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Dormancy of 'Imperial Gala' apple and 'Hosui' pear tree buds in a region of low chill occurrence

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ABSTRACT. The objective of this work was to evaluate the dormancy dynamic of Imperial Gala apple tree buds and Hosui pear tree buds in a region of low chill occurrence. Experiments were conducted between April and August in 2007 and 2008. Branches were collected every two weeks from an orchard at Porto Amazonas (Paraná State, Brazil). On the last sampling day, an additional set of branches was collected and refrigerated between 4°C and 7°C for 1,440 hours. Dormancy was evaluated using a biological test of single node cuttings isolated in growth chambers (GC) at 25°C with 16 hours of light exposure. The number of chill hours (CH) and chill units (CU) for the region were recorded. The two species were evaluated in separate experiments. We used 11 completely randomized treatments with four replicas for each species. The peak of endodormancy for the Imperial Gala apple tree buds occurred in early June 2007 and from middle June to early July in 2008. The endodormancy of the Hosui pear tree buds oscillated between April and August in 2007 and peaked between June and early July in 2008.

Keywords: *Malus domestica*, *Pyrus communis*, ecophysiology, budburst, endodormancy.

Dormência de gemas de macieira 'Imperial Gala' e pereira 'Hosui' em região de baixa ocorrência de frio

RESUMO. O objetivo da pesquisa foi avaliar a dinâmica da dormência de gemas de macieira 'Imperial Gala' e de pereira 'Hosui' em região de baixa ocorrência de frio. Os experimentos foram realizados no período de abril a agosto dos anos de 2007 e 2008 com coletas de ramos a cada duas semanas no município de Porto Amazonas, Paraná, Brasil. Na última coleta, um grupo adicional de ramos foi coletado e mantido em refrigerador a temperatura de 4 a 7°C por 1.440h. A avaliação da dormência foi realizada pelo teste biológico de estacas de nós isolados em câmaras de crescimento (BOD) a 25°C e fotoperíodo de 16h. Foram quantificadas horas de frio (HF) e unidades de frio (UF) ocorridas na região. As duas espécies foram avaliadas como experimentos distintos. O delineamento experimental adotado foi o completamente casualizado com 11 tratamentos e quatro repetições para cada espécie. A endodormência mais intensa de gemas de macieira 'Imperial Gala' ocorreu no início de junho em 2007 e da metade de junho ao início de julho em 2008. A endodormência de gemas de pereira 'Hosui' apresentou oscilações entre abril e agosto de 2007 e foi mais intensa de junho ao início de julho em 2008.

Palavras-chave: *Malus domestica*, *Pyrus communis*, ecofisiologia, brotação, endodormência.

Introduction

Bud dormancy has been studied in several fruit tree species from temperate climates to understand its start, maintenance and end, in special the pome fruits, with apple trees (CARVALHO et al., 2006), pear trees (CARVALHO et al., 2012; MARAFON et al., 2011b) and quince trees (BETTIOL NETO et al., 2011). Cultivars of Gala apple group are the most important varieties in Brazil and represented 60% of total apple produced (PETRI et al., 2011). Hosui pear is one of the most cultivated in Brazil and has shown an increase in planting area (FAORO; ORTH, 2010).

It has been shown that bud growth, or rather lack of growth, is a response to a combination of environmental factors (ecodormancy), the influence of other plant organs (paradormancy), or biochemical and physiological events that occur inside the bud (endodormancy) (LANG et al., 1987).

Endodormancy is the most important phase of fruit production, but the processes related to its start, maintenance and end remain poorly understood. The expansion of apple and pear tree orchards in regions with warmer winters has made the artificial ending of dormancy an essential

practice (OLIVEIRA et al., 2008; RUFATO et al., 2010). To ensure the efficacy of this practice, the physiological aspects of endodormancy and its end must be clarified. The end of endodormancy is fundamental for the formation of a balanced plant with well-distributed structural and fruit-bearing branches such that the plant's maximum productive potential can be achieved (CARVALHO et al., 2010a; PETRI; LEITE, 2004).

The objective of this work was to evaluate the dormancy dynamic of Imperial Gala apple tree buds and Hosui pear tree buds in a region of infrequent chill occurrence.

Material and methods

Experiments were conducted between April and August in 2007 and 2008. One-year-old healthy intact mixed branches, at an oblique position in relation to the top of the tree, were collected from adult plants of homogenous growth. Imperial Gala apple trees and Hosui pear trees were found in the orchard of the Fazenda Perboni in Porto Amazonas, Paraná State, Brazil (25° 55' S; 49° 90' W, at an average height of 795 m). To evaluate the natural occurrence of chill, the number of hours of chill (≤ 7.2°C) and the chill units were measured according to the North Carolina model (SHALTOUT; UNRATH, 1983) and the modified North Carolina model using the software Hora Frio™, developed by Epagri, Brazil, and climate data provided by Instituto Tecnológico Simepar.

For each species, 40 branches were sampled every two weeks from April 11, 2007 and April 9, 2008 until August of the same year, when budburst initiates for both species (10 sampling events in total). On the last sampling day, an additional set of branches was collected and kept refrigerated between 4°C and 7°C for 1,440 hours so to provide enough cold to trigger the end of dormancy (CARVALHO; ZANETTE, 2004).

Dormancy was assessed using a biological test inside a growth chamber (GC – EL202, Eletrolab™) at 25°C and with a 16 hours photoperiod. The central portion of the branches was divided into 6 cm long stakes with only the apical bud left. The leaves remaining on the branches collected in April and June were removed with scissors, but stalks were left to fall off naturally during the experimental period. For each experimental set we used 10 stakes planted in plastic vases using moistened vermiculite as substrate. Each vase was covered with a plastic PVC film with five ventilation holes of 2 mm diameter each. Tests were repeated four times, with a total of 40 stakes being used for each species and each experimental date.

To assess bud development, the stakes were individually checked every two days for a maximum period of 40 days. The buds were classified using the following developmental stages: 'Green Tip' (GT: a noticeable change of color, the tip of the bud becomes greenish) and 'Open Bud' (OB: open leaves appear). A third stage, 'Green Bud', was considered for the pear tree buds due to the necrosis of the apical buds during the experiment, and the base of the buds became greenish at the start of budburst (CARVALHO et al., 2010b).

The average bud break time (ABT) was calculated as the mean number of days between the start of the experiment and the day GT was observed. The final bud break rate (FBR) was calculated as the proportion of buds that achieved GT, and the vigorous bud rate (VBR) was calculated as the percentage of stakes with buds that achieved the GT stage and later reached the OB stage [VBR = (% of stakes with buds at OB stage) x 100/FBR]. The velocity of bud break (VB) was calculated using the following equation:

$$VB = \Sigma(n_i/t_i) \text{ (buds day}^{-1}\text{)},$$

where:

n_i is the number of buds that reached the GT stage at time 'i';

t_i is the time passed from the start of the experiment (i = 1 to 40).

The two species were evaluated in separate experiments. Experiments for each species were completely randomized with four replicas. An analysis of variance was used to compare the treatments, and the means of significantly different treatments were compared using Tukey's test at a significance level of 5%.

Results and discussion

In 2007 and 2008, 245 and 170 chill hours (CH, temperature below 7.2°C) were recorded during the sampling period, respectively (Table1). The chill recorded in the region was insufficient for both of the studied cultivars. The Imperial Gala variety, which originated from the Gala apple tree variety, requires 700 CH (RUFATO et al., 2010) and the Hosui pear tree variety requires 721 CH to break bud dormancy (FAORO, 2001).

Several negative values of chill unities (CU) were recorded: -881.5 CU in 2007 and -86.5 CU

in 2008. This finding indicates an accumulation of high temperatures since the beginning of the sampling period in April. In 2007, positive chill unities were recorded only at the end of May and July. In 2008, the cold was more intense from June to July (Table 1). Using the modified North Carolina model implemented in the software Hora Frio™ (HF), which does not consider the cancelling effect of high temperatures, 501.95 CU and 755.10 CU were recorded in 2007 and 2008, respectively (Table 2). From the HF data alone, it could be concluded that in 2007 the cold was more intense. However, the analysis based on CU models shows that the cold was more intense in 2008.

The period in April before the intense endodormancy was characterized as paradormancy because most plants still had leaves, and their experimental removal led to low ABT values. These low ABT values were similar to the values that were recorded in August, when endodormancy was almost completed (Table 3). According to Crabbé and Barnola (1996), the removal of leaves during paradormancy allows buds to budburst due to the elimination of competition for water and nutrients.

Beginning in May, endodormancy began with a gradual increase in ABT, which was more evident in 2007. In the period after the most intense endodormancy in 2007, a period of high temperatures occurred and zero CH were recorded. This finding could have influenced the low ABT values on June 20 and the subsequent increase in July. Only after the return of low temperatures ABT was the reduced to 15.6 days on August 14, characterizing the end of endodormancy. In 2008, despite CH being less frequent, periods of cold instability were not recorded. As a result, the ABT gradually decreased until August 13 (Table 3).

Table 1. Hours of chill (≤ 7.2°C) and chill units calculated using the North Carolina model for the Porto Amazonas, Paraná State, Brazil in 2007 and 2008.

Period	Hours of chill ≤ 7.2°C		Period	Hours of chill ≤ 7.2°C	
2007	Between dates	Accumulated	2008	Between dates	Accumulated
04/01 to 04/11	0	0	04/01 to 04/09	0	0
04/11 to 04/25	0	0	04/09 to 04/23	0	0
04/25 to 05/09	8	8	04/23 to 05/07	24	24
05/09 to 05/23	1	9	05/07 to 05/21	5	29
05/23 to 06/10	101	110	05/21 to 06/04	15	44
06/10 to 06/20	0	110	06/04 to 06/18	66	110
06/20 to 07/02	22	132	06/18 to 07/02	30	140
07/02 to 07/18	11	143	07/02 to 07/16	23	163
07/18 to 08/01	95	238	07/16 to 07/30	1	164
08/01 to 08/14	7	245	07/30 to 08/13	6	170
Period	Chill Units		Period	Chill Units	
2007	Between dates	Accumulated	2008	Between dates	Accumulated
04/01 to 04/11	-248.0	-248.0	04/01 to 04/09	-105.0	-105.0
04/11 to 04/25	-327.5	-575.5	04/09 to 04/23	-105.0	-210.0
04/25 to 05/09	-123.5	-699.0	04/23 to 05/07	-9.5	-219.5
05/09 to 05/23	-660	-765.0	05/07 to 05/21	13.0	-206.5
05/23 to 06/10	75.5	-689.5	05/21 to 06/04	-30.5	-237.0
06/10 to 06/20	-148.0	-837.5	06/04 to 06/18	30.0	-207.0
06/20 to 07/02	-7.0	-844.5	06/18 to 07/02	92.5	-114.5
07/02 to 07/18	-94.0	-938.5	07/02 to 07/16	32.5	-82.0
07/18 to 08/01	126.0	-812.5	07/16 to 07/30	-3.5	-121.5
08/01 to 08/14	-69.0	-881.5	07/30 to 08/13	35.0	-86.5

Table 2. Chill Units (CU) calculated using the software Hora Frio™, based on the modified North Carolina model, recorded for the orchard of Imperial Gala apple trees and Hosui pear trees for each sampling date in Porto Amazonas, Paraná State, Brazil in 2007 and 2008.

Sampling dates (2007)	Accumulated CU (North Carolina Model)	Sampling dates (2008)	Accumulated CU (North Carolina Model)
04/11	0.0	04/09	0.0
04/25	0.0	04/23	10.83
05/09	28.08	05/07	100.22
05/23	58.31	05/21	157.72
06/10	210.42	06/04	253.90
06/20	178.07	06/18	341.95
07/02	265.69	07/02	489.21
07/18	294.39	07/16	607.37
08/01	488.77	07/30	640.88
08/14	501.95	08/13	755.10

Table 3. Average bud break time (ABT), final bud break rate (FBR), velocity of bud break (VB) and vigorous bud rate (VBR) from the biological tests of the isolated nodes of Imperial Gala apple trees sampled in Porto Amazonas, Paraná State, Brazil in 2007 and 2008.

Sampling dates	ABT (Days)*		FBR (%)*		VB (Buds day^{-1})*		VBR (%)*	
07/04/11	16.5	de	37.5	d	0.25	de	87.5	a
07/04/25	16.2	e	57.5	bcd	0.35	cde	80.4	a
07/05/09	18.7	bcd	65.0	abcd	0.38	cde	75.9	a
07/05/23	19.1	bc	65.0	abcd	0.34	de	100.0	a
07/06/10	26.2	a	47.5	cd	0.18	e	100.0	a
07/06/20	12.9	f	100.0	a	0.79	b	100.0	a
07/07/02	20.8	b	70.0	abcd	0.39	cde	100.0	a
07/07/18	18.8	bcd	82.5	abc	0.38	cde	100.0	a
07/08/01	17.1	cde	82.5	abc	0.46	cd	100.0	a
07/08/14	15.6	e	92.5	ab	0.61	bc	91.0	a
07/08/14+Cold**	7.7	g	85.0	abc	1.12	a	73.0	a
CV (%)	5.77		22.56		22.34		12.49	
08/04/09	12.6	bcd	100.0	a	0.84	bc	75.0	ab
08/04/23	11.2	bcd	95.0	a	0.85	bc	87.2	a
08/05/07	14.1	bc	96.7	a	0.55	cde	75.0	ab
08/05/21	12.9	bc	97.5	a	0.82	bcd	88.9	a
08/06/04	12.4	bcd	100.0	a	0.86	bc	97.5	a
08/06/18	21.4	a	92.5	a	0.45	e	91.7	a
08/07/02	21.4	a	95.0	a	0.48	de	43.3	b
08/07/16	13.3	bc	100.0	a	0.78	bcde	95.0	a
08/07/30	15.1	b	100.0	a	0.71	bcde	82.5	a
08/08/13	10.7	cd	100.0	a	1.00	ab	70.0	ab
08/08/13+Cold**	8.7	d	100.0	a	1.25	a	95.0	a
CV (%)	11.95		3.63		18.31		17.42	

*Means followed by different letters are significantly different (Tukey's test at a 5% significance level). **Treatment with 1,440 hours of cold (4 to 7°C).

Treatment with 1,440 h of additional cold caused a significant decrease in ABT in 2007 (7.7 days). In 2008, the ABT reduction (8.7 days) was not significantly different from the natural reduction that was observed until August 13 (Table 3). According to the estimated occurrence of cold temperatures, it is possible to conclude that in 2008, despite having fewer CH, colder temperatures were reported and CU were higher than in 2007. This conclusion could be the result of the negative effects of higher temperatures, which were estimated using CU methods (Tables 1 and 2). These facts characterize an ecodormancy in 2008 because the temperatures were not favorable to natural budburst. The habitat conditions, with insufficient CH, did not prevent the natural end of endodormancy.

These results indicate that Imperial Gala apple tree buds may not need cold to exit endodormancy in the field. During both study years, fewer than half of the required CH occurred, and in 2008, endodormancy ended naturally. The metabolic changes in bud tissues need to be further investigated to develop more precise methods to evaluate the end of dormancy. According to Marodin et al. (2002), the achievement of a threshold value, i.e., the total sum of CH that is sufficient to cause the end of bud dormancy in temperate fruit trees, is not the best way to evaluate the adaptation of most species. Buds from Flamecrest peach trees budburst irregularly, even after a total of 758 hours below 7.2°C, which is more than what is required by this species.

During the period of highest ABT, the FBR and VB were low, reinforcing that the 2007 buds tended to have low budburst. However, in 2008, the FBR remained high throughout the experimental period, and the VB was low. The VBR did not change much in 2008, indicating that this could be a less important variable for the assessment of dormancy (Table 3). The limitation of initial bud growth that is imposed by dormancy also affects the delayed start of budburst but does not prevent complete growth during budburst.

The peak of ABT from the biological test indicates a more intense endodormancy in apple trees (CARVALHO; ZANETTE, 2004). However, ABT values for pear tree buds in 2007 showed three peaks: April 11, June 10 and August 1. In 2008, the variation in ABT was more homogenous, peaking between June 18 and July 2 (Table 4). By analysing both years, it is possible to establish that the ABT peak on June 10, 2007 is correlated to a more intense dormancy peak, similar to the one observed in 2008. The other two peaks, before and after June 10, are indicative of the lower tendency for bud growth, which may be a consequence of other environmental or internal factors.

During the sampling events of April 2007 and 2008, only high temperatures were observed, particularly in 2007. Positive CH and CU values did not accumulate in the orchard, resulting in negative CU values (Tables 1 and 2). Thus, at least for that stage, the temperature may not have been the cause of the observed differences between the years.

Table 4. Average bud break time (ABT), final bud break rate (FBR), velocity of bud break (VB) and vigorous bud rate (VBR) from the biological tests of the isolated nodes of Hosui pear trees sampled in Porto Amazonas, Paraná State, Brazil in 2007 and 2008.

Sampling dates	ABT (Days)*		FBR (%)*		VB (Buds day^{-1})*		VBR (%)*	
07/04/11	28.8	a	17.5	b	0.07	c	70.9	ab
07/04/25	18.7	de	80.0	a	0.42	b	77.0	ab
07/05/09	23.3	bcd	70.0	a	0.32	bc	61.7	b
07/05/23	19.9	bcde	70.0	a	0.33	bc	100.0	a
07/06/10	23.9	abc	85.0	a	0.37	b	100.0	a
07/06/20	19.5	cde	70.0	a	0.36	b	100.0	a
07/07/02	22.5	bcd	95.0	a	0.46	b	100.0	a
07/07/18	23.0	bcd	85.0	a	0.37	b	100.0	a
07/08/01	24.6	ab	80.0	a	0.32	bc	73.9	ab
07/08/14	15.0	e	77.5	a	0.56	b	89.5	ab
07/08/14+Cold**	4.1	f	90.5	a	1.77	a	20.7	c
CV (%)	10.17		25.35		23.94		16.07	
08/04/09	18.7	bc	55.0	bcd	0.37	cde	21.1	efg
08/04/23	15.3	c	25.0	de	0.21	de	8.3	fg
08/05/07	14.0	c	2.5	e	0.02	e	0.0	g
08/05/21	19.2	bc	45.0	cd	0.28	de	45.7	cde
08/06/04	14.0	c	95.0	a	0.75	cd	91.9	a
08/06/18	29.1	a	60.0	abcd	0.24	de	57.6	bcd
08/07/02	24.2	ab	40.0	de	0.18	de	0.0	g
08/07/16	16.9	bc	95.0	a	0.59	cde	73.6	abc
08/07/30	12.2	cd	80.0	abc	0.91	c	35.4	def
08/08/13	3.4	e	92.5	ab	3.82	a	15.0	efg
08/08/13+Cold**	4.1	de	95.0	a	2.65	b	84.2	ab
CV (%)	22.08		25.54		27.09		33.74	

*Means followed by different letters are significantly different (Tukey's test at a 5% significance level). **Treatment with 1,440 hours of cold (4 to 7°C).

The budburst of pear tree buds from the biological tests was unusual; they occurred at the apical portion of the bud (green tip stage) or at the base of the bud (green bud stage), due to apical tissue necrosis. At the start of endodormancy, the ABT peak can be attributed to physiological problems in the bud, such as the abortion of buds that starts before winter. The second peak observed in August could be attributed to a secondary dormancy, which is the consequence of a lack of cold. The less intense winter of 2007 could have induced this secondary dormancy, which finished completely after the experimental treatment of 1,440 additional CH (Table 4). In 2008, the greater accumulation of CU (Table 2) reduced the ABT to a level similar to the one obtained after the treatment with additional cold

During the phase that precedes bud budburst in Hosui pear trees, high levels of sorbitol and sucrose are found at the base of the bud (RODRIGUES et al., 2006). Starch levels also vary and can be used as an indicator of the phase that precedes budburst, i.e., the end of dormancy. These factors, combined with apical necrosis, induce growth through a new germination at the base of the bud, resulting in the stage know as Green Bud. The variables FBR, VB, and VBR did not change much in 2007 but did vary in 2008 when FBR and VB values were at their highest after July. VBR variations were not homogenous and not related to the intensity of dormancy (Table 4).

Both the start and end of endodormancy may be related to several factors that are linked to the energetic metabolism of the bud, the allocation of reserves, carbohydrate flux, short distance nutrient transfer, and hormonal regulation (CRABBÉ; BARNOLA, 1996; MARAFON et al., 2011a). Environmental conditions may have an independent effect on each of these factors, making the evaluation of the intensity of dormancy more difficult.

Conclusion

The peak of endodormancy for the Imperial Gala apple tree buds occurred in early June 2007 and from middle June to the beginning of July 2008 in a region of low chill occurrence.

The endodormancy of Hosui pear tree buds cultivated in a region of low chill occurrence oscillated between April and August in 2007 and was more intense from June to the beginning of July in 2008.

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