Adaptability and stability of fruit set and production of peach trees in a subtropical climate

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ABSTRACT: Brazilian peach breeding programs have been established to improve peach [*Prunus persica* (L.) Batsch] production, yield consistency, quality, and disease resistance. Every year several genotypes are selected and their traits must be assessed. This study aimed to evaluate adaptability and stability of fruit set and production of peach genotypes in a subtropical climate, using the GGE biplot methodology. The experimental design was completely randomized with three replicates (trees) in a factorial arrangement of 29 × 3 for genotype and growing season, respectively. The genotypes 'Conserva 1129', 'Rubimel', 'Kampai', 'Tropic Beauty', and 'Cascata 967' had the greatest adaptability and stability for fruit set. The genotypes 'Conserva 681', 'Santa Áurea', 'Atenas', 'Kampai', 'Cascata 962', 'Tropic Beauty' and 'Cascata 967' had the greatest production adaptability and stability. The GGE-biplot methodology classified the peach tree genotypes with regard to adaptability and stability of fruit set and production.

Introduction

The spread of commercial peaches [*Prunus persica* (L.) Batsch] to subtropical and tropical regions has increased rapidly in recent years. This increase is especially noticeable in Brazil, where 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 a late frost risk 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 to 400 chilling hours below 7.2 °C) (Byrne et al., 2000; Topp et al., 2008). Therefore, Brazilian peach breeding programs have been introduced designed to improve peach production, yield consistency, quality, and disease resistance (Raseira et al., 2003; Medeiros et al., 2011; Sachet et al., 2013).

Mild winters with a wider range of temperature conditions during dormancy have been related to several physiological and biological disturbances leading to the appearance of a high level of floral anomalies and flower bud drops, which compromise blooming (Lamp et al., 2001; Bassi et al., 2006; Oukabli and Mahhou, 2007; Nava et al., 2009; Couto et al., 2010). Chilling, when insufficient, poses problems for trees that have to overcome endodormancy and can consequently result in low fruit set and yield for genotypes not suitably adapted.

The study of genotype × environment interaction is important for success in temperate fruit cultivation (Gil, 1997). In this sense, knowledge of the adaptability and stability of fruit set and production in different locations or years is crucial when the objective is to increase crop production potential. Thus, the aim of this work was to evaluate adaptability and stability for fruit set and production of peach genotypes in a subtropical climate using the GGE biplot methodology.

Materials and Methods

The evaluations were made from 2008 to 2010 in Pato Branco, in the state of Paraná, Brazil (26°10′ S; 52°41′ W, 764 m a.s.l.). The local climate is classified as subtropical humid (Cfa – by Köeppen Classification). The number of hours with temperatures below 12 °C or 7.2 °C or above 20 °C was recorded from May to Aug (Figure 1). Temperatures below 7.2 °C are traditionally used to determine chilling accumulation (Weinberger, 1950). However, nowadays temperatures below 12 °C are also effective for chilling accumulation (Erez and Couvillion, 1987; 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 work against the accumulation of chilling (Erez et al., 1979).

Twenty-nine peach genotypes (Figure 2), most of which originated in Pelotas, in the state of Rio Grande do Sul, Brazil (31°52' S; 52°21' W; 13 m a.s.l.), were evaluated during the 2008/2009, 2009/2010 and 2010/2011 growing seasons. Each genotype was represented by three plants. Trees were grown in a 4 m × 5 m spacing and pruned twice a year (winter and summer). The experiment used a completely randomized design. Five one-year-old shoots, 25 to 30 cm long, per plant were randomly selected from around the canopy for fruit set. The trees were five years old in 2008. 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.
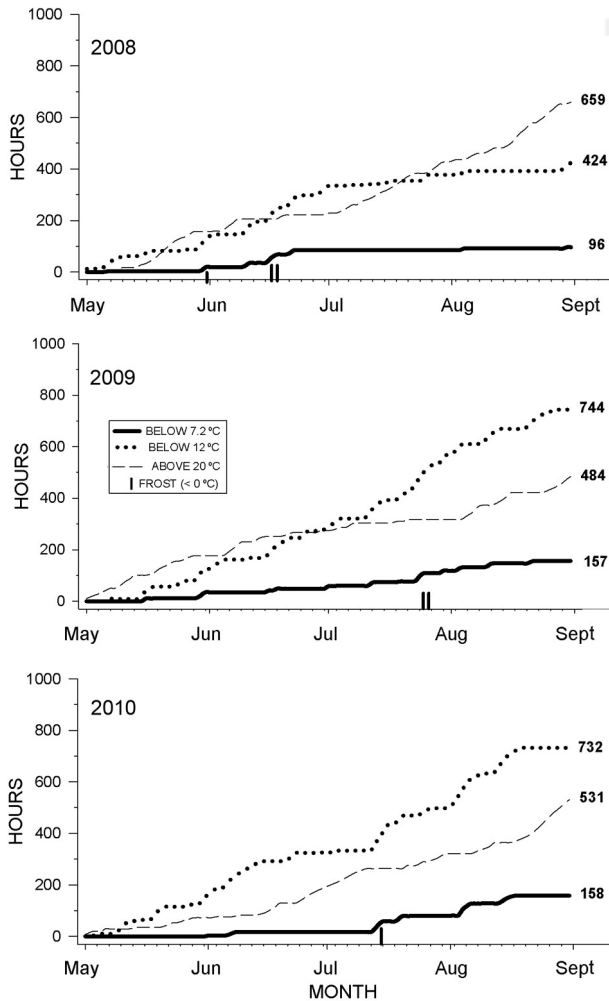
Figure 1 – Temperatures below 7.2 °C or 12 °C or above 20 °C from May to Aug from 2008 to 2010 in Pato Branco, state of Paraná, Brazil.
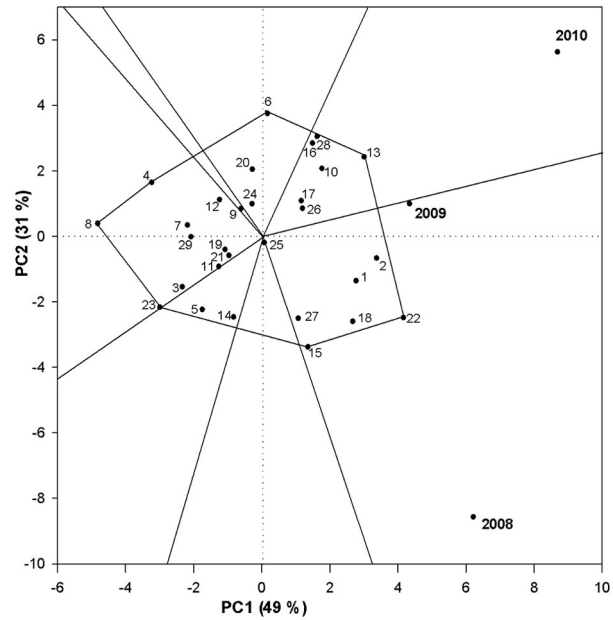

Figure 2 – SREG analysis (sites regression) graph- GGE (genotype and genotype-environment interaction) biplot of 29 peach tree genotypes evaluated over three growing seasons (2008 to 2010) for fruit set in Pato Branco, state of Paraná, Brazil. Tropic Beauty (1), Rubimel (2), Conserva 985 (3), Bonão (4), Tropic Snow (5), Conserva 1127 (6), Conserva 1187 (7), Conserva 1153 (8), Âmbar (9), Atenas (10), Conserva 844 (11), Libra (12), Kampai (13), Cascata 1063 (14), Cascata 962 (15), Conserva 1223 (16), Cascata 1055 (17), Cascata 967 (18), Cascata 1070 (19), Conserva 871 (20), Conserva 1186 (21), Conserva 1129 (22), Cascata 587 (23), Cascata 1065 (24), Conserva 681 (25), Conserva 977 (26), Conserva 655 (27), Santa Áurea (28) and Conserva 688 (29). PC1 = Principal Component 1 and PC2 = Principal Component 2.

The evaluation of fruit set was carried out between 30 and 35 days after full bloom. The evaluation of tree production was made by multiplying the total number of fruits by the average fruit weight of each genotype and the results were expressed in kg per tree. For fruit numbering, all fruits in three trees of each genotype were counted close to harvest. The weight average was measured collecting 30 fruits at the beginning, at full and at the end of harvest totaling 90 fruits per genotype per year.

To analyze the adaptability and stability of fruit set and tree production, the GGE (genotype main effect plus genotype by environment interaction effect) biplot methodology (Yan and Rajcan, 2002) was used, based on the following model:

$$Y_{ij} - \overline{y}_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

where Y_{ij} represents the average of genotype i in the year j; $\overline{y}_j$ is the mean of all genotypes in the year j; $\lambda_1 \xi_{i1} \eta_{j1}$ the first principal component (PC1); $\lambda_2 \xi_{i2} \eta_{j2}$ the second principal component (PC2); λ_1 and λ_2 are the self values associated with PC1 and PC2, respectively; ξ_{i1} and ξ_{i2} the scores of PC1 and PC2, respectively, for genotype i; η_{j1} and η_{j2} 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 fruit set or tree production would be due only to genotype and the genotype × environment interaction (Yan and Rajcan, 2002).

In each graph, a polygon was constructed to join the points that represent the most distant genotypes in relation to the origin of the axes. Later, perpendicular lines were designed for each polygon edge passing

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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 the more adapted the genotypes (in this case, for fruit set or tree production). A PC2 value near zero indicates more stable genotypes. The graphical biplot may also identify the ideal environment (year), indicated by a year that has a high value for PC1 and a value near zero for PC2 (Yan and Kang, 2003).

The normality and homogeneity of the data were checked by Shapiro-Wilk and Bartlett's tests, respectively. 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). The graphs were generated using R Program Software for PC (R Development Core Team, 2010 package "GGEBiplotGUI").

Results and Discussion

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. This year was the one with the highest accumulation of temperatures above 20 °C among the years studied. 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 towards heat accumulation was observed. Of the years studied, this was the year with the greatest sum of temperatures above 20 °C compared with temperatures below 12 °C (Figure 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. No long period of heat, with temperatures above 20 °C, was observed, particularly in June. Although not intense, the chilling was continuous, without abrupt temperature fluctuations (no periods of heat). Dangerous frosts were observed at the end of July (Figure 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 this year, chilling accumulation was observed only from mid-July, with the occurrence of no dangerous frost (Figure 1).

Genotypes, growing season and the interaction of genotype × growing season were significant for fruit set and production (Table 1). During the three growing seasons, the response of fruit set and production differed among genotypes, which indicates the existence of a genotype-environment interaction. This interaction is expressed by the GGE biplot model.

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. Principal components analyses performed in this work showed that 81 % and 84 % of the total variability observed for fruit set and tree production, 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 (Gauch Jr., 1988). In the GGE biplot model the effects of genotype and genotype-environment interaction are multiplicative.

The PC1 was directly connected to the genotypic effect allowing for almost perfect correlation between the variable analyzed and the PC1 score. Therefore, the PC1 represented 49 % and 60 % of the original data variability in the experiment for fruit set (Figure 2) and tree production (Figure 3), respectively. The difference (51 %, for fruit set, and 40 %, for tree production) is related to interaction genotypes × growing seasons (PC2: 31 %, for fruit set, and 24 %, for tree production) and error (20 %, for fruit set, and 16 %, for tree production).

For fruit set, the year 2009 was the environment that could be considered the closest to the ideal because it was the most stable (near the PC2 axis origin) and promoted good fruit set (Table 2). The years 2008 and 2010 were the most unstable (far from the PC2 axis origin) with poor fruit set (Table 2), which allowed for better discrimination among the genotypes (Figure 2).

The SREG-GGE biplot graph for fruit set was divided into seven sectors. The principal sectors grouped the years 2008 and 2009, and the following genotypes: 'Conserva 1129' (22), 'Cascata 967'(18), 'Rubimel'(2), 'Tropic Beauty' (1), 'Cascata 962' (15); 'Conserva 655' (27), 'Conserva 681' (25) and especially 'Conserva 1129' (22) with the greatest fruit set. The other sector grouped the year 2010 and the genotypes 'Kampai' (13), 'Santa Áurea' (28), 'Atenas' (10), 'Conserva 1223' (16), 'Cascata 1055' (17), 'Conserva 977' (26), with 'Kampai' being the genotype with the greatest fruit set for this year.

Genotypes 'Conserva 681' (25), 'Cascata 1065' (4) and 'Âmbar' (9) had fruit set near the general average (50 %) and remained stable during the three years of

Table 1 – Source of variation, degree of freedom (df), and mean squares for fruit set and production for twenty nine peach tree genotypes in three growing seasons, from 2008 to 2010.

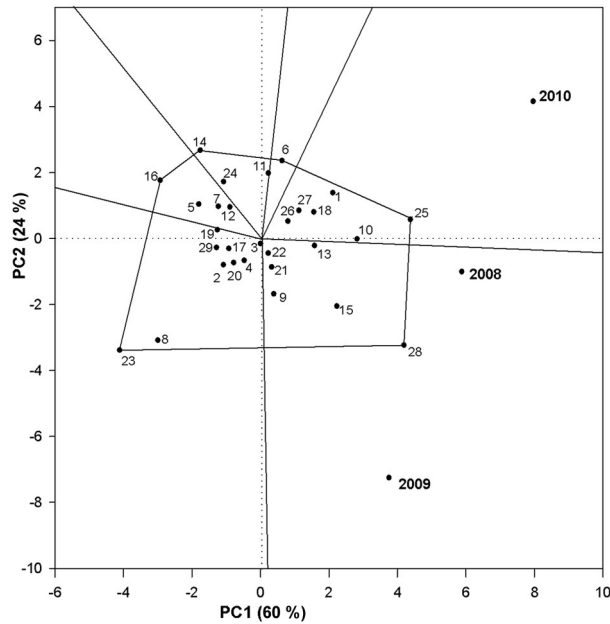| Source of variation	df	Mean Square	
		Fruit set	Production
Genotypes	28	1818.4**	1388.3**
Years	2	9068.1**	2237.6**
Genotypes × Years	56	1014.4**	357.1**
Error	174	110.0	128.8
Mean		50.4	48.5
CV(%)		21	23

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

Figure 3 – SREG analysis (sites regression) graph - GGE (genotype and genotype-environment interaction) biplot of 29 peach tree genotypes evaluated in three growing seasons (2008 to 2010) for trees production (kg per trees) in Pato Branco, state of Paraná, Brazil. Tropic Beauty (1), Rubimel (2), Conserva 985 (3), Bonão (4), Tropic Snow (5), Conserva 1127 (6), Conserva 1187 (7), Conserva 1153 (8), Âmbar (9), Atenas (10), Conserva 844 (11), Libra (12), Kampai (13), Cascata 1063 (14), Cascata 962 (15), Conserva 1223 (16), Cascata 1055 (17), Cascata 967 (18), Cascata 1070 (19), Conserva 871 (20), Conserva 1186 (21), Conserva 1129 (22), Cascata 587 (23), Cascata 1065 (24), Conserva 681 (25), Conserva 977 (26), Conserva 655 (27), Santa Áurea (28) and Conserva 688 (29). PC1 = Principal Component 1 and PC2 = Principal Component 2.

Table 2 – Mean grouping test for fruit set and production for twenty nine peach tree genotypes in three growing seasons, from 2008 to 2010.

Genotypes	Fruit set	Production
	%	kg per tree
Tropic Beauty (1)	65.7 a*	56.0 b
Rubimel (2)	70.1 a	40.2 c
Conserva 985 (3)	34.3 d	48.8 c
Bonão (4)	26.7 e	44.6 c
Tropic Snow (5)	38.0 d	37.6 d
Conserva 1127 (6)	44.2 c	49.1 c
Conserva 1187 (7)	34.3 d	45.3 c
Conserva 1153 (8)	17.6 e	27.8 e
Âmbar (9)	48.9 c	51.1 c
Atenas (10)	61.1 b	65.0 b
Conserva 844 (11)	45.8 c	48.1 c
Libra (12)	42.1 c	44.7 c
Kampai (13)	68.8 a	60.8 b
Cascata 1063 (14)	49.1 c	35.7 d
Cascata 962 (15)	62.1 b	64.3 b
Conserva 1223 (16)	58.1 b	33.1 d
Cascata 1055 (17)	56.6 b	42.2 c
Cascata 967 (18)	69.2 a	54.0 b
Cascata 1070 (19)	46.5 c	45.9 c
Conserva 871 (20)	47.5 c	44.4 c
Conserva 1186 (21)	42.7 c	54.1 b
Conserva 1129 (22)	77.0 a	50.7 c
Cascata 587 (23)	33.7 d	20.2 e
Cascata 1065 (24)	49.0 c	44.6 c
Conserva 681 (25)	56.0 b	75.1 a
Conserva 977 (26)	59.3 b	54.4 b
Conserva 655 (27)	58.7 b	51.3 c
Santa Áurea (28)	61.5 b	76.3 a
Conserva 688 (29)	37.0 d	41.1 c
Years		
2008	40.8 C	45.6 B
2009	61.1 A	45.6 B
2010	49.3 B	54.4 A

*Means followed by same lower case letter, by genotypes, and capital letter, by years, in the column, does not differ (Scott-Knott test, $p \leq 0.05$).

evaluation. The genotypes 'Conserva 1153' (8) 'Bonão' (4) and 'Cascata 587' (23) had the lowest fruit set (Figure 2 and Table 2).

For tree production, the year 2008 was the most stable (near the PC2 axis origin) and promoted reasonable production for most of the genotypes, with an average of 45.6 kg per tree. The years 2009 and 2010 were the most unstable (far from the PC2 axis origin), which allowed for better discrimination among the genotypes, 2010 being the year with the greatest average production in the years studied (Figure 3 and Table 2).

The SREG-GGE biplot graph for tree production (Figure 3) was divided into six sectors. The principal sectors grouped the years 2008 and 2009, and the following genotypes: 'Santa Áurea' (28), 'Cascata 962' (15), 'Âmbar' (9), 'Conserva 1186' (21), 'Conserva 1129' (22) and 'Kampai' (13). The other sector grouped the year 2010 and the genotypes 'Conserva 681' (25), 'Atenas' (10), 'Tropic Beauty' (1), 'Cascata 967' (18), 'Conserva 655' (27) and 'Conserva 977' (26).

The genotypes 'Rubimel' (2), 'Bonão' (4), 'Conserva 871' (20), 'Cascata 1055' (17), 'Conserva 688' (29), 'Cascata 1070' (19), 'Libra' (12), 'Conserva 1187' (7) and 'Tropic Snow' (5) had a similar level of production when compared with each other, but were below the overall average (48.5 kg per tree). 'Cascata 587' (23) and 'Conserva 1153' were the most unstable (Figure 3). The first had the greatest chilling requirement among the genotypes studied, and the second had serious problems with floral bud abortion (data not shown).

Temperatures above 20 °C during the endodormancy period and temperatures above 24 °C near the bloom period, as observed in 2008 (Figure 1), may explain the low fruit set and production in that year (Table 2). Dangerous frosts after fruit set, as observed in 2009 (Figure 1), were the cause of instability and low production observed in this year (Figure 3 and Table 2). In Southern

Brazil, the occurrence of frost usually coincides with the period of flowering and fruit development (Raseira et al., 1992) and is one of the serious problems found in peach cultivation. On the other hand, chilling negation by high temperatures is a cause of low budbreak in peach (Richardson et al., 1974; Erez et al. 1979). Temperatures above 24 °C during pre-blooming and blooming are related to abnormal development of pollen and ovules (Nava et al., 2009; Couto et al., 2010), leading to low flower fertilization and, consequently, low fruit set.

In 2010, despite having the same chill accumulation as in 2009 (Figure 1), it occurred later, and was not as effective in overcoming dormancy of flower buds, with heat accumulation during pre-blooming period, from the beginning of to mid July (Figure 1), causing lower fruit set than in 2009, but more than in 2008 (Table 2). Frost in late July was not dangerous, but caused fruit drop in a few genotypes that had already reached full bloom. The heat, during pre-blooming, and the frost, after blooming, were responsible for instability observed in both fruit set and production in 2010 (Figure 2 and Figure 3).

Rodrigo and Herrero (2002) observed that an increase in temperature accelerated flower bud development causing a hastening in flowering time and following hand-pollination, reduced fruit set in apricot. At anthesis, flowers that had developed in warmer conditions weighed less and showed less development of the pistil than control flowers. 'Tropic Beauty' (1), 'Kampai' (13), 'Cascata 967' (18), 'Santa Áurea' (28), 'Atenas' and 'Conserva 681' (25) appear to tolerate higher temperatures during the dormancy period, thus maintaining good fruit set (Figure 2) and production (Figure 3) even in years with low chill and high heat accumulation, as in 2008.

The development of varieties with low chilling requirement with good tolerance to high temperatures during flowering, make production more consistent (Sherman and Lyrene, 1984), especially in subtropical regions in low latitudes, in which temperatures above 20 °C often occur. 'Conserva 1153' (8) and 'Cascata 587' (23) had low fruit set (Figure 2) and tree production (Figure 3) in the years studied. Ensuring good fruit set is important, but this alone is not sufficient for good production. Production is a function of orchard density, flower density, index of fruit set and fruit size for all species, varieties and climatic conditions (Dennis Jr., 1981).

Excellent yields were obtained when there is good fruit set and fruit size. However, after fruit set, the number of fruits per plant is generally standardized by thinning practices; a fact that occurred in this experiment, therefore, from the thinning, production will be defined by fruit size of each genotype. Yamaguchi et al. (2002) found both cell number and cell size differences were significantly correlated with peach fruit size, although the correlation coefficients between cell number and fruit weight were consistently higher.

In sweet cherry, differences in mesocarp thickness were correlated with both cell number and cell size (Yamaguchi et al., 2004). Mesocarp cell number was remarkably stable and virtually unaffected by the environment as neither growing location nor physiological factors that reduced final fruit size altered the cell numbers. Cell length was also different among the cultivars ($p < 0.05$), but failed to contribute to the overall difference in fruit size. Cell length was influenced by the environment, indicating that cultural practices that maximize mesocarp cell size should be used to achieve a fruit size potential of the cultivar (Olmstead et al., 2007).

Other related genotype-dependent floral biology factors affect fruiting in temperate fruit species, such as flower bud production, flower production, flower bud drop, flowering time, percentage pollen germination, height difference between the stigma and the superior plane of the anthers, percentage of aborted pistils, autogamy level, fruit set and fruit production (Ruiz and Egea, 2008). Some of these characteristics may have contributed to the reduction of the average fruit set and production in the genotypes studied, even those genotypes that had sufficient chilling accumulation. These causes should be elucidated in future work.

In conclusion, genotypes 'Conserva 1129', 'Rubimel', 'Kampai', 'Tropic Beauty' and 'Cascata 967'demonstrated the greatest adaptability and stability for fruit set. The genotypes 'Conserva 681', 'Santa Áurea', 'Atenas', 'Kampai', 'Cascata 962', 'Tropic Beauty' and 'Cascata 967' demonstrated the greatest adaptability and stability of production (kg per tree). The GGE-biplot methodology was successful in classifying peach tree genotypes with regard to adaptability and stability of fruit set and production.

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