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Thidiazuron with Mineral Oil as Alternative Bud Break Promoter for Apple Trees

José Luiz Petri[1], André Amarildo Sezerino[1], Cristhian Leonardo Fenili[2*] and Gentil Carneiro Gabardo[3]

[1]EPAGRI/Experimental Station of Caçador, Caçador, Brazil.
[2]State University of Santa Catarina, Agroveterinary Sciences Center, Lages, Brazil.
[3]High Valley of the Rio do Peixe University (UNIARP), Caçador, Brazil.

Authors' contributions

This work was carried out in collaboration among all authors. Author JLP designed the study and wrote the protocol. Authors CLF, GCG and AAS performed the statistical analysis and wrote the first draft of the manuscript. Author AAS managed the analyses of the study and the translation of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This work aims to evaluate the efficiency of Revent® 500 SC (Thidiazuron) concentrations as a bud breaker promoter in apple trees, cv. Maxi Gala and Supreme Fuji, through phenology, sprouting of buds, fruit set and production per plant.
Place and Duration of Study: The experiments were carried out in southern Brazil, municipality of Caçador / SC, during the seasons from 2017 to 2019, in the cultivars Fuji Suprema and Maxi Gala / Marubakaido / M9.
Methodology: The treatments were 1. Control (without application); 2. Mineral Oil (MO) 3.5% + Hydrogenated Cyanamide (HC) 0.35%; 3. MO 3.5% + HC 0.5%; 4. MO 3.5% + Thidiazuron (TDZ) 0.005%; 5. MO 3.5% + TDZ 0.01%; 6. MO 3.5% + TDZ 0.015%; 7.MO 3.5% + TDZ 0.02%; 8.MO 3.5% + TDZ 0.025%, applied in stages B and C. Several variables were evaluated such as phenology, sprouting of axillary and terminal buds, fruit set, production per plant and average fruit mass.

**Corresponding author: E-mail: cristhianfenili@hotmail.com;*

Results: All treatments with bud breakers advanced the phenological stages in relation to the control in the three years. In the sprouting of the axillary and terminal buds, all treatments were superior to the control. TDZ treatments showed higher sprouting of axillary buds in 2017/18 compared to standard treatments with hydrogenated cyanamide. In plant production, the treatment MO 3.5% + TDZ 0.02% was higher than the other treatments in the 2018/19 and 2019/20 seasons, in both cultivars. TDZ associated with mineral oil is efficient in inducing the sprouting of 'Maxi Gala' and 'Fuji Suprema' apple trees and can be used to recover sprouts from previous years.

Keywords: Malus domestica borkh; bud breaking; phenology.

1. INTRODUCTION

The most important apple (*Malus domestica* Borkh) producing regions in southern Brazil are located in climatically marginal areas, in terms of cold intensity. The average of refrigeration units is 1,000 in regions with 1,000 meters of altitude and 1,800 for regions above 1,200 m, according to the North Carolina model [1]. Under these conditions, the phenomenon known as delayed sprouting and flowering occurs, where sprouting and flowering are later compared to regions with colder winters, and the date of sprouting varies from year to year, depending on the amount of cold that occurred during the winter [2]. Under these conditions, chemical treatment is needed to induce bud break apple trees. As a result, there is less uneven flowering and sprouting, symptoms that characterize the lack of adaptation to the region [3]. Problems related to the lack of cold present with different intensities according to the region and year, due to the great variability of the amount of cold accumulated in different producing regions of temperate climate fruits in Brazil [4]. As the plant ages, branches devoid of sprouting are observed over the years, which reduces the productive potential.

The use of chemical compounds makes the production of temperate climate fruits in sub-tropical regions viable [5]. Several products have already been used to induce bud break in apples, Petri et al. [6] cite several chemical substances effective in bud breaking, such as mineral oil, calcium cyanamide, potassium nitrate, hydrogenated cyanamide, dinitro-ortho-cresol (DNOC), dinitro-ortho-butyl-phenol (DNOPB), dinitro- butylphenol (DNBP), thiorhoea, sodium pentachlorophenolate, TCMTB (2-thiocythiomethylthio) benzothiazole 30%), thidiazuron and gibberellic acid. However, due to phytotoxicity, most of these substances were banned [7]. Commercially, the main practice (standard technique) of bud break promoter in apples under cold conditions has been the use of hydrogenated cyanamide (HC) and mineral oil (MO), in Brazil and in other countries such as Israel, Mexico and South Africa [7]. Despite being an effective treatment, producers are dependent on a single molecule on the market. In addition to raising the cost of production and being harmful to man and the environment [8]. Another obstacle regarding hydrogenated cyanamide is that its use is restricted to some countries, which may in the future harm Brazilian exports [9].

A new generation of products has been developed since the 2000s, which have inorganic nitrogen, amino acids, polysaccharides, glutamic acid and mineral nutrients in their composition, often showing results similar to standard treatment of mineral oil plus hydrogen cyanamide [10]. Work using calcium nitrate and/or mineral oil adding to other sources of inorganic nitrogen has improved the efficiency of these products [11], but with an increase in cost. Thidiazuron (TDZ) has been shown to be effective in bud breaking of aged apple buds [12]. This is important, especially with the new high density planting systems, both in plant formation and in the fruiting phase, it is important to obtain as much sprouting as possible to avoid lack of production branches as a result of poor sprouting [13]. Thus, this work aims to evaluate the efficiency of concentrations of Revent® 500 SC (TDZ) as a bud breaker promoter in apple, cv. Maxi Gala and Fuji Supreme, through phenology, sprouting of buds, fruit set and production per plant.

2. MATERIALS AND METHODS

The experiments were carried out at the EPAGRI Experimental Station in Caçador (latitude 26º82 "S, longitude 50 º99"W, altitude 960 meters). During the seasons from 2017 to 2019, apple trees, cultivars Fuji Suprema and Maxi Gala / Marubakaido / M9 were evaluated, conducted in the central leader system with a spacing of 4.0 m x 1.0 m, with 2,500 plants / ha. The adopted pollination scheme was based on the use of two producing cultivars in the same proportion, with Maxi Gala being a pollinator of cv. Fuji Supreme and contrariwise. An average of 6 bee hives per hectare were used to pollinate the flowers. The plants were managed according to the recommendations of the apple tree production system [14].

The experimental design used was randomized blocks with eight treatments, including a control treatment and another standard treatment, usually used in the region, and five replications, each unit being composed of a plant and two borders. The two border plants were not used in the experimental analysis, serving only to avoid contamination with drift from other treatments. The treatments were applied between stages B (swollen bud or silver tip) and C (green tip), before bud sprouting, and 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). The products were applied in a single spray carried out between phenological stages B and C (before the green tip started).

The evaluations were carried out regarding phenology, determining the phenological stages C-C3 (green tip up to 1.3 cm green), beginning of sprouting and beginning, full and end of flowering. Axillary bud break determined in five branches of the year's growth per plant, counting the total number of buds and the number of buds sprouted at 30 and 60 days after the application of the treatments. Terminal bud break determined in a lateral branch, being counted the total of terminal buds and sprouted buds at 30 and 60 days after the application of the treatments. In this same side branch, the number of floral clusters and number of fruits were counted to calculate the fruit set. At harvest, the number of fruits per plant (fruits $plant^{-1}$), average fruit weight (g), yield (kg $plant^{-1}$) and production per ha was determined by harvesting all the fruits of each plant.

The results obtained were subjected to analysis of variance, whose significant variables ($p<0.05$) had the means compared by Scott-Knott test at 5% probability of error. The analysis procedures were performed using the Sisvar program, version 5.6 [15]. Percentage data were transformed by the arc sine formula $[(x+1)/100]^{1/2}$ before being submitted to ANOVA.

3. RESULTS AND DISCUSSION

All phenological stages were advanced in relation to the control treatment and reduced the number of days from the beginning to the end of flowering, with full flowering being advanced in both cultivars and in the three years (Fig. 1). Among the treatments, there were small differences in the date of full flowering, showing that the concentration of CH and TDZ did not influence the phenological stages of Cvs. Maxi Gala and Fuji Supreme. Petri et al. [7] observed that bud break promoters mixed with MO advanced apple tree flowering. There were small variations in the number of days from the beginning to the end of flowering between the years studied and these differences found in the beginning of sprouting and flowering depended on the climatic conditions of the year, and the variation in the number of cold units that occurs in winter, influences the flowering period [16]. However, the control treatment always had a longer flowering period. According to Pasa et al. [17], the anticipation of flowering with bud break promoters is greater in early applications after completing the dormancy. Bud break promoters shorten the period between full bloom and the end of bloom. Marchi et al. [18] also found that the application of MO in apple trees anticipates flowering and reduces the period.

Table 1. Treatments performed on apple trees cv. Maxi Gala e Fuji Suprema. Caçador/SC

Treatments (active ingredient dose)	Application phenological stage
1. Control	Without application
2. MO 3,5% + HC 0,35%	Between B-C
3. MO 3,5% + HC 0,5%	Between B-C
4. MO 3,5 % + TDZ 0,005%	Between B-C
5. MO 3,5 % + TDZ 0,01%	Between B-C
6. MO 3,5% + TDZ 0,015%	Between B-C
7.MO 3,5 % + TDZ 0,02%	Between B-C
8.MO 3,5% + TDZ 0,025%	Between B-C

Note: Spray volume: 1,000 L/ha^{-1}. MO: mineral oil; HC: hydrogenated cyanamide; TDZ: thidiazuron; B-C: before green tip start

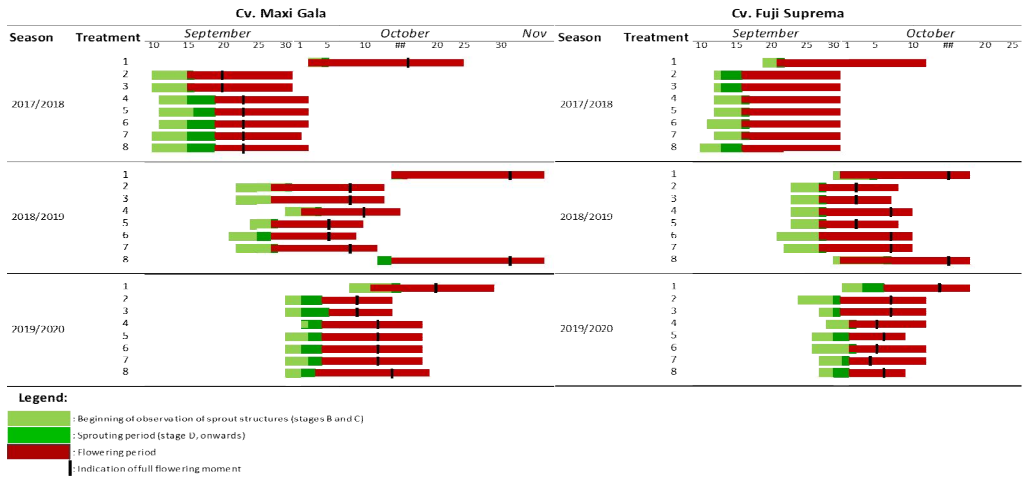

Fig. 1. Evolution of the phenological stages of the 'Maxi Gala' and 'Fuji Suprema' apple tree with different treatments of bud breaking promoters, in three seasons. Caçador, SC

Axillary bud break was higher in all treatments compared to the control treatment, in all years, except for treatments MO 3.5% + TDZ 0.01%, MO 3.5% + TDZ 0.015% and MO 3 .5% + 0.02% TDZ, in Cv. Fuji Suprema in the 2019/2020 season, at 60 days after application, which did not differ from the control treatment (Table 2). The TDZ treatments were superior in 2017/18 to the standard treatments with hydrogenated cyanamide, and in 2018/19 the standard treatment was superior to the TDZ treatments, with the exception of the 0.015% TDZ treatment. It is noteworthy that the treatment of MO 3.5% + T DZ 0.02% provided 86.6% of sprouting compared to the control treatment with 1.6% or to the treatment of MO 3.5% + HC 0.35 % with 47.6%, in 2017/18. It was observed that the TDZ treatments promoted the sprouting of buds that had not sprouted in the previous year, which did not occur with the standard treatment with HC. However, the TDZ treatments developed smaller leaves in the fruiting structures than the standard treatment. The importance of axillary bud break is highlighted, as these will form the fruiting structures for the following year, which is confirmed by De Martin et al. [11].

Regarding terminal bud break, all treatments were superior to the control treatment and the TDZ treatments did not differ from the HC treatments regardless of the concentration (Table 3). It is noteworthy that in 'Fuji Suprema' the treatment of MO 3.5% + TDZ 0.025%, with 96.2% of sprouting of the terminal buds compared to 31.1% of the control treatment and 92.5% of the standard treatment. Usually the terminal buds, as they are floriferous, sprout more than the axillary buds, due to the lower cold requirement and apical dominance [19]. According to Francescatto et al. [16], the lack of axillary bud break favors the terminal bud break and compromises the formation of reproductive organs, favoring excessive vegetative development.

The fruit set was higher in the treatments with TDZ compared to the control treatment and treatments with HC in 2017/18 in 'Maxi Gala', and in 'Fuji Suprema' only the treatments MO 3.5% + TDZ 0.02% and MO 3.5% + TDZ 0.025%, did not differ from the control and standard treatments (Table 4). In 2018/2019, only MO 3.5% + TDZ 0.005% was superior to the other treatments, in the 'Maxi Gala'. In 'Fuji Suprema', in 2018/2019, all treatments showed lower fruit set, with no differences between them, in relation to the control treatment. According to Hernandez and Craig, [20] in certain situations, a drastic reduction in fruit set can be achieved by using bud break promoters, due to the nutritional competition established between vegetative and reproductive drains.

In the production per plant, the treatment MO 3.5% + TDZ 0.02% presented higher production in relation to the other treatments in the 2018/19 and 2019/20 seasons, in the two cultivars (Table 5). In 2017/18 there were no significant differences between treatments, in Cv. Maxi Gala and at 'Fuji Suprema', the treatment of MO 3.5% + TDZ 0.015% was superior to the others, with an increase of 186.2% compared to the control treatment and 163.2% compared to the standard treatment.

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

Treatment	Bud break of axillary buds (%)					
	30 DADB			60 DADB		
	2017/18	2018/19	2019/20	2017/18	2018/19	2019/20
	cv. Maxi Gala					
1. Control	0.0 d	1.6 c	3,4 c	1.6 d	5.0 c	5,0 c
2. MO 3,5% + HC 0,35%	46.9 b	45.9 a	39,8 a	47.6 b	60.5 a	43,3 a
3. MO 3,5% + HC 0,5%	33.7 c	39.0 a	43,3 a	33.7 c	50.4 b	49,1 a
4. MO 3,5 % + TDZ 0,005%	72.4 a	19.4 b	30,8 a	76.4 a	31.4 b	34,0 a
5. MO 3,5 % + TDZ 0,01%	75.1 a	37.6 a	28,0 a	78.3 a	49.3 b	28,3 a
6. MO 3,5% + TDZ 0,015%	82.8 a	54.1 a	28,5 a	84.3 a	68.6 a	36,1 a
7.MO 3,5 % + TDZ 0,02%	84.7 a	27.4 b	13,5 b	86.6 a	42.2 b	17,0 b
8.MO 3,5% + TDZ 0,025%	78.5 a	-	28,5 a	79.4 a	-	38,6 a
CV (%)	22,3	25,0	23,5	21,3	23,0	22,2
	cv. Fuji Suprema					
1. Control	1.1 e	0.6 c	2,3 d	6.2 c	11.8 b	12,5 c
2. MO 3,5% + HC 0,35%	61.4 c	50.3 b	40,9 b	67.8 b	65.5 a	48,9 b
3. MO 3,5% + HC 0,5%	38.7 d	41.5 b	46,2 b	54.4 b	68.2 a	57,0 b
4. MO 3,5 % + TDZ 0,005%	73.8 b	70.5 a	33,8 b	78.7 a	79.3 a	43,3 b
5. MO 3,5 % + TDZ 0,01%	86.7 a	36.4 b	16,0 c	88.3 a	43.2 a	29,0 c
6. MO 3,5% + TDZ 0,015%	87.2 a	68.8 a	26,8 b	87.4 a	72.5 a	33,5 c
7.MO 3,5 % + TDZ 0,02%	73.5 b	39.2 b	11,0 c	76.2 a	60.0 a	21,9 c
8.MO 3,5% + TDZ 0,025%	90.3 a	-	68,9 a	91.1 a	-	78,1 a
CV (%)	15,3	23,9	19,8	14,6	23,2	17,3

*Means followed by the same letter, in the column, do not differ from each other by the Scott-Knott test (P≤0.05). * ns: not significant (P≥0.05). DADB – days after the dormancy breaking.*

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

Treatment	Bud break of terminal buds (%)					
	30DADB			60DADB		
	2017/18	2018/19	2019/20	2017/18	2018/19	2019/20
	cv. Maxi Gala					
1. Control	2.6 b	4.0 c	26,4 c	20.9 b	49.6 b	44,2 c
2. MO 3,5% + HC 0,35%	83.9 a	87.0 a	97,0 a	87.7 a	87.9 a	97,8 a
3. MO 3,5% + HC 0,5%	75.8 a	81.3 a	87,9 a	91.2 a	81.9 a	90,3 a
4. MO 3,5 % + TDZ 0,005%	86.7 a	31.4 b	69,4 b	89.7 a	43.8 b	77,9 b
5. MO 3,5 % + TDZ 0,01%	86.4 a	73.3 a	66,6 b	92.8 a	73.3 a	81,7 b
6. MO 3,5% + TDZ 0,015%	90.6 a	89.8 a	84,1 a	90.8 a	89.8 a	92,1 a
7.MO 3,5 % + TDZ 0,02%	92.8 a	83.2 a	63,3 b	97.7 a	85.0 a	78,0 b
8.MO 3,5% + TDZ 0,025%	94.8 a	-	48,2 c	96.2 a	-	64,8 b
CV (%)	17,9	13,8	15,1	15,2	12,9	14,3
	cv. Fuji Suprema					
1. Control	31.1 b	56.0 b	74,9 b	74.3 b	74.2 ns	88,7 b
2. MO 3,5% + HC 0,35%	92.5 a	90.3 a	98,6 a	98.2 a	90.3	100,0 a
3. MO 3,5% + HC 0,5%	84.5 a	96.4 a	98,7 a	94.5 a	98.9	100,0 a
4. MO 3,5 % + TDZ 0,005%	83.4 a	86.8 a	83,2 b	98.7 a	87.7	96,7 b
5. MO 3,5 % + TDZ 0,01%	91.6 a	88.5 a	82,2 b	93.4 a	93.7	92,8 b
6. MO 3,5% + TDZ 0,015%	91.1 a	80.8 a	76,6 b	93.0 a	88.0	91,0 b
7.MO 3,5 % + TDZ 0,02%	87.4 a	90.2 a	79,6 b	94.3 a	94.3	89,0 b
8.MO 3,5% + TDZ 0,025%	96.2 a	-	73,3 b	98.4 a	-	91,8 b
CV (%)	12,9	16,9	14,5	12,8	17,3	15,2

*Means followed by the same letter, in the column, do not differ from each other by the Scott-Knott test (P≤0.05). * ns: not significant (P≥0.05). DADB – days after the dormancy breaking*

Table 4. Fruit set (%) of 'Maxi Gala' and 'Fuji Suprema' apple trees, treated with different bud break promoters, in two seasons. Caçador, SC

Treatment	Fuit set (%)			
	cv. Maxi Gala		cv. Fuji Suprema	
	2017/18	2018/19	2017/18	2018/19
1. Control	5,1 b	0.0 b	43.3 b	156.4 a
2. MO 3,5% + HC 0,35%	5.4 b	3.5 b	20.9 b	22.9 b
3. MO 3,5% + HC 0,5%	6.4 b	4.1 b	58.7 b	24.0 b
4. MO 3,5 % + TDZ 0,005%	42.6 a	79.9 a	244.0 a	20.1 b
5. MO 3,5 % + TDZ 0,01%	29.7 a	19.4 b	176.5 a	43.5 b
6. MO 3,5% + TDZ 0,015%	58.5 a	24.2 b	175.2 a	65.0 b
7.MO 3,5 % + TDZ 0,02%	26.6 a	15.6 b	105.7 b	15.9 b
8.MO 3,5% + TDZ 0,025%	31.8 a	-	49.5 b	-
CV (%)	65,5	115,8	68,7	51,7

*Means followed by the same letter, in the column, do not differ from each other by the Scott-Knott test (P≤0.05). * ns: not significant (P≥0.05)*

Table 5. Production per plant (kg and number of fruits) of 'Maxi Gala' and 'Fuji Suprema' apple trees, treated with different bud break promoters, in three seasons. Caçador, SC

Treatment	Production per plant					
	Mass (kg)			Number of fruits		
	2017/18	2018/19	2019/20	2017/18	2018/19	2019/20
	cv. Maxi Gala					
1. Control	6.1 ns	4,6 b	6,7 b	60.6 b	42,6 b	65,8 ns
2. MO 3,5% + HC 0,35%	7.4	4,6 b	8,1 b	68.6 b	31,0 c	59,0
3. MO 3,5% + HC 0,5%	9.7	5,5 b	3,9 b	83.6 b	41,6 b	33,6
4. MO 3,5 % + TDZ 0,005%	19.1	5,4 b	7,8 b	207.6 a	50,2 b	66,2
5. MO 3,5 % + TDZ 0,01%	10.1	5,3 b	7,7 b	113.4 b	46,8 b	63,6
6. MO 3,5% + TDZ 0,015%	12.5	5,5 b	9,7 b	139.2 a	55,8 b	89,2
7.MO 3,5 % + TDZ 0,02%	10.0	9,1 a	15,7 a	109.8 b	72,2 a	98,6
8.MO 3,5% + TDZ 0,025%	15.1	6,2 b	6,4 b	177.2 a	58,2 b	63,6
CV (%)	58,8	38,0	43,8	26,9	35,5	32,1
	cv. Fuji Suprema					
1. Control	8.0 b	19,3 b	9,5 b	85.0 b	155,4 a	81,4 b
2. MO 3,5% + HC 0,35%	8.7 b	13,2 c	6,3 b	90.8 b	103,8 b	60,8 b
3. MO 3,5% + HC 0,5%	9.8 b	13,8 c	5,6 b	100.8 b	96,8 b	54,6 b
4. MO 3,5 % + TDZ 0,005%	13.9 b	15,7 c	8,4 b	154.0 a	136,4 a	76,4 b
5. MO 3,5 % + TDZ 0,01%	15.1 b	17,5 b	7,4 b	161.4 a	150,4 a	63,8 b
6. MO 3,5% + TDZ 0,015%	22.9 a	17,8 b	8,8 b	211.8 a	163,4 a	80,4 b
7.MO 3,5 % + TDZ 0,02%	13.0 b	23,6 a	19,1 a	147.2 a	178,4 a	155,2 a
8.MO 3,5% + TDZ 0,025%	11.4 b	14,0 c	10,8 b	143.0 a	112,6 b	87,6 b
CV (%)	36,8	29,5	33,4	19,6	29,7	27,8

*Means followed by the same letter, in the column, do not differ from each other by the Scott-Knott test (P≤0.05). * ns: not significant (P≥0.05)*

Table 6. Average fruit mass (g) of 'Maxi Gala' and 'Fuji Suprema' apple trees, treated with different bud break promoters, in three seasons. Caçador, SC

Treatment	Average fruit mass (g)					
	cv. Maxi Gala			cv. Fuji Suprema		
	2017/18	2018/19	2019/20	2017/18	2018/19	2019/20
1. Control	96.3 b	101,6 b	94.4 ns	104,6 c	123,9 b	117,3 ns
2. MO 3,5% + HC 0,35%	109.5 a	137,3 b	98.1	152,4 a	130,8 a	105,6
3. MO 3,5% + HC 0,5%	113.1 a	117,4 b	95.0	130,8 b	142,0 a	101,7
4. MO 3,5 % + TDZ 0,005%	92.9 b	118,0 b	90.9	107,5 c	116,4 b	111,1
5. MO 3,5 % + TDZ 0,01%	86.0 b	122,7 b	94.3	107,3 c	117,5 b	117,8
6. MO 3,5% + TDZ 0,015%	92.1 b	108,2 b	108.2	97,9 c	109,7 b	108,5
7.MO 3,5 % + TDZ 0,02%	89.3 b	185,5 a	88.1	126,9 b	132,9 a	122,7
8.MO 3,5% + TDZ 0,025%	82.9 b	104,2 b	82.6	108,3 c	122,7 b	123,2
CV (%)	13,5	12,3	11,6	12,7	7,0	10,9

*Means followed by the same letter, in the column, do not differ from each other by the Scott-Knott test (P≤0.05). * ns: not significant (P≥0.05)*

The average fresh mass of the fruits presented variable results (Table 6), which can be attributed to differences in productivity and to the advance of flowering, prolonging the cycle, but due to lesser sprouting of axillary buds, the control treatment tends to produce in terminal buds (brindyles), where the fruits are larger [16].

4. CONCLUSION

TDZ 0.005 to 0.025% associated with MO 3.5% is efficient bud break promoter of the apple tree Cv. Maxi Gala and Fuji Suprema, compared to the standard treatment of MO 3.5% + HC 0.35%, as it increases the bud sprouting percentage and maintains plant productivity.

TDZ induces the sprouting of old buds and can be used to recover failures in sprouting from previous years.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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