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Botanic and physiology

Reapplication of bud break promoters in 'Fuji Suprema' apple trees

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Abstract -The aim of this work was to verify the effectiveness of the reapplication of bud break producers on flowering, sprouting and production of 'Fuji Suprema' apple trees. The experiment was carried out in an experimental orchard located in the municipality of Caçador, SC, during 2016/2017 to 2019/2020 seasons. Treatments were applied at stages B and C, and those with reapplication, from 7 to 14 days after the first application. Phenology, axillary and terminal bud break, frui set, production per plant and average fruit mass were evaluated. Phenology was advanced in relation to control with the application of bud break promoters. However, treatments applied at stage B provided greater advance in relation to applications at stage C. In axillary and terminal bud break, all treatments were superior to control. In some seasons, the sequential application of bud break promoters increased bud sprouting compared to single application treatment. There is no reduction fruit set in treatments with sequential application in relation to single application. In plant production, sequential applications did not differ from single application. The average fruit mass was not altered by the sequential application of bud break promoters.

Index Terms: *Malus domestica*, bud breaking, phenology

Reaplicação de indutores de brotação na macieira cv. Fuji suprema

Resumo - O objetivo do trabalho foi verificar o efeito da reaplicação dos indutores de brotação na floração, brotação e produção da macieira 'Fuji Suprema'. O experimento foi desenvolvido em pomar experimental localizado no município de Caçador-SC, durante os ciclos de 2016/2017 a 2019/2020. Os tratamentos foram aplicados nos estádios B e C, e os com reaplicação, de 7 a 14 dias após a primeira aplicação. Foram realizadas a avaliação da fenologia, a brotação de gemas axilares e terminais, a frutificação efetiva, a produção por planta e a massa média dos frutos. A fenologia foi adiantada em relação à testemunha com a aplicação dos indutores de brotação. Todavia, os tratamentos aplicados no estádio B propiciaram maior adiantamento em relação às aplicações no estádio C. Na brotação das gemas axilares e terminais, todos os tratamentos foram superiores à testemunha. Em alguns ciclos, a aplicação sequencial de indutores de brotação aumentou a brotação de gemas em relação ao tratamento de uma única aplicação. Não se observa redução da frutificação efetiva nos tratamentos com aplicação sequencial em relação à aplicação única. Na produção por planta, as aplicações sequenciais não diferiram da aplicação única. A massa média dos frutos não foi alterada pela aplicação sequencial de indutores de brotação.

Termos para Indexação: *Malus domestica*, quebra de dormência, fenologia.

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Introduction

In Brazil, apple cultivation is located in the Southern region, in areas where the cold requirement of the main cultivars is almost never fully satisfied (PETRI et al., 2008). In this sense, under milder winter conditions, several artificial practices to overcome dormancy have been used in order to minimize some of the problems resulting from cold deficiency, providing adequate sprouting and flowering in the main temperate climate species, enabling production even in sub-tropical regions (BENMOUSSA et al., 2018). Under conditions of insufficient chilling, temperate climate fruit trees present abnormalities in relation to bud breaking, with repercussions during the vegetative cycle and causing reduction in both fruit productivity and quality (PASA et. Al., 2018). Both regularity and amount of cold are indispensable for the natural breaking of dormancy. Among practices that most respond to bud breaking promotion under these conditions is the use of chemicals, called bud breaking promoters. Sprouting and flowering are delayed compared to regions with colder winters, with bud breaking date varying from year to year, depending on the amount of cold (PASA, et. Al., 2018).

Producers have difficulty in predicting the flowering date and even using mathematical models, results can be inconsistent (LUEDELING; BORWN, 2011). With reduction of the bud breaking rate, the total leaf area is reduced, thereby reducing the total plant photosynthesis. This fact can lead to deficiency in plant nutrition, with the most diverse consequences such as low fruit set and reduction of the cycle between flowering and maturation.

Bud breaking and flowering promotion of fruit trees in already implanted orchards by means of spraying with bud breaking promotion is the practical way to minimize problems caused by insufficient cold (PETRI et al., 2008). From the 1980s onwards, mineral oil (MO), hydrogen cyanamide (HC), and the combination of both, became the products most widely used to promote the bud breaking of temperate fruit trees (MOHAMED, 2008). A new generation of products was developed from the 2000s due to restrictions on the use of hydrogen cyanamide, which has high toxicity (HERNÁNDEZ; CRAIG, 2011). New molecules, which contain inorganic nitrogen, amino acids, polysaccharides, glutamic acid and mineral nutrients, such as Erger®, Syncron®, Thidiazuron (TDZ), Siberio® and Bluprins®, in mixture with calcium nitrate ($Ca(NO3)_2$) or mineral oil, have effect on the bud breaking promotion of apple trees, often presenting results similar to those of standard treatment using mineral oil plus hydrogen cyanamide (PASA et al., 2018; FENILI et al., 2018; HAWERROTH et al., 2010).

In some situations, there may be great variability in the response of plants to the application of promoters, and there may be insufficient breaking, requiring a new intervention. Sequential application is a new technique, which consists of reapplying the treatment and can be carried out on the whole plant or only on the upper part of the crown, standardizing bud breaking and flowering. Few studies have been carried out with reapplications of bud breaking promoters, but tests on apple seedlings and orchards located in low-altitude regions, show the effectiveness of this technique (GOULARTE et al., 2018; GARCIA et al., 2019). With new high-density planting systems, both in plant formation and in the fruiting stage, it is important to obtain as much bud breaking as possible to avoid lack of production branches as a result of deficient bud breaking.

The aim of this work was to verify the effectiveness of the reapplication of bud break promoters on flowering, sprouting and production of ‘Fuji Suprema’ apple trees.

Material and methods

The experiment was carried out in an experimental orchard located in the municipality of Caçador, SC (latitude 26º46’S, longitude 51º W, altitude of 960 m a.s.l.), during the 2016/2017 to 2019/2020 seasons. According to Köppen’s classification, the climate of the region is classified as Cfb - temperate constantly humid, with mild summer. The average annual rainfall is 1653.2 mm and the average relative humidity is 77.9%. According to Petri et al. (2010), the average cold accumulation during the autumn and winter periods is 928 cold units, North Carolina Modified model (EBERT, et al., 1986).

Ten-year-old ‘Fuji Suprema’ plants grafted onto Marubakaido rootstock and M-9 interstock were used. The planting density used was 2,500 plants ha^{-1}, with spacing of 4 m between rows and 1 m between plants, with plants being managed in the central leader system. The pollination scheme adopted was based on the use of two producing cultivars in the same proportion, with ‘Maxi Gala’ cultivar pollinating ‘Fuji Suprema’ cultivar and vice versa. An average of 6 hives per hectare was used to pollinate flowers. From the experiment implementation to the end of the study, the orchard was conducted according to management practices recommended for apple production system (SEZERINO, 2018).

The experimental design used was randomized blocks, with five replicates, each unit consisting of one plant and two borders. The two bordering plants were not used in the experimental analysis, serving only to avoid contamination with drift from other treatments. Treatments are shown in Table 1. The application of bud breaking promoters was performed with the aid of a motorized backpack sprayer (20 L), with tip containing three DS nozzles, with spray volume equivalent to 1000 L.ha^{-1}, during the morning period (09:00 am and 10:00 am). Treatments were applied at stage B (swollen bud or silver tip) and C (green tip) and those with reapplication, from 7 to 14 days after the first application. Phenology was evaluated for stages C-C3 (green tip up to 1.3 cm green), beginning of bud breaking and beginning, full and final flowering, axillary bud break, terminal bud break, fruit set, production per plant, number of fruits per plant and average fruit weight. The beginning of flowering was considered when plants had 5% of open flowers, full bloom when more than 80% of flowers were open and end of flowering when the last flowers were open.

Table 1- Treatments and stages of application carried out on the 'Fuji Suprema' apple tree, in four seasons. Caçador-SC.

Treatment	Application	Reapplication
1.Control	-	-
2. OM 3,5% + HC 0,7%	Phenological stage B	-
3. (OM 3,5% + HC 0,7%) + (OM 3,5% + HC 0,7%)	Phenological stage B	7 DA
4. (OM 3,5% + HC 0,7%) + (OM 3,5% + HC 0,7%)	Phenological stage B	14 DA
5. (OM 3,5% + HC 0,7%) + OM 3,5%	Phenological stage B	7 DA
6. (OM 3,5% + HC 0,7%) + OM 3,5%	Phenological stage B	14 DA
7. (OM 3,5% + HC 0,7%) + HC 1,0%	Phenological stage B	7 DA
8. (OM 3,5% + HC 0,7%) + HC 1,0%	Phenological stage B	14 DA
9. (OM 3,5% + HC 0,7%) + HC 0,7%	Phenological stage C	5 DA
10. (OM 3,5% + HC 0,7%) + (OM 3,5% + HC 0,7%)	Phenological stage C	10 DA
11. (OM 3,5% + HC 0,7%) + OM 3,5%	Phenological stage C	10 DA

OM = Mineral oil; HC = Hydrogenated cyanamide (Dormex®); Stage B = swollen gem or silver tip; Stage C = green tip; DA = days after the first application.

Axillary bud break was obtained from the count of buds sprouted and not sprouted in five previously selected twigs, located in the middle third of the plant. A lateral branch of each plant was selected for the counting of sprouted and non-sprouted terminal buds to estimate the terminal bud breaking percentage. Fruit set was obtained from the relationship between number of fruits and number of flower clusters counted during full bloom ([number of fruits / flower clusters] x100), with counts performed on the same side branch being used to estimate terminal bud breaking. The number of fruits per plant and production per plant were obtained through the total harvest of ripe fruits. Harvest was carried out on two moments, according to the date of application of bud break promoters.

The results obtained were submitted to analysis of variance, whose significant variables ($p < 0.05$) had means compared by the Scott-Knott test at 5% error probability. Analysis procedures were performed using the Sisvar software, version 5.6 (FERREIRA, 2010). Percentage data were transformed by the arc sine formula $[(x+1)/100]^{1/2}$ before being submitted to ANOVA.

Results and discussion

Phenology was advanced in relation to control treatment with the application of bud break promoters, regardless of stage of application and sequential application. Regarding application stages, treatments applied at stage B provided greater advancement compared to applications at stage C (Figure 1). Sequential application had little effect compared to single application, the same occurring with the reapplication only of mineral oil (MO) or hydrogen cyanamide (HC). The greatest effect on the flowering advancement was observed with the application stage, which corroborates results of Petri et al. (2012). George et al. (2002) reported that bud break promoters can be used to modulate the bud breaking and flowering season. There is also influence of the year in relation to the anticipation of phenological stages, which is related to cold intensity. The greatest advancements of full flowering were 18, 26, 24 and 21 days in relation to treatment without bud break promoters (Figure 1). Applications at stage B also showed advancement in the phenological stages in relation to those applied at stage C, but less than those observed in relation to plants without treatment. Hawerroth et al. (2010) also observed flowering advancement with applications of mineral oil plus hydrogen cyanamide. According to Pasa et al. (2018), flowering advancement with bud break promoters is greater in early applications after completing endo dormancy. Bud break promoters shorten the period between full flowering and end of flowering. Marchi et al. (2017) also found that the application of MO in apple trees anticipates flowering and reduces the period.

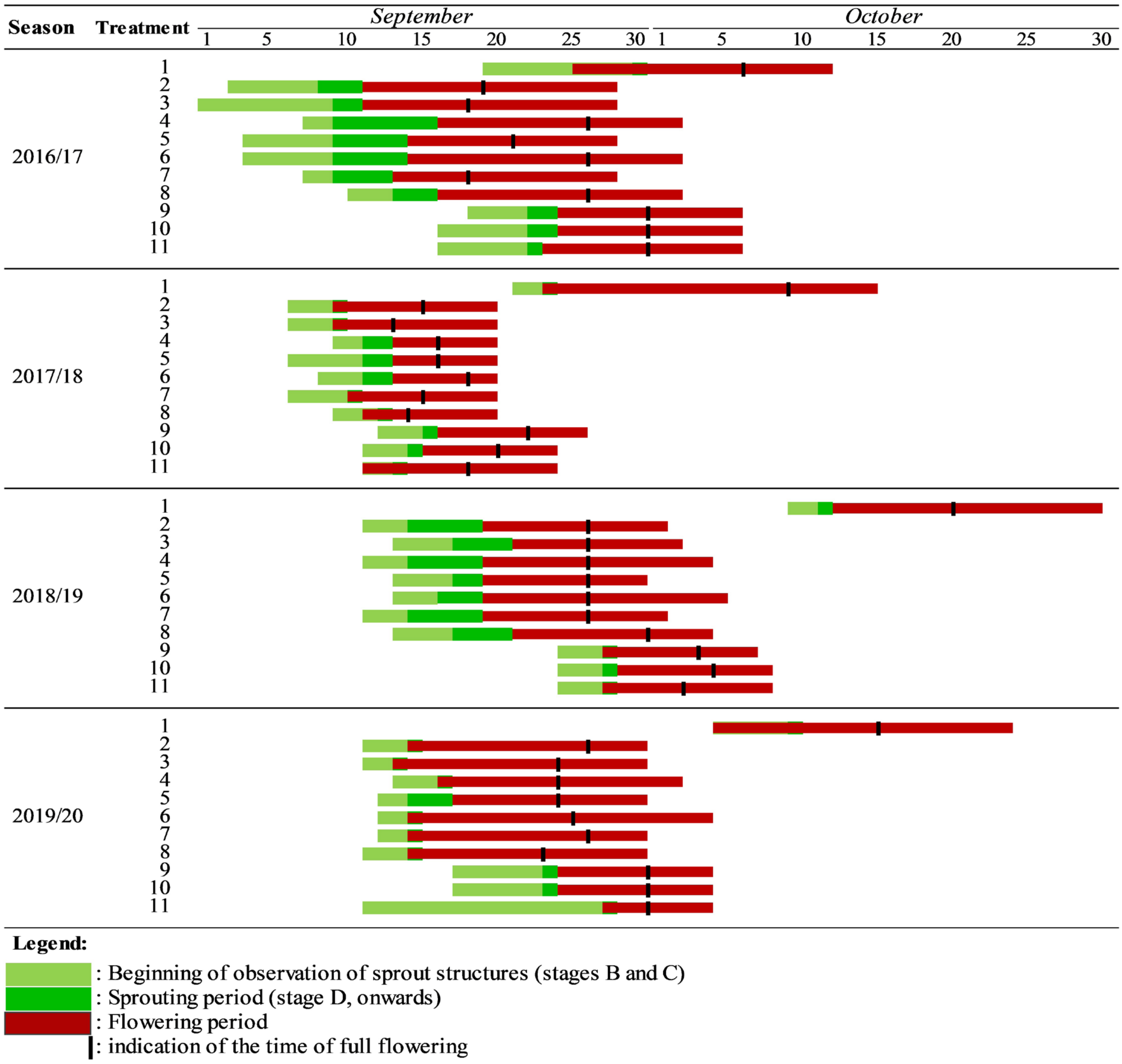

Figure 1- Evolution of the phenological stages of the 'Fuji Suprema' apple tree with different treatments of bud breaking promoters, in four seasons. Caçador-SC.

Regarding axillary bud break, all treatments differed significantly from control treatment; however, treatments MO 3.5% + HC 0.7% stage B + MO 3.5% + HC 0.7% 7 DA, MO 3.5% + HC 0.7% stage B + MO 3.5% + HC 0.7% 14 DA and MO 3.5% + HC 0.7% stage B + MO 3.5% 7 DA were equal to or higher than the others treatments in the four years of evaluation and did not show reduction trend according to the year (Table 2). It is noteworthy that in 'Fuji Suprema' cultivar, axillary bud break in the control treatment varied from 0.0% to 17.2% according to the year and in treatments with bud break promoters from 11.4% to 89.5%, which is in agreement with De Martin et al. (2017).

Table 2 - Bud break of axillary buds (%) at 30 and 60 days after the dormancy breaking of 'Fuji Suprema' apple trees, treated with different bud break promoters, in four seasons. Caçador-SC.

Treatment	Bud break of axillary buds (%)							
	2016/17	2017/18	2018/19	2019/20	2016/17	2017/18	2018/19	2019/20
	30 days after the dormancy breaking				60 days after the dormancy breaking			
1.	1.9 c	0.0 d	0.0 c	1.4 c	17.2 c	15.3 b	7.7 c	7.2 c
2.	47.8 b	47.3 b	55.4 a	52.1 b	58.0 b	41.5 a	57.2 b	58.6 b
3.	73.0 a	73.7 a	49.0 a	70.4 a	77.0 a	75.6 a	51.6 b	82.8 a
4.	73.6 a	58.8 a	44.2 a	62.1 a	78.1 a	67.2 a	50.0 b	65.8 b
5.	78.2 a	61.8 a	38.7 a	65.0 a	79.8 a	69.2 a	46.5 b	74.2 a
6.	67.6 a	49.9 b	52.5 a	42.8 b	73.5 a	63.2 a	59.2 b	47.9 b
7.	80.2 a	62.1 a	59.6 a	55.0 b	83.1 a	63.9 a	63.2 b	74.5 a
8.	74.1 a	55.2 b	48.4 a	48.6 b	75.3 a	62.2 a	56.1 b	57.6 b
9.	48.2 b	24.1 c	11.9 b	68.5 a	81.7 a	49.7 a	60.9 b	77.8 a
10.	60.2 b	35.1 c	11.4 b	72.4 a	80.4 a	58.2 a	78.6 a	89.5 a
11.	45.3 b	48.4 b	20.8 b	60.3 a	75.8 a	68.9 a	77.0 a	77.3 a
CV (%)	12.1	15.9	20.5	19.9	10.3	23.5	16.0	20.8

Averages followed by the same letter in the columns do not differ by the Scott-Knott test at 5% probability.

In the terminal bud break located at the end of twigs, all treatments were significantly superior to control treatment at 30 days after full flowering. At 60 days, only in the year 2019/20, they did not differ significantly. Regarding single application treatment, none of sequential application treatments was significantly superior at 30 days after full flowering and at 60 days only in the year 2017/18, there were treatments with sequential application superior than single application treatment (Table 3). As terminal buds are flowery, they usually sprout more than axillary buds due to the lower cold requirement and apical dominance (UBER, 2019). According to Francescatto (2014), the lack of axillary bud break favors the breaking of terminal buds and compromises the formation of reproductive organs, favoring excessive vegetative development.

Table 3 - Bud break of terminal buds (%) at 30 and 60 days after the dormancy breaking of 'Fuji Suprema' apple trees, treated with different bud break promoters, in four seasons. Caçador, SC.

Treatment	Bud break of terminal buds (%)							
	2016/17	2017/18	2018/19	2019/20	2016/17	2017/18	2018/19	2019/20
	30 days after the dormancy breaking				60 days after the dormancy breaking			
1.	30.6 d	8.0 c	7.3 b	26.7 b	74.3 b	61.7 c	57.9 b	89.7 ns
2.	96.9 a	86.6 a	84.4 a	91.9 a	98.7 a	84.2 b	91.3 a	96.3
3.	95.7 a	93.2 a	94.3 a	95.6 a	100.0 a	97.0 a	94.9 a	96.8
4.	90.9 a	92.2 a	95.6 a	94.5 a	98.4 a	96.9 a	92.7 a	97.5
5.	96.4 a	91.7 a	90.6 a	94.8 a	99.1 a	95.5 a	90.6 a	96.4
6.	82.5 b	85.0 a	86.1 a	93.1 a	97.3 a	88.7 b	88.0 a	95.0
7.	96.0 a	93.8 a	95.1 a	92.8 a	98.8 a	100.0 a	95.0 a	100.0
8.	94.5 a	87.4 a	89.3 a	87.1 a	99.6 a	95.5 a	95.0 a	94.4
9.	79.1 b	73.2 b	89.4 a	91.8 a	95.5 a	84.9 b	89.4 a	94.6
10.	80.3 b	71.0 b	71.0 a	94.1 a	100.0 a	80.7 b	93.8 a	96.7
11.	67.0 c	75.5 b	86.4 a	87.3 a	95.7 a	82.0 b	92.3 a	92.1
CV (%)	13.6	14.1	16.4	14.7	7.3	14.4	13.6	17.4

Averages followed by the same letter in the columns do not differ by the Scott-Knott test at 5% probability. ns = not significant (p>0,05).

The set of axillary and terminal bud break shows better sprouting with sequential applications, with increase mainly in the axillary bud breaking, which are responsible for the formation of the fruiting structures for the following year.

The highest fuit set percentages were observed in the control treatment in years when it showed significant differences. No reduction in frui set was observed in treatments with sequential application in relation to single application, nor between reapplication dates and applications that involve MO plus HC reapplication (Table 5). The reduction in fuit set is due to the flowering concentration with the use of bud break promoters, which can increase the risk of poor pollination, especially if the environmental conditions are unfavorable to the work of bees (HERNANDEZ; CRAIG, 2011).

Regarding production per plant, only in the 2017/18 cycle, most treatments exceed the control treatment; however, sequential applications did not differ from single application treatment. In the 2016/17 season, treatments MO 3.5% + HC 0.7% stage C + MO 3.5% + HC 0.7% 10 DA and MO 3.5% + HC 0.7% stage C + MO 3.5% 10 DA were superior to single application treatment. As for the number of fruits per plant, behavior was similar to production per plant in kilograms (Table 4).

Table 4- Production per plant (kg and number of fruits) of 'Fuji Suprema' apple trees, treated with different bud break promoters, in four seasons. Caçador, SC.

Treatment	Production per plant					
	2016/17	2017/18	2019/20	2016/17	2017/18	2019/20
		kg			Number of fruits	
1.	33.3 a	5.8 b	9.5 ns	313.6 a	57.8 ns	101.6 ns
2.	21.0 b	11.1 a	6.4	149.4 b	102.8	60.0
3.	26.6 b	9.3 a	7.3	219.6 b	79.8	72.4
4.	27.3 b	10.0 a	8.5	187.8 b	87.4	98.4
5.	29.2 b	10.3 a	7.7	219.6 b	102.0	77.6
6.	44.0 a	11.7 a	8.4	391.8 a	116.4	92.4
7.	15.7 b	9.2 a	5.9	112.2 b	90.6	57.8
8.	34.7 b	13.0 a	8.7	229.0 b	115.4	87.4
9.	29.2 b	5.4 b	9.8	265.8 a	61.0	97.8
10.	41.7 a	6.2 b	6.7	371.2 a	69.6	67.6
11.	38.2 a	8.9 a	9.3	323.8 a	96.2	100.6
CV (%)	30.2	40.0	44.3	18.4	24.2	23.9

Averages followed by the same letter in the columns do not differ by the Scott-Knott test at 5% probability. ns = not significant (p>0,05).

Table 5- Fruit set (%) and average fruit mass (g) of 'Fuji Suprema' apple trees, treated with different bud break promoters, in four seasons. Caçador, SC.

Treatment	Fruit set				Average fruit mass		
	2016/17	2017/18	2018/19	2019/20	2016/17	2017/18	2019/20
			%			g	
1.	331.2 a	62.9 ns	251.4 a	76.0 ns	107.2 b	91.3 b	90.2 ns
2.	46.6 c	33.8	15.9 b	44.5	140.0 a	100.7 b	107.7
3.	22.6 c	59.6	32.6 b	68.2	127.8 b	116.7 a	98.7
4.	26.5 c	46.5	33.5 b	74.9	146.2 a	114.5 a	88.6
5.	74.9 b	88.7	43.7 b	25.7	133.0 a	102.4 b	99.1
6.	89.9 b	60.0	41.3 b	109.5	114.3 b	100.9 b	93.5
7.	22.4 c	42.4	7.5 b	35.0	140.4 a	103.7 b	104.1
8.	76.5 b	113.0	53.2 b	68.9	153.6 a	113.5 a	103.3
9.	80.2 b	37.6	21.4 b	76.1	112.3 b	89.3 b	101.0
10.	155.4 b	60.4	44.1 b	50.8	114.3 b	92.6 b	97.2
11.	152.5 b	67.9	30.9 b	45.7	123.3 b	88.9 b	92.7
CV (%)	52.0	69.4	51.2	70.1	12.0	12.7	10.8

Averages followed by the same letter in the columns do not differ by the Scott-Knott test at 5% probability. ns = not significant (p>0,05).

Regarding the average fruit mass, there were sequential application treatments that were significantly superior to control treatment in 2016/17 and 2017/18 seasons, but only in the 2017/18 season, single application treatment was inferior to some sequential application treatments (Table 5). The increase in the average fruit mass may be related to flowering anticipation and uniformity and to the better plant leafing, since increases in the sprouting percentage were observed, which contribute to larger leaf area.

Conclusion

The application of bud break promoters at stage B advances the phenological stages of 'Fuji Suprema' apple trees in relation to their application at stage C, regardless of reapplication and reapplication time interval.

Sequential application of bud break promoters increases the sprouting percentage of axillary and terminal buds of 'Fuji Suprema' apple trees according to the season and does not reduce fruit set in relation to single application.

The reapplication of mineral oil to break the dormancy of 'Fuji Suprema' apple trees increases plant productivity in seasons with low cold accumulation in the winter.

The sequential application of bud break promoters does not change the average mass of 'Fuji Suprema' apples.

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