Original scientific paper
Journal of Central European Agriculture, 2020, 21(1), p.113-123
DOI: /10.5513/JCEA01/21.1.2459

Branching of nursery apples and plums using various branching inducing methods

Rozvětvování jabloní a slivoní pomocí různých metod indukce větvení ve školce

Luděk LAŇAR[1] (✉), Martin MÉSZÁROS[1], Klára KYSELOVÁ[1], Jan NÁMĚSTEK[1], Josef SUS[2], Hana BĚLÍKOVÁ[1], Patrik ČONKA[1]

[1] Research and Breeding Institute of Pomology Holovousy Ltd., Czech Republic

[2] Czech University of Life Sciences Prague, Czech Republic

✉ Corresponding author: lanar@vsuo.cz

Received: February 27, 2019; accepted: July 25, 2019

ABSTRACT

Chemical (benzyladenine - BA, gibberelins - $GA_{4/7}$), mechanical (leaf pinching), and combined treatments were tested in 2015 and 2016 to increase the number and length of sylleptic side shoots (feathers) on apple (´Rubinola´, ´Topaz´/M9) and plum (´Elena´, ´Tophit´/St. J. A) trees. The numbers of feathers of three different lengths (1-10, 10-30, and >30 cm) were measured as the main indicator of quality along with other important morphological characteristics. The numbers of all feathers on both apple cultivars were the highest when BA was applied four times. However, mainly an increase in the numbers of shorter feathers was observed in both years. The efficiency of leaf pinching of apple trees was low. The numbers of all feathers and feathers 1-10 and 10-30 cm in length were the highest in both plum cultivars when BA was applied four times in both years. In contrast to apples, the induction of feathers longer than 30 cm improved in plum cultivars when pinching was used. Thus this approach can be also effective in organic production.

Keywords: cytokinins, gibberellins, *Malus*, *Prunus*, pinching, sylleptic branching

ABSTRAKT

V letech 2015 a 2016 byla testována chemická (6-benzyladenin - BA, gibereliny - $GA_{4/7}$) a mechanická (seštipování listů) ošetření a jejich kombinace pro zvýšení počtu a délky bočních syleptických výhonů (obrostu) jabloní (´Rubinola´, ´Topaz´/M9) a slivoní (´Elena´, ´Tophit´/St. J. A). Hlavním indikátorem kvality výpěstků byl počet výhonů tří různých délek (1-10, 10-30 a >30 cm) spolu s dalšími důležitými měřenými morfologickými charakteristikami. Obě jabloňové odrůdy měly nejvyšší počet výhonů při čtyřikrát opakovaném ošetření BA, ale vliv byl v obou letech zaznamenán pouze na zvýšení počtu kratších výhonů. Seštipování listů mělo u jabloní malou efektivitu. Obě slivoňové odrůdy měly nejvyšší celkový počet výhonů a počty výhonů délky 1-10 cm a 10-30 cm také při čtyřikrát opakovaném ošetření BA v obou letech. Na rozdíl od jabloní byl ale počet výhonů délky nad 30 cm u slivoní nejvíce podpořen v případě provedení samotného seštipování. Proto by seštipování mohlo být efektivně využíváno i v ekologické produkci.

Klíčová slova: cytokininy, gibereliny, *Malus*, *Prunus*, seštipování, syleptické větvení

INTRODUCTION

The induction of branching is a critical operation used to increase the quality of planting material and its potential to bring higher and earlier yields in the first years after planting (van Oosten, 1978; Sadowski et al., 2007). Nowadays, the most common planting material for the establishment of the preferred spindle type trees is the well-branched knip tree for apples (van den Berg, 2003) and branched one-year-old maiden tree for plums. Ideally, they both have a dominant central leader and a large number of side shoots (feathers). These types of shoots are formed from lateral buds developed in the same growing season (Champagnat, 1954) and they usually have the desired width of the crotch angle (Wertheim, 1978). Natural branching of many apple and plum cultivars is insufficient (Magyar and Hrotkó, 2002; Kviklys, 2006) and may decrease even more due to the weakly growing rootstocks (Kviklys, 2004). Several methods affecting apical dominance are used to increase the production of feathers and many of them have been tested in the last decades. The most frequently used and reliable mechanical method is the pinching of the youngest leaves keeping the desired conical shape of the trees and wide crotch angle of feathers (Wertheim, 1978; van den Berg, 2003). The main advantage of this approach is its potential to be applied in organic production that has recently attracted attention. Nevertheless, the effectiveness of pinching varies (Volz et al., 1994; Jung and Lee, 2008) and is quite laborious. Another option is chemical induction that is quicker and less labour-intensive. Although many chemicals were tested (Quinlan and Preston, 1973; Cody et al., 1985; Elfving, 2010; Nečas et al., 2018), cytokinin benzyladenine (BA) and a mixture of benzyladenine with gibberellins (GA 4/7 or GA 3) are considered both most universal and reliable (Magyar and Hrotkó, 2002; Elfving and Visser, 2006; Elfving, 2010; Lordan et al., 2017). BA is the main agent inducing branching while GA usually increases the length of the feathers (Magyar and Hrotkó, 2002; Dorić et al., 2015). Chemical induction has also some disadvantages such as the inaccessibility of the compounds in some countries and danger of tip damage when high concentrations are used or mistakes during application are made. Chemical and mechanical methods are sometimes combined to increase branching even on poorly branching cultivars/species (Hrotkó et al., 1997; Kviklys, 2006; Bektas and Ersoy, 2010). Natural conditions (Wertheim and Estabrooks, 1994; Tromp, 1996; Tromp and Boertjes, 1996; Lindhagen, 1998) as well as management in the tree nurseries (Hague and Neilsen, 1991; Wilson and Jarassamrit, 1994; Médiène et al., 2002; Cook et al., 2004) are crucial to achieve plentiful branching. Additive N fertilization is considered as the possible way to increase the number and possibly even the length of the feathers (Médiène et al., 2002; Cook et al., 2004).

Since many of the factors affect the final branching, the study of proper, effective, and safe methods remain to be the issue for each cultivar/rootstock combination and conditions including the number of treatments, chemicals, safe concentrations, combinations, and optimal timing of the treatments.

The objective of this research was to test the universality of the treatments and to see effect of various treatments on the architecture of two difficult-to-branch apple cultivars with Vf scab resistance and two plum cultivars. Since chemical substances are not permitted in organic nursery production, the generally accepted method of leaf pinching was also tested.

MATERIALS AND METHODS

Site and plant material

The experimental nursery was located in the Research and Breeding Institute of Pomology, Holovousy, Czech Republic (50.3730808N, 15.5803983E). The trees were planted in the loamy brown soil in nursery replant irrigated plots. Two different fruit species were used, each represented by two cultivars and grafted on dwarfing or semi dwarfing rootstock: (i) apple (´Topaz´, ´Rubinola´/M9) and (ii) European plum (´Tophit´, ´Elena´/St. Julien A). Experimental plots were planted in 2014 and 2015 and the trees were treated and assessed in 2015 and 2016. One-year-old budded European plum trees spaced 1.2 x 0.25 m were used for the branching induction.

Rooted rootstocks were budded in August of the first year. In the second growing season all the feathers growing lower than 55 cm above ground were gradually removed during the growth of the terminal shoot as it is common in commercial trees. Treatment using different branch-inducing methods began after most of the trees exceeded 60 cm in height. Trees of an approximate height of 60–90 cm were selected and marked, and then used in the experiment and further analysed. Two-year-old knip trees spaced 1.2 x 0.3 m were used for branch induction on apples. Knip trees were grown from bench grafted plants. They grew and formed whips by the end of the first year. These whips were headed 65 cm above ground at the end of winter. Only the whips of a diameter of at least 7 mm at a height of 65 cm were marked and included in the treatments. Common plant protection management was applied. During the critical time of the formation of sylleptic shoots (from June to July), the weather conditions were hot and dry with a significant temperature drop in mid-June in 2015. In 2016, the weather was mild and stable with temperatures around 20-25 °C.

Treatments

Various chemical, mechanical, and combined branch-inducing methods were used to induce and stimulate the growth of feathers. The following products were used for chemical induction: Globaryll 100 containing benzyladenin (BA) at a concentration of 100 $g \cdot l^{-1}$, Gibb Plus containing 10 $g \cdot l^{-1}$ gibberellins GA4/7 (both Globachem NV, Sint Truiden, Belgium) and Progerbalin® LG containing benzyladenine 18.8 $g \cdot l^{-1}$ + gibberellins GA4/7 18.8 $g \cdot l^{-1}$ (L. Gobbi, Genova, Italy). The surfactant Silwet L-77® in a dose of 1.5 $ml \cdot l^{-1}$ (Momentive Performance Materials, Friendly, WV, USA) was used in each application. A common household hand sprayer was used for the application of the mixture producing approximately 3 ml with each spray. This volume was sufficient to moisten few of the top leaves and also flew down and moisten around 20 cm of the terminal shoot. Leaf pinching was used as the mechanical method, i.e. partial removal of the youngest developing leaves (approximately half of the blade) while leaving the growing tip and meristem intact. A combination of the both mentioned techniques was also used in some treatments.

The following treatments were tested:

- C - Untreated control – trees were left unsprayed
- BA2 - Globaryll 100 applied 2x, dose 1000 $mg \cdot l^{-1}$ BA
- BA4 - Globaryll 100 applied 4x, dose 1000 $mg \cdot l^{-1}$ BA
- BA2+4N - Globaryll 100 applied 2x, dose 1000 $mg \cdot l^{-1}$ BA + urea, dose 5000 $mg \cdot l^{-1}$ applied 4 x 10 days apart. The first two urea applications occurred always 3 days after the BA spray.
- BA2+GA2 - Globaryll 100 applied 2x, dose 1000 $mg \cdot l^{-1}$ BA followed by two applications of Gibb Plus, dose 1000 $mg \cdot l^{-1}$ $GA_{4/7}$
- BAGA2 - Progerbalin® LG applied 2x, dose of 500 $mg \cdot l^{-1}$ BA + 500 $mg \cdot l^{-1}$ $GA_{4/7}$
- BAGA2D - Progerbalin® LG applied 2x, dose of 1000 $mg \cdot l^{-1}$ BA + 1000 $mg \cdot l^{-1}$ $GA_{4/7}$
- P4 - pinching 4x
- P2+BA2 - pinching 2x combined with Globaryll 100 applied 2x, dose 1000 $mg \cdot l^{-1}$ BA
- P2+BAGA2 - pinching 2x combined with Progerbalin® LG applied 2x, dose 500 $mg \cdot l^{-1}$ BA + 500 $mg \cdot l^{-1}$ $GA_{4/7}$

Phytohormones were applied in 10-day intervals. Pinching alone was applied in 7-day intervals. During the treatments combining pinching and application of phytohormones, the interval of pinching was 10 days and phytohormones were applied three days after each pinching. The apple trees were treated first when the terminal shoot reached a length of 10-20 cm above the heading cut. European plums were treated for the first time when the terminal shoot of most of the trees reached a height of 60–90 cm. The treatments applied for individual cultivars and years are summarized in Table 1.

Measurements

The length of the terminal shoot (TSLgth) on apples was measured on a one-year-old part of the central leader from the heading cut to the top excluding the two-year-old trunk below the heading cut. Branching was assessed

Table 1. Schedule of applied treatments for each cultivar and year

Cultivar	´Rubinola´		´Topaz´		´Elena´		´Tophit´	
Treat./Year	2015	2016	2015	2016	2015	2016	2015	2016
C	x	x	x	x	x	x	x	x
BA2	x	x	x	x	x	x	x	x
BA4	x	x	x	x	x	x	x	x
BA2+4N	x	x	x	x				
BA2+GA2	x	x	x	x	x	x	x	x
BAGA2	x	x	x	x	x	x	x	x
BAGA2D	x		x					
P4	x	x	x	x	x	x	x	x
P2+BA2		x		x				
P2+BAGA2		x		x				

by counting the number of feathers in three lengths: short feathers 1–10 cm (ShortF), medium feathers 10–30 cm (MedF), and long feathers (LongF) longer than 30 cm. Spurs shorter than 1 cm were excluded from assessments. Thus, the total number of feathers (TotF) was obtained. The height of the first feather (FFHght) was measured as the distance from the heading cut to the first feather. Branching of European plums was assessed in the same way used for apples. Since these trees were one year old, some parameters were measured in a different way. The length of the terminal shoot (TSLgth) was measured from the bud union to the top. The height of the first feather (FFHght) was measured as the distance from the bud union to the first feather. Moreover the trunk diameter (TDiam) for plums was measured 10 cm above the bud union. The characteristics were determined for both fruit species at the dormant stage of the trees after leaf fall in both years.

Layout and data analysis

The trial was established in a randomized complete block design for each cultivar. Three replications of 10 plants were used for each treatment of European plum and three replications of 12 apple plants. Marked plants initially designated for assessment exhibiting some growth interruption due to damage of the growing tip that affected the branching were excluded from all analyses. Data were tested for normality and homogeneity of variance. Since only some parameters met these conditions, the data were analysed using the nonparametric Kruskal-Wallis test and mean separation was achieved using the Wilcoxon-Mann-Whitney test with ´R´ statistical software (R core team, 2018). The assessment of the variables in single factorial analysis was carried out applying the Kruskal-Wallis test.

RESULTS

Apples

The cultivar ´Rubinola´ had in 2015 the longest terminal shoots in C and significantly shorter in BA4 and BAGA2D (Table 2). In 2016, the terminal shoots were longest in C and BA2+GA2 while BA4 produced the shortest ones (Table 3). In C, the position of the first feather was the highest for all the treatments in both years. The number of feathers was the highest in BA4 and lowest in C and P4 in both years. The number of short feathers was the highest in BA4 in both years. The number of short feathers was lower in C, P4 and BAGA2

Table 2. The mean values of terminal shoot length, first feather height, number of all feathers, and feathers of three lengths of apple cv. ´Rubinola´ in 2015

Treatment	TSLgth (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	125.1 a	37.4 a	0.57 f	0.19 e	0.27 c	0.11 c
BA2	120.5 ab	9.8 cd	4.34 d	3.34 c	0.59 c	0.42 bc
BA2+GA2	114.2 ab	17.7 bc	5.30 cd	2.46 cd	1.92 b	0.92 b
BA2+4N	121.4 ab	5.5 e	7.13 b	4.87 b	1.64 b	0.62 bc
BA4	112.5 b	7.8 de	13.37 a	8.61 a	4.13 a	0.63 bc
BAGA2	116.8 ab	27.4 b	1.49 e	0.62 e	0.46 c	0.41 bc
BAGA2D	103.5 c	12.5 c	6.51 bc	2.00 d	2.38 b	2.14 a
P4	114.7 ab	28.4 b	0.65 f	0.33 e	0.13 c	0.20 bc

Means within columns followed by the same letters do not differ significantly at P≤0.05

Table 3. The mean values of terminal shoot length, first feather height, number of all feathers, and feathers of three lengths of apple cv. ´Rubinola´ in 2016

Treatment	TSLgth (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	125.2 a	31.6 a	0.53 f	0.17 e	0.08 e	0.28 c
BA2	106.0 c	4.0 e	9.76 c	4.38 b	4.21 bc	1.18 b
BA2+GA2	130.8 a	5.3 de	9.51 c	4.43 b	3.22 cd	1.86 a
BA2+4N	108.9 c	3.9 e	9.47 c	3.71 bc	4.71 b	1.06 b
BA4	94.2 d	4.7 e	17.1 a	10.83 a	5.31 ab	0.97 b
P2+BA2	106.8 c	14.5 c	11.48 b	4.63 b	6.41 a	0.44 c
BAGA2	112.7 bc	14.3 c	4.74 e	1.62 d	1.97 d	1.15 b
P2+BAGA2	103.4 c	19.6 b	7.78 d	2.65 cd	4.57 b	0.57 c
P4	117.7 b	10.6 cd	0.66 f	0.24 e	0.08 e	0.34 c

Means within columns followed by the same letters do not differ significantly at P≤0.05

in 2015 and in C and P4 in 2016. In 2015, the number of medium feathers was the highest in BA4 and the lowest in P4, C, BAGA2 and BA2. In 2016, the number of medium feathers was higher in P2+BA2 and BA4 and lower in C and P4. In 2015 the number of long feathers was the highest in BAGA2D of all the treatments. In 2016, the number of long feathers was the highest in BA2+GA2 and lower in C, P4, P2+BA2 and P2+BAGA2.

The terminal shoots of the cultivar ´Topaz´ were longer in C than in BA2, P4, BA2+4N and BAGA2 in 2015 (Table 4). In 2016 the terminal shoots were the longest in BA2+GA2 and shorter in treatments P4 and P2+BA2 (Table 5). The first feather grew the highest up in BAGA2 (2015) and in C (2016) and was lower in BA2, BA4, BA2+GA2 and BA2+4N in 2015. The same treatments complemented with BAGA2 had lower first feather height in 2016. The total number of feathers grew highest in BA4 in both years. The total number of all feathers was the lowest in C in 2015 and in C with P4 in 2016. The number of short feathers was the highest in BA4 and lower in C and P4 in 2015. In 2016 the number of short feathers was higher in BA4, BAGA2, BA2, P2+BA2 and

Table 4. The mean values of terminal shoot length, first feather height, number of all feathers, and feathers of three lengths of apple cv. ´Topaz´ in 2015

Treatment	TSLgth (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	129.3 a	12.4 b	2.14 e	1.50 d	0.44 e	0.19 e
BA2	109.5 b	2.9 c	9.68 c	3.32 bc	4.06 b	2.29 ab
BA2+GA2	117.2 ab	4.2 c	11.74 b	3.91 b	4.66 b	3.17 a
BA2+4N	112.4 b	5.0 c	9.57 c	3.83 b	3.89 b	1.86 abc
BA4	120.5 ab	3.8 c	15.68 a	6.11 a	8.11 a	1.46 c
BAGA2	115.3 b	15.7 a	6.06 d	2.67 c	2.56 c	0.83 d
P4	110.9 b	12.2 b	5.89 d	2.49 cd	1.63 d	1.77 bc

Means within columns followed by the same letters do not differ significantly at P≤0.05

Table 5. The mean values of terminal shoot length, first feather height, number of all feathers, and feathers of three lengths of apple cv. ´Topaz´ in 2016

Treatment	TSLgth (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	77.8 bc	11.7 a	5.00 d	3.64 c	1.30 e	0.06 c
BA2	73.9 c	2.2 c	11.82 bc	5.18 ab	5.74 bc	0.91 a
BA2+GA2	93.1 a	2.2 c	12.89 b	4.11 bc	8.19 a	0.59 b
BA2+4N	73.3 c	2.2 c	11.38 bc	3.97 c	6.24 b	1.18 a
BA4	72.1 c	2.3 c	14.41 a	5.56 a	8.41 a	0.44 b
P2+BA2	68.7 d	4.2 b	12.18 bc	4.90 abc	7.03 ab	0.26 bc
BAGA2	80.6 b	3.3 c	10.48 c	5.43 a	4.57 c	0.48 b
P2+BAGA2	74.3 c	4.2 b	11.71 bc	4.43 abc	7.17 ab	0.11 bc
P4	68.7 d	6.4 b	5.43 d	2.61 d	2.65 d	0.17 bc

Means within columns followed by the same letters do not differ significantly at P≤0.05

P2+BAGA2, whereas in P4 the number was the lowest. In 2015 the number of medium feathers was the highest in BA4 and the lowest in C. In 2016 the number of medium feathers was higher in BA4, BA2+GA2, P2+BAGA2 and P2+BA2 and the lowest in C. In 2015 the number of long feathers was higher in BA2+GA2, BA2 and BA2+4N and the lowest in C. In 2016, the number of long feathers was higher in BA2+4N and BA2 and lower in C, P2+BAGA2, P4 and P2+BA2. Cultivar ´Topaz´ was also treated with BAGA2D but this treatment damaged the growing tips and was not assessed and not included in the analysis.

The effect of the cultivar and treatment had a statistically significant effect on all the parameters (P = 0.05; Table 6). The effect of the year was significant in all the parameters except the number of long feathers.

Plums

No significant differences in the length of the terminal shoot of the cultivar 'Elena' were monitored in 2015 (Table 7). In 2016, the length of the terminal shoot after all the treatments was similar except for treatment P4 after which the shoots were the shortest (Table 8). No significant differences were observed in trunk diameter

Table 6. The effect of the cultivar, treatment, and year on parameters of apple analysed using the Kruskal-Wallis test

Factor	TSLgth (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
Cultivar	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Year	<0.001	<0.001	<0.001	<0.001	<0.001	0.1618

Table 7. The means of terminal shoot length, trunk diameter, first feather height, number of all feathers, and feathers of three lengths of plum cv. ´Elena´ in 2015

Treatment	TSLgth (cm)	TDiam (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	232.3 a	1.61 a	61.5 a	4.80 c	1.33 d	1.17 d	2.30 b
BA2	226.0 a	1.67 a	52.6 a	10.96 b	5.60 b	2.44 bc	2.92 b
BA2+GA2	235.1 a	1.74 a	53.8 a	10.04 b	3.08 c	2.83 bc	4.13 ab
BA4	231.5 a	1.75 a	52.3 a	18.35 a	8.92 a	5.88 a	3.54 ab
BAGA2	230.6 a	1.71 a	62.3 a	6.71 c	2.29 cd	1.52 cd	2.90 b
P4	218.0 a	1.67 a	56.1 a	10.52 b	1.77 d	3.26 b	5.48 a

Means within columns followed by the same letters do not differ significantly at P≤0.05

Table 8. The means of terminal shoot length, trunk diameter, first feather height, number of all feathers, and feathers of three lengths of plum cv. ´Elena´ in 2016

Treatment	TSLgth (cm)	TDiam (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	240.8 a	2.11 a	65.9 a	2.61 d	0.30 e	0.15 d	2.15 b
BA2	235.0 a	2.00 a	59.3 ab	8.68 c	5.28 c	1.88 c	1.52 b
BA2+GA2	230.9 a	1.96 a	54.7 b	11.30 b	6.78 b	2.19 c	2.33 b
BA4	230.6 a	2.07 a	56.0 ab	16.15 a	8.35 a	5.04 a	2.77 b
BAGA2	241.8 a	2.62 a	60.0 a	1.59 d	0.44 e	0.26 d	0.89 c
P4	189.2 b	1.96 a	63.8 a	9.73 bc	1.03 d	3.60 b	5.10 a

Means within columns followed by the same letters do not differ significantly at P≤0.05

among the treatments in both years. The height of the first feather did not exhibit significant differences related to treatments in 2015. In 2016, the height of the first feather was lower in BA2+GA2 than in C, P4 and BAGA2. The number of all feathers was the highest in BA4 regardless of the year. The number of all feathers was lower in C and BAGA2 in both years. The number of short feathers was the highest in BA4 in both years. The number of short feathers was lower in C, P4 and BAGA2 (2015) and C and BAGA2 (2016). The number of medium feathers was the highest in BA4 and lower in C and BAGA2 in both years. The number of long feathers was the highest in P4 and lower in C, BAGA2 and BA2 in 2015. In 2016, the number of long feathers was the highest in P4 and the lowest in BAGA2.

The terminal shoots of the cultivar ´Tophit´ were longer in BAGA2 and BA2+GA2 and the shortest in P4 in 2015 (Table 9). No significant differences were observed in the length of terminal shoots among the treatments in 2016 (Table 10).

Table 9. The means of terminal shoot length, trunk diameter, first feather height, number of all feathers, and feathers of three lengths of plum cv. ´Tophit´ in 2015

Treatment	TSLgth (cm)	TDiam (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	204.0 bc	1.88 a	56.1 a	7.31 d	2.28 d	1.55 c	3.48 ab
BA2	203.8 c	1.90 a	47.8 b	14.10 b	7.74 b	3.10 b	3.26 ab
BA2+GA2	213.6 ab	1.90 a	49.5 ab	13.23 b	7.03 b	2.84 b	3.35 ab
BA4	197.1 c	1.85 a	49.0 ab	21.17 a	13.60 a	4.77 a	2.80 b
BAGA2	224.0 a	2.02 a	52.3 ab	10.83 c	4.38 c	2.84 b	3.92 ab
P4	181.3 d	1.79 a	51.0 ab	10.50 c	2.46 d	2.54 b	5.14 a

Means within columns followed by the same letters do not differ significantly at P≤0.05

Table 10. The means of terminal shoot length, trunk diameter, first feather height, number of all feathers, and feathers of three lengths of plum cv. ´Tophit´ in 2016

Treatment	TSLgth (cm)	TDiam (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
C	187.0 a	2.19 a	59.6 a	5.43 e	0.89 c	1.11 d	3.43 a
BA2	176.3 a	2.04 a	52.9 bc	10.28 c	5.52 b	2.56 bc	2.20 a
BA2+GA2	193.9 a	2.19 a	53.5 bc	12.24 b	4.97 b	3.48 b	3.79 a
BA4	169.5 a	2.08 a	52.4 c	17.21 a	8.75 a	5.39 a	3.07 a
BAGA2	185.8 a	2.16 a	51.4 c	11.36 bc	4.71 b	3.36 b	3.29 a
P4	184.7 a	2.07 a	58.9 ab	7.15 d	1.07 c	2.22 c	3.85 a

Means within columns followed by the same letters do not differ significantly at P≤0.05

There were no significant differences in trunk basal diameters among the treatments in both years. The height of the first feather was significantly lower only in BA2 as compared to C in 2015. In 2016, the height of the first feather was lower than in C for all treatments except P4. The number of all feathers was the highest in BA4 and the lowest in C in both years.

The number of short feathers was the highest in BA4 and lowest in C and P4 in both years. The number of medium feathers was the highest in BA4 and the lowest in C in both years. The number of long feathers was higher in P4 than in BA4 in 2015, whereas there were no significant differences in 2016.

The effect of the cultivar and the year was significant in all parameters (P = 0.05; Table 11). The effect of the treatment was significant in all parameters except for the trunk diameter.

Table 11. The effect of the cultivar, treatment, and year on parameters of European plum analysed using the Kruskal-Wallis test

Factor	TSLgth (cm)	TDiam (cm)	FFHght (cm)	TotF	ShortF 1-10 cm	MedF 10-30 cm	LongF >30 cm
Cultivar	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0025
Treatment	<0.001	0.1434	<0.001	<0.001	<0.001	<0.001	<0.001
Year	<0.001	<0.001	<0.001	<0.001	<0.001	0.0373	0.0021

DISCUSSION

As expected, acquired results show that the quadruple application of benzyladenine (BA4) has always been the most effective in increasing the number of feathers on apples. This finding is in accordance with previous results reported by Wertheim and Estabrooks (1994) and Hrotkó et al. (2000). Nevertheless, the increase concerned mainly short and medium feathers. Although these feathers are useful, the main commercial indicator of quality is typically the number of feathers longer than 30 cm. On ´Rubinola´cultivar, the long feathers (>30 cm) were difficult to induce. In 2015, the highest number of the longest feathers on ´Rubinola´ using BAGA2D was accompanied by the growth suppression of the terminal shoot and marginal leaf necrosis. Moreover, the growing tip of 'Topaz' was damaged by this treatment. Therefore, branching was not assessed in this cultivar. This problem confirmed that the mixture of benzyladenine and gibberellins at a concentrations of 1000 mg·l^{-1} each was too high.

Consistently effective treatment which would increase the number of long (>30 cm) feathers for both apple cultivars was not found. The best solution appears to be combining benzyladenine application followed by separate applications of gibberellin. This approach is similar to that of Popenoe and Barritt (1988) and Volz et al. (1994) who applied it successfully to apple trees. This separate application first awakens the buds with benzyladenine and then gibberellin sprays (BA2+GA2) stimulates elongation growth. The subsequent application is more effective than the application of benzyladenine and gibberellin mixtures in a single spray (BAGA2). The mixture was often less effective than two applications of benzyladenine (BA2) alone.

Another strategy leading to an increase in the number and/or length of feathers was an increase in N fertilization during the branching period. Hague and Neilsen (1991), Médiène et al. (2002), and Cook et al. (2004) demonstrated the positive effect of N on the quality of sylleptic branching. Nevertheless, realized experiment did not confirm the impact of N fertilization combined with benzyladenine applications and no effect was observed in comparison with just double benzyladenine application. The only exception was the total number of all feathers on ´Rubinola´ in 2015 that was however related to a higher number of short and medium-sized feathers.

Pinching alone (P4) did not affect any apple cultivar with an exception of only slight effect on ´Topaz´ in 2015. This result is in accordance with the reports of Volz et al. (1994), Kviklys (2006), and Jung and Lee (2008) who also observed that leaf pinching of apples was not very effective. Combination of this technique with benzyladenine applications (P2+BA2) only slightly increased the total number of shoots on ´Rubinola´, with no effect on ´Topaz´, and the number of the longest shoots did not change either, as compared to double benzyladenine applications (BA2) to both cultivars. Pinching combined with a mixture of benzyladenine and gibberellins (P2+BAGA2) did not provide any better results in terms of the total number of feathers or number of long feathers. The results generally demonstrated that the effect of combinations of mechanical and chemical methods was negligible on the tested cultivars. These results were similar to the findings of Hrotkó et al. (1997) and Bektas and Ersoy (2010).

On plums, the quadruple benzyladenine application led to the highest number of all feathers, but, similar to apples, these were mostly short and medium feathers. In contrast to apples, pinching was generally the most effective method of increasing the number of long feathers (>30 cm), though it did not increase too much the number of all shoots compared to the control. Pinching can be recommended for plums, however, it should be carried out by skilled workers because it requires more attention to keep the growing tip (meristem) intact. Similar to apples, the treatment combining separate sprays of gibberellins after benzyladenine (BA2+GA2) can slightly increase the number of all feathers and long feathers in comparison to only a double benzyladenine application (BA2). This confirms a small but positive impact of gibberellins applied after benzyladenine and corresponds with the results published by Magyar and Hrotkó (2002). On the other hand, sprays with a mixture of these compounds (BAGA2) usually resulted in lower numbers of shoots than benzyladenine application alone and was generally less effective.

Considering the effect of treatments on other crown parameters, it is obvious that in all the well-branching treatments the height of the first feather of both species was as desired. Magyar and Hrotkó (2002) confirmed on plums that increasing BA concentrations caused smaller growth of trunk diameter. Results from both experimental years showed that the trunk diameter of plums did not differ in reaction to applied treatment. The length of the terminal shoot was generally reduced by pinching and by benzyladenine application. This effect was also observed by Wertheim (1978), Cody et al. (1985), and Magyar and Hrotkó (2002). Even though this effect was registered in results, it was negligible from the practical point of view. Gibberellins generally slightly reduced this shortening effect, an issue that was also shown by Dorić et al. (2015). Comparing the cultivars, the apple ´Topaz´ branched easier than ´Rubinola´ and the plum ´Tophit´ branched more readily than ´Elena´. Generally, branching was better in 2016 than in 2015 and can be attributed to the better conditions during the time of syllepsis (Lindhagen, 1998). Nevertheless, the effects of other factors such as the strength of the root system influenced by the previous year could not be refuted (Cook et al., 2004; Jacyna, 2007).

Obviously, no universal treatment giving ideal results exists. If the goal of the nurseryman is to have as many of the longest feathers as possible then the best solution for apples seems to be the combination of benzyladenine applications followed by gibberellin applications. For plums multiple leaf pinching appears to be effective. On the other hand, if the fruit grower requires trees with as many feathers as possible regardless of their length (e.g. for super-spindle orchards) then multiple applications of benzyladenine should be used.

CONCLUSIONS

The highest number of all feathers was achieved for both species when BA was applied four times. This treatment led mainly to the increase in numbers of shorter feathers. The efficiency of pinching was poor and the combination of pinching and phytohormone application was not very productive in apples either. In contrast to apples, most of the feathers longer than 30 cm grew when pinching alone was carried out on plum cultivars. Benzyladenine followed by gibberellin applications had a slight but positive effect on the number and quality of branching in both species.

ACKNOWLEDGEMENTS

The research was supported by the Ministry of Agriculture, Czech Republic, Project NAZV No. QJ 1510081 and by the Ministry of Education, Youth and Sports, Czech Republic, Project NPU I. No. LO1608.

REFERENCES

Bektas, M., Ersoy, N. (2010) Branch induction on apple (*Malus domestica* L.) nursery trees: Effects of Perlan (GA4+7+6BA) and pinching. Journal of Food, Agriculture & Environment, 8 (3&4), 651-654. DOI: https://doi.org/10.1234/4.2010.3287

Cody, C., Larsen, F. E., Fritts, R. Jr. (1985) Induction of lateral branches in tree fruit nursery stock with propyl 3-t-butylphenoxy acetate (MB 25, 105) and Promalin (GA_{4+7} + 6-benzyladenine). Scientia Horticulturae, 26 (2), 111-118. DOI: https://doi.org/10.1016/0304-4238(85)90003-2

Cook, N. C., De Wit, I., Wustenberghs, H., Andersone, D., Keulemans, J., Coucke, W. (2004) Rootstock and nutrition modify sylleptic branching in sweet cherry cv. 'Bigarreau Van'. Acta Horticulturae, 658, 45-49. DOI: https://doi.org/10.17660/ActaHortic.2004.658.2

Champagnat, P. (1954) Recherches sur les rameaux anticipés des végétaux ligneux. Revue et de Cytologie et de Biologie Végétales, 15, 1-51.

Dorić, M., Keserović, Z., Magazin, N., Milić, B. (2015) The effects of BA and BA+ GA_{4+7} on the main shoot growth dynamics and the feather formation in two-year-old 'knip-boom' apple trees. In: Proceedings of 50th Croatian & 10th International Symposium on Agriculture. Opatija, Croatia, 16-20 February 2015, University of Zagreb, 555-559.

Elfving, D. C. (2010) Plant bioregulators in the deciduous fruit tree nursery. Acta Horticulturae, 884, 159-166. DOI: https://doi.org/10.17660/ActaHortic.2010.884.18

Elfving, D. C., Visser, D. B. (2006) The use of bioregulators in the production of deciduous fruit trees. Acta Horticulturae, 727, 57-66. DOI: https://doi.org/10.17660/ActaHortic.2006.727.4

Hague, E. J., Neilsen, D. (1991) Rapid production methods for Ottawa-3 rootstock and branched apple nursery stock. HortScience, 26 (11), 1416-1419. DOI: https://doi.org/10.21273/HORTSCI.26.11.1416

Hrotkó, K., Magyar, L., Ronay, Z. (2000) Improved feathering on apple nursery trees by BA application. Acta Horticulturae, 514, 113-119. DOI: https://doi.org/10.17660/ActaHortic.2000.514.12

Hrotkó, K., Magyar, L., Yao, C., Rónay, Z. (1997) Effect of repeated BA (benzyladenine) application on feathering of 'Idared' apple nursery trees. Acta Horticulturae, 463, 169-175. DOI: https://doi.org/10.17660/ActaHortic.1998.463.19

Jacyna, T. (2007) Growth correlations in apple nursery trees. Annales Universitatis Mariae Curie-Sklodowska, 17, 9-16.

Jung, H. W., Lee, J. Y. (2008) Physical treatments influencing lateral shoot development in one-year-old ´Fuji´/M.9 nursery apple trees. Horticulture environment and Biotechnology, 49 (5), 265-270.

Kviklys, D. (2004) Apple rootstock effect on the quality of planting material. Acta Horticulturae, 658, 641-645. DOI: https://doi.org/10.17660/ActaHortic.2004.658.97

Kviklys, D. (2006) Induction of feathering of apple planting material. Agronomijas Vestis, 9, 58-63.

Lindhagen, M. (1998) Predicting branching in young apple trees (*Malus domestica* Borkh.). Acta Horticulturae, 456, 125-131. DOI: https://doi.org/10.17660/ActaHortic.1998.456.14

Lordan, J., Robinson, T. L., Sazo, M. M., Cowgill, W., Black, B. L., Huffman, L., Grigg-McGuffin, K., Francescatto, P., McArtney, S. (2017) Use of plant growth regulators for feathering and flower suppression of apple nursery trees. HortScience, 52 (8), 1080-1091. DOI: https://doi.org/10.21273/HORTSCI11918-17

Médiène, S., Pagès, L., Jordan, M. O., Le Bot, J., Adamowicz, S. (2002) Influence of nitrogen availability on shoot development in young peach trees [*Prunus persica* (L.) Batsch]. Trees, 16 (8), 547-554. DOI: https://doi.org/10.1007/s00468-002-0204-4

Magyar, L., Hrotkó, K. (2002) Effect of 6-benzyladenine (BA) and gibberellic acid (GA4+7) application on feathering of plum cultivars in nursery. Acta Horticulturae, 577, 345-349. DOI: https://doi.org/10.17660/ActaHortic.2002.577.59

Nečas, T., Wolf, J., Kiss, T., Láčík, J., Letocha, T. (2018) Use of different plant growth regulators for control of shoot branching in apple and pear trees. Acta Horticulturae, 1206, 225-232. DOI: https://doi.org/10.17660/ActaHortic.2018.1206.31

Popenoe, J., Barritt, B. H. (1988) Branch induction by growth regulators and leaf removal in ´Delicious´ apple nursery stock. HortScience, 23 (5), 859-862.

Quinlan, J. D., Preston, A. P. (1973) Chemical induction of branching in nursery trees. Acta Horticulturae, 34, 123-128. DOI: https://doi.org/10.17660/ActaHortic.1973.34.14

R Core team (2018): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sadowski, A., Mackiewicz, M., Dziuban, R. (2007) Growth and early bearing of apple trees as affected by the type of nursery trees used for planting. Acta Horticulturae, 732, 447-455. DOI: https://doi.org/10.17660/ActaHortic.2007.732.68

Tromp, J. (1996) Sylleptic shoot formation in young apple trees exposed to various soil temperature and air humidity regimes in three successive periods of the growing season. Annals of Botany, 77 (1), 63-70. DOI: https://doi.org/10.1006/anbo.1996.0008

Tromp, J., Boertjes, B. C. (1996) The effect of air temperature in successive periods of the growing season on sylleptic shoot formation in young apple trees. Plant Growth Regulation, 19 (2), 177-182. DOI: https://doi.org/10.1007/bf00024583

van den Berg, A. (2003) Certified Nursery Tree Production in Holland. The compact fruit tree, 36 (2), 43-45.

van Oosten, H. J. (1978) Effect of initial tree quality on yield. Acta Horticulturae, 65, 123-127. DOI: https://doi.org/10.17660/ActaHortic.1978.65.19

Volz, R. K., Gibbs, H. M., Popenoe, J. (1994) Branch induction on apple nursery trees – effects of growth-regulators and defoliation. New Zealand Journal of Crop and Horticultural Science, 22, 277-283. DOI: https://doi.org/10.1080/01140671.1994.9513836

Wertheim, S. J. (1978) Manual and chemical induction of side-shoot formation in apple-tree nursery. Scientia Horticulturae, 9 (4), 337-345. DOI: https://doi.org/10.1016/0304-4238(78)90043-2

Wertheim, S. J., Estabrooks, E. N. (1994) Effect of repeated sprays of 6-benzyladenine on the formation of sylleptic shoots in apple in the fruit-tree nursery. Scientia Horticulturae, 60 (1-2), 31-39. DOI: https://doi.org/10.1016/0304-4238(94)90060-4

Wilson, S. J., Jarassamrit, N. (1994) Nursery factors influencing lateral shoot development in a spur type apple cultivar. Scientia Horticulturae, 56 (3), 207-2015. DOI: https://doi.org/10.1016/0304-4238(94)90003-5