EVALUATION OF WINTER TEMPERATURES ON APPLE BUDBREAK USING GRAFTED TWIGS[1]

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ABSTRACT - Temperature is the main climate factor related to induction, maintenance and dormancy release in apple (*Malus domestica* Borkh.). The inadequate chilling exposure in apples causes budbreak problems, resulting in decrease in yield potential. Thus, the knowledge of physiological principles and environmental factors determining the dormancy phenomenon, especially winter temperature effects, it is necessary for the efficient selection of cultivars in a productive region. In addition, it is indispensable to adapt the orchard management aiming to decrease the problems caused by lack chilling during winter. The objective of this study was to evaluate the influence of different thermal conditions during the dormancy period on budbreak of apple cultivars. One-year-old twigs of 'Castel Gala' and 'Royal Gala' cultivars, grafted on M7 rootstock, were submitted to temperatures of 5, 10 and 15ºC for different exposure periods (168; 336; 672; 1,008 and 1,344 hours). After treatments execution, the plants were kept in a greenhouse at 25ºC. Budbreak was quantified when accumulated 3,444; 6,888; 10,332; 13,776; 17,220 and 20,664 GDHºC after temperature treatments. The cultivars responded differently to temperature effect during the winter period. The temperature of 15°C during winter shows a greater effectiveness on 'Castel Gala' apple budbreak while in the 'Royal Gala' apples the temperatures of 5 and 10ºC show better performance. 'Castel Gala' cultivar (low chilling requirement) may supply its physiological necessities, may be capable to budburst, even when subjected to higher temperatures in relation to 'Royal Gala' apples (high chilling requirement).
Index terms: *Malus domestica*, dormancy, chilling requirement, grafted twigs, apical dominance.

AVALIAÇÃO DE TEMPERATURAS HIBERNAIS NA BROTAÇÃO DE GEMAS DE MACIEIRA UTILIZANDO RAMOS ENXERTADOS

RESUMO - A temperatura é o principal fator ambiental relacionado à indução, manutenção e superação da dormência da macieira (*Malus domestica* Borkh.). O inadequado suprimento em frio para esta espécie determina a ocorrência de problemas relacionados à brotação, repercutindo na diminuição do potencial produtivo. Dessa forma, o conhecimento dos princípios fisiológicos e dos fatores ambientais determinantes no fenômeno da dormência, sobretudo o efeito das temperaturas hibernais, faz-se necessário para a eficiente seleção de cultivares em determinada região produtora, assim como para eficiente elaboração e adequação de práticas culturais para minimização de problemas causados pelo insuficiente acúmulo de frio hibernal. O objetivo deste trabalho foi avaliar a influência de diferentes condições térmicas durante o período de dormência na brotação de gemas de cultivares de macieira. Ramos de um ano das cultivares Castel Gala e Royal Gala, enxertadas no porta-enxertos M7, foram submetidas às temperaturas de 5; 10 e 15ºC, durante diferentes períodos de exposição (168; 336; 672; 1.008 e 1.344 horas). Após a efetivação dos tratamentos, as plantas foram mantidas em casa de vegetação a 25ºC. A brotação foi quantificada quando acumulada soma térmica de 3.444; 6.888; 10.332; 13.776; 17.220 e 20.664 GDHºC após os tratamentos térmicos. As cultivares estudadas responderam diferentemente às temperaturas durante o período hibernal. A temperatura de 15ºC apresentou maior efetividade na brotação de gemas da cultivar Castel Gala, enquanto as temperaturas de 5 e 10ºC apresentaram melhor desempenho na cultivar Royal Gala. A cultivar Castel Gala (menor requerimento em frio) pode suprir suas necessidades fisiológicas, sendo capaz de brotar, mesmo quando submetida a temperaturas mais altas em comparação a macieiras Royal Gala.
Termos para indexação: *Malus domestica*, dormência, requerimento em frio, ramos enxertados, dominância apical.

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INTRODUCTION

Dormancy is the mechanism that plants use to protect sensitive tissue from unfavorable climatic conditions (CAMPOY et al., 2011). At the end of the growing season, perennial plants, like temperate fruit trees, cease development and assume a dormant and freezing tolerant state protecting buds against unfavourable winter conditions. The development of correlative inhibitions during the summer period leads to the suspension of bud growth and the onset of dormancy. The temperature is considered the most relevant environmental factor acting in the processes of induction and overcoming dormancy in temperate fruit trees (PÉREZ; LIRA, 2005). Heide and Prestrud (2005) demonstrate that low temperature consistently induces growth cessation and dormancy induction in apple, regardless of photoperiodic conditions.

The production of temperate fruit trees is highly influenced by dormancy. Insufficient chilling causes abnormal patterns in budbreak and development in temperate zone fruit trees cultivated in warm climates (BONHOMME et al., 2005). Low percentage and heterogeneity along the stem in budbreak and flowering and other anomalies occur in temperate fruit trees grown in subtropical conditions, when chilling requirement is not satisfied (LEITE et al., 2006). According to Petri and Leite (2004), others anomalies are manifested during growing season of apples trees cultivated in the absence of adequate winter chilling, causing the decrease of yield and fruit quality. Additionally, a reduction in chilling accumulation also has been shown in different areas (BALDOCCHI; WONG, 2008; LUEDELING et al., 2009) and it will intensify the management problems of temperate fruit crops in the future. Due it this significant influence on fruit production it is primordial the knowledge of the factors interacting in dormancy process, especially the winter temperatures.

In warm climates, modeling the temperature effect on chilling accumulation and the response of various bud types to chilling may enable the growers to optimize the timing of the application of dormancy-breaking chemicals as well as aid in cultivar selection for a specific site (NAOR et al., 2003). Without an understanding of the temperatures influencing dormancy, the improvement of management practices for dormancy release or to identify the actual state of bud dormancy, needed to define the correct timing of various cultural practices, is essential.

‘Castel Gala’ and ‘Royal Gala’ apples are somatic mutation of ‘Gala’ apples. ‘Castel Gala’ differs of the original cultivar by chilling requirement, while ‘Royal Gala’ differs by the color and greater handling fruit resistance. The chilling requirement of ‘Castel Gala’ apples is less than 400 chilling hours (CH) below 7.2 ºC (CH< 7.2 ºC) during the winter, while ‘Royal Gala’ cultivar needs more than 800 CH < 7.2°C (DENARDI; SECCON, 2005). Despite these cultivars presented different chilling requirements, there is no information on their response to different temperatures in the dormancy period.

Precise determination of the temperature requirements for breaking dormancy is nearly impossible under field conditions, where solar radiation, diurnal fluctuations in temperature and other factors cannot be controlled (DENNIS JR., 2003). Thus, the most used methodology in studies about dormancy in deciduous fruit trees are based on subjected detached twigs of the trees to different thermal conditions during the winter, assessing the effectiveness of treatments by budbreak percentage. Despite the wide use of this method, it presents limited time for evaluation due to low maintenance and longevity of tissues, may mask the potential of budbreak in vegetative and flower buds. The methodology using grafted twigs in autumn, tested by Wagner Junior et al. (2006, 2009) and Chavarria et al. (2009) in peach trees, may be interesting in apple trees because the lower tissue dehydration than detached twigs, allowing extend the period for plant material assessment.

The objective of this research was to evaluate the influence of different thermal conditions during the dormancy period on budbreak of apple cultivars with different chilling requirements, using grafted twigs methodology.

MATERIAL AND METHODS

The study was carried out in Pelotas, states of Rio Grande do Sul, Brazil (31º41’ S, 52°21’ W) during the 2007 year. One-year-old twigs of ‘Gala Castel’ and ‘Royal Gala’ apples (*Malus domestica* Borkh.), with average length of 30 cm, average diameter of 10 mm and containing approximately 14 buds, were grafted on M7 clonal rootstocks through wedge grafts.

The twigs were collected in the second half of May, when it had accounted 140 chilling units according North Carolina Model modified by Ebert et al. (1986). The twigs collected were grafted on M7 rootstocks, and the plants resulted were kept at temperatures of 18ºC for 45 days to complete welding and promote callus formation at the grafting point. One-year-old M7 rootstocks collected were previously transplanted in plastic bags with two liters of substrate. The substrate contained soil, sand and waste organic poultry litter in the proportion of 2:1:1, showing the following chemical properties: organic matter 5.0%; pH_{H2O} 6.4; pH_{SMP} 6.2, P 34.1 mg dm^{-3}; K 160.0 mg dm^{-3}; Al 0.0 $cmol_c$ dm^{-3}; Ca 6.3 $cmol_c$ dm^{-3}; Mg 3.3 $cmol_c$ dm^{-3}.

Thereafter, fifteen groups of 12 plants were separated for each cultivar, and this groups were subjected to different temperatures (5, 10 and 15 ºC) in fitotrons without light, during different exposure periods (168; 336; 672; 1,008 and 1,344 hours). Each hour that the plants stayed a certain temperature was considered as a chilling unit (CU). After the execution of treatments, the plants were transferred to a greenhouse at 25°C and evaluated when the heat exposure reached 3,444; 6,888; 10,332; 13,776; 17,220 and 20,664 growing degree hours (GDHºC), whereas the minimum baseline temperature of 4.5ºC (RICHARDSON et al., 1975). The evaluations consisted of determining the percentage of budbreak, considering the budburst when it was observed 'green tip' phase (stage C).

The experimental design was completely randomized, with four replications, using a factorial arrangement (3x5x6), with three temperatures during dormancy period, five levels of chilling exposure and six levels of heat exposure. Each replication was composed of three plants. The results were transformed by expression arc sine $(x/100)^{1/2}$ and submitted to analysis of variance - ANOVA ($p<0.05$). The comparation of treatment means were performed by Tukey test at 5% significance. The variables were also tested using regression polynomial analysis.

RESULTS AND DISCUSSION

There triple interaction between the factors temperature, chilling and heat exposure was not significant on budbreak in both cultivars studied, as exposed in the analysis of variance (Table 1). The simple effects of interactions temperature x chilling exposure, temperature x heat exposure, and chilling exposure x heat exposure were significant in 'Royal Gala' apples, while the only significant interaction in 'Castel Gala' apples was observed between chilling exposure and heat exposure. For both cultivars the main effect of the factors temperature and chilling exposure were significant (Table 1).

Analyzing temperature effect in 'Castel Gala' apples may be observed that temperature of 15ºC provide the highest budbreak in relation to temperatures 5 and 10ºC (Table 2). The temperature effect on budbreak was variable between chilling exposures in 'Royal Gala' apples. When the plants were exposed to 168, 336 and 672 CU did not observed differences among temperatures evaluated on budbreak of 'Royal Gala' apples. Although increasing the period of chilling exposure at 5 and 10ºC showed higher budbreak than 15ºC in 'Royal Gala' apples. The differential effect of temperatures during dormancy period between the apple cultivar on budbreak indicate that cultivars with lower chilling requirement (Castel Gala) may supply its physiological necessities, may be capable to budburst, even when subjected to higher temperatures when compared to cultivars with higher chilling requirement (Royal Gala). Putti et al. (2003b), using single node cutting biological test, also observed that the effectiveness of temperature to overcome dormancy varies among apple cultivars, where cultivars with lower chilling requirement have effective temperatures higher than cultivars with higher chilling requirement. The same response was obtained by Chavarria et al. (2009), using the grafted twigs methodology in peach trees, where the temperatures of 15ºC during winter promoted satisfactory percentage of budbreak and flowering in low chill cultivars, such as 'Turmalina' cultivar.

'Castel Gala' had the same response on budbreak with the increase the period of exposure of both temperatures, justified by no significant effect of temperature x chilling exposure interaction (Table 2). In contrast, the three temperatures evaluated responded differently to exposure period on budbreak 'Royal Gala' apples (Table 2). In the average of three temperatures evaluated during dormancy period, the budbreak of Castel Gala apples had a linear increase against the increase in the period of exposure to temperatures (Figure 1). The 'Royal Gala' apples, when exposed to 5ºC during the winter, showed linear response in the budbreak, increasing the budburst with the increasing of period of exposure in this temperature (Figure 1). When 'Royal Gala' apples were exposed to 10 and 15ºC was observed quadratic response on budbreak by increase of period of exposure of these temperatures. The percentage of budbreak remained minimal until the exposure of 381.4 and 423.1 CU (minimal point of equation = -b/2c) to 10ºC and 15ºC, respectively. From these periods of exposure, the budbreak increased with the chilling exposure increase.

Analyzing the budbreak in function of chilling exposure in different temperatures of heat accumulation, may be observed that the effect of chilling exposure increase on budbreak of 'Castel Gala' was significant at 6,888 GDHºC of heat accumulation, while the effect of chilling exposure was significant at 13,776 GDHºC in Royal Gala apples (Figure 2). These results indicate that 'Castel Gala' presents lower heat requirement to budburst when compared to 'Royal Gala' apples, as the effect of increased the chilling exposure on budbreak is manifested with the decrease of heat accumulation. Citadin et al. (2001) observed inverse relationship between the effects of chilling and heat accumulation on the blooming time of peach cultivars. Similarly, Albuquerque et al. (2008) showed that greater chilling exposure lead to a reduction of heat requirement in sweet cherries, where the average blooming date was earlier for cultivars with lower chilling requirements but not for those with lower heat requirements, whereas the latest-blooming cultivar needed the highest chill and heat accumulations for its flowering. In general, 'Castel Gala' apples showed higher percentage of budbreak than the 'Royal Gala', and the differences between these cultivars were maximized with the increasing of chilling exposure and heat accumulation (Figure 2). These results show that the 'Castel Gala' cultivar presents lower chilling requirement than 'Royal Gala', like indicated by Denardi and Seccon (2005).

The low percentage of budbreak showed by the cultivars used, even in long periods of chilling exposure, may be justified by the gradient of apple budbreak, in which there were predominance of budbreak in terminal buds regardless of thermal condition occurred during winter. Putti et al. (2003a, 2003b) also obtained low percentage of budbreak in apple cultivars with medium and high chilling requirement, even with high chilling exposure. The first buds overcome dormancy may influence the intensity of the other dormant buds still dormant, where the early budbreak in terminal buds inhibits the growth of other buds in a typical case of apical dominance. According to Petri and Leite (2004), trees in mild winter climates have terminal growth stimulated, which inhibits the budbreak in axillary buds. Chavarria et al. (2009), Wagner Junior et al. (2006, 2009) did not reported problems related to budbreak limited in axillary buds with the method using grafted twigs in peach, obtaining budbreak percentage over 50% in the highest chilling exposure tested. The low percentage of budbreak in both apple cultivars in the method using grafted twigs may be associated to the high apical dominance characteristic of apples trees. According to Erez (2000), the apical dominance varies among species, with greater polarity or acrotony in pomefruits than cherry, peach and plum. As a result of a positional advantage, the terminal buds, in the absence of correlative inhibitions, is capable of establishing dominance and, thus, a clearly defined acrotonic bud-bursting tendency (COOK; JACOBS, 1999).

Strong apical dominance in apples coupled with the low chilling requirements of the terminal bud combine to mask chilling effects on axillary buds (NAOR et al., 2003). Therefore, these authors, when used apple trees within pots, suggested that the twigs were oriented horizontally in order to decrease the effects of apical dominance on budbreak of axillary buds, because the apical dominance effects was higher in twigs vertically conducted than in the field conditions. The low percentages of budbreak obtained in this study suggest the necessity to adequate the methodology using grafted twigs for dormancy studies to estimate chilling requirements of apple cultivars. Results showed by Naor et al. (2003) suggested that the maintenance of the plants in oblique position during the chilling treatments exposure provide greater similarity to the field conditions, because the most of twigs have oblique insertion in the tree branches in plants developed under natural orchard conditions. Thus, the apical dominance level in plants under controlled conditions may be equalized to that observed in field conditions, where the plant responses to chilling treatments on budbreak may be similar in both conditions.

TABLE 1 - Summary of analysis of variance for budbreak parameter in 'Castel Gala' and 'Royal Gala' apples submitted to different thermal conditions during winter period. Pelotas, Rio Grande do Sul, Brazil, 2007.

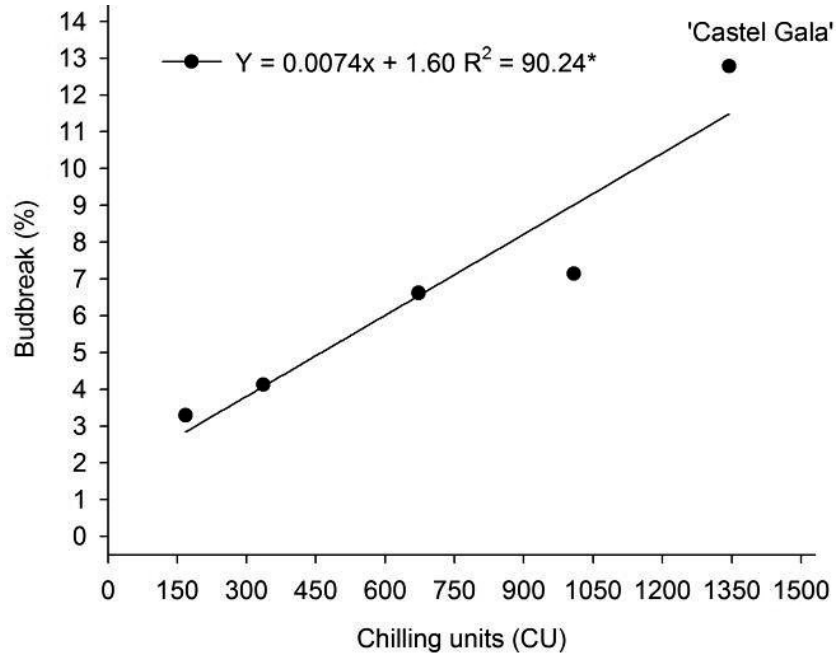
Variation Source	DF	Mean Square			
		'Castel Gala' budbreak[1]		'Royal Gala' budbreak[1]	
Temperature (T)	2	0.143	*	0.106	*
Chilling exposure (C)	4	0.360	*	0.289	*
Heat units (H)	5	0.865	*	0.279	*
T x C	8	0.010	ns	0.015	*
T x H	10	0.004	ns	0.015	*
C x H	20	0.027	*	0.059	*
T x C x H	40	0.004	ns	0.005	ns
Error	270	0.0091		0.005	
General mean		6.79		1.39	
CV (%)		44.58		60.53	

DF – degrees of freedom; [1] variables transformed by arc sen $(x/100)^{1/2}$ expression; ns - no significant by F test ($p<0.05$); * significant by F test at 5 % of probability.

TABLE 2- Effect of temperatures and chilling exposure during winter period on budbreak of 'Castel Gala' and 'Royal Gala' apples. Pelotas, Rio Grande do Sul, Brazil, 2007.

Temperature	Budbreak (%)					
	Chilling exposure					
	168 CU	336 CU	672 CU	1,008 CU	1,344 CU	Mean
	'Castel Gala'					
5ºC	2.74	3.40	4.65	5.63	11.90	5.67b
10ºC	2.10	3.91	7.72	7.47	10.45	6.33b
15ºC	5.03	5.05	7.47	8.32	16.10	8.38a
	'Royal Gala'					
5ºC	0.00a	0.00a	1.62a	4.87a	6.22a	2.54
10ºC	0.99a	0.97a	1.18a	3.19a	6.30a	2.53
15ºC	0.00a	0.00a	0.00a	1.04b	3.04b	0.82

Means followed by the same letters in the column do not differ significantly by Tukey test ($p<0.05$). CU – chilling units.



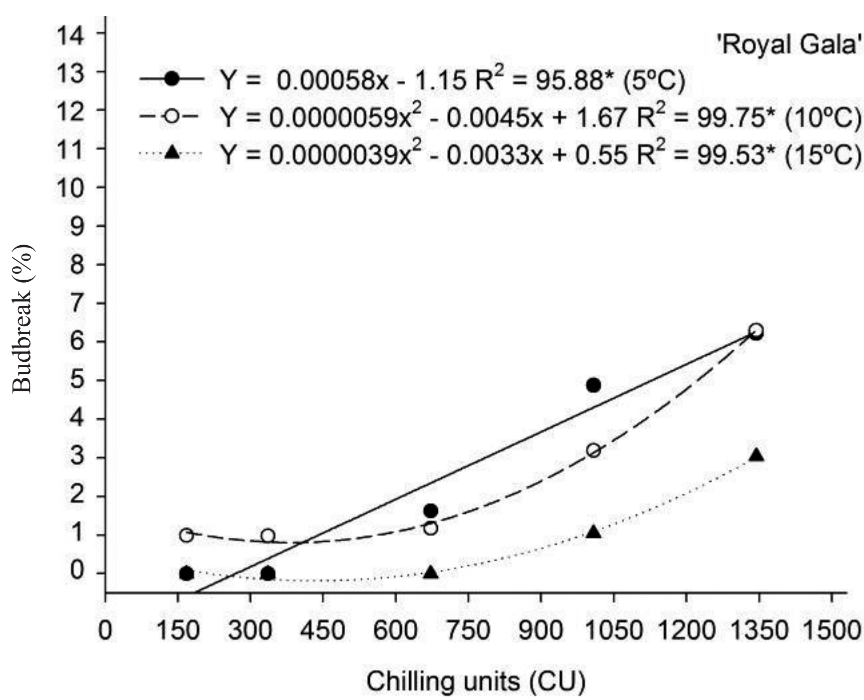


FIGURE 1- Budbreak in ‘Castel Gala’ and ‘Royal Gala’ apples in response to different temperatures and chilling exposure during the winter period. Pelotas, Rio Grande do Sul, Brazil, 2007.

*Significant equation by F test ($p<0.05$).

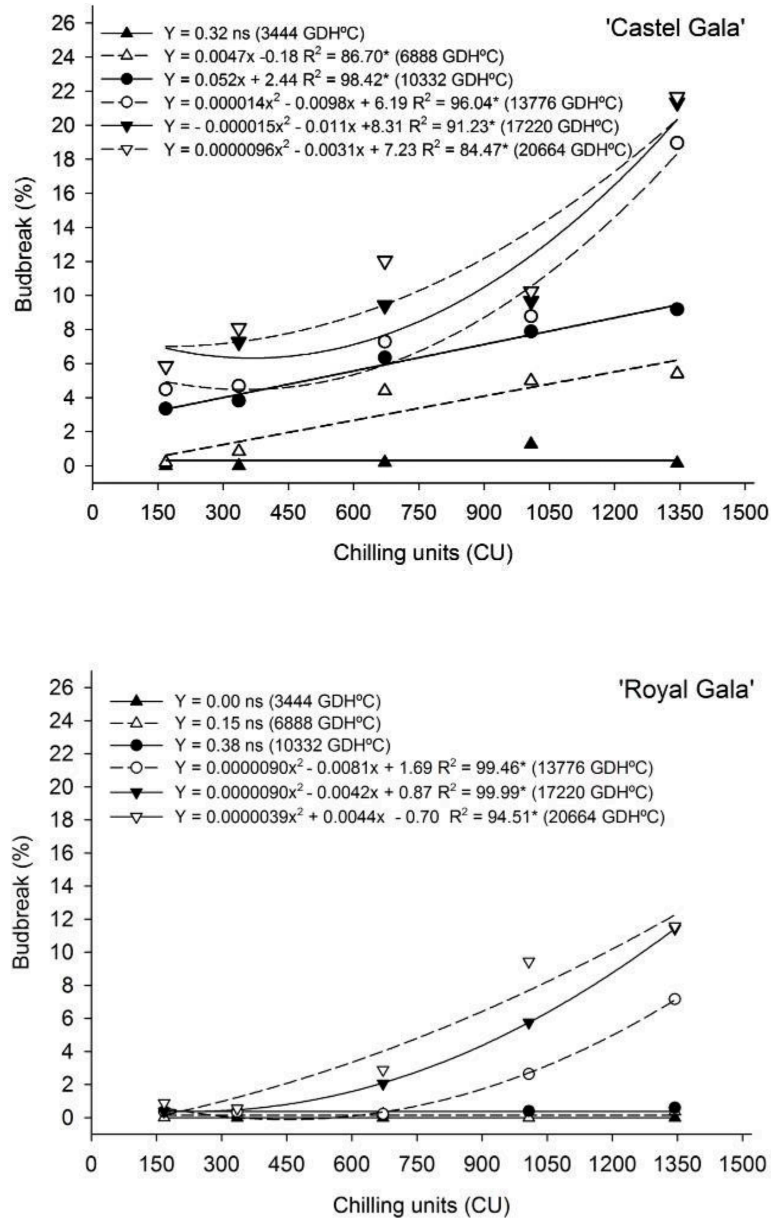


FIGURE 2 - Effect of chilling exposure during winter period and heat units on budbreak of ‘Castel Gala’ and ‘Royal Gala’ apples. Pelotas, Rio Grande do Sul, Brazil, 2007.

*Significant equation by F test ($p<0.05$).

CONCLUSIONS

1-'Castel Gala' cultivar (low chilling requirement) may be capable to budburst even when subjected to higher temperatures compared to 'Royal Gala' apples (high chilling requirement).

2-The winter temperature more effective to budburst 'Castel Gala' apples was 15°C, while the temperatures of 5 and 10ºC show better performance on budbreak of 'Royal Gala' apples.

3-The acrotonic tendency of apple limits the budbreak of axillary buds in the grafted twigs methodology.

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