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Leaf pinching and phytohormones – two important components for the branching induction on sweet cherry

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Abstract: The promising branching agent cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid] is not permitted in the EU and the low vigour rootstocks preferred by growers make the branching of young sweet cherry (*Prunus avium*) trees difficult in the temperate zone production regions. To increase the number and length of new branches ("feathers") on such trees, chemical (6-benzyladenine [BA], gibberellic acid [$GA_{4/7}$]), mechanical (leaf pinching, summer notching) and various combined treatments were tested from 2015–2018. The numbers of feathers divided into three different lengths (1–10 cm, 10–30 cm and > 30 cm) were assessed as the main indicator of quality, supplemented with other morphological characteristics. Summer notching induced an insufficient number of feathers and led to some negative effects on the trees. The number of feathers from BA or BA with $GA_{4/7}$ treatment also was insufficient. The effect of pinching alone was variable. The number of all feathers generally was the highest when pinching was combined with BA, regardless of the year or cultivar.

Keywords: *Prunus avium*; notching; sylleptic branching; benzyladenine; surfactant

In Europe, the spindle training is the main canopy architecture for growing sweet cherry (*Prunus avium*) trees. The best nursery tree for spindle training has numerous well-developed side branches originating from sylleptic shoots (feathers) which usually have the desired qualities to become productive long-lasting branches. The occurrence of syllepsis (overcoming apical dominance) is dependent on many environmental (Tromp 1996; Tromp, Boertjes 1996) and biological conditions like the cultivar and rootstock (Cook et al. 2004; Baryla et al. 2014). There are two common ways of growing sweet cherries in nurseries. The first is bench-grafting the scion on thicker rootstock and growing two-year-old knip trees (van den Berg 2003); these exhibit stronger growth and respond better to induction of sylleptic branching in the second year. This is the main advantage, although there are also some substantial disadvantages, such as the higher price of rootstock, greater demand for graft-wood and sometimes too strong trees. The second is summer budding of smaller rootstocks and growing one-year-old trees. These smaller trees, however, do not branch so easily, and branching is further decreased by the use of dwarfing rootstocks (Cook et al. 2004; Baryla et al. 2014) and frequent suboptimal conditions in temperate zone growing regions. This nursery tree type is cheaper, and if it is well-branched, it is widely usable.

To improve feathering, some chemical and mechanical methods have been tested. Cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid] was very promising (Elfving,

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Visser 2006b; Elfving, Visser 2006c; Elfving 2010; Stanisavljević et al. 2015), but it is unavailable in the EU and in many regions of the world. Of the many chemicals tested by Wolf et al. (2018), the most effective and available branching agent was the cytokinin 6-benzyladenine (BA) often applied with gibberellins $GA_{4/7}$ or GA_3 (Hrotkó et al. 1998; Hrotkó et al. 1999; Elfving, Visser 2006a; Koyuncu, Yildirim 2008; Moghadam, Zamanipour 2013). Leaf pinching is a mechanical method that removes (by pinching out) some of the youngest leave blades while the growing tip (meristem) stays intact (Neri et al. 2004). Another mechanical method that occasionally can be used for prolepsis induction is the notching of one-year-old whips at the end of winter (Greene, Autio 1994; Elfving, Visser 2007; von Bennewitz et al. 2014). This technique is nevertheless labour-demanding, extends the growing period in the nursery by one year, and may increase susceptibility to disease infections such as bacterial canker (*Pseudomonas syringae*) in some climates.

Our goal was to find the most effective way to increase sylleptic branching on one-year-old trees grown on weak rootstocks in the temperate zone. In 2015 and 2016, the focus was on testing combinations of chemical and mechanical methods, and great efforts were made to test a summer notching technique on new cultivars with unknown branching ability. Notching was not performed in early spring as is sometimes used to induce proleptic branching, but during the summer on growing terminal shoots in order to activate the side buds in leaf axils and induce sylleptic branching. In the following years, the experiments were conducted on two older cultivars with contrasting branching ability, first to test combined treatments and second to test the importance of the rate of the surfactant.

MATERIAL AND METHODS

The experimental nursery was located at the Research and Breeding Institute of Pomology, Holovousy, Czech Republic. The trees were planted in medium fertile replant irrigated plots. Two new cultivars of unknown branching ability, 'Tamara' and 'Kasandra', were used in 2015 and 2016 (Experiment 1); the difficult-to-branch 'Samba' and easy-to-branch 'Kordia' were used in 2017 (Experiment 2) and 2018 (Experiment 3). All were budded in summer on dwarfing rootstock Gisela 5. One-year-old trees spaced 1.2 × 0.25 m were used for the induction of branching. All the sylleptic shoots up to 55 cm above the soil were gradually removed during the growth of the central leader. They were removed in a softwood stage, approximately at length 2–5 cm. The trees were first treated when the terminal shoot of most trees reached a height between 50–80 cm. Dates of first treatment were the following: 4/6/2015, 9/6/2016, 12/6/2017, and 28/5/2018. June and July is the crucial time for sylleptic branching, and the weather conditions differed for each of the four experimental years. The climate in 2015 was hot and dry with some periods of lower temperatures in June and July, and 2016 was mild and stable with temperatures around 20–25°C. The climate in 2017 was stable and hotter, but 2018 was very hot and dry with some periods of lower temperature. Maximal temperatures, minimal temperatures and air humidity are given in Figs 1 and 2.

Various chemical, mechanical and combined methods were used. The following products were included in chemical induction: Globaryll 100 containing benzyladenine (BA) in a concentration of 100 g/l, Gibb Plus containing gibberellins $GA_{4/7}$ 10 g/l (both Globachem NV, Sint-Truiden,

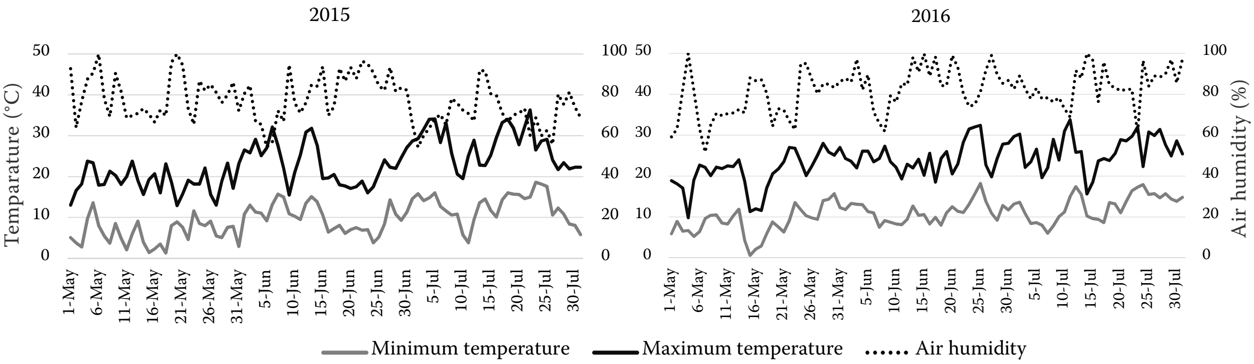

Fig. 1. Daily minimum and maximum temperatures (°C) and average relative humidity (RH%) from 1st May to 31st July 2015 and 2016 at the Research and Breeding Institute of Pomology, Holovousy, Czech Republic

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Table 1. List of treatments used in Experiments 1–3. The rates of active ingredients are in mg/l

Treatment	Description	Ex. 1	Ex. 2	Ex. 3
C	untreated control	x	x	x
BAGA2	Progerbalin 1,000 2×	x	x	
P2+BAGA2	pinching 2× + Progerbalin 1,000 2×	x	x	
P2+BAGA2+N	pinching 2× + Progerbalin 1,000 2× + notching	x		
P4+N	pinching 4× + notching	x		
P2+BA2+N	pinching 2× + Globaryll 1,000 2× + notching	x		
P2+NBAGA	pinching 2× + notching immediately followed with an application of Progerbalin 1,000 1× (Ex. 1 only in 2016)	x	x	
BAGA2D	Progerbalin 2,000 2× (only Samba)		x	
BA2	Globaryll 1,000 2×		x	
BA2+GA2	Globaryll 1,000 2× (first two sprays) + Gibb Plus 2× (third and fourth spray)		x	
P2+BA2	pinching 2× + Globaryll 1,000 2×		x	
P4	pinching 4×		x	x
P4+BA3	pinching 4× + Globaryll 1,000 3×		x	x
BA3	Globaryll 1,000 3×			x
BA3 3S	Globaryll 1,000 with Silwet 3 ml/l 3×			x
BA3 5S	Globaryll 1,000 with Silwet 5 ml/l 3×			x
BA3 10S	Globaryll 1,000 with Silwet 10 ml/l 3×			x
10S	Silwet 10 ml/l 3×			x

Belgium) and Progerbalin® LG containing benzyladenine 18.8 g/l + gibberellins $GA_{4/7}$ 18.8 g/l (L. Gobbi, Genova, Italy). Unless specified otherwise, Silwet L-77® in a dose of 1.5 ml/l (Momentive Performance Materials, Friendly, WV, USA) was always used as a surfactant. A household hand sprayer was used to apply ~3 ml at each spray, moistening few of the top leaves and around 20 cm of the shoot. Two mechanical techniques were used. Pinching – partial removing of the youngest developing leaves (approximately 2/3 of the blade) with the growing tip and meristem remaining intact. The second was modified summer notching. Notching cuts were made with a hacksaw blade approx. 5 mm above leaf axillary buds deep enough to feel the cutting of the xylem tissues. Around 10 to 15 notches were made on each plant at a height of 60–85 cm. At this time, the tissues in the notched area were becoming woody (19/7/2015, 11/7/2016, 3/7/2017). Combinations of these methods were tested several times as well. The treatments of Experiments 1–3 are summarized and described in Table 1. Phytohormones were applied in 10-day intervals. Pinching alone was applied in a 7-day interval. In the treatments combining pinching and application of phytohormones, the interval of

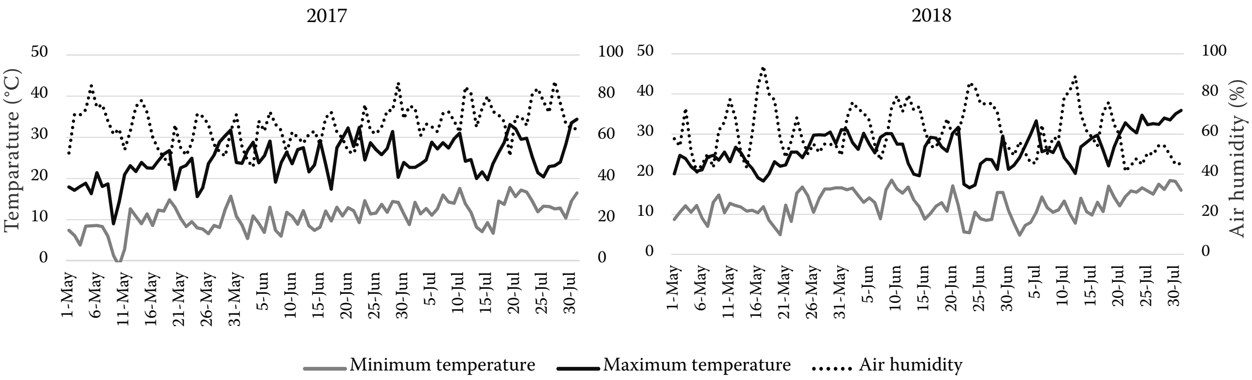

Fig. 2. Daily minimum and maximum temperatures (°C) and average relative humidity (RH%) from 1st May to 31st July 2017 and 2018 at the Research and Breeding Institute of Pomology, Holovousy, Czech Republic

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Table 2. Mean height, number of nodes and diameter of the central leader as well as the height of the first side shoot, shoot number and shoot types along the central leader of 'Kasandra' sweet cherry grafted on Gisela 5 in 2015 and 2016

Treatment	Central leader length (cm)	Nodes on central leader (No.)	Trunk diameter (cm)	Height of first shoot (cm)	Shoots per tree (No.)	Shoots 1–10 cm (No.)	Shoots 10–30 cm (No.)	Shoots > 30 cm (No.)
2015								
C	154.4^{a}	63.8^{a}	1.76^{a}	69.0^{a}	1.1^{c}	0.1^{a}	0.0^{b}	1.0^{c}
BAGA2	157.1^{a}	61.1^{a}	1.69^{ab}	67.1^{a}	0.8^{c}	0.1^{a}	0.0^{b}	0.8^{c}
P2+BAGA2	141.4^{bc}	53.7^{b}	1.67^{b}	65.0^{a}	2.7^{b}	0.2^{a}	0.6^{a}	1.9^{b}
P2+BAGA2+N	142.4^{b}	54.2^{b}	1.84^{a}	61.7^{a}	2.9^{b}	0.1^{a}	0.1^{b}	2.6^{b}
P2+BA2+N	133.7^{cd}	48.9^{c}	1.77^{a}	63.3^{a}	4.5^{a}	0.3^{a}	0.5^{a}	3.7^{a}
P4+N	128.5^{d}	48.2^{c}	1.59^{b}	64.9^{a}	3.0^{b}	0.1^{a}	0.9^{a}	2.1^{b}
2016								
C	149.0^{a}	56.4^{a}	1.84^{a}	56.9^{a}	0.7^{b}	0.0^{a}	0.1^{c}	0.6^{b}
BAGA2	146.4^{a}	54.7^{a}	1.74^{a}	62.6^{a}	0.5^{b}	0.0^{a}	0.0^{c}	0.5^{b}
P2+BAGA2	127.4^{b}	47.7^{b}	1.74^{a}	63.8^{a}	2.9^{a}	0.2^{a}	0.7^{ab}	2.0^{a}
P2+BAGA2+N	112.5^{c}	44.6^{b}	1.69^{a}	61.1^{a}	3.0^{a}	0.2^{a}	1.3^{a}	1.4^{a}
P2+BA2+N	113.8^{c}	45.1^{b}	1.70^{a}	62.3^{a}	3.9^{a}	0.3^{a}	1.5^{a}	2.2^{a}
P4+N	117.0^{c}	46.2^{b}	1.75^{a}	61.6^{a}	3.1^{a}	0.2^{a}	0.8^{ab}	2.1^{a}
P2+NBAGA	134.3^{b}	52.6^{a}	1.66^{a}	60.7^{a}	3.1^{a}	0.1^{a}	0.3^{b}	2.6^{a}

different letters within columns represent significant differences at $P \leq 0.05$ by the Wilcoxon-Mann-Whitney test

pinching was 10 days and phytohormones were applied three days after each pinching. Notching was applied independently on one date each year.

At the end of each season, we measured the length of the central leader from the bud union to the tip (the number of nodes on this central leader was counted in Experiment 1), height of the first shoot as a distance from the bud union to the first feather, trunk diameter 10 cm above the graft union and the number of feathers divided into three different lengths of 1–10 cm, 10–30 cm and > 30 cm.

The trial was established in randomized complete blocks for each cultivar. Three replications of 10 plants were used for each treatment. The data were not normally distributed in several parameters, thus they were analysed by the Kruskal-Wallis test and mean separation was done with the Wilcoxon-Mann-Whitney test using 'R' statistical software (R core team 2018).

RESULTS

Experiment 1 (2015–16)

On 'Kasandra', all the treatments except BAGA2 and C led to shorter central leaders in both years (Table 2). 'Tamara' had shorter central leaders in all treatments except BAGA2 compared to the control in 2015 (Table 3). In 2016, central leaders were significantly shorter only in P2+BAGA2+N, P2+BA2+N, P4+N (Table 3). These results indicated that the BAGA2 treatment did not differ from the control, but the other treatments usually led to a reduction in tree height. Statistical results of the node number of the central leader were more or less in accordance with the length of the central leader for both cultivars and years. In 2015, the trunk diameter was significantly thinner in treatments P4+N and P2+BAGA2 on 'Kasandra'. There were no significant differences in the trunk diameter of 'Kasandra' in 2016 and of 'Tamara' in both years as compared to the control. In terms of the first branch height, no significant differences were found on 'Kasandra', whereas on 'Tamara', it was significantly lower in C and BAGA2 than in the other treatments in both years. The total number of branches induced on 'Kasandra' was significantly lower in the C and BAGA2 treatments in both years, and in 2016, it was highest in P2+BA2+N. On 'Tamara', the total number of shoots was significantly lower in the C and BAGA2 treatments in 2015 and in C, BAGA2 and P4+N treatments in 2016. The highest number of shoots was in the

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Table 3. Mean height, number of nodes and diameter of the central leader as well as the height of the first lateral shoot, shoot number and shoot types along the central leader of 'Tamara' sweet cherry grafted on Gisela 5 in 2015

Treatment	Central leader length (cm)	Nodes on central leader (No.)	Trunk diameter (cm)	Height of first shoot (cm)	Shoots per tree (No.)	Shoots 1–10 cm (No.)	Shoots 10-30 cm (No.)	Shoots > 30 cm (No.)
2015								
C	175.1^{a}	61.5^{a}	1.62^{a}	60.7^{b}	0.4^{c}	0.0^{c}	0.0^{b}	0.4^{c}
BAGA2	172.4^{ab}	59.4^{ab}	1.54^{a}	59.7^{b}	0.2^{c}	0.0^{c}	0.0^{b}	0.2^{c}
P2+BAGA2	160.7^{bc}	55.1^{bc}	1.64^{a}	70.7^{a}	3.3^{a}	0.6^{a}	0.3^{a}	2.4^{ab}
P2+BAGA2+N	147.7^{c}	51.3^{d}	1.55^{a}	73.1^{a}	2.1^{b}	0.2^{b}	0.2^{a}	1.7^{b}
P2+BA2+N	149.5^{c}	53.0^{cd}	1.58^{a}	65.1^{a}	3.4^{a}	0.6^{a}	0.3^{a}	2.6^{a}
P4+N	149.6^{c}	54.0^{bc}	1.50^{a}	67.4^{a}	1.4^{b}	0.1^{b}	0.1^{ab}	1.3^{b}
2016								
C	150.9^{a}	52.8^{b}	1.54^{ab}	59.1^{b}	0.8^{bc}	0.0^{a}	0.1^{b}	0.7^{a}
BAGA2	147.2^{a}	53.1^{b}	1.44^{b}	57.5^{b}	0.2^{c}	0.0^{a}	0.0^{b}	0.1^{b}
P2+BAGA2	144.3^{a}	51.3^{b}	1.58^{a}	79.0^{a}	1.2^{ab}	0.0^{a}	0.2^{ab}	1.0^{a}
P2+BAGA2+N	130.8^{b}	48.4^{bc}	1.52^{ab}	79.6^{a}	1.1^{ab}	0.0^{a}	0.4^{a}	0.7^{a}
P2+BA2+N	123.9^{bc}	47.1^{c}	1.46^{ab}	74.1^{a}	1.8^{a}	0.0^{a}	0.7^{a}	1.1^{a}
P4+N	119.6^{c}	46.8^{c}	1.39^{b}	75.4^{a}	0.2^{c}	0.0^{a}	0.1^{b}	0.1^{b}
P2+NBAGA	156.5^{a}	58.4^{a}	1.38^{b}	78.3^{a}	1.0^{ab}	0.0^{a}	0.0^{b}	1.0^{a}

different letters within columns represent significant differences at $P \leq 0.05$ by the Wilcoxon-Mann-Whitney test

Table 4. Assessment of sweet cherry cultivar, treatment and effect of year on growth parameters analysed using the Kruskal-Wallis test in Experiment 1

Factor	Central leader length (cm)	Nodes on central leader (No.)	Trunk diameter (cm)	Height of first shoot (cm)	Shoots per tree (No.)	Shoots 1–10 cm (No.)	Shoots 10–30 cm (No.)	Shoots >30 cm (No.)
Cultivar	***	ns	***	***	***	ns	***	***
Treatment	***	***	***	*	***	***	***	***
Year	***	***	ns	ns	**	***	***	***

ns – not significant, *significant difference at $P \leq 0.05$, **significant difference at $P \leq 0.01$, ***significant difference at $P \leq 0.001$

P2+BA2+N treatment on 'Tamara'. The numbers of commercially important shoots (length > 30 cm) more or less corresponded with the total number of side shoots, especially on 'Kasandra'. Generally, the treatments that combined pinching and phytohormone applications led to higher shoot numbers. Hardly any reaction to summer notching was observed in both years and cultivars. The effect of cultivar was statistically significant for all parameters, with the exception of central leader node number and number of 1–10 cm shoots (Table 4). The effect of treatment was significant for all parameters. The effect of year was significant for all parameters except basal diameter of the trunk and height of the first branch.

Experiment 2 (2017)

The central leaders of 'Kordia' were longer for C and treatments where only phytohormones were used without pinching (Table 5). 'Samba' had the longest central leaders in BAGA2D and BA2+GA2 treatments, and shorter in P4 and P4+BA3 treatments (Table 6). The trunk diameter differed significantly from the control only in 'Kordia' treated with P2+NBAGA; 'Samba' did not differ significantly from the control. The height of the first branch of 'Kordia' was not significantly different, but the height of the first shoot of 'Samba' was higher than the control in treatments BAGA2D and P2+BAGA2. For the P4+BA3, P2+BAGA2, and

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Table 5. The length and diameter of the central leader as well as the height of the first lateral shoot, shoot number and shoot types on the central leader of 'Kordia' sweet cherry grafted on Gisela 5 in 2017

Treatment	Central leader length (cm)	Trunk diameter (cm)	Height of first shoot (cm)	Shoots per tree (No.)	Shoots 1–10 cm (No.)	Shoots 10–30 cm (No.)	Shoots > 30 cm (No.)
C	174.8[a]	1.53[ab]	79.0[a]	1.7[de]	0.0[a]	0.2[a]	1.5[c]
BAGA2	169.3[a]	1.50[ab]	94.0[a]	1.5[de]	0.1[a]	0.2[a]	1.3[c]
P2+BAGA2	153.4[b]	1.51[ab]	78.2[a]	3.8[ab]	0.1[a]	0.5[a]	3.2[b]
P2+NBAGA	139.3[c]	1.38[c]	79.3[a]	2.7[bcd]	0.0[a]	0.2[a]	2.5[b]
BA2	176.4[a]	1.51[ab]	77.4[a]	1.9[cde]	0.0[a]	0.1[a]	1.8[bc]
BA2+GA2	169.2[a]	1.41[bc]	77.0[a]	0.7[e]	0.0[a]	0.2[a]	0.6[d]
P2+BA2	147.4[bc]	1.47[ab]	76.4[a]	3.0[bc]	0.0[a]	0.3[a]	2.6[b]
P4	139.5[c]	1.47[abc]	76.4[a]	2.7[bcd]	0.0[a]	0.2[a]	2.5[b]
P4+BA3	134.3[c]	1.59[a]	73.6[a]	5.0[a]	0.0[a]	0.4[a]	4.6[a]

different letters within columns represent significant differences at $P \leq 0.05$ by the Wilcoxon-Mann-Whitney test

Table 6 . The length and diameter of the central leader as well as the height of the first lateral shoot, shoot number and shoot types on the central leader of 'Samba' sweet cherry grafted on Gisela 5 in 2017

Treatment	Central leader length (cm)	Trunk diameter (cm)	Height of first shoot (cm)	Shoots per tree (No.)	Shoots 1–10 cm (No.)	Shoots 10–30 cm (No.)	Shoots > 30 cm (No.)
C	143.0[b]	1.52[ab]	63.8[c]	0.8[c]	0.0[b]	0.1[b]	0.6[c]
BAGA2	137.3[bc]	1.47[b]	62.1[c]	1.0[bc]	0.0[ab]	0.1[b]	0.9[bc]
P2+BAGA2	143.9[b]	1.64[a]	74.5[ab]	2.6[a]	0.2[a]	0.7[a]	1.7[ab]
P2+NBAGA	134.3[c]	1.46[b]	70.6[abc]	2.2[ab]	0.1[a]	0.1[b]	2.0[a]
BA2	140.8[b]	1.43[b]	64.4[c]	0.6[c]	0.0[b]	0.1[b]	0.5[c]
BA2+GA2	159.8[a]	1.49[b]	69.2[abc]	0.9[bc]	0.0[b]	0.0[b]	0.9[bc]
P2+BA2	135.2[bc]	1.60[a]	68.8[abc]	2.5[a]	0.1[a]	0.7[a]	1.8[a]
P4	124.6[d]	1.48[b]	68.7[abc]	1.0[bc]	0.0[b]	0.0[b]	1.0[abc]
P4+BA3	126.8[cd]	1.44[b]	73.2[abc]	1.7[abc]	0.3[a]	0.1[b]	1.4[abc]
BAGA2D	165.7[a]	1.62[a]	89.3[a]	0.6[c]	0.0[b]	0.0[b]	0.6[c]

different letters within columns represent significant differences at $P \leq 0.05$ by the Wilcoxon-Mann-Whitney test

P2+BA2 treatments, the total number of shoots on 'Kordia' was significantly higher than for the control treatments and for the P2+BAGA2, P2+BA2, and P2+NBAGA treatments on 'Samba'. The number of shoots > 30 cm roughly reflected the total number of lateral shoots.

As in Experiment 1, shoot numbers were higher in the treatments that combined pinching and phytohormone applications. The higher shoot number in treatments with notching was the result of the previous pinching because almost no reaction to notching was found.

Experiment 3 (2018)

On 'Kordia', the central leader was significantly shorter in both pinching treatments, but there were no significant differences on 'Samba' (Table 7). The trunk diameter of 'Kordia' was significantly smaller in the P4+BA3 treatment, but 'Samba' did not differ statistically significantly from the control. On 'Kordia', there were no statistically significant differences in the height of the first shoot compared to the control. No side shoots were formed on control trees of 'Samba' and there were no significant differences in

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Table 7. The length and diameter of the central leader as well as the height of the first lateral shoot, shoot number and shoot types on the central leader of 'Kordia' and 'Samba' sweet cherry grafted on Gisela 5 in 2018

Treatment	Central leader length (cm)	Trunk diameter (cm)	Height of first shoot (cm)	Shoots per tree (No.)	Shoots 1–10 cm (No.)	Shoots 10–30 cm (No.)	Shoots > 30 cm (No.)
Kordia							
C	182.1[a]	1.47[a]	87.6[abc]	0.5[c]	0.0[b]	0.1[d]	0.4[b]
P4	140.5[b]	1.39[a]	86.2[bc]	2.1[ab]	0.1[ab]	0.7[abc]	1.2[a]
P4+BA3	123.6[b]	1.20[b]	76.2[c]	3.0[a]	0.5[a]	1.8[a]	0.6[ab]
BA3	166.6[a]	1.35[ab]	98.6[a]	1.0[c]	0.2[ab]	0.3[cd]	0.5[b]
BA3 3S	169.4[a]	1.39[a]	95.2[ab]	1.4[abc]	0.2[ab]	0.5[bcd]	0.7[ab]
BA3 5S	167.1[a]	1.36[ab]	93.2[ab]	1.2[bc]	0.3[ab]	0.4[bcd]	0.6[ab]
BA3 10S	164.0[a]	1.40[a]	92.5[ab]	2.6[ab]	0.4[a]	1.0[ab]	1.1[ab]
10S	171.5[a]	1.34[ab]	90.0[ab]	0.3[c]	0.0[b]	0.0[d]	0.3[b]
Samba							
C	122.3[a]	1.27[ab]	0.0[b]	0.0[c]	0.0[c]	0.0[a]	0.0[a]
P4	122.1[a]	1.28[a]	84.0[a]	0.2[bc]	0.1[bc]	0.0[a]	0.0[a]
P4+BA3	124.7[a]	1.27[ab]	77.5[a]	0.1[bc]	0.0[c]	0.0[a]	0.1[a]
BA3	130.1[a]	1.26[ab]	113.9[a]	0.5[abc]	0.4[abc]	0.1[a]	0.0[a]
BA3 3S	124.3[a]	1.21[ab]	115.4[a]	0.3[abc]	0.2[abc]	0.1[a]	0.0[a]
BA3 5S	133.8[a]	1.27[ab]	112.2[a]	0.4[abc]	0.3[abc]	0.1[a]	0.0[a]
BA3 10S	120.5[a]	1.19[ab]	104.5[a]	0.6[ab]	0.5[ab]	0.1[a]	0.0[a]
10S	125.3[a]	1.14[b]	110.1[a]	0.9[a]	0.8[a]	0.1[a]	0.0[a]

different letters within columns represent significant differences at $P \leq 0.05$ by the Wilcoxon-Mann-Whitney test

the height of the first shoot among the other treatments. The total number of shoots on 'Kordia' was significantly higher in the P4+BA3, BA3 10S, and P4 treatments than in the control. On 'Samba', total shoot number was significantly higher than the control only in the 10S and BA3 10S treatments; nevertheless, the number was low and mainly was comprised of the shortest shoots 1–10 cm. There were almost no shoots longer than 10 cm on 'Samba'.

DISCUSSION

Most studies of the branching ability of sweet cherries have been done with vigorous rootstocks or in hotter and more climatically favourable regions (Hrotkó et al. 1999; Neri et al. 2004; Elfving, Visser 2006b; Koyuncu, Yildirim 2008; Moghadam, Zamanipour 2013). Evidence of effective treatments applicable to often suboptimal temperate zone conditions and to trees on low-vigour rootstocks is scarce (Baryla et al. 2014). Our results revealed that the best improvement in syllepsis among the years and tested cultivars were attained with a combination of pinching and phytohormones. It also showed that the use of phytohormones alone or pinching alone was not effective enough in these conditions. This is in accordance with results of Neri et al. (2004) who successfully used a very similar technique of single deblading and its combination with BA application.

Summer notching did not increase branching. Greene and Autio (1994), Elfving and Visser (2007), Atay and Koyuncu (2013), and von Bennewitz et al. (2014) reported increased branching when late winter notching was used. The higher shoot numbers recorded in combined treatments with summer notching were a reaction to the preceding application of pinching or phytohormones. The buds below the notching cuts sometimes exhibited activity, but they did not grow into shoots longer than 1 cm. Moreover, summer notching led to some negative effects, like temporary wilting of leaves and tips. Elfving and Visser (2007) reported a better reaction to late winter notching when it was combined with phytohormone application;

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nevertheless, summer notching immediately followed by an application of phytohormones did not increase its effectiveness in our experiments.

Frequent branching usually led to shorter central leaders and may be ascribed to the effect of BA (Hrotkó et al. 1998; Hrotkó et al. 1999; Hrotkó et al. 2000) or leaf pinching (Wustenberghs, Keulemans 1999) since both reduce growth or simply to the allocation of growth resources like carbon and nitrogen to the new lateral shoots rather than to the elongating leader. Gibberellins in mixtures with BA or as a subsequent spray did not substantially increase the length of the central leader or number of longer laterals as was reported by Hrotkó et al. (1999). The phytohormone concentrations that we used were higher in comparison with previous studies (Hrotkó et al. 1998; Atay, Koyuncu 2003; Neri et al. 2004; Elving, Visser 2006c; Koyuncu, Yildirim 2008; Moghadam, Zamanipour 2013). Nevertheless, even when BA+$GA_{4/7}$ was used at a double rate of 2000 mg/l, it did not increase branching. The issue that was neglected with regard to phytohormone application was the use of surfactants and their importance (Wustenberghs, Keulemans 1999; Laňar et al. 2015). Based on that, in the final year we decided to test the importance of rate of an added surfactant (Silwet L-77). For this experiment, the nursery trees grew from somewhat weaker rootstocks, and there were also sudden drops of temperature after a very hot period during June. These two factors could negatively influence the syllepsis; however, the highest rate of added surfactant (10 ml/l) increased branching of ´Kordia´ and did not cause any damage, which indicates its use may be advantageous.

Figures 1 and 2 with humidity and temperature course during a critical time of branching in each year show a certain variability of the conditions in Central Europe among the years. For example, the drops of temperatures after some more favourable period may decrease the natural or induced branching (Tromp 1996; Tromp, Boertjes 1996). The effect of the year was tested in Experiment 1 and significant differences were proved for most of the parameters. The year effect was connected with generally higher means for central leader height, nodes on the central leader shoots per tree and shoot length classes in 2015 compared to 2016 on both cultivars. It is in contrast with the expected impact of temperature drops in 2015 at the beginning of June when the treatments usually start and strongest branching goes on. The year 2016 was more stable and possibly more suitable for branching but the results were worse. It means the influence of the year could not be ascribed only to the expected impact of temperatures and air humidity during branching. The other factors should be also considered as important for interannual variability. For example, the temperature and the humidity during and a few hours after phytohormone application can influence its uptake and utilization (Lordan et al. 2017). We assume that even the factors and climatic conditions of the previous year can influence the syllepsis in next year e.g. by initial strength of budded plants and their root system (Wustenberghs, Keulemans 1999; Cook et al. 2004), nevertheless, we do not have any data evidence that could confirm this assumption. Generally, the efforts should be made to grow rootstocks and trees as strongly as possible. This can be promoted by planting in the best available soils (van den Berg 2003).

In all four seasons, the applied treatments did not result in high-quality trees because they did not make enough feathers longer than 30 cm, thus further research is needed to find the effective way for successful sweet cherry branching stimulation in conditions of Central Europe.

CONCLUSION

The application of phytohormones alone was not sufficiently effective.

A higher rate of Silwet L-77 combined with benzyladenine improved effectiveness.

Pinching alone was usually less effective than in combination with phytohormones.

Summer notching showed no potential for syllepsis inducement.

The combination of pinching and phytohormone application was the most effective method to induce branching of sweet cherries on dwarfing rootstocks in less favourable conditions.

Further research is needed to improve the branching induction efficiency of sweet cherries in such conditions on a commercially acceptable level.

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