



Adaptability and stability of 34 peach genotypes for leafing under Brazilian subtropical conditions



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ABSTRACT

This study aimed to evaluate adaptability and stability for leafing of peach genotypes in a subtropical climate. The design was completely randomized with three replicates (trees) and five branches per replicate in a factorial arrangement of 34×4 for genotypes and years, respectively. The beginning of budburst (5%), final budburst (75%) and fruit-bearing shoots formed at 45 days after the end of the budburst were evaluated for four years (2007–2010). The number of hours of temperature below 7.2 °C or 12 °C or above 20 °C from May to August was recorded. Adaptability and stability analyses were performed using GGE biplot methodology. ‘Cascata 1063’, ‘Cascata 1303’, ‘Conserva 1187’, ‘Conserva 1223’, ‘Conserva 1396’, ‘Kampai’, ‘Libra’ and ‘Santa Áurea’ were the peach tree genotypes with the greatest adaptability and stability for budburst trait. For fruit-bearing shoots formed, the genotypes ‘Conserva 1127’, ‘Conserva 1216’ and ‘Conserva 681’ had the greatest adaptability and stability. A high percentage of budburst does not necessarily lead to a high percentage of fruit-bearing shoots development. ‘Ambar’, ‘Bonão’, ‘Conserva 655’, ‘Kampai’, ‘Libra’, ‘Rubimel’ and ‘Santa Áurea’, showed a good percentage of budburst and development of fruit-bearing shoots, remained stable for both traits and are considered the best adapted.

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1. Introduction

The spread of commercial growing of temperate fruit crops to subtropical and tropical regions has increased rapidly in recent years. This increase is especially noticeable with peaches in Brazil, where the climatic conditions are highly variable. Subtropical humid zones, located in Southern Brazil, have hot, humid, rainy summers that favor disease development. Furthermore, inconsistent winter dormancy conditions, caused by conflicting air masses of tropical and polar origins, result in both insufficient chill accumulation in some years or sites and late frost danger during bloom. Temperatures above 20 °C during the endodormancy period, considered undesirable (Erez et al., 1979), are also frequent. The cultivars better adapted to Brazil have low chilling requirements (0–400 chilling hours below 7.2 °C) (Byrne et al., 2000; Topp et al., 2008). The Brazilian peach breeding programs have developed germplasms by combining local cultivars with breeding materials from the USA. These programs have been working to improve

the production, yield consistency, quality, and disease resistance (Raseira et al., 2003; Medeiros et al., 2011).

A high level of budburst is needed, but not enough, to obtain a high yield and good foliage cover. Even if a bud is breaking and a vegetative growth is emerging, normal development is not secured. With a vegetative bud, a typical rosette formation testifies to an incomplete dormancy release (Erez, 2000). Fuchigami and Nee (1987) suggested that the breaking of rest involves two distinct processes: bud release and stem elongation. This phenomenon indicates two stages that can be easily separated, i.e., the actual budburst and the second stage of elongation of the axis and further development of new fruit-bearing shoots.

Thus, the aim of this work was to evaluate the adaptability and stability of leafing based on budburst and new fruit-bearing shoot formation of peach tree genotypes developed for subtropical conditions.

2. Materials and methods

The evaluations were conducted from 2007 to 2010 in Pato Branco, Paraná State, Brazil (26°10' S; 52°41' W, 764 m a.s.l.). The local climate is classified as subtropical humid (Cfa – by Köppen Classification).

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Table 1
Chilling hours (CH) below 12 °C accumulated until the date of budburst (BB) and range of budburst (RB). Average (2007–2010).

Genotypes	CH	BB (5% green tip)	RB (days)
Ambar	336	29-June ± 9 ^a	13 ± 2 ^a
Atenas	310	24-June ± 7	15 ± 4
Bonão	260	17-June ± 10	9 ± 3
Cascata 587	652	13-August ± 8	9 ± 4
Cascata 962	435	13-July ± 10	12 ± 3
Cascata 967	488	18-July ± 13	14 ± 5
Cascata 1055	596	2-August ± 7	16 ± 5
Cascata 1063	357	4-July ± 10	16 ± 7
Cascata 1065	596	2-August ± 9	13 ± 8
Cascata 1070	580	3-August ± 4	11 ± 3
Cascata 1303	369	8-July ± 6	11 ± 7
Conserva 655	361	6-July ± 5	20 ± 2
Conserva 681	521	30-July ± 10	12 ± 5
Conserva 688	407	11-July ± 10	12 ± 2
Conserva 844	353	5-July ± 11	21 ± 10
Conserva 871	568	4-August ± 18	7 ± 2
Conserva 977	375	7-July ± 8	17 ± 4
Conserva 985	353	6-July ± 11	19 ± 8
Conserva 1127	311	25-June ± 6	9 ± 3
Conserva 1129	571	1-August ± 4	12 ± 9
Conserva 1153	291	24-June ± 9	12 ± 4
Conserva 1186	421	14-July ± 8	14 ± 7
Conserva 1187	357	4-July ± 10	12 ± 2
Conserva 1205	357	6-July ± 11	18 ± 9
Conserva 1216	265	10-June ± 4	11 ± 7
Conserva 1223	330	30-June ± 6	19 ± 6
Conserva 1396	304	25-June ± 7	8 ± 5
Kampai	322	26-June ± 10	12 ± 5
Libra	238	14-June ± 11	9 ± 3
Olímpia	441	13-July ± 9	13 ± 1
Rubimel	315	26-June ± 6	11 ± 4
Santa Áurea	581	2-August ± 16	15 ± 10
T. Beauty	240	12-June ± 12	14 ± 5
T. Snow	355	7-July ± 11	18 ± 8

^a Standard deviation.

Thirty-four peach genotypes were evaluated from 2007 to 2010 (Table 1). Each genotype was represented by three plants. Five one-year-old shoots, 25–30 cm long, per plant were randomly selected around the canopy for budburst analysis and fruit-bearing shoot formation. The trees were four and seven years old in 2007 and 2010, respectively. The orchard received standard fungicide and insecticide sprays, pruning and fertilization, similar to the treatments used in commercial orchards. No chemical means were used to break dormancy.

The experiment used a completely randomized design with three replicates, each represented by five twigs, and two factors, genotypes (34) and years (4).

2.1. Chilling and heat accumulation during the dormancy period

The number of hours with temperatures below 12 °C or 7.2 °C or above 20 °C was recorded from May to August (Fig. 1). Temperatures below 7.2 °C are traditionally used to determine chilling accumulation (Weinberger, 1950). Nowadays, temperatures below 12 °C are also considered effective for chilling accumulation (Erez and Couvillon, 1987; Fishman et al., 1987a,b; Citadin et al., 2002; Chavarria et al., 2009), especially for low chilling genotypes. Temperatures above 20 °C are undesirable during the dormant period, as they deny the accumulation of chilling (Erez et al., 1979).

The chilling accumulation for budburst of each genotype was calculated by the sum of hours of temperatures below 12 °C from May until 5% of vegetative budburst. Measures were made for four years.

2.2. Phenology of budburst

Five one-year-old shoots per plant were sampled. Their lengths were recorded and the total number of vegetative buds, on each, was counted. Twice a week, the number of buds that reached the green tip stage was recorded. The beginning, full, and end of budburst were considered to have occurred when green tip stage rise 5%, 50%, and 75%, respectively.

Range of budburst was calculated as the number of days elapsed from 5% to 75% of total of budburst.

2.3. Percentage of budburst and percentage of fruit-bearing shoot formation

To calculate the percentage of budburst, the following equation was used: $PBB = TNVBGT * 100 / TNVB$, where PBB is the percentage of budburst, TNVBGT is the total number of vegetative buds that reach the green tip stage, and TNVB is the total number of vegetative buds.

The percentage of buds, that gave rise to fruit-bearing shoots, was recorded 45 days after the final date of budburst.

2.4. Adaptability and stability of budburst and fruit-bearing shoot formation

To analyze the adaptability and stability of budburst and fruit-bearing shoot formation, the GGE (genotype main effect plus genotype by environment interaction effect) biplot methodology was used, based on the following model:

$$y_{ij} - \bar{y}_j = \gamma_1 \varepsilon_{i1} \rho_{j1} + \gamma_2 \varepsilon_{i2} \rho_{j2} + \varepsilon_{ij}$$

where y_{ij} represents the average of genotype i in the year j ; \bar{y}_j is the mean of all genotypes in the environment j ; $\gamma_1 \varepsilon_{i1} \rho_{j1}$ is the first principal component (PC1); $\gamma_2 \varepsilon_{i2} \rho_{j2}$ is the second principal component (PC2); γ_1 and γ_2 are the self values associated with PC1 and PC2, respectively; ε_{i1} and ε_{i2} are the scores of PC1 and PC2, respectively, for genotype i ; ρ_{j1} and ρ_{j2} are the self values associated with PC1 and PC2, respectively, for the year j ; and ε_{ij} is the error ij associated with the model (Yan and Kang, 2003). In the GGE biplot method, only the genetic effect and the genotype × environment interaction are considered to be relevant, and both must be considered simultaneously in the evaluation of the cultivars. The two main axes represent most of the variation in the data, considering the environment effect as fixed, i.e., the variation in budburst or fruit-bearing shoot formation would be only due to genotype and the genotype × environment interaction (Yan and Rajcan, 2002).

In each graphic, a polygon was constructed to join the points that represent the most distant genotypes in relation to the origin of the axes in each quadrant. Later perpendicular lines were designed for each polygon edge passing through the origin, separating it into sections. The genotypes in each sector showed the best performance in environments/years included in that sector (Yan and Kang, 2003).

A PC1 value near the origin indicates that the genotypes have means close to the general mean (represented by the origin of the lines). As the value becomes more distant and to the right of the origin, the greater the value of the variable can be considered and more adapted are the genotypes (in this case, for percentage of budburst or fruit-bearing shoots formed). A PC2 value near the zero indicates the more stable genotypes. The graphical biplot may also identify the ideal environment (year), indicated by the year that has a high value for PC1 and a value near zero for PC2 (Yan and Kang, 2003).

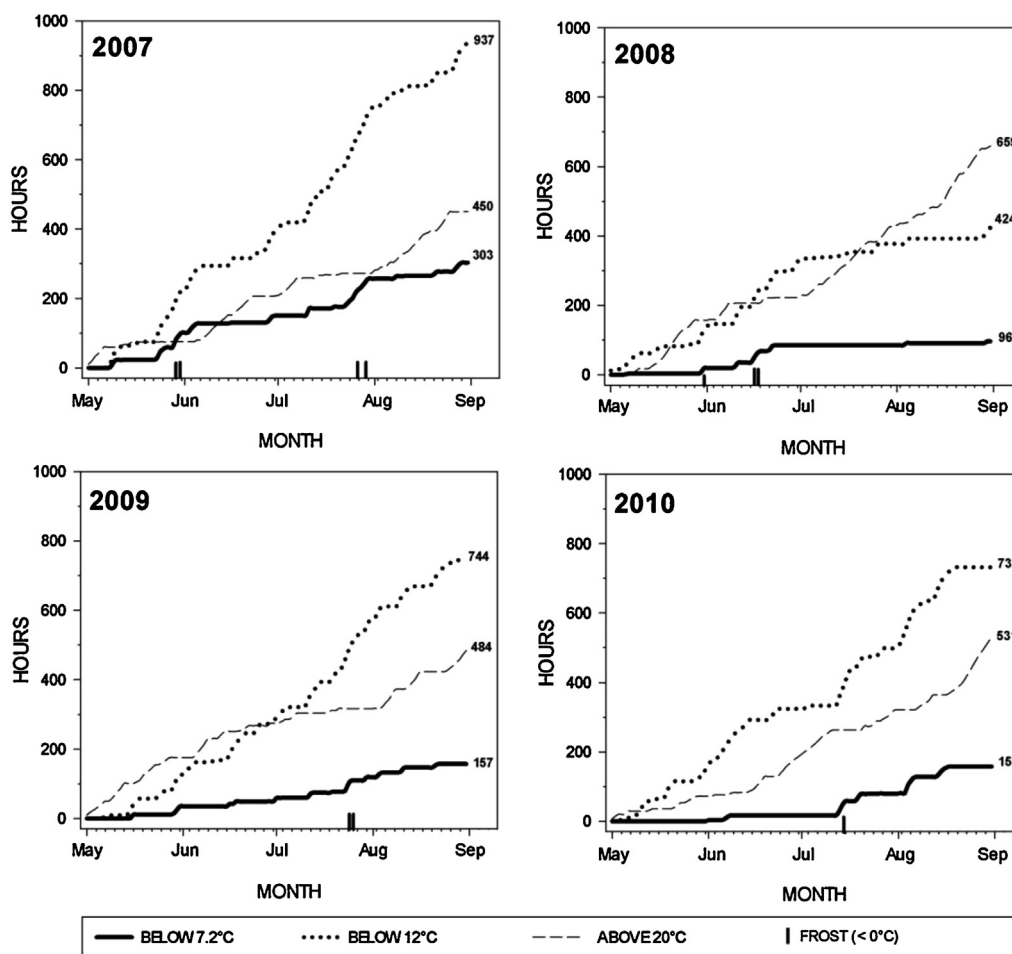


Fig. 1. Temperatures below 7.2 °C or 12 °C or above 20 °C from May to August from 2007 to 2010 in Pato Branco, Paraná.

2.5. Statistical analysis

The normality and homogeneity of the data were checked by Shapiro–Wilk and Bartlett’s tests, respectively, using the computer application R (R Development Core Team, 2010). Then, an analysis of variance (ANOVA) was conducted, with genotypes grouped by Scott–Knott’s grouping test ($p \leq 0.05$) using GENES Program Software for PC (Cruz, 2006). Analyses of adaptability and stability were performed using GGE biplot methodology (Yan and Rajcan, 2002), and the graphs were generated using R Program Software for PC. In addition, the scores were reversed and designed using the RLPlot program Software for PC for better visualization and interpretation.

3. Results

3.1. Chilling accumulation

In 2007, from May to August, chilling accumulation was 937 h below 12 °C and 303 h below 7.2 °C, while the temperatures above 20 °C amounted to 450 h. That year was the one with the highest chilling accumulation among the four studied years. The month of May was cold, with frosts and few occurrences of temperatures over 20 °C. In June, there was almost no increase in temperatures below 7.2 °C, but there was a slight increase in temperatures over 20 °C. Finally, in July and August, there was another chilling accumulation, which peaked in late July, with frosts that damaged the flowers and/or fruit in the precocious cultivars (Fig. 1).

In 2008, chilling accumulation was 424 h below 12 °C and 96 h below 7.2 °C, while the temperatures above 20 °C amounted to 659 h. That year was the one with the highest accumulation of temperatures above 20 °C among the four studied years. May was mild, with night temperatures below 12 °C and short periods with diurnal temperatures above 20 °C. Chilling accumulation was observed from the end of May until mid-June, when frost occurred. After this, a tendency for heat accumulation was observed. Among the studied years, that was the year with the greatest sum of temperatures above 20 °C compared with temperatures below 12 °C (Fig. 1).

In 2009, chilling accumulation was 744 h below 12 °C and 157 h below 7.2 °C, while the temperatures above 20 °C amounted to 484 h. Although 2009 accumulated less chilling than 2007, no long period of heat, with temperatures above 20 °C, was observed, particularly in June, similar to what was observed in 2007. Although not intense, the chilling was continuous, without abrupt temperature fluctuations (no periods of heat). Frost was observed at the end of July (Fig. 1).

In 2010, chilling accumulation was 732 h below 12 °C and 158 h below 7.2 °C, while temperatures above 20 °C amounted to 531 h. In that year, chilling accumulation was observed only from mid-July, with the occurrence of frost (Fig. 1).

3.2. Phenology of budburst

The budburst of most genotypes occurred from mid-June to mid-July, which characterizes the prevalence of genotypes with low chilling accumulation.

Table 2
Analysis of variance of the budburst and fruit-bearing shoots for 34 genotypes during four years, from 2007 to 2010.

Source	df	Means square	
		Budburst	Fruit-bearing shoots
Genotypes (G)	33	1177.75**	654.48**
Years (Y)	3	3493.29**	2138.15**
G × Y	99	279.72**	270.21**
Error	272	95.48	90.12
Mean		75.15	28.72
C.V. (%)		13.00	33.04

** Significant at $p \leq 0.01$ by *F* test.

The largest range of budburst, 21 days, was observed in 'Conserva 844', and the smallest, 8 days, in 'Conserva 1396'. The others ranged from 9 to 20 days (Table 1).

3.3. Budburst and fruit-bearing shoot formation

Genotypes, growing season and the interaction of genotype × growing season were significant for the percentage of budburst and fruit-bearing shoot formation (Table 2).

The data regarding the beginning of budburst and percentage of budburst are given in Tables 1 and 3, respectively.

In 2010, the average budburst was near 67%, the lowest among the four studied years. Differences among years were not observed

Table 3
Means grouping test for the percentage of budburst in 34 peach tree genotypes in four years (2007–2010).

Genotypes	% Budburst			
	2007	2008	2009	2010
Ambar	85.04 A a	72.78 A b	78.98 A a	55.06 B b
Atenas	73.26 A a	82.07 A a	76.69 A a	60.54 B b
Bonão	69.30 A b	78.26 A b	83.51 A a	73.17 A a
Cascata 587	74.40 B a	64.72 B c	72.64 B b	94.65 A a
Cascata 962	68.55 B b	83.04 A a	94.72 A a	82.15 A a
Cascata 967	72.38 A a	75.56 A b	88.52 A a	40.13 B c
Cascata 1055	63.87 A b	43.25 B d	75.38 A b	33.36 B c
Cascata 1063	73.15 A a	88.52 A a	87.25 A a	79.50 A a
Cascata 1065	37.07 B c	42.09 B d	79.58 A a	36.15 B c
Cascata 1070	64.51 B b	61.24 B c	83.14 A a	48.95 B c
Cascata 1303	88.51 A a	93.26 A a	87.28 A a	84.99 A a
Conserva 655	79.57 A a	84.09 A a	90.59 A a	65.98 B b
Conserva 681	60.57 B b	69.66 A b	79.57 A a	45.10 B c
Conserva 688	69.55 B b	91.88 A a	80.44 A a	63.25 B b
Conserva 844	76.70 A a	80.46 A b	89.48 A a	82.92 A a
Conserva 871	73.80 A a	74.05 A b	79.78 A a	87.29 A a
Conserva 977	67.17 B b	83.01 A a	66.67 B b	57.10 B b
Conserva 985	71.20 A b	56.04 B c	72.08 A b	53.92 B b
Conserva 1127	82.86 A a	95.75 A a	87.36 A a	75.49 A a
Conserva 1129	68.51 A b	75.56 A b	43.12 B c	56.63 B b
Conserva 1153	82.55 A a	85.09 A a	87.64 A a	66.81 B b
Conserva 1186	62.64 B b	88.68 A a	81.89 A a	52.10 B b
Conserva 1187	88.55 A a	84.63 A a	83.96 A a	92.56 A a
Conserva 1205	74.76 A a	77.45 A b	71.32 A b	50.59 B b
Conserva 1216	84.07 A a	93.06 A a	89.22 A a	69.93 B a
Conserva 1223	91.15 A a	88.51 A a	90.36 A a	92.76 A a
Conserva 1396	81.83 A a	84.84 A a	82.44 A a	78.20 A a
Kampai	85.57 A a	80.46 A b	96.58 A a	82.98 A a
Libra	74.38 A a	86.63 A a	70.99 A b	74.71 A a
Olímpia	63.60 B b	77.28 A b	89.35 A a	77.65 A a
Rubimel	79.52 A a	83.75 A a	78.12 A a	62.20 B b
Santa Áurea	81.11 A a	90.62 A a	83.10 A a	87.13 A a
Tropic Beauty	74.38 A a	70.56 A b	83.51 A a	79.42 A a
Tropic Snow	58.97 B b	56.45 B c	84.00 A a	61.96 B b
Average	73.62	77.74	81.44	67.53
C.V. (%)	14.26	7.45	15.83	12.53

Means followed by the same capital letter (line) and lower case letter (column) do not differ by the Scott–Knott test ($p = 0.05$).

Table 4
Means grouping test for the percentage of fruit-bearing shoots in 34 peach tree genotypes in four years (2007–2010).

Genotypes	% Fruit-bearing shoots			
	2007	2008	2009	2010
Ambar	42.51 A b	24.78 A a	27.81 A c	35.45 A b
Atenas	46.13 A b	44.99 A a	25.20 B c	33.88 B c
Bonão	30.25 A c	25.53 A a	39.11 A b	22.74 A c
Cascata 587	20.09 B d	33.96 A a	37.11 A b	20.77 B c
Cascata 962	36.60 A b	28.79 A a	17.62 A c	29.18 A c
Cascata 967	25.81 A c	11.45 B b	15.05 B c	38.53 A b
Cascata 1055	4.50 A d	7.03 A b	21.68 A c	13.07 A c
Cascata 1063	18.43 B d	11.33 B b	42.43 A b	22.43 B c
Cascata 1065	66.11 A a	34.43 B a	18.38 C c	55.90 A a
Cascata 1070	14.34 A d	14.78 A b	19.87 A c	24.91 A c
Cascata 1303	17.91 A d	17.34 A b	18.58 A c	17.82 A c
Conserva 655	50.67 A b	30.12 B a	38.27 A b	21.32 B c
Conserva 681	24.43 B c	23.82 B a	32.53 B c	43.26 A b
Conserva 688	29.03 A c	15.52 A b	32.83 A c	26.19 A c
Conserva 844	24.65 A c	19.88 A b	36.67 A b	26.73 A c
Conserva 871	41.01 A b	25.05 B a	39.40 A b	43.55 A b
Conserva 977	35.68 A b	19.93 B b	49.85 A a	37.27 A b
Conserva 985	29.98 B c	13.19 C b	53.62 A a	32.10 B c
Conserva 1127	30.68 B c	36.83 B a	44.72 A b	51.15 A a
Conserva 1129	18.27 A d	25.24 A a	19.43 A c	23.43 A c
Conserva 1153	27.65 B c	28.13 B a	55.39 A a	57.50 A a
Conserva 1186	29.41 A c	15.78 A b	15.30 A c	23.47 A c
Conserva 1187	13.85 A d	18.23 A b	28.87 A c	23.10 A c
Conserva 1205	39.90 A b	9.03 B b	54.05 A a	53.96 A a
Conserva 1216	31.06 A c	25.51 A a	37.65 A b	30.04 A c
Conserva 1223	23.79 B c	13.69 B b	51.48 A a	39.71 A b
Conserva 1396	25.32 A c	19.37 A b	24.16 A c	32.44 A c
Kampai	24.94 A c	19.88 A b	21.70 A c	28.85 A c
Libra	27.29 A c	30.46 A a	22.94 A c	26.61 A c
Olímpia	32.09 A c	19.29 A b	21.77 A c	19.03 A c
Rubimel	30.31 A c	16.92 B b	14.80 B c	39.12 A b
Santa Áurea	27.67 A c	22.93 A a	30.97 A c	27.50 A c
Tropic Beauty	27.29 A c	25.05 A a	23.54 A c	37.15 A b
Tropic Snow	46.25 A b	19.64 B b	21.90 B c	32.03 B c
Average	29.82	21.99	31.01	31.06
C.V. (%)	35.73	18.38	32.99	35.02

Means followed by the same capital letter (line) and lower case letter (column) do not differ by the Scott–Knott test ($p = 0.05$).

for the genotypes 'Bonão', 'Cascata 1063', 'Cascata 1303', 'Conserva 1127', 'Conserva 1187', 'Conserva 1223', 'Conserva 1396', 'Conserva 844', 'Conserva 871', 'Kampai', 'Libra', 'Santa Áurea' and 'Tropic Beauty', which all had the highest percentage of budburst in 2010 (Table 3).

Although some genotypes had little or no variation, the variability in percentage of fruit-bearing shoot formation was large for the following: 'Atenas', 'Cascata 1063', 'Cascata 1065', 'Cascata 587', 'Cascata 967', 'Conserva 1127', 'Conserva 1153', 'Conserva 1205', 'Conserva 1223', 'Conserva 655', 'Conserva 681', 'Conserva 871', 'Conserva 977', 'Conserva 985', 'Rubimel' and 'Tropic Snow' (Table 4).

In 2008, the genotypes 'Cascata 1063', 'Cascata 967', 'Conserva 1187', 'Conserva 1205', 'Conserva 1223', 'Conserva 681', 'Conserva 871', 'Conserva 977', 'Conserva 985' and 'Tropic Snow' had good or sufficient budburst (Table 3) but the smallest formation of fruit-bearing shoots (Table 4). Thus, these cultivars had difficulty converting budburst into fruit-bearing shoots, which was most likely caused by insufficient chilling (Fuchigami and Nee, 1987). By contrast, the genotype 'Cascata 1065' had, in 2007 and 2010, low budburst but a high percentage of fruit-bearing shoot formation (Tables 3 and 4), showing a great capacity to convert budburst into fruit-bearing shoots.

The genotypes that had the smallest percentages of fruit-bearing shoot formation among the studied years were 'Cascata 1055',

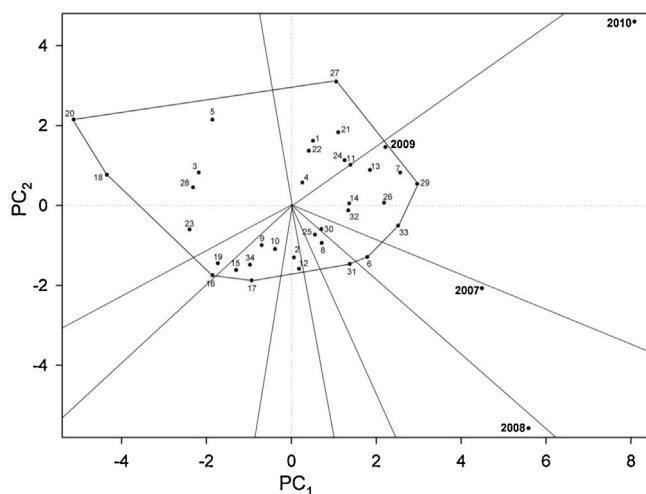


Fig. 2. Graphic of the SREG analysis (sites regression) – GGE (genotype and genotype–environment interaction) of 34 peach tree genotypes evaluated in four growing seasons (2007–2010) for budburst. Tropic Beauty (1), Rubimel (2), Conserva 985 (3), Bonão (4), Tropic Snow (5), Conserva 1127 (6), Conserva 1187 (7), Conserva 1153 (8), Ambar (9), Atenas (10), Conserva 844 (11), Conserva 688 (12), Kampai (13), Cascata 1063 (14), Conserva 1205 (15), Cascata 967 (16), Conserva 1186 (17), Cascata 1055 (18), Conserva 1129 (19), Cascata 1065 (20), Conserva 871 (21), Olímpia (22), Conserva 681 (23), Cascata 962 (24), Conserva 655 (25), Santa Áurea (26), Cascata 587 (27), Cascata 1070 (28), Conserva 1223 (29), Libra (30), Conserva 1216 (31), Conserva 1396 (32), Cascata 1303 (33), Conserva 977 (34).

'Cascata 1070', 'Cascata 1303', 'Conserva 1129' and 'Conserva 1187' (Table 4).

3.4. Genotype adaptability and stability

The SREG (sites regression) obtained by genotype and genotype–environment interaction (GGE biplot) was performed to provide an easy visualization of the complete data set in a reduced dimension plot. The principal components analyses performed in this work showed that 81.94% and 79.11% of the total variability observed for budburst and fruit-bearing shoots formation, respectively, could be explained by the first two components: PC1 and PC2. Thus, PC1 and PC2 are expressive and can explain the genotype and genotype–environment interaction.

For budburst, the year 2009 was the environment that could be considered the closest to the ideal because it was the most stable (near PC2 axis) and promoted a good budburst. The years 2010 and 2008 were the most unstable (far from PC2 axis), which enabled better discrimination among the genotypes (Fig. 2).

The graphic of the SREG–GGE biplot for budburst was divided into nine sectors. The principal sectors grouped the years 2009 and 2010, and the following genotypes had higher budburst and better stability for this trait: 'Cascata 1063' (14), 'Cascata 1303' (33), 'Conserva 1187' (7), 'Conserva 1223' (29), 'Conserva 1396' (32), 'Kampai' (13) and 'Santa Áurea' (26). The second sector grouped the year 2008 and the genotypes 'Conserva 1153' (8), 'Conserva 1216' (31) and 'Conserva 655' (25). Each of these cultivars had budburst greater than the general average of the genotypes, particularly 'Conserva 1216' (31). The third sector grouped by the year 2007 and the genotypes 'Conserva 1127' (6) and 'Libra' (30); both had early budburst and are considered to have a very low chilling accumulation (Table 1). The genotypes 'Ambar' (9), 'Atenas' (10), 'Bonão' (4), 'Conserva 1153' (8), 'Conserva 655' (25), 'Libra' (30), 'Rubimel' (2) had a percentage of budburst near the general average of the genotypes (75.15%). All of these cultivars began budburst before July 15 and are considered to have either very low or low chilling accumulation (Table 1).

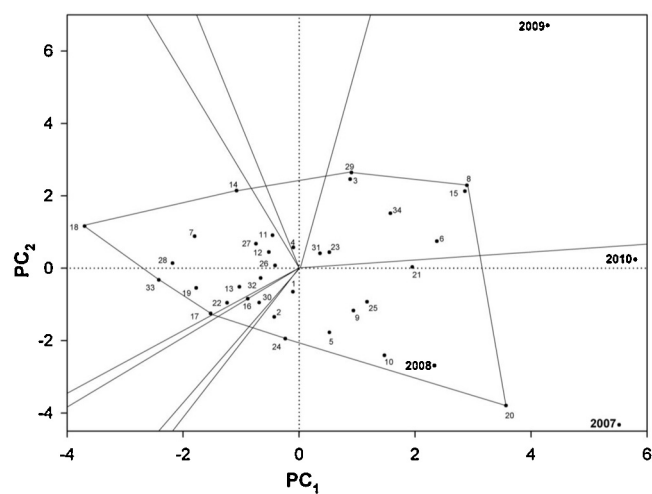


Fig. 3. Graphic of the SREG analysis (sites regression) – GGE (genotype and genotype–environment interaction) of 34 peach tree genotypes evaluated in four growing seasons (2007–2010) for fruit-bearing shoots. Tropic Beauty (1), Rubimel (2), Conserva 985 (3), Bonão (4), Tropic Snow (5), Conserva 1127 (6), Conserva 1187 (7), Conserva 1153 (8), Ambar (9), Atenas (10), Conserva 844 (11), Conserva 688 (12), Kampai (13), Cascata 1063 (14), Conserva 1205 (15), Cascata 967 (16), Conserva 1186 (17), Cascata 1055 (18), Conserva 1129 (19), Cascata 1065 (20), Conserva 871 (21), Olímpia (22), Conserva 681 (23), Cascata 962 (24), Conserva 655 (25), Santa Áurea (26), Cascata 587 (27), Cascata 1070 (28), Conserva 1223 (29), Libra (30), Conserva 1216 (31), Conserva 1396 (32), Cascata 1303 (33), Conserva 977 (34).

The genotypes 'Cascata 1065' (20), 'Cascata 1055' (18), 'Tropic Snow' (5), 'Conserva 985' (3), 'Cascata 1070' (28), 'Conserva 681' (23), 'Conserva 1129' (19), 'Cascata 967' (16), 'Conserva 1205' (15), 'Conserva 1186' (17), 'Conserva 977' (34) had budburst below the general mean (Fig. 2).

For fruit-bearing shoot formation, the years 2009 and 2007 were less stable and more variable (far from PC2 axis), whereas the year 2010 had the highest average of fruit-bearing shoot formed (Fig. 3). The graphic of the SREG–GGE biplot for fruit-bearing shoot formation was divided into eight sectors, with the principal sector formed by the years 2010, 2008 and 2007 and the genotypes 'Tropic Beauty' (1), 'Rubimel' (2), 'Cascata 962' (24), 'Tropic Snow' (5), 'Ambar' (9), 'Conserva 655' (25), 'Conserva 871' (21), 'Atenas' (10), and 'Cascata 1065' (20). The highest percentage of fruit-bearing shoots was observed in 'Cascata 1065' (20). A second sector comprised the year 2009 and the genotypes 'Conserva 1216' (31), 'Conserva 681' (23), 'Conserva 1223' (29), 'Conserva 985' (3), 'Conserva 977' (34), 'Conserva 1127' (6), 'Conserva 1205' (15), and 'Conserva 1153' (8). The genotypes 'Cascata 1055' (18), 'Cascata 1303' (33), and 'Cascata 1070' (28) had the lowest percentage of fruit-bearing shoots.

'Conserva 1127' (6), 'Conserva 681' (23), 'Conserva 1216' (31), 'Conserva 655' (25), and 'Conserva 871' (21) had the highest average of fruit-bearing shoots and were the most stable among all the genotypes. The genotypes 'Atenas' (10), 'Conserva 1153' (8), 'Conserva 1223' (29), 'Conserva 985' (3), and 'Cascata 1065' (20) also had good fruit-bearing shoots (right of the origin of the axes) but were unstable during the studied years (far from PC2 axis). The genotypes 'Libra' (30), 'Tropic beauty' (1), 'Bonão' (4), 'Santa Áurea' (26), 'Conserva 1396' (32), 'Kampai' (13), 'Conserva 688' (12), 'Conserva 844' (11), 'Cascata 587' (27), 'Cascata 967' (16), 'Rubimel' (2), and 'Olímpia' (22) had a fruit-bearing shoots average near the general average (28.78%) (Fig. 3) and were considered satisfactory because these genotypes also had a high percentage of budburst (Table 3).

The genotypes 'Cascata 1065' (20), 'Tropic Snow' (5), 'Conserva 977' (34), and 'Conserva 985' (3) had the lowest budburst (Table 3 and Fig. 2). They also had high fruit-bearing shoots and were unstable (Table 4 and Fig. 3).

4. Discussion

For all studied years, the genotypes with the highest percentage of budburst, except 'Conserva 871', are all considered to be low chilling and early budburst, *i.e.*, these genotypes were not influenced by temperature oscillation and the different chilling accumulations during the four years evaluated and showed good stability and no negation of chilling by high temperatures. In contrast, the genotypes that showed a reduction in budburst and fruit-bearing shoots in the years with low chill accumulation, as observed in 2008, likely have more sensitivity to negation of chilling by temperatures above 20 °C that occur during the endodormancy period, as observed by Couvillon and Erez (1985).

The Utah model developed by Richardson et al. (1974) adopted a wide optimum between 3 °C and 9 °C with reduced effect at higher and lower temperatures. Faust et al. (1997) proposed that cultivars with a very low chilling requirement have only superficial endodormancy (s-endodormancy) and do not have deep endodormancy (d-endodormancy). Thus, some genotypes can leaf satisfactorily without the occurrence of temperatures below 7.2 °C. In this study, there was also a satisfactory accumulation and a more evenly distribution of temperatures below 12 °C compared with those for temperatures below 7.2 °C (Fig. 1). Temperatures below 12 °C are effective in overcoming endodormancy, as verified by Erez and Couvillon (1987), Fishman et al. (1987a,b) and Citadin et al. (2002). Chavarria et al. (2009) showed that some cultivars responded satisfactorily to temperatures below 15 °C to overcome endodormancy, especially s-endodormancy cultivars. These observations would explain the uniform and good budburst and branch formation of some genotypes even in those years with a low level of chilling accumulation.

In some genotypes with medium to low chilling accumulation for budbreak, such as 'Cascata 962' and 'Olímpia', the lowest vegetative budburst was obtained in 2007, which was the year with the greatest accumulation of cold. This result demonstrates that for some genotypes, the accumulation of cold above the real requirements does not always lead to an increase in the percentage of budburst. This effect was also observed by Gariglio et al. (2006). In addition to a good percentage of budburst, peach trees must have good development of fruit-bearing shoots with vegetative and flower buds, an essential condition to ensure good crop production in the next cycle. For some genotypes, such as 'Cascata 1303', 'Conserva 1187', 'Kampai', and 'Cascata 1063', shoots did not develop, and a low percentage of fruit-bearing shoots was observed despite the high percentage of budburst (Figs. 2 and 3). This result may be due to the low chilling accumulation, which was sufficient to induce good budburst but not enough to induce fruit-bearing shoots (Fuchigami and Nee, 1987). Other factors that could have contributed to the reduction in fruit-bearing shoot formation include the occurrence of temperatures above 20 °C, which increases the competition for assimilates between the vegetative buds and developing fruits, as well as the correlative inhibitions.

Some genotypes, such as 'Cascata 1065', 'Conserva 985', and 'Conserva 1205' had, in general, a low percentage of budburst but a high percentage of fruit-bearing shoot formation (Figs. 2 and 3, respectively), enough to ensure good yields.

Pérez (2002) observed that genotypes with a high chilling requirement, originated from high elevations, had dramatically decreased vigor when planted in warm ecosystems, whereas genotypes from the subtropics were more stable across environments and even slightly more vigorous in warmer ecosystems.

Genotypes that showed percentages of budburst and fruit-bearing shoots far below the general mean, such as 'Cascata 1070', 'Conserva 1129', 'Cascata 967', and 'Conserva 1186', are

considered poorly adapted to local conditions because they require up to 400 h of chilling (≤ 12 °C) and have late budburst (Table 1). Despite having the lowest percentage of budburst (Fig. 2) and fruit-bearing shoots (Fig. 3), the genotype 'Cascata 1055' had a high density of buds, allowing these trees to have a good, sufficiently vigorous structure that requires little pruning and ensures good harvests. In contrast, 'Conserva 871' is considered stable for the percentage of fruit-bearing shoots; it had a percentage of budburst above the overall mean (Fig. 2) but a low density of buds and blind nodes along the branch showing no adaptation.

In 2010, the average budburst was the lowest among the four years (Table 3). In this year, the chilling accumulation occurred mainly from mid-July (Fig. 1), after the start of budburst in most cultivars (Table 1). This chilling was not effective in overcoming endodormancy and the induction of budburst in early budburst genotypes with low and medium chilling accumulation for budbreak, but it did stimulate the budburst of late budburst genotypes with higher chilling accumulation for budbreak, as observed in 'Cascata 587'. This genotype was likely favored by the late chilling that occurred after mid-July, even though it was considered the most unstable one (Fig. 2). The genotypes with low and/or very low chilling accumulation for budbreak had good budburst even in the years with low chilling accumulation, as observed in 2010 (until mid-July) (Fig. 1) for 'Tropic Beauty', 'Bonão', 'Santa Áurea', 'Conserva 1223', 'Libra', 'Conserva 1216', 'Conserva 1396', and 'Cascata 1303' (Table 3).

Chilling that occurred after mid-July in 2010 stimulated the late budburst cultivars but may have had deleterious effects through the effects of frost and thus may have been responsible for reducing budburst (blind nodes) in the genotypes that, during this period, had already overcome endodormancy. Very early budburst genotypes, however, showed no damage, by having leaves that were already expanded (*i.e.*, a well developed leaf area index) this may have mitigated the effects of the frost.

In temperate fruit trees, endogenous and environmental factors interact differently for a particular genotype. Environmental conditions including climate variation among years affect bud endodormancy and ecodormancy (Ashcroft et al., 1977), and their chilling (Viti et al., 2010) and heat (Citadin et al., 2001) requirements, respectively. There are genetic differences among genotypes that establish the depth of endodormancy (chilling requirement) and ecodormancy (heat requirement). The interaction of these factors may have contributed to the adaptability and stability for budburst and fruit-bearing shoots formation of the genotypes.

5. Conclusions

Under the conditions of this study, the following can be concluded:

- 'Cascata 1063', 'Cascata 1303', 'Conserva 1187', 'Conserva 1223', 'Conserva 1396', 'Kampai', 'Libra' and 'Santa Áurea' were the peach tree genotypes with the greatest adaptability and stability for budburst trait;
- 'Conserva 1127', 'Conserva 1216' and 'Conserva 681' were the genotypes with the greatest adaptability and stability for fruit-bearing shoot formation;
- a high percentage of budburst does not necessarily lead to a high percentage of fruit-bearing shoot development;
- 'Âmbar', 'Bonão', 'Conserva 655', 'Kampai', 'Libra', 'Rubimel' and 'Santa Áurea', showed a good percentage of budburst and development of fruit-bearing shoots, remained stable for both traits and are considered the best adapted.

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