot L^{-1}$ NAA + NAs treatment in each year of the study. The highest number of small fruits was recorded in 2011, where NAA + NAs application caused the occurrence of significantly more small fruits compared to the NAA applied alone. In each year of the study the percentage of small fruits in the total number of fruits per tree was higher in NAA + NAs than in NAA treatment.

Table 5. Fruit set, fruit weight, small fruits number (<45 mm) and yield of chemically thinned 'Fuji' apple (2010–2012)

Year	Treatments	No. of fruits·cm^{-2} TCSA[a]	No. of fruits·100^{-1} clusters	Total no. of fruits·tree^{-1}	No. of fruits <45 mm·tree^{-1}	Fruits <45 mm (%)	Fruit weight (g)	Yield of fruits >45mm (kg·tree^{-1})
2010	control	17.4 a	89.2 a	150.3 c	–	–	198.2 bc	29.8 b
	0.3 ml·L^{-1} NAA	9.5 a	82.1 a	107.0 a	10.11 a	9.5	211.6 c	20.5 a
	0.3 ml·L^{-1} NAA + NAs	11.4 a	85.5 a	151.3 c	13.44 ab	8.9	193.3 a–c	26.7 b
	0.6 ml·L^{-1} NAA	11.4 a	69.4 a	129.0 b	15.0 ab	11.6	184.7 ab	21.1 a
	0.6 ml·L^{-1} NAA + NAs	12.7 a	81.8 a	147.7 c	23.4 b	15.8	178.0 a	22.1 a
Average for NAA		12.4 A	95.0 A	118.0 A	12.6 A	10.1	198.2 A	20.8 A
Average for NAA + NAs		12.1 A	83.7 A	149.5 B	18.4 A	12.0	185.7 A	24.4 B
2011	control	12.6 a	141.4 a	184.5 b	–	–	183.4 a	33.8 c
	0.3 ml·L^{-1} NAA	11.7 a	124.9 a	154.7 ab	68.8 a	44.5	220.2 b	18.9 b
	0.3 ml·L^{-1} NAA + NAs	9.1 a	134.2 a	138.0 a	67.5 a	48.9	211.7 b	14.9 ab
	0.6 ml·L^{-1} NAA	9.0 a	118.3 a	118.3 a	50.0 a	42.3	230.5 b	15.8 ab
	0.6 ml·L^{-1} NAA + NAs	9.4 a	102.8 a	153.2 ab	104.7 b	68.3	224.1 b	10.9 a
Average for NAA		10.4 A	121.6 A	136.5 A	59.4 A	43.4	225.4 A	17.3 B
Average for NAA + NAs		9.3 A	118.5 A	145.6 A	86.1 B	58.6	217.9 A	12.9 A
2012	control	9.1 a	102.8 b	155.2 b	–	–	172.6 a	26.8 a
	0.3 ml·L^{-1} NAA	7.6 ab	66.8 a	123.2 a	0 a	0.0	209.2 bc	25.8 a
	0.3 ml·L^{-1} NAA + NAs	6.3 a	58.6 a	107.2 a	2.2 ab	2.1	206.6 b	21.7 a
	0.6 ml·L^{-1} NAA	7.0 ab	64.9 a	108.0 a	3.5 ab	3.2	227.6 c	23.8 a
	0.6 ml·L^{-1} NAA + NAs	7.7 ab	63.4 a	125.2 a	4.5 b	3.6	192.5 ab	23.2 a
Average for NAA		7.3 A	65.9 A	115.6 A	1.8 A	1.6	218.4 B	24.8 A
Average for NAA + NAs		7.0 A	61.0 A	116.2 A	3.4 A	2.9	199.6 A	22.5 A
	Statistical significance:							
	treatment	ns	ns	**	**	–	**	**
	year	*	**	**	**	–	**	**
	treatment × year	ns	ns	*	**	–	**	**
	formulation	ns	ns	*	*	–	**	*

[a] For explanations see Table 3.

Table 6. Fruit quality of chemically thinned 'Fuji' apple (2010–2012)

Year	Treatments	Fruit firmness ($kg\cdot cm^{-2}$)	Starch index (1–10)	TSS[a] (%)	TA (g×l)
2010	control	7.7 c	7.6 b	11.3 a	0.41 c
	0.3 $ml\cdot L^{-1}$ NAA	7.1 a	7.6 b	10.9 a	0.31 a
	0.3 $ml\cdot L^{-1}$ NAA + NAs	7.6 bc	7.0 a	11.2 a	0.38 bc
	0.6 $ml\cdot L^{-1}$ NAA	7.2 a	7.8 b	11.2 a	0.39 c
	0.6 $ml\cdot L^{-1}$ NAA + NAs	7.5 b	8.0 b	10.9 a	0.34 ab
Average for NAA		7,2 A	7.7 A	11.1 A	0.35 A
Average for NAA + NAs		7,5 B	7.5 A	11.0 A	0.36 A
2011	control	7.2 b	6.2 b	11.1 a	0.28 a
	0.3 $ml\cdot L^{-1}$ NAA	7.2 b	5.2 a	11.7 ab	0.30 ab
	0.3 $ml\cdot L^{-1}$ NAA + NAs	7.2 b	5.5 ab	12.5 b	0.35 c
	0.6 $ml\cdot L^{-1}$ NAA	7.1 ab	5.7 ab	12.3 b	0.33 bc
	0.6 $ml\cdot L^{-1}$ NAA + NAs	6.9 a	6.0 b	11.1 a	0.29 ab
Average for NAA		7,2 A	5.5 A	12.0 A	0.32A
Average for NAA + NAs		7,1 A	5.8 A	11.8 A	0.32 A
2012	control	7.2 a	7.0 a	13.2 a	0.30 a
	0.3 $ml\cdot L^{-1}$ NAA	6.9 a	7.1 a	12.3 a	0.30 a
	0.3 $ml\cdot L^{-1}$ NAA + NAs	6.9 a	6.9 a	12.8 a	0.35 a
	0.6 $ml\cdot L^{-1}$ NAA	6.9 a	7.1 a	12.9 a	0.35 a
	0.6 $ml\cdot L^{-1}$ NAA + NAs	7.0 a	6.8 a	13.6 a	0.36 a
Average for NAA		6.9 A	7.1 A	12.6 A	0.32 A
Average for NAA + NAs		6.9 A	6.9 A	13.2 A	0.36 A
Statistical significance:					
	treatment	**	**	**	**
	year	**	*	ns	**
	treatment × year	**	*	ns	*
	formulation	*	ns	ns	ns

[a] For explanations see Table 4

Fruit weight was inconsistently affected by the treatments in cv. 'Fuji' in different years (tab. 5). In 2010 fruit weight was unaffected by the treatments, except for 0.6 $ml\cdot L^{-1}$ NAA + NAs where it was reduced. In 2011, all applied treatments increased the average fruit weight, although the number of small fruits was the highest. Fruit weight was slightly reduced in treatments where NAs were added compared to NAA applied alone, but not significantly. In 2012, fruit weight was significantly decreased in treatments with NAA + NAs compared to NAA applied alone, at the rate of 0.6 $ml\cdot L^{-1}$.

Fruit firmness of cv. 'Fuji' was decreased by the thinning treatments in 2010 and 2011 compared to the control (tab. 6). Starch index was also decreased in 0.3 $ml\cdot L^{-1}$ NAA + NAs in 2010 and 0.3 $ml\cdot L^{-1}$ NAA in 2011, while thinning inconsistently affected TSS content and titratable acidity of fruits of cv. 'Fuji'. The effect of formulation (with or without NAs) was significant only in the case of fruit firmness in 2010, where fruit firmness was increased by adding NAs to NAA.

DISCUSSION

Inconsistencies in thinning effects of NAA have been previously reported. By studying 12 apple cultivars, Robinson [2006] concluded that the decrease of fruit set and increase of fruit weight were related to the concentration of NAA in a curvilinear manner, meaning that intermediate chemical concentrations (8.5 mg·L^{-1}) were the most effective. Stopar [2002] reported that in cv. 'Golden Delicious' the higher yield of fruits larger than 70 mm in diameter and higher mean fruit weight were achieved by thinning with 5 rather than with 20 mg·L^{-1} NAA, while fruit set was reduced to the similar number of fruits per cm^2 TCSA by both NAA treatments. On the other hand, Marini [2002] reported a negative linear relationship between fruit set in 'Golden Delicious' and the concentration of NAA applied. The present results with apple cultivar 'Golden Delicious' cannot clearly confirm the previous results because the decrease of fruit set induced by the increasing rate of NAA was not statistically confirmed, while it was dependent on the year of the present study. The number of fruits per cm^2 TCSA, 100 flower clusters and per tree were not affected by the mixture of NAA and NAs, meaning that the thinning response of 'Golden Delicious' to NAA was not improved by adding NAs as was assumed.

Fruit weight of 'Golden Delicious' was higher with treatments than in the control, while it was not affected by the concentration of NAA. However, fruit weight was significantly increased by adding NAs to NAA in two of the three years of the experiment. The effect of NAA thinning on apple fruit size is related to a reduced competition among fruits [Stover et al. 2001], therefore, at an unaffected fruit set, the obtained increase in fruit weight must be related to the direct effects of NAs. According to Wort [1976], K-naphthenate treatment caused an increased rates of CO_2 fixation, greater photosynthetic efficacy and higher photosynthetic rates in bush bean plants (*Phaseolus vulgaris* L.), which resulted in a greater growth of plants. The better supply of assimilates to the fruits treated with NAs might contribute to their better growth and finally higher fruit weight at harvest. Chitu et al. [2010] applied NAs to apple as a growth enhancing component of 'Nutrinaft' complex products containing also macronutrients, mesonutrients, micronutrients and ecological fungicides. A stimulative effect was demonstrated concerning fruit weight and diameter in Idared and Jonatan apple cultivars. It is assumed that the second phase of fruit growth (phase 75–79, stage 3 on BBCH scale) was affected by the growth enhancing component of the products (NAs), leading to a greater fruit size at harvest. However, considering the results presented, it was not possible to clearly distinguish the contribution of the NAs from the effect of complex nutrient mixture. The assumption that fruit size of 'Golden Delicious' could be improved by adding NAs to NAA for chemical thinning is confirmed by the present research.

Jones et al. [1991] reported that NAA was not effective in 'Fuji' in reducing fruit set or increasing fruit weight, but increased the number of fruits smaller than 45 mm in diameter. They suggest there is a direct retarding effect of NAA on fruit growth in 'Fuji'. The weak response of 'Fuji' to NAA applied for fruit thinning was confirmed by the present experiment, while fruit weight was affected inconsistently. Fruits smaller than 45 mm in diameter were detected in all treatments. A higher number of small fruits occurred when NAs were added to NAA, especially at higher concentration, which might be due to surfactant [Pavlović et al. 2015] and hormonal activity of NAs [Ansari et al. 1989, Ćirin-Novta 2002] that accentuated retarding effects of NAA to fruit growth.

According to Black et al. [1995b], a 10°C difference in air temperature (between 16 and 26°C) can result in a 37% change in NAA uptake by the abaxial surface of apple leaf. Over-response manifested in the inhibition of apple fruit growth might be expected under warmer conditions. Such was the case in 2012, when the air temperature at the time of the application was 27°C while daily temperature reached 29.4°C (tab. 2). According to the label recommendation (Fruitone N, Amvac Chemical Corp., USA) NAA should not be used for thinning if the air temperature is above 26.7°C because small or misshapen fruits may occur. However, the smallest number of small fruits was recorded in 2012. In 2012, the smallest fruit set was recorded, especially regarding the number of fruits per 100 flower clusters, indicating the weakest competition among fruits within a spur. The greatest negative effect of NAA on fruit size was previously recorded on fruits with intraspur competition [Black et al. 2000]. In the present research, the decrease in fruit set caused by NAA applications overcame the direct retarding effect of NAA on fruit growth, leading to the increase in the average fruit weight compared to the control and smaller number of small fruits in 2012. The addition of NAs modulated thinning effects of NAA in apple cv. ‘Fuji’, but in a negative way, by further retarding fruit growth, which is why it is not recommended for cultural practice.

It was assumed that the addition of NAs to NAA used for fruit thinning of apple cultivars ‘Golden Delicious’ and ‘Fuji’ would not significantly affect the quality of fruits. In the first year of the experiment, fruit firmness was lower in treatments with NAA + NAs compared to the NAA applied alone in cv. ‘Golden Delicious’, while was higher in cv. ‘Fuji’. Fruit firmness is considered to be negatively correlated with fruit weight which increases in thinning treatments [Siddiqui and Bangerth 1995]. Thinning with NAA + NAs increased fruit weight more than NAA applied alone in cv. ‘Golden Delicious’. Very large fruit size such was in NAA + NAs treatments (244.3 g in average) might be the reason for softer flesh. Fruit firmness of both apple cultivars highly depended on the year of the study and year × treatment interaction. Therefore the inconsistent effects of two formulations (NAA or NAA + NAs) on fruit firmness are not contradicted with the assumption. The effect of formulation was not significant for starch index, TSS content and titratable acidity.

CONCLUSIONS

NAA applied alone did not consistently reduce fruit set in apple cultivar ‘Golden Delicious’, while it caused the increase in fruit weight in each of the three experimental years. The addition of NAs to NAA did not alter the effectiveness of NAA in reducing fruit set, while it significantly increased fruit weight compared to NAA applied alone in two of the three years of the experiment.

NAs modulated the effect of NAA on fruit weight of apple cultivar ‘Fuji’ by retarding fruit growth and causing a larger number of small fruits to occur compared to NAA applied alone.

Chemical thinning in apple orchards is performed in order to consistently maintain high yields and, at the same time, shift fruits to a higher size category by increasing their weight. The advantage of a combined application of NAA and NAs in apple cultivar 'Golden Delicious' would be in achieving a sufficient level of thinning required for the regular annual cropping, wherein the loss in yield due to fruit abscission would be compensated by an additional increase in fruit weight. In apple cultivar 'Fuji', NAs accentuated the negative effects of NAA, therefore their combined application is not recommended for fruit thinning. The addition of NAs to NAA did not negatively affect the quality of fruits.

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WPŁYW KWASU NAFTENOWEGO (NAs) NA REAKCJĘ JABŁONI 'GOLDEN DELICIOUS' I 'FUJI' NA CHEMICZNE PRZERZEDZANIE ZA POMOCĄ NAA

Streszczenie. NAA (kwas naftylooctowy) nierównomiernie przerzedza owoce jabłoni jeśli chodzi o zawiązki i masę oraz może spowodować małe i źle uformowane owoce. Odnosząc się do działania hormonalnego, właściwości substancji powierzchniowo czynnych oraz wpływu kwasu naftenowego (Nas) na metabolizm auksyn w tkance roślinnej, to zakłada się, że reakcję na przerzedzanie oraz rozmiar można polepszyć poprzez dodanie NAs do NAA do chemicznego przerzedzania jabłek. Celem badania była ocena skuteczności przerzedzania mieszaniny NAA i NAs u dwóch komercyjnie hodowanych odmian jabłoni: 'Golden Delicious' oraz 'Fuji', o których wiadomo, że reagują różnie na zastosowanie NAA. Zastosowano następujące zabiegi podczas 3-letniego okresu badań (2010–2012): 10 mg·L^{-1} NAA, 10 mg·L^{-1} NAA + 1,56 mg·L^{-1} NAs, 20 mg·L^{-1} NAA, 20 mg·L^{-1} NAA + 3,12 mg·L^{-1} NAs oraz kontrola bez zabiegów. Dodatek NAs do NAA nie zmienił skuteczności NAA w zmniejszaniu zawiązków, natomiast istotnie zwiększył masę owoców w porównaniu z zastosowaniem samego NAA w dwóch z trzech lat doświadczenia. NAs regulował wpływ NAA na masę owoców odmiany 'Fuji' poprzez opóźnianie wzrostu owoców i podwyższenie liczby małych owoców w porównaniu z zastosowaniem samego NAA.

Słowa kluczowe: kwas naftylooctowy, zawiązek, plon, masa owoców, jakość owoców

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