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Effective temperature for overcoming dormancy of 'Fuyu' persimmon tree buds

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ABSTRACT
The objective of this study was to evaluate the effective temperature for overcoming the dormancy of 'Fuyu' persimmon tree buds. Stem samples were collected three times between 2013 and 2014. Stems were maintained in a climate incubator chamber at 3, 6, 9, and 12 °C. For each temperature, five numbers of additional chilling hours (CH) (0, 240, 384, 528, and 672 CH) were studied. The experimental design was completely randomized in a 5 × 4 factorial design (chilling hours × temperatures) with four replications with 10 cuttings. The maintenance of branches at cold temperatures from 3 to 12 °C intensified endodormancy of the buds when the plants were at the beginning of endodormancy. The most effective temperatures for overcome dormancy when the buds were in transition from paradormancy to endodormancy were from 3 to 6 °C. When the buds were already in endodormancy, temperatures of 3, 6, 9, and 12 °C were effective for the accumulation of cold and overcoming dormancy. The increase in the number of chilling hours from 3 to 12 °C induced budburst and the temperature of 12 °C was able to slowly induce and overcome bud dormancy.

Keywords: *Diospyros kaki*; chilling hours; budburst; biological test.

INTRODUCTION

Bud dormancy includes the phases of paradormancy, endodormancy and ecodormancy. In endodormancy, often called true dormancy, budburst is repressed by endogenous factors of the bud, which requires cold to start a new growth cycle (LANG et al., 1987). The start and homogeneity of the budburst are determined by the time and intensity the plant exposure to low temperatures, variables depending on the species or cultivar (ANZANELLO et al., 2018; PARK; PARK, 2020).

The importance of knowing the chill requirement of a cultivar and the chill present in a given region has increased in light of future scenarios of global climate change. Insufficient chill may cause bad budburst, which compromises the production since it yields low quality or irregular fruits, as well as the distribution of branches in the plant (ATKINSON et al., 2013; JONES et al., 2013).

Chilling requirements in 'Fuyu' persimmon tree were quantified (FAQUIM et al., 2007). However, intensities of bud exposure to different low temperatures during chill treatment were not considered. According to PUTTI et al. (2003), genetic variability between different cultivars limits the determination of chill requirement if the effective temperatures to overcome dormancy are unknown.

Considering that the effective temperature to overcome dormancy is that which is capable of inducing maximum budburst, and that different levels of temperature below 12 °C have a positive effect in overcoming dormancy (HEIDE; PRESTRUD, 2005; PARK; PARK, 2020), knowing the effective temperature for persimmon budburst can help in

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determining chill requirement and agricultural zoning of cultivars, besides allowing the projection of the effects caused by climate change. The objective of this study was to evaluate the effective temperature for overcoming the dormancy of 'Fuyu' persimmon tree buds.

MATERIAL AND METHODS

Samples of one-year-old persimmon 'Fuyu' branches with 30 to 40 cm long, located in the oblique position of the crown, were collected on three dates on the fourth week of April, on the third week of June and on the fourth week of July 2013 and 2014.

The branches were collected from 17-year-old mother plants, in the commercial organic orchard Sítio São Marcos, located in Campina Grande do Sul (25°18'S, 49°03'W and at an average height of 918 m), state of Paraná, Brazil. In order to evaluate the natural chill that occurred from April 1, 2013 and 2014 until the date of the last collection of branches, the number of chilling hours (CH) below or equal to 7.2 and 12 °C (WEINBERGER, 1950) and chilling units according to the modified North Carolina model (SHALTOUT; UNRATH, 1983) were calculated (Table 1).

Table 1. Chilling hours below or equal to 7.2 °C and 12 °C, and chilling units calculated by the modified North Carolina model, registered by the Meteorological Station of Simepar, in Pinhais, Paraná state, Brazil.

Periods	Chilling hours ≤ 7.2 °C		Chilling hours ≤ 12 °C		Chilling units	
2013	**Between dates**	**Accumulated**	**Between dates**	**Accumulated**	**Between dates**	**Accumulated**
04/01 a 04/23	0	0	44	44	4	4
04/24 a 06/17	36	36	257	301	14	18
06/18 a 07/30	113	149	411	712	93	111
2014	**Between dates**	**Accumulated**	**Between dates**	**Accumulated**	**Between dates**	**Accumulated**
04/01 a 04/22	0	0	0	0	0	0
04/23 a 06/16	21	21	204	204	26.5	26.5
06/17 a 07/29	37	58	344	548	75	101.5

Samples of branches, packed in moistened newspaper and in transparent polyethylene bags, were kept in climatic incubator chambers, in the dark, and subjected to the four constant temperatures of 3, 6, 9, and 12 °C. For each temperature, five numbers of additional chilling hours at room temperature (0, 240, 384, 528, and 672 CH) were studied in order to assess the budburst through the biological test.

The experimental design was completely randomized, with 5 × 4 factorial arrangements (chilling hours × temperatures) with four repetitions of 10 cuttings per experimental unit. The collection times and years have were evaluated individually.

Biological tests were carried out in growth rooms at a temperature of 25 °C and a photoperiod of 16 h. The upper portion of the branches was divided into 6 cm long cuttings, keeping only the upper lateral vegetative bud. The cuttings were kept in pots with moist vermiculite and covered in transparent polyethylene bags in order to maintain the humidity (CARVALHO; BIASI, 2019).

The cuttings were evaluated individually every 2 days, for a period of up to 40 days after the experiment was installed, according to the international *Biologische Bunde-sanstalt, Bundessortenamt, and CHemical industry* (BBCH) scale for growth parameters *green tip* (GT) (BBCH 07 – beginning of bud burst: first green leaf tips just visible) and *open bud* (OB) (BBCH 10 – first leaves separating) (GARCÍA-CARBONELL et al., 2002). Based on these parameters, the following variables were calculated: average budburst time (ABT), which represents the average number of days spent between the installation of the experiment and detection of the GT period; the final budburst rate (FBR), which represents the percentage of cuttings with buds that reached GT; the vigorous budburst rate (VBR), which represents the percentage of cuttings with buds that presented the GT stage and evolved to the OB stage [VBR = (% cuttings with buds on OB stage) × 100/FBR]; and the velocity of budburst (VB), which evaluates the occurrence of budburst as a function of budding time given by equation $VB = \Sigma (ni \cdot ti^{-1})$ ($buds \cdot day^{-1}$) where ni = number of buds that reached GT stage in i time, and ti = time after test installation (i = 1 to 40).

The VBR and VB variables were analyzed for use in calculating the dormancy index (DI) of buds, which classifies the answer obtained from budburst in endodormancy classes for the persimmon tree through the Eq. 1:

$$DI = ABT \times (k \times FBR + w \times VB + VBR)^{-1} \quad (1)$$

with the constants k and w being 4 and 1, respectively. According to CARVALHO; BIASI (2012), the bud dormancy of persimmon tree is classified as absent when the DI is less than 2.50; weak when the DI is between 2.51 and 4.50; moderate when the DI is between 4.51 and 8.00; intense when the DI is between 8.01 and 12.00; and deep, when the DI is greater than 12.00.

Variances of the treatments were tested for homogeneity through the Bartlett's test. The values of the DI variable did not show the homogeneity of variances in the second collection of 2013 and were therefore transformed to log (x). The means of the treatments with a significant difference in the F-test in analysis of variance were submitted to the Scott–Knott test at the 1% level of error probability.

RESULTS AND DISCUSSION

The transition was observed to be not well defined from paradormancy to endodormancy in persimmon tree. The low temperatures acted differently in these two phases, since they induced endodormancy when the plants were still in paradormancy. They also encouraged budburst when the plants were already endodormant.

In April 2013, the buds that did not receive additional chill presented a DI greater than 8.0 and an ABT of 34.12 days (Table 2), values that indicate intense dormancy (CAMPOY et al., 2011b; CARVALHO; BIASI 2012; EL YAACOUBI et al., 2016).

Table 2. Dormancy index (DI), average budburst time (ABT) and final budburst rate (FBR) of 'Fuyu' persimmon tree buds in April 2013.

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			DI		
0	8.05 aA	8.05 aA	8.05 aA	8.05 aA	8.05
240	5.18 bA	4.31 bA	5.27 bA	4.93 bA	4.92
384	7.69 aA	7.96 aA	6.42 bB	5.74 bB	6.95
528	7.49 aA	7.32 aA	5.98 bB	4.72 bB	6.38
672	7.19 aB	4.84 bC	8.57 aA	5.47 bC	6.52
Means	7.12	6.50	6.86	5.78	
CV(%)			14.65		
			ABT (days)		
0	34.12	34.12	34.12	34.12	34.12 a
240	22.92	21.86	23.48	22.41	22.67 b
384	22.86	20.84	22.25	22.12	22.02 c
528	22.81	23.92	24.03	22.38	23.29 b
672	20.69	19.63	24.00	20.98	21.33 c
Means	24.68^{ns}	24.07	25.58	24.40	
CV(%)			7.54		
			FBR (%)		
0	77.50	77.50	77.50	77.50	77.50 a
240	82.50	92.50	85.00	85.00	86.25 a
384	43.33	37.50	52.50	60.00	48.33 b
528	46.67	50.25	62.50	87.50	61.73 b
672	50.00	60.00	47.50	72.50	57.50 b
Means	60.00 B	63.55 B	65.00 B	76.50 A	
CV(%)			28.19		

Means followed by the same lower-case letters in a column and capital letters on the lines do not differ significantly by the Scott–Knott test ($p < 0.01$). CV = coefficient of variation. ^{ns} = not significant.

This limitation of growth may not have occurred in response to the endodormancy of the buds, as the dormancy intensity determined by DI and ABT did not decrease with the extended amount of time the buds remained at cold temperatures between 240 and 672 CH. If it were endodormancy, chill accumulation should have overcome dormancy with a decrease in DI and ABT (CAMPOY et al., 2011b; 2011c; ABBOTT et al., 2015). In April 2013, the buds had not been chilled under 7.2 °C (Table 1), and in this case, only the decrease of the photoperiod (Fig. 1) should have acted as an environmental factor to stop plant growth.

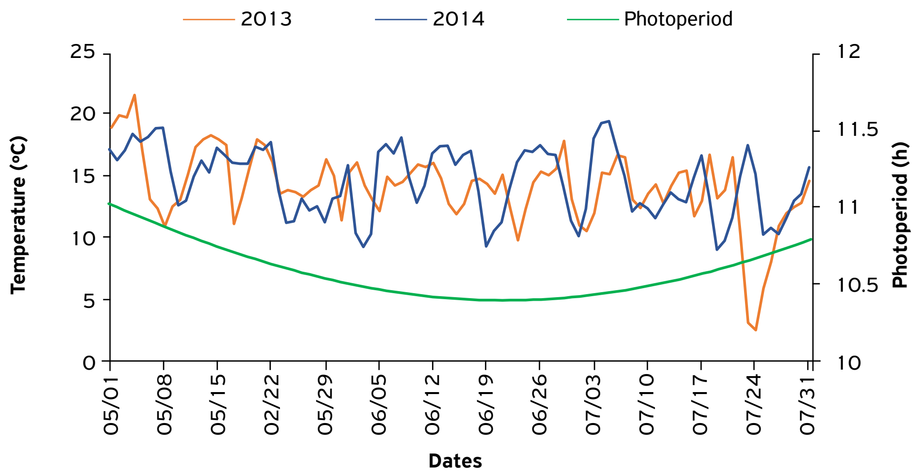

Figure 1. Average daily temperature and photoperiod registered in the period from May to July 2013 and 2014, by the Meteorological Station of Simepar, in Pinhais, state of Paraná, Brazil.

The smallest budburst may have been influenced, mainly, by the paradormancy still installed, which limited budburst soon after the collection of the branches. Therefore, the decrease in DI, ABT and high FBR, with the accumulation of an additional 240 CH, may have occurred due to the paralyzation of the paradormancy effect, since these buds remained isolated from the plant for a longer period until they were kept in optimal growth conditions, when compared with the buds that did not receive additional chill.

The extended amount of time the buds remained at cold temperatures, between 240 and 672 CH, was not sufficient to promote the budburst potential near DI value indicative of the absence of dormancy. The chill accumulation of up to 672 additional CH may have induced the buds to enter endodormancy since the low temperatures have dual function: to initiate and to end dormancy (BALANDIER et al., 1993; JACOBS et al., 2002; HEIDE; PRESTRUD, 2005; CAMPOY et al., 2011b, 2011c; BILAVČÍK et al., 2012).

The high value of ABT and FBR without additional chill is not in accordance with periods of endodormancy in fruit trees of temperate climate, since the relationship between ABT and FBR tends to be reversed (EL YAACOUBI et al., 2016). With the accumulation of an additional 384 CH, there was a decrease in FBR, which remained low up to an additional 672 CH, even with the supply of 504 CH that is the persimmon's requirement to release dormancy (FAQUIM et al., 2007). The accumulation of an additional 672 CH should have increased the number of budburst if the plant was actually in endodormancy.

The temperatures 3, 6, 9, and 12 °C induced endodormancy. However, temperatures 3 and 6 °C were more efficient than 9 and 12 °C since the buds submitted to the two lower temperatures had higher DI with additional 384 and 528 CH. The buds kept at 12 °C had higher FBR, indicating that higher temperatures may induce endodormancy, but more slowly than colder temperatures. Apple trees that were kept at 12 °C needed a longer exposure time at this temperature than the plants kept at 6 and 9 °C in order to enter and exit dormancy (HEIDE; PRESTRUD, 2005).

In June 2013, buds that did not receive additional chill presented lower DI and ABT (Table 3) when compared to April 2013. Possibly, the chill accumulation in the field of 36 CH below 7.2 °C (Table 1) and the decrease in the photoperiod (Fig. 1) induced the plant to enter endodormancy.

At that time, there was still a residual effect of paradormancy, since the buds maintained or decreased DI and ABT, with a high FBR between additional 0 and 240 CH (Table 3). The supply of additional 384 and 528 CH increased DI and ABT, and decreased FBR, as noted in April 2013. This indicates that the buds were at the beginning of endodormancy and that the maintenance of branches in cold temperatures intensified it (BALANDIER et al., 1993; JACOBS et al., 2002; HEIDE; PRESTRUD, 2005; CAMPOY et al., 2011b; 2011c; BILAVČÍK et al., 2012).

Table 3. Dormancy index (DI), average budburst time (ABT) and final budburst rate (FBR) of 'Fuyu' persimmon tree buds in June 2013.

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			DI		
0	6.01	6.01	6.01	6.01	6.01 c
240	5.19	4.07	3.90	4.73	4.47 c
384	14.09	12.28	26.86	17.47	17.68 a
528	11.90	14.96	8.73	8.78	11.09 b
672	4.54	3.91	7.33	6.41	5.55 c
Means	8.35 ^{ns}	8.25	10.56	8.68	
CV(%)			21.61		
			ABT (days)		
0	25.00 bA	25.00 bA	25.00 cA	25.00 aA	25.00
240	20.05 bA	19.54 cA	20.20 dA	23.18 aA	20.74
384	30.23 aA	25.65 bB	33.15 aA	28.23 aB	29.32
528	30.83 aA	32.07 aA	25.35 cB	23.83 aB	28.02
672	23.20 bB	19.88 cB	28.38 bA	25.88 aA	24.33
Means	25.86	24.43	26.42	25.22	
CV(%)			12.49		
			FBR (%)		
0	85.00	85.00	85.00	85.00	85.00 a
240	82.50	92.50	95.00	95.00	91.25 a
384	50.00	47.50	23.34	20.00	35.21 c
528	62.50	56.67	70.00	62.50	62.92 b
672	95.00	95.00	72.50	77.50	85.00 a
Means	75.00 ^{ns}	75.33	69.17	68.00	
CV(%)			25.38		

Means followed by the same lower-case letters in a column and capital letters on the lines do not differ significantly by the Scott–Knott test ($p < 0.01$). CV = coefficient of variation. ^{ns} = not significant.

The accumulation of an additional 672 CH increased budburst, as observed by the decrease in DI and ABT, and the increase in FBR. The most efficient temperatures for inducing budburst under this condition were 3 and 6 °C, as they provided lower ABT of 23.20 and 19.88 days, respectively, with low DI and high FBR.

In July 2013, buds that did not receive additional chill kept a moderate dormancy intensity with DI equal to 6.70 (Table 4), as observed in June 2013. However, the chill accumulated in the field at 149 CH below 7.2 °C (Table 1) may have intensified the endodormancy of the plants, as the additional chill provided an increase in the growth capacity of the buds.

At that time, the chill's action in overcoming dormancy was better visualized since the increase of the bud's exposure time in cold temperatures provided a lower ABT of 13.94 days and a higher FBR of 96.26%, with DI indicating weak dormancy. These results confirm that chill accumulation when plants are already in endodormancy provides a more efficient dormancy overcoming (BALANDIER et al., 1993; JACOBS et al., 2002; CAMPOY et al., 2011c; YAMANE, 2014). According to CARVALHO et al. (2010), it is considered that obtaining ABT below 14 days is indicative of the absence of endodormancy in 'Fuyu' persimmon tree, especially if allied with FBR above 90%.

In April 2014, buds that did not receive additional chill presented only 5% of budburst (Table 5) and, therefore, were not statistically analyzed. The absence of sprouting may have occurred in response to the paradormancy, as during gathering plants still had leaves and fruits that may have inhibited the growth (LANG et al., 1987). According to CARVALHO et al. (2010), persimmon's paradormancy is intense and difficult to overcome because, under natural conditions, the inhibition is only overcome by harvesting or by the natural fall of the leaves.

The supply of an additional 240 CH partially overcame paradormancy, decreasing DI and ABT and increasing FBR (Table 5), as was observed in April of 2013. However, the values of DI and ABT were still high up to the accumulation of an additional 528 CH, which demonstrates a lower budburst capacity. This behavior indicates that the maintenance of the branches in cold temperatures induced endodormancy (JACOBS et al., 2002; HEIDE; PRESTRUD, 2005; BILAVČÍK et al., 2012), since until the collection of the branches, there was no chill accumulation below 7.2 °C (Table 1). Therefore, the plant had not received a low temperature stimulus, only a stimulus from the decreasing photoperiod (Fig. 1).

Table 4. Dormancy index (DI), average budburst time (ABT) and final budburst rate (FBR) of 'Fuyu' persimmon tree buds in July 2013.

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			DI		
0	6.70	6.70	6.70	6.70	6.70 a
240	5.72	4.50	5.59	7.01	5.70 b
384	3.86	3.65	4.37	4.31	4.05 c
528	3.56	2.58	2.73	2.79	2.92 d
672	3.38	2.53	2.83	2.63	2.84 d
Means	4.65 ^{ns}	4.19	4.44	4.69	
CV(%)			20.77		
			ABT (days)		
0	24.80	24.80	24.80	24.80	24.80 a
240	25.70	23.10	25.33	25.78	24.98 a
384	20.48	19.93	21.43	20.55	20.59 b
528	14.95	13.95	12.75	14.13	13.94 c
672	17.55	14.20	15.20	14.25	15.30 c
Means	20.70 ^{ns}	19.20	19.90	19.90	
CV(%)			12.07		
			FBR (%)		
0	70.03	70.03	70.03	70.03	70.03 c
240	90.15	95.05	85.08	72.53	85.70 b
384	97.55	100.00	95.05	92.45	96.26 a
528	90.03	95.08	77.53	90.03	88.16 b
672	92.53	99.90	92.53	92.53	94.37 a
Means	88.06 A	92.01 A	84,04 B	83.51 B	
CV(%)			11.01		

Means followed by the same lower-case letters in a column and capital letters on the lines do not differ significantly by the Scott–Knott test ($p < 0.01$). CV = coefficient of variation. ^{ns} = not significant.

After an additional 672 CH, the buds presented an indicative of weak dormancy, with a lower ABT when they were kept at 3, 6 and 9 °C. Under this condition, the temperature of 6 °C was more efficient for budburst, as it provided the lowest ABT (16.98 days). A temperature of 12 °C was able to induce endodormancy, but more slowly than the lower temperatures. Only after an additional 528 CH the DI increased again for intense dormancy.

In June 2014, the plants could be transitioning from paradormancy to endodormancy, stimulated by accumulation in the field of 36 CH below 7.2 °C (Table 1) and by the short photoperiod (Fig. 1). There was still paradormancy effect: the buds that did not receive additional chill presented a high FBR when the DI still indicated moderate dormancy, and a high ABT of 24.78 days (Table 6). The chill accumulation up to an additional 384 CH decreased or maintained the values of DI and ABT; with an additional 528 CH, DI and ABT increased and FBR decreased, indicating that low temperatures induced the buds to enter endodormancy (JACOBS et al., 2002; HEIDE; PRESTRUD, 2005; CAMPOY et al., 2011b; 2011c; BILAVČÍK et al., 2012).

The maintenance of the branches at an additional 672 CH stimulated budburst, since an increase in the FBR with a decrease of the DI and of the ABT (Table 6) was observed, as noted in June 2013. The temperature of 6 °C was the most efficient for overcoming dormancy because 100% of buds sprouted with an ABT of 10.53 days and an DI equal to 1.77, which classifies dormancy as absent.

Buds kept at 12 °C showed a moderate DI and a decrease in the FBR values from 87.58% to 52.53% after additional 672 CH (Table 6). This behavior can be explained by the double action that high temperatures as 12 °C may have in dormancy, since they may have inhibited, by the stimulus of cold, the growth of the buds, even if more slowly. Under such condition, a chill accumulation of additional 672 CH or more is required. Still, these temperatures may have also stimulated growth by providing heat for the resumption of metabolic activity. The buds may have maintained a higher respiratory activity with a higher energy demand, when compared to buds kept at colder temperatures, with higher consumption of internal energy reserves in order to maintain metabolism at the expense of budburst (SØNSTEBY; HEDIE, 2014).

Table 5. Dormancy index (DI), average budburst time (ABT) and final budburst rate (FBR) of 'Fuyu' persimmon tree buds in April 2014.

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			DI		
0*	-	-	-	-	-
240	12.66 cA	5.27 bD	6.92 cC	8.27 aB	8.28
384	14.75 bB	12.68 aC	20.67 aA	3.76 cD	12.97
528	18.07 aA	4.98 bD	15.58 bB	8.35 aC	11.75
672	3.95 dB	3.11 cB	3.74 dB	5.47 bA	4.07
Means	12.36	6.52	11.73	6.46	
CV(%)			8.08		
			ABT (days)		
0*	-	-	-	-	-
240	32.48 aA	26.15 bB	30.25 bA	29.83 aA	29.68
384	29.33 bB	31.75 aA	33.19 aA	20.43 cC	28.68
528	26.00 cB	23.36 cB	30.14 bA	24.89 bB	26.10
672	19.75 dB	16.98 dC	19.68 cB	24.43 bA	20.21
Means	26.89	24.56	28.31	24.89	
CV(%)			6.62		
			FBR (%)		
0*	5.00	5.00	5.00	5.00	5.00
240	57.53 bB	92.53 aA	87.58 aA	67.53 cB	76.29
384	30.15 cC	53.33 bB	30.03 cC	100.00 aA	53.42
528	20.00 cC	87.53 aA	45.03 bB	50.00 dB	50.64
672	92.53 aA	97.58 aA	97.58 aA	87.53 bA	93.81
Means	50.05	82.74	65.05	76.30	
CV(%)			12.63		

Means followed by the same lower-case letters in a column and capital letters on the lines do not differ significantly by the Scott–Knott test ($p < 0.01$). CV = coefficient of variation. * Treatment not analyzed due to the low FBR found.

In July 2014, the ambient chill of 58 CH under 7.2 °C (Table 1) was not sufficient to decrease the DI observed in June 2014 because the buds that did not receive additional cold showed a DI indicative of moderate dormancy (Table 7).

With the provision of an additional 240 CH, the DI decreased to either weak or absent dormancy; however, with additional 384 CH, the DI increased again to moderate dormancy at 3, 6 and 9 °C or to intense dormancy at 12 °C, since there was an increase in the ABT and a decrease in the FBR. At that time, field environmental conditions may not have been sufficient for the plants to be in complete endodormancy, and the provision of an additional 384 CH decreased the growth capacity of the buds.

After an additional 528 CH, the buds presented a DI that indicated weak dormancy, with a higher FBR and a decreased ABT, although the ABT did not decrease too much in relation to buds that did not receive additional cold.

Although the initial physiological condition of 2013 and 2014 buds was different, the response of the buds to the chill was similar, although it occurred at different times of collection when comparing different years. The dynamics of the variation of the ABT of buds with additional CH in June 2014 and of the buds in April 2013 was similar (Fig. 2). The tendency to this behavior while at chill temperatures continued in the following collections, with the dynamics of the variation of the TMB of the buds in July 2014 and of the buds in June 2013 being similar (Fig. 2).

Table 6. Dormancy index (DI), average budburst time (ABT) and final budburst rate (FBR) of 'Fuyu' persimmon tree buds in June 2014.

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			DI		
0	5.67 bA	5.67 aA	5.67 aA	5.67 cA	5.67
240	5.11 cA	3.38 bB	3.76 bB	5.27 cA	4.38
384	3.37 dA	3.52 bA	3.79 bA	3.43 dA	3.53
528	7.50 aB	5.76 aC	6.43 aC	8.53 aA	7.05
672	3.99 dB	1.77 cC	3.99 bB	6.25 bA	4.00
Means	5.13	4.02	4.73	5.83	
CV(%)			11.03		
			ABT (days)		
0	24.78 aA	24.78 aA	24.78 aA	24.78 aA	24.78
240	18.96 cA	17.58 cA	17.99 bA	19.45 cA	18.50
384	17.55 cA	17.29 cA	18.28 bA	16.63 dA	17.44
528	21.96 bA	21.54 bA	22.14 aA	22.06 bA	21.92
672	17.58 cA	10.53 dB	18.82 bA	18.47 cA	16.35
Means	20.17	18.34	20.40	20.28	
CV(%)			6.89		
			FBR (%)		
0	87.58 aA	87.58 aA	87.58 aA	87.58 aA	87.58
240	70.00 bB	97.58 aA	87.58 aA	67.53 bB	80.67
384	95.05 aA	87.53 aA	87.53 aA	87.53 aA	89.41
528	52.58 cB	70.03 bA	65.03 bA	42.53 cB	57.54
672	80.05 aB	100.00 aA	87.53 aB	52.53 cC	80.06
Means	77.05	88.57	83.04	67.54	
CV(%)			11.62		

Means followed by the same lower-case letters in a column and capital letters on the lines do not differ significantly by the Scott–Knott test ($p < 0.01$). CV = coefficient of variation.

Table 7. Dormancy index (DI), average budburst time (ABT) and final budburst rate (FBR) of 'Fuyu' persimmon tree buds in July 2014.

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			DI		
0	6.77 aA	6.77 aA	6.77 aA	6.77 bA	6.77
240	2.70 dA	2.31 cA	2.27 cA	2.60 cA	2.47
384	5.46 bA	7.32 aB	7.89 aB	9.18 aA	7.46
528	1.76 dB	4.02 bA	4.14 bA	3.70 cA	3.41
672	3.95 cA	2.90 cA	3.08 cA	3.79 cA	3.43
Means	4.13	4.66	4.83	5.21	
CV(%)			18.64		
			ABT (days)		
0	18.31 bA	18.31 cA	18.31 bA	18.31 bA	18.31
240	13.55 cA	12.79 dA	12.48 dA	12.30 cA	12.78
384	24.52 aA	25.04 aA	21.43 aB	26.92 aA	24.48
528	10.55 cB	20.40 bA	17.50 bA	17.55 bA	16.50
672	19.75 bA	16.15 cB	15.84 cB	16.25 bB	16.99
Means	17.34	18.54	17.11	18.26	
CV(%)			12.42		

continue...

Table 7. Continuation...

Chilling hours	Temperatures (°C)				Means
	3	6	9	12	
			FBR (%)		
0	50.08 cA	50.08 cA	50.08 cA	50.08 bA	50.08
240	87.53 bB	97.58 aA	97.58 aA	80.08 aB	90.68
384	87.53 bA	65.03 bB	50.00 cC	57.58 bB	65.03
528	100.00 aA	95.08 aA	72.52 bC	82.58 aB	87.58
672	92.53 bA	100.00 aA	90.00 aA	75.08 aB	89.48
Means	83.56	81.58	72.07	69.07	
CV(%)			8.34		

In 2013 and 2014, the field chill of 149 and 58 CH, respectively, at temperatures below 7.2 °C (Table 1), was lower than required for the budburst of buds from the ‘Fuyu’ persimmon tree (FAQUIM et al., 2007). Even with the use of the modified North Carolina model, only 111 CU at the end of July 2013 and 101.5 CU at the same period of 2014 were obtained (Table 1).

Prolonged paradormancy on persimmon trees until June, 2013, and July, 2014, with buds still in transition to endodormancy, may have occurred due to low accumulation of chill and temperature fluctuations. Mild winter conditions induce shallow dormancy with the initiation of paradormancy, and when buds are kept at temperatures below 12 °C, an increase in the inhibition processes that may be associated with weak endodormancy takes place subsequently (MALAGI et al., 2015). For these authors, cultivars of low demand in chill situations, such as the ‘Eva’ apple tree, present only paradormancy when cultivated in those environmental conditions. The behavior that indicates endodormancy was observed only in July 2013, because after the accumulation of CH, the ABT was around 14 days (Fig. 2), which indicates absence of dormancy (CARVALHO et al., 2010).

Temperatures below 12 °C act as additional chill for the induction and breaking of dormancy (HEIDE; PRESTRUD, 2005). It was verified that 712 and 548 CH below 12 °C occurred in the field in 2013 and 2014 (Table 1), respectively, and that, for the persimmon tree, that may have been enough for natural budburst. According to JACOBS et al. (2002), dormancy progression is more accurately described when chill is calculated based on the number of hours below 13 °C. The increasing of the photoperiod may also have contributed to the breaking of the dormancy of the persimmon tree in the field, as also seen in apricot trees, for which the breaking of dormancy is favored by longer day lengths (CAMPOY et al., 2011a).

Knowledge of the dormancy stage is important for the interpretation of the effect of different temperatures and of chill accumulation in budburst. When buds were in the transition from paradormancy to endodormancy, temperatures of 3 and 6 °C were more efficient in the breaking of the dormancy. However, in July 2013, when buds were already in endodormancy, and after an accumulation of 672 CH, a significant difference in the effect of temperatures from 3 to 12 °C on the DI and on the ABT (Table 4) was not observed, that is to say, those temperatures were equally efficient on the breaking of the dormancy of the buds. JACOBS et al. (2002) also found no differences among temperatures of 1, 4, 7, 10 and 13 °C for the budburst of endodormant apple and pear tree buds. Oriental pear cultivars showed that temperatures from −1.9 to 12.0 °C were effective for chilling accumulation and 2.1 to 4.0 °C was the most effective range for chilling accumulation and bud burst, whereas temperatures above 14 °C exhibited negative accumulation values (PARK; PARK, 2020). According to CAMPOY et al. (2011b), the positive effect of higher temperatures on dormancy break only becomes evident after partial accumulation of chill in the field. In July 2013, plants had accumulated in the field 149 CH below 7.2 °C and 712 CH below 12 °C.

In July 2013, the field chill accumulation of 712 CH and the supply of additional 672 CH, both at temperatures below 12 °C, totaling 1384 CH below 12 °C, reduced the intensity of the dormancy of the buds; however, the DI still indicated weak dormancy. Therefore, the natural breaking of the dormancy on persimmon tree buds in the field may occur. However, budburst may still be under the plant’s capacity in weather conditions that indeed supply sufficient chill. Subtropical regions and the expected climate changes may delay dormancy break and cause-poor budburst with little distribution of branches along the plant and impairment of the production (ATKINSON et al., 2013; JONES et al., 2013).

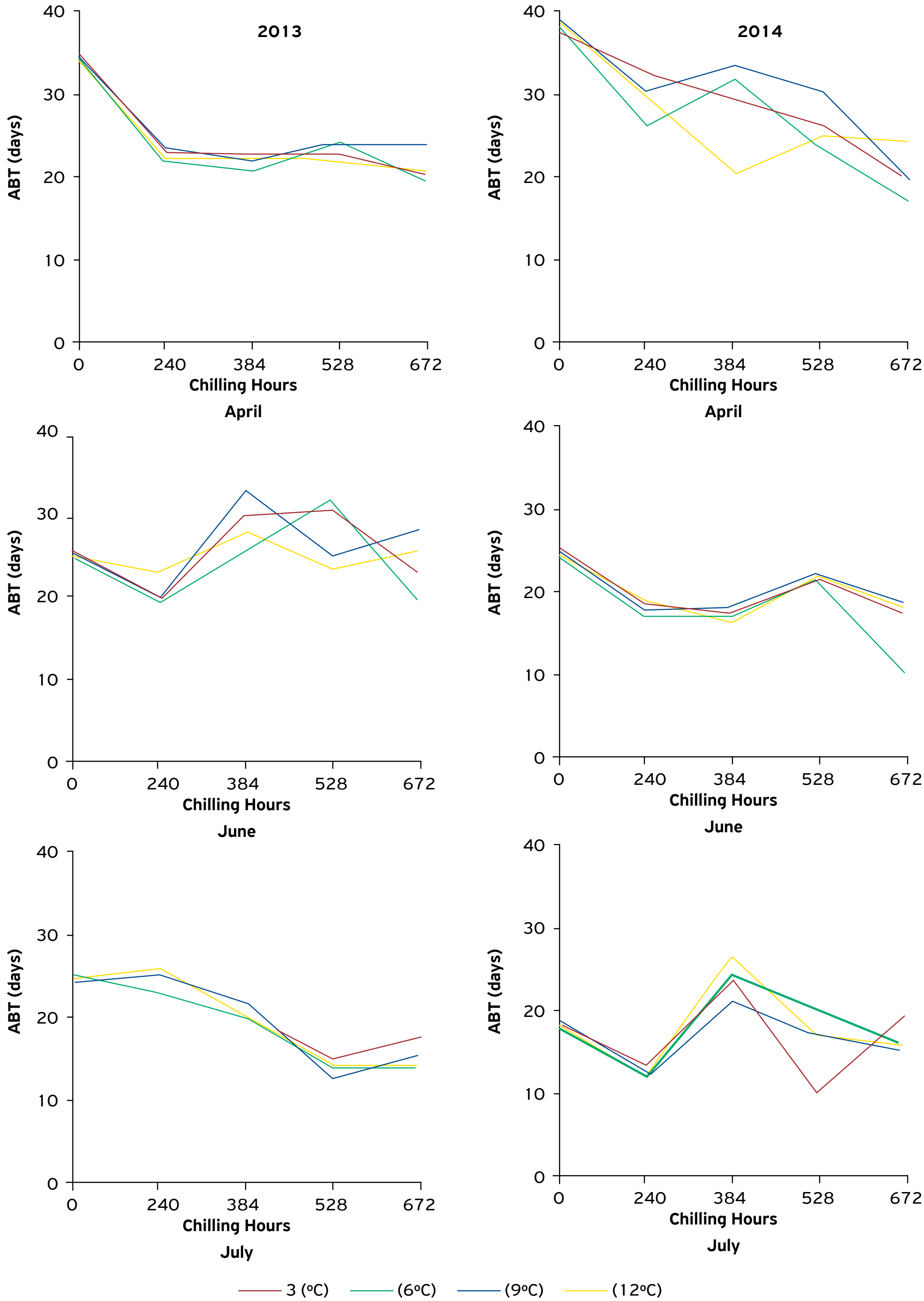

Figure 2. Average budburst time (ABT) of 'Fuyu' persimmon tree buds in April, June and July 2013 and 2014.

CONCLUSION

When plants are at the transition from paradormancy to endodormancy, the keeping of branches in chill temperatures of 3, 6, 9, and 12 °C induces the endodormancy of 'Fuyu' persimmon tree buds. When the buds are in the transition from paradormancy to endodormancy, the temperatures of 3 and 6 °C are more effective in breaking the dormancy of the 'Fuyu' persimmon tree buds than those of 9 and 12 °C.

When the buds are already in endodormancy, temperatures of 3, 6, 9, and 12 °C are effective for breaking dormancy. The temperature of 12 °C is capable of inducing dormancy, but more slowly, requiring a larger number of chilling hours.

AUTHORS' CONTRIBUTIONS

Conceptualization: Zanette, F.; Carvalho, R.I.N. **Data curation:** Pereira, G.P. **Formal analysis:** Pereira, G.P. **Funding acquisition:** Biasi, L.A.; Zanette, F. **Investigation:** Pereira, G.P.; Francisco, F. **Methodology:** Pereira, G.P.; Francisco, F. **Project administration:** Zanette, F.; Carvalho, R.I.N.; Biasi, L.A. **Resources:** Pereira, G.P.; Francisco, F. **Supervision:** Zanette, F.; Carvalho, R.I.N.; Biasi, L.A. **Validation:** Pereira, G.P.; Francisco, F. **Visualization:** Pereira, G.P.; Zanette, F. **Writing – original draft:** Pereira, G.P. **Writing – review & editing:** Biasi, L.A.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed during this study are included in this published article.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest in the publication.

ETHICAL APPROVAL

Not applicable.

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