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ORIGINAL ARTICLE

Evaluation of low-chill peach and nectarine cultivars in a temperate-subtropical climate transition zone of central-eastern Argentina

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Abstract
Peach is a dynamic crop in terms of breeding. The central area of Santa Fe, Argentina, constitutes a transition zone between temperate and subtropical climate. This work aimed to evaluate the reproductive traits and internal fruit quality of twenty-five introduced low-chill peach and nectarine cultivars. The percentage of vegetative and floral budbreak, flower density and the percentage of fruit set were calculated for each cultivar. At harvest, fruit firmness, juice content, total soluble solids of the juice, and acid concentration were determined. Fruit color was also measured by determining the Hunter coordinates. Principal component analysis allowed segregating cultivars with similar properties: (i) those with reddish fruit coloration, low fruit size and fruit yield; (ii) those with high fruit yield and fruit size; (iii) those with high total soluble solid content, juiciness and ratio, and later maturation; and (iv) those with high fruit set and fruit acidity. Although cultivars can be chosen according to these characteristics, the most recommended cultivars that combined the best characteristics of fruit quality and reproductive behavior were 'Fla 91-8c', 'Rojo dos', 'Nect 22', 'Tropic Snow', 'Hermosillo', 'Jubileo', 'Fla 1-8 bis', and 'Chimarrita'.

Keywords Acid content · Color · Flesh firmness · Flower density · Fruit set · *Prunus persica*

Introduction

After apple, peach is the second most important temperate fruit tree crop in the world. Traditional peach cultivars have a winter chilling requirement of 500–800 chill hours (Scorza and Okie 1991).

In terms of breeding, peach is a dynamic crop, and only during the 1990s more than 500 new cultivars were developed around the world by different breeding programs (Scorza and Okie 1991). Since many of these cultivars require fewer chilling hours (for which they were called "low-chill cultivars"), they were selected for tropical and subtropical areas, which allowed the expansion of the peach crop to new cultivation areas such as Southern California (Hagillih et al. 2000), central and northern Florida (Ferguson et al. 2008), and the desert of Arizona in the USA (Bradley 2001), as well as to countries such as Australia (Porter et al. 1996), Brazil, South Africa, Thailand (Byrne and Boonprakob 2008), and Japan (Maneethon et al. 2007).

In Argentina, the traditional peach production areas have been the provinces of Mendoza and Buenos Aires (Carrá de Toloza 2001; Arroyo and Valentini 2018). Although in a smaller proportion, peach is also cultivated in Córdoba province, the southern area of Santa Fe province, and the region known as "Alto Valle de Río Negro y Neuquén" in Patagonia. The introduction of low-chill peach cultivars allowed the expansion of peach cultivation to warmer areas such as the provinces of Salta and Jujuy in the north of the country (Curzel 2017), and to a lesser extent, to the province of Misiones (Piekún et al. 2001) and the central and northern area of Santa Fe province (Gariglio et al. 2009, 2012).

In the central area of Santa Fe province, fruit tree crops have been introduced and evaluated as alternatives for the

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diversification of the horticultural system characterized by annual crops (Gariglio et al. 2009; Weber et al. 2013; Travadelo et al. 2017). The climate has been classified as temperate humid with no dry season and very hot summers (Köppen 1948), with high variability because it constitutes a transition zone between the temperate and subtropical climate of the south and north of the country, respectively. Winter chilling accumulation reaches 300 chilling hours on average (García 2012), thus only allowing the cultivation of low-chill peach cultivars, which have been evaluated during the past 15 years. Currently, only seven cultivars are recommended for the central area of Santa Fe (Gariglio et al. 2009; 2012); however, because of the rapid varietal renewal, new cultivars should be continuously evaluated. Although each peach cultivar has its own specific harvest time, which lasts for about 10 days, and peaches have a short-shelf life (Orazem et al. 2011; Prinsi et al. 2011), the cultivation of a large number of peach cultivars with a harvesting period in succession in time may allow a farm, or an entire production area, to achieve a long harvesting period and a long presence in the regional market. These characteristic of peach production can explain the importance of the continuous work on the evaluation of peach cultivars for productivity, fruit quality, and harvest time along the years.

Currently, in the central area of Santa Fe, we have an important collection of low-chill peach and nectarine genotypes with nearly 30 accessions. The external fruit quality and harvesting time of these accessions have been previously evaluated (Giovannelli et al. 2014), but the reproductive traits over the years and the internal fruit quality have not yet been described. The aim of this work was to evaluate the reproductive traits and internal fruit quality of the low-chill peach and nectarine cultivars last introduced in the central area of Santa Fe, Argentina.

Materials and methods

This work was conducted in an experimental orchard located in the area of Esperanza, Santa Fe, Argentina (31°25′S, 60°50′W, altitude 40 m above sea level) over three consecutive years (2010–2012). Twenty-five low-chill peach and nectarine (*Prunus persica* (L.) Batsch) genotypes mainly from Brazil and the USA were tested. All cultivars were grafted onto 'Cuaresmillo' seedling rootstocks. At the beginning of the experiment, the trees of 11 of the cultivars were 10-years old, while the remaining 15 were 3-years old (Giovannelli et al. 2014). 'Flordaking' was used as a control cultivar because its performance in the region is better known (Gariglio et al. 2006, 2012). The trees were planted 5 × 3 m apart on an Abruptic Argiudoll soil, provided with supplementary drip irrigation and trained to the standard open vase system. Fertilization, pest management and pruning were made following normal commercial practices. Five trees of each cultivar were chosen by their uniformity in size and vigor.

Yield components

During the winter, ten homogeneous current season shoots per plant were randomly selected 1.8 m above the ground level, and their lengths and number of vegetative and floral buds were measured. The number of flowers and/or fruits was weekly measured in the selected twigs from the release of dormancy to the pit hardening stage. Flower density was subsequently expressed as the maximum number of flowers reached per meter of shoots (flowers m^{-1}), and the percentage of fruit set was expressed as the relation between the number of fruits at pit hardening and the flower density in each selected twig (number of fruits/number of flowers × 100). The percentage of floral and vegetative buds that broke dormancy was also measured.

The number of fruits per plant was counted at pit hardening, and fruit load was adjusted to 1.5 fruits cm^{-2} of trunk cross sectional area (TCSA) to standardize the fruit crop load in plants of different ages. At harvest, the number of fruit per plant was counted again and fruit yield estimated multiplying by the average fruit weight. Fruit yield was expressed per unit of TCSA (g cm^{-2} TCSA) and used in multivariate analysis. The TCSA of each tree was calculated from a circumference measurement taken 20 cm above the graft union.

Fruit quality

The harvest time of each cultivar began when the background color of the skin changed from light green to yellow or white, according the flesh color of the cultivar. Twenty fruits per tree and cultivar were picked for their characterization. After harvest, the fruit samples were kept in the laboratory until the flesh firmness reached 20 Newton (N), which is considered as the most suitable for fresh consumption (Rizzante et al. 2008). To measure the evolution of the flesh firmness, half of the fruits sampled were used.

On the remaining fruits (10 fruits per plant), fruit firmness was determined using a fruit pressure tester Effegi with an 8-mm-diameter flat cylinder. Juice content was obtained from a portion of the flesh tissue (100 g) which was pressed and then filtered on a muslin cloth type. The juice content was expressed as percentage of juice (juice volume (ml) / fresh weight (g) × 100). Total soluble solids (TSS) of the juice were measured by a digital refractometer (ATAGO, Model Pal-1 0-32 °Brix) and acid concentration was determined by titration of 10 cm^3 of juice diluted in 150 ml of distilled water with 0.1 N NaOH. Fruit color was measured by determining the Hunter coordinates *L*, *a**, *b**, *h** and *C** (CIELAB scale) in the skin and flesh tissue of the fruit; two measurements were made at the equatorial area in both the sun-exposed and shaded sides of the fruit, using a Minolta colorimeter (Chroma Meter CR-400). External fruit characteristics such as fruit size and percentage of red over-color of the skin were not presented because they have been characterized earlier (Giovannelli et al. 2014).

Statistical analysis

A randomized complete block design with a single tree plot of five replications was used. The data were tested for normal distribution and variance homogeneity and means were compared by the Duncan test using the software Statgraphics plus for Windows 3.1 (Statistical Graphics Corp). A 5% probability level was used to indicate significant differences between treatments. Multivariate analysis was used to determine principal component analysis (PCA) with the objective to segregate genotypes based on similar properties. This analysis was performed by means of the InfoStat software (Di Rienzo et al. 2017).

Results and discussion

The percentage of vegetative budbreak of the low-chill peach and nectarine cultivars studied reached a mean value of 67.7%. 'Aurora' was the only cultivar that showed a percentage of vegetative budbreak below 60% (51.4%), whereas, 'Jubileo' showed the highest value of vegetative budbreak (> 80%) (Fig. 1). The cultivars with greater cold requirements (> 600 chill hours) than that offered by the climate of the central area of Santa Fe also reached values of vegetative budbreak close to 50%, although they sprouted 67 days later than the earliest low-chill cultivars (Gariglio et al. 2009). As known, chilling accumulation increases the percentage of budbreak (Gariglio et al. 2006; Okie and Blackburn 2011a) and reduces the time and heat accumulation required for budbreak (Okie and Blackburn 2011b). As 'Aurora' is a low-chilling cultivar, the low percentage of sprouting observed in the present study seems to depend on its own intrinsic characteristics.

The percentage of reproductive buds that broke dormancy and reached the flowering stage showed an average value of 62.1%. 'Jubileo', 'Fla 91-8c', 'Marfin' and 'Chimarrita' showed the highest percentage of floral budbreak (> 72.5%), whereas, 'Maciel' and 'Sunwright' (< 35%) and 'Aurora' and 'Brasil' (< 50%) showed the lowest (Fig. 2a). 'Flordaking', which was the reference cultivar, had 68.6% of floral budbreak. The percentage of flower budbreak also increases with chilling accumulation; however, unlike that observed with vegetative buds, excessive chilling causes reduction of flower budbreak in excised shoots of low-chilling peaches (Gariglio et al. 2006).

The average flower density was 18.0 flowers m^{-1} of mixed shoots. 'Marfin' showed the highest value (49.0 flowers m^{-1}), followed by 'Flordagem', 'Carolina' and 'Tropic Snow', whereas, 'Maciel', 'Sunwright', 'Brasil' and 'Flordaking' showed the lowest flower density (fewer than 10 flowers m^{-1} of mixed shoot) (Fig. 2b).

The average percentage of fruit set was 38.4%. 'Flordastar', 'Marfin' and 'Flodaprince' showed values higher than 79.53%, whereas, 'Brasil', 'Lara' and 'Sunwright' had low fruit set (< 15%) (Fig. 3).

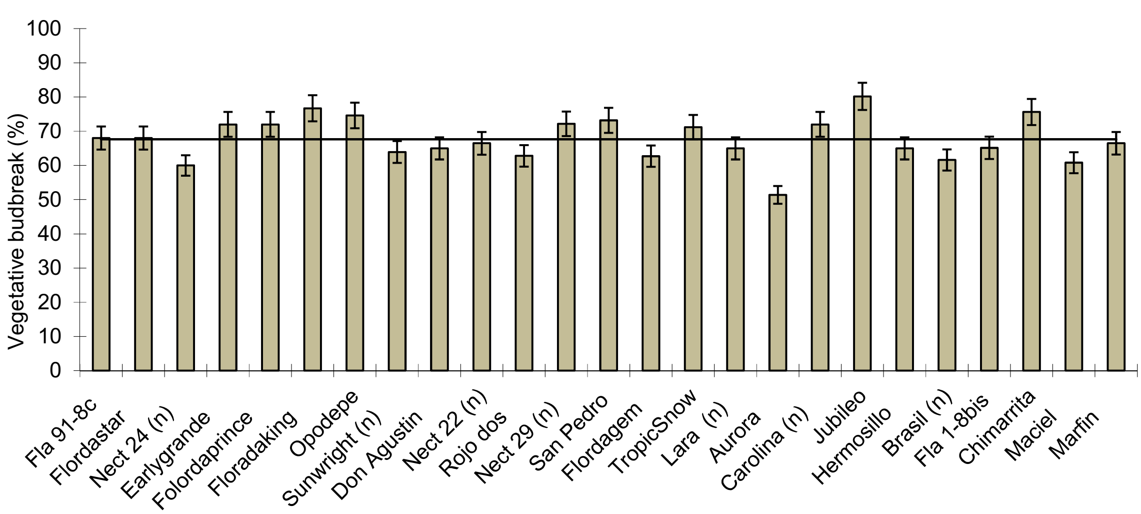

Fig. 1 Vegetative budbreak (%) of different low-chill peach and nectarine cultivars recently grown in the central area of Santa Fe province, Argentina. The horizontal solid line represents the mean value

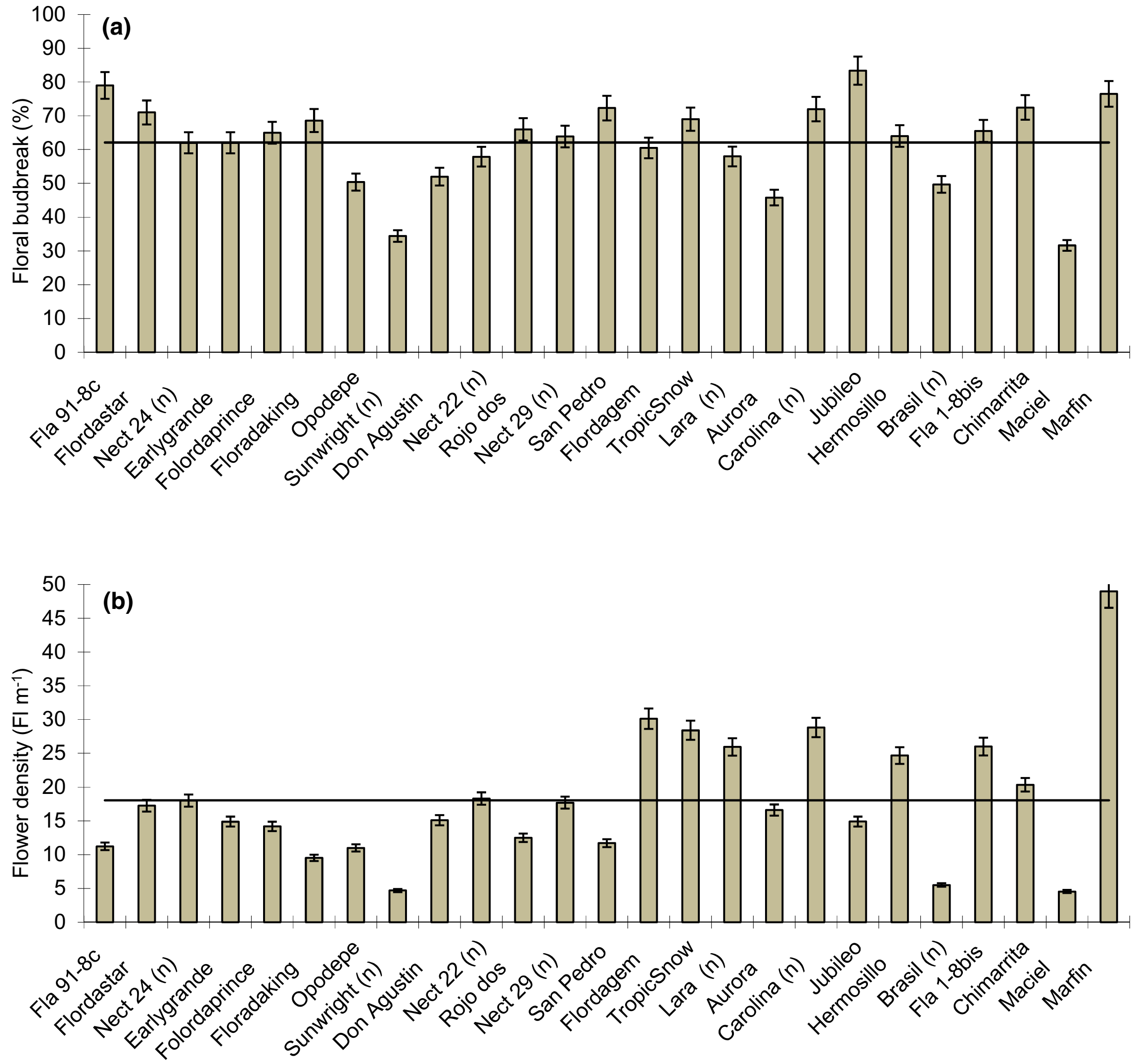

Fig. 2 Floral budbreak (%) **a**, and flower density (Fl m^{-1}) **b** of different low-chill peach and nectarine cultivars grown in the central area of Santa Fe province, Argentina. The horizontal solid line represents the mean value

The bloom density observed in this study was lower than that observed in previous ones (Gariglio et al. 2012), but, conversely, fruit set (%) was greater. In the state of Querétaro, in the central subtropical area of Mexico, a positive relationship of flowering density with fruit set (%) and fruit yield was observed (Pérez 2004). Similarly, in a previous work we have reported that 'Flordaking' showed a linear relationship between flower density and the number of fruit set, with a slope value close to the unity (0.97). These last results demonstrate that, at least in the cv. 'Flordaking' and with a flower density < 70 flowers m^{-1} of mixed shoot, flower density did not affect the percentage of fruit set of peach trees (Gariglio et al. 2012). Similar results were obtained under different climatic conditions and with other cultivars (González Rossia et al. 2007). In contrast, in other fruit tree crops such as citrus, the percentage of fruit set is greatly negatively affected by flower density (Guardiola et al. 1984; Micheloud et al. 2018).

Flower density does not seem to be a limiting factor for peach crops yield, as is the fruit set. In the central area of Santa Fe, the fruit set is the most critical factor to reach high peach tree productivity because blooming and fruit set take place during a period with high variability of the air temperature and frequent late frost occurrence (García et al. 2013; Weber et al. 2013). Low-chill peach cultivars with high flower density have a longer flowering period (Gariglio et al. 2009) and ability to set fruit again after the occurrence of unfavorable environmental conditions (Pérez 2004); consequently, these cultivars show greater yield stability both in the central area of Santa Fe

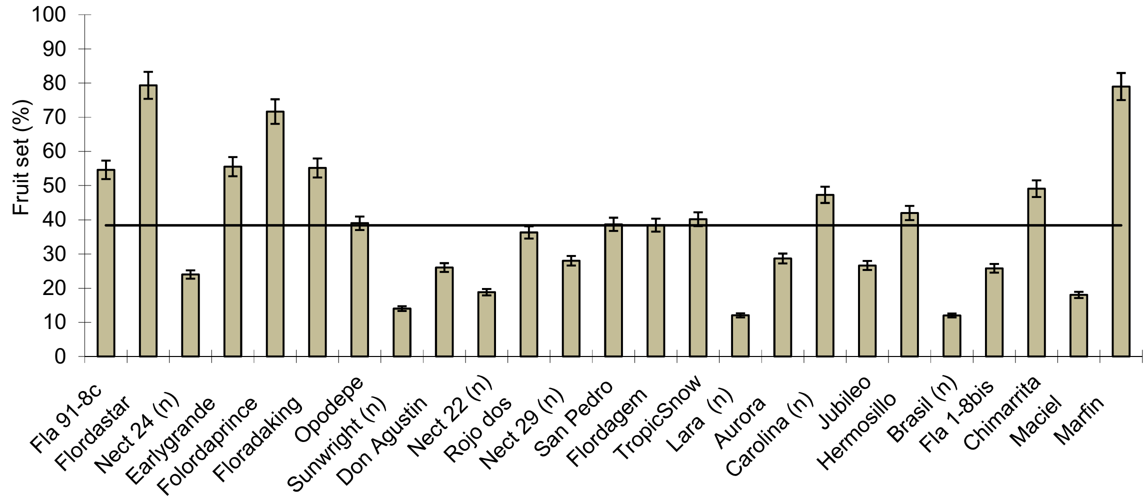

Fig. 3 Percentage of fruit set of different low-chill peach and nectarine cultivars grown in the central area of Santa Fe province, Argentina. The solid line represents the mean value

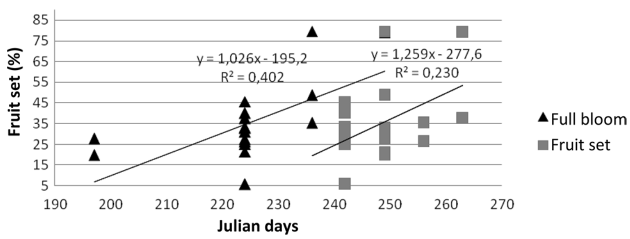

Fig. 4 Relationships between the time of full bloom and fruit set occurrence with the percentage of fruit set for different low-chill peach and nectarine cultivars grown in the central area of Santa Fe province, Argentina

(Gariglio et al. 2009) and other subtropical areas (Pérez 2004), and can explain the correlation of fruit set and fruit yield with flower density observed in different previous studies (Pérez 2004; Milatović et al. 2010; Penso et al. 2018). Similarly, mixed shoot should not be headed back during winter pruning because this practice will reduce the duration of the flowering period and stimulate vegetative growth, both factors that negatively affect fruit set and fruit yield of low-chilling peach (Weber et al. 2013).

In agreement with the variability of the temperature in the central area of Santa Fe, the phenology of low-chill peach cultivars recorded previously (Giovannelli et al. 2014), and the fruit set measured in this study, we observed a significant relationship between the time of bloom and time of fruit set, and the percentage of fruit set. The later the occurrence of full bloom or fruit set, the higher the final percentage of fruit set of the cultivar. In the present study, the percentage of fruit set increased by 1.02 or 1.26% for each day of delay in the time of bloom or fruit set, respectively (Fig. 4). This behavior can be explained by the fact that cultivars with later flowering and fruit set have low risk of frost damage or at least low risk of unfavorable temperature conditions during the most critical phenological stages of the crop (Gariglio et al. 2009; García et al. 2013).

In the present study, crop load was adjusted to 1.5 fruit per unit of TCSA (fruit cm^{-2}) at the beginning of pit hardening. After fruit thinning, 3-year-old plants had 90–100 fruits per plant, whereas, 10-year-old plants had 260–280 fruits per plant. However, as a consequence of their low flower density and/or fruit set, some cultivars, such as 'Sunwright', 'Don Agustín', 'Lara', 'Brasil', and 'Maciel', could not attain the defined crop load (1.5 fruit cm^{-2} TCSA) and the number of fruit per plant mentioned above. Excluding these cultivars, in the other cases, fruit yield was in close relationship with fruit size, a parameter described in a previous work (Giovannelli et al. 2014). Fruit yield ranged from 100.6 to 277.5 g cm^{-2} of TCSA for 'Carolina' (*n*) and 'Jubileo', respectively. 'Carolina' (*n*), 'Nectarine 24' and the peaches 'Flordastar', 'Rojo dos' and 'San Pedro 1633' showed lower fruit size (Giovannelli et al. 2014), and consequently lower fruit yield. The fruit size of these cultivars resulted lower than the threshold of 100 g considered appropriate for fresh marketing in the European Community (Badenes et al. 1998). Commercial peach crop load in Murcia (Spain), for example, ranges from 3 to 4 fruits cm^{-2} TCSA (Conejero et al. 2010), whereas, in Morro Redondo (Rio Grande do Sul, Brazil), a crop load of 2.25 fruits cm^{-2} TCSA allows adequate fruit size, fruit yield and return bloom for the low-chill peach cv. 'Jubileu' (Giovanaz et al. 2016). Consequently, under the agroecological conditions of the central area of Santa Fe province, the crop load used in our study (1.5 cm^{-2} TCSA of fruit) should have allowed expressing the potential of the different parameters of fruit quality for each cultivar (including fruit size).

Regarding fruit color, the proportion of red over-color of the skin surface improves fruit appearance and has a positive effect on consumer acceptance, while green color has the opposite effect (Scorza and Okie 1991; Orazem et al. 2011). In this work, the proportion of red over-color of the skin tissue was not measured because it was quantified in a previous study (Giovannelli et al. 2014). The Nectarines 'Carolina', 'Sunwright' and 'Nect 24' were those which showed the highest proportion of red over-color of the skin tissue. Among the peach cultivars, 'Hermosillo', 'Earlygrande' and 'Rojo dos' showed the best red over-color. In contrast, 'Jubileo' and 'Maciel' did not show red over-color of the skin while other nine cultivars showed low values ($<30\%$) (Giovannelli et al. 2014). As the proportion of red over-color does not increase after harvest (Scorza and Okie 1991; Prinsi et al. 2011), it is essential to improve orchard management to reach adequate red fruit coloration before harvesting, according to the market requirements. For example, the extension of the red over-color for early and mid-period production in new selections for low chill Mediterranean climate areas is above 80% in average (Caruso et al. 2016).

In relation with the Hunter parameters, positive values of a^* indicate reddish coloration, whereas, negative values indicate the presence of green color (Jha 2010). The a^* value of the skin tissue was higher in the nectarines 'Carolina' and 'Sunwright' (Table 1), which were also the cultivars with the greatest proportion of red over-color in the skin (Giovannelli et al. 2014). 'Nect 29', 'Rojo dos', 'Nect 22', 'Flordastar', 'Hermosillo' and 'Nect 24' also showed high values of a^*. The a/b ratio followed the same tendency as a^* (Table 1), and both variables were highly correlated ($r^2=0.947$; $y=0.035x$, where $x=a^*$, $y=a/b$).

L^* (lightness) showed relatively homogeneous values among peach cultivars, ranging from 68.2 to 55.7, with the exceptions of 'Hermosillo' and 'Rojo dos', which had low L^* values (49.8 and 47.4, respectively). Nectarines generally showed lower L^* values than peaches, with the exception of 'Brazil' (57.1) and 'Nect 29' (55.2). 'Sunwright' showed the lowest L^* value (38.5). Since $L^*=0$ is black and $L^*=100$ is white in the L^* (lightness) axis (Jha 2010), peach cultivars showed lighter coloration than nectarine ones (Table 1).

The value of the hue angle h^* corresponds to a threshold of color distinction power, i.e. the least distinction in color that can be noticed by the trained human eye (Jha 2010). In the present study, the hue angle h^* of peaches almost doubled that of nectarines (Table 1). Among the peach cultivars studied, 'Rojo dos', 'Hermosillo' and 'Fla 1-8 bis' showed low values of h^*.

The parameter C^* was higher in 'Jubileo', 'Aurora' and 'Maciel' (Table 1), which are cultivars with scarce proportion of red over-color of the skin (Giovannelli et al. 2014). Nectarines showed intermediate or low C^* values, but, in this case, we observed no segmentation of peaches and nectarines, as it occurred with the parameter L^*.

The color of the flesh tissue showed a relatively high value of a^* for the cultivars 'Jubileo' and 'Maciel', and to a lesser extent for 'Hermosillo', 'Nect 22', 'Marfín', 'Flordagem' and 'Rojo dos' (Table 2). Positive values of a^* indicate the presence of red coloration in the flesh, which in the case of 'Jubileo' and 'Maciel' was higher than that of the skin tissue (Tables 1 and 2). The white-fleshed cultivars 'Chimarrita', 'Brazil' and 'Tropic Snow', together with the yellow flesh nectarine 'Sunwright' showed lower negative values of a^* which indicates the presence of green coloration instead of red coloration of the flesh (Table 2).

The a/b ratio showed the same tendency as the parameter a^*; furthermore, both in the flesh and in the skin tissue, a

Table 1 Colorimetric characteristics of the skin fruit tissue of different low-chill peach and nectarine cultivars grown in the central area of Santa Fe province, Argentina

Cultivars	CIE color parameters				
	*a**	*a/b*	*L**	*h**	*C**
Aurora	4.82kl	0.099gh	63.41cd	83.12de	50.04a
Brasil (*n*)	−2.00op	−0.063j	57.09gh	83.64de	37.25gh
Carolina (*n*)	30.22a	1.187a	42.71l	39.20k	40.80e
Chimarrita	−0.96no	−0.029ij	62.76de	87.11cd	36.05hi
Don Agustín	−0.64no	−0.015ij	67.79a	89.78bc	44.82bc
Earlygrande	14.34ef	0.423de	59.79fg	65.41hi	39.22fg
Fla 1-8 bis	7.34ij	0.177g	57.92gh	61.00i	39.83ef
Fla 91-8 c	11.89fg	0.338e	57.39gh	70.28gh	39.47fg
Flordagem	11.13gh	0.299e	55.66h	71.72gh	41.44de
Flordaking	8.73hi	0.233ef	61.15de	75.04fg	41.47de
Flordaprince	3.66kl	0.081h	64.04cd	83.65de	46.75b
Flordastar	17.32e	0.519d	56.49h	78.07ef	43.92cd
Hermosillo	17.28e	0.568d	49.79i	58.81i	36.79gh
Jubileo	1.96mn	0.039i	66.06ab	87.61cd	50.45a
Lara (*n*)	12.47fg	0.460d	45.98jk	60.19i	34.03i
Maciel	−5.72p	−0.117k	68.16a	96.51a	49.54a
Marfín	−2.50op	−0.073j	63.78bc	90.67ab	36.86gh
Nect 22 (*n*)	21.78d	0.740c	48.28ij	52.24j	40.04ef
Nect. 24 (*n*)	17.00e	0.464d	44.57kl	42.42k	37.51gh
Nect 29 (*n*)	25.85bc	1.056b	55.23h	62.77i	44.30bc
Opodepe	5.64kl	0.148g	60.39rf	79.00ef	40.68e
Rojo dos	22.20cd	0.764c	47.44ij	50.61j	39.75ef
San Pedro1633	7.04jk	0.158g	63.21cd	79.96ef	46.20bc
Sunwright (*n*)	28.27ab	1.267a	38.48m	36.19k	37.55gh
Tropic Snow	2.94lm	0.090gh	61.31de	81.58ef	35.35hi

Different letters in the same column indicate statistically significant differences according to the Duncan test ($p \le 0.05$)

L^* lightness, a^* bluish–green/red–purple hue component, b^* yellow/blue hue component, C^* chroma, h^* hue angle

Table 2 Colorimetric characteristics of the flesh fruit tissue of different low-chill peach and nectarine cultivars grown in the central area of Santa Fe province, Argentina

Cultivars	CIE color parameters				
	*a**	*a*/*b*	*L**	*h**	*C**
Aurora	1.86ef	0.031cd	68.72fg	88.23de	60.97ab
Brasil (*n*)	−9.81j	−0.294k	76.35a	106.31ab	34.84i
Carolina (*n*)	1.73ef	0.029cd	68.86fg	88.33de	60.01bc
Chimarrita	−10.49j	−0.338k	74.00bc	108.65a	32.79i
Don Agustín	−1.02gh	−0.018f	72.06ef	90.99d	57.12de
Earlygrande	−1.47gh	−0.028fg	73.35cd	91.58d	52.99fg
Fla 1-8 bis	−0.81gh	−0.013f	68.82fg	90.71d	62.35a
Fla 91-8 c	−1.10gh	−0.019f	72.72de	91.15d	56.59ef
Flordagem	2.26cd	0.040c	65.97gh	87.61de	56.45ef
Flordaking	−1.31gh	−0.025fg	74.23bc	91.41d	53.28fg
Flordaprince	1.81ef	0.033c	69.22fg	88.10de	54.59fg
Flordastar	−1.87gh	−0.035g	74.27ab	92.02d	53.52fg
Hermosillo	4.03b	0.074b	62.70i	85.08e	55.09fg
Jubileo	10.02a	0.171a	70.41ef	80.30f	59.55bc
Lara (*n*)	−2.56gh	−0.047gh	62.17i	92.62d	54.62fg
Maciel	8.02a	0.160a	70.00ef	80.52f	59.35bc
Marfín	3.72bc	−0.162h	72.21ef	102.31b	30.25i
Nect 22 (*n*)	3.72bc	0.072b	70.71ef	85.66e	51.96g
Nect. 24 (*n*)	0.48gh	0.009e	72.09ef	89.35de	55.59fg
Nect 29 (*n*)	0.55gh	0.010e	73.62cd	89.45de	56.53ef
Opodepe	−1.58gh	−0.030fg	72.48de	91.70d	53.61fg
Rojo dos	2.11de	0.036c	70.14ef	88.05de	58.11cd
San Pedro1633	1.51g	0.027cd	71.98ef	88.45de	56.43ef
Sunwright (*n*)	−7.83ij	−0.216i	63.87hi	99.19c	38.69h
Tropic Snow	−5.92i	−0.254j	74.68ab	104.06b	24.14j

Different letters in the same column indicate statistically significant differences according to the Duncan test ($p \leq 0.05$)

*L** lightness, *a** bluish–green/red–purple hue component, *b** yellow/blue hue component, *C** chroma, *h** hue angle

strong relationship between *a** and *a*/*b* was observed. In contrast, no relationship was observed between the *a** value measured in the flesh and that of the skin tissue ($r = 0.24$; $p = 0.2511$).

The lightness (*L**) of the flesh color (Table 2) showed a narrow range of variation in comparison with that of the skin. While the *L** value on the skin varied from 38.5 to 68.2 (Table 1), those of the flesh ranged from 76.3 to 62.2 (Table 2). We also observed a significant but weak relationship between the *L** value measured in the pulp and that measured in the skin tissue ($p = 0.0189$; $r = 0.47531$). Similarly, in a comparative analysis of peach and nectarine genotypes in Arkansas, USA, Felts et al. (2019) found that the value of *L** in the skin was lower than that in the flesh tissue.

The values of the hue angle *h** for the flesh tissue were, on average, 35.7% higher than those for the skin. Only the cultivar 'Jubileo' had an *h** value lower in the flesh than in the skin. Felts et al. (2019) also observed that the flesh has a trend for higher values than the skin. However, the relationship between the values of *h** in the skin and those in the flesh tissue was not significant ($p = 0.2179$).

The *C** value of the pulp was, on average, 27% higher than that of the skin and also showed great variability. The *C** value in the flesh tissue was lower than that in the skin only in three white flesh cultivars ('Brazil', 'Chimarrita' and 'Tropic Snow'). The *C** values of the flesh and skin tissues showed a significant and moderate relationship ($p = 0.0076$; $r = 0.54$), thereby being the parameter of both tissues that showed the best relationship. The color parameters measured in this work could be used in the future to estimate other fruit attributes because color is an indirect measure of other quality attributes such as flavor and pigment content (Pathare et al. 2013).

Regarding TSS, it is known that it is highly variable and depends on environmental, cultural, and genetic factors (Prinsi et al. 2011), even in fruits from the same plant, and similar size and degree of maturity (Ramina et al. 2008). One of the environmental factors with great effect on the TSS content is the radiation captured by the fruit, a parameter that can explain the higher TSS content of fruits located outside the canopy (Romeu et al. 2015). The TSS of the peach juice is usually between 9 and 15 °Brix (Orazem et al. 2011), although it is well-known that low-chill cultivars have slightly lower values (Ramina et al. 2008). In this study, the TSS was above this threshold values for all cultivars, except for 'Flordastar' (8.5°Brix) (Table 3). 'Brasil' showed the highest TSS content (17.5°Brix), whereas, 'Rojo dos', 'Chimarrita' and 'Fla 1-8bis' also had high TSS contents (> 12.5 °Brix).

The titratable acidity (TA) of peach juice, expressed as malic acid, showed high variability. Normally, TA ranges from 0.9 to 1.6% of the fresh weight (Bassi and Monet 2008). In the present study, TA ranged from 0.3 to 1.3% (Table 3). Peaches and nectarines can be classified as having high or low acidity, being 0.9% of malic acid content the threshold value for this division (Orazem et al. 2011). According to this criterion, the peach cultivars 'Flordastar', 'Fla 91-8c', 'Earlygrande', 'Rojo dos', 'Tropic Snow', 'Fla 1-8bis' and 'Hermosillo', and the nectarine cultivars 'Carolina', 'Nect 29' and 'Lara' should be classified as fruit of high acidity. It is also known that TA decreases during fruit ripening, and that the malic/citric acid ratio increases during peach maturation, facts that are even more pronounced in the cultivars with high acidity (Prinsi et al. 2011). Moreover, TA tends to be higher in early peach cultivars, so that TA plays a key role in fruit quality, affecting the balance of flavors. However, high acidity should not be interpreted as a negative attribute of peach quality (Orazem et al. 2011) since fruit flavor depends on the concentration of malic acid, the malic/citric acid ratio, and the content of sugars (Jha 2010; Orazem

Table 3 Total soluble solid (TSS) content (°Brix), titratable acidity (TA), TSS/TA ratio, and juiciness (%) of the fruits of different low-chill peach and nectarine cultivars grown in the central area of Santa Fe province, Argentina

Cultivars	TSS (°Brix)	TA Malic acid (%)	TSS/TA ratio	Juiciness (%)
Aurora	12.3de	0.6e	21ef	62cd
Brasil (*n*)	17.5a	0.8d	21ef	66c
Carolina (*n*)	10.0jk	1.3ab	8n	56ef
Chimarrita	12.5cd	0.4f	32b	81a
Don Agustin	9.1mn	0.8d	12kl	56ef
Earlygrande	9.4kl	1.0c	9lm	25j
Fla 1-8bis	12.5bc	1.1c	12kl	80a
Fla 91-8c	8.9mn	1.0c	9lm	61cd
Flordagem	11.4gh	0.8d	15i	66c
Flordaking	9.1mn	0.4f	24d	61cd
Flordaprince	9.2mn	0.6e	22de	49fg
Flordastar	8.5n	1.2b	7n	53f
Hermosillo	11.2hi	1.2ab	9lm	64cd
Jubileo	10.1j	0.8d	13ij	73b
Lara (*n*)	11.9ef	1.0c	12jk	47g
Maciel	12.0ef	0.8d	15hi	57ef
Marfin	11.8fg	0.3fg	35a	57ef
Nect 22 (*n*)	10.0jk	0.4f	27c	59e
Nect 24 (*n*)	9.7kl	0.6e	19fg	52f
Nect 29 (*n*)	9.1mn	1.0c	9lm	51f
Opodepe	10.9hi	0.6e	19fg	41hi
Rojo dos	13.0b	1.3a	10kl	43h
SanPedro1633	9.2lm	0.3g	32b	56ef
Sunwright (*n*)	10.6i	0.6e	18gh	50fg
Tropic Snow	11.5fg	1.1c	11kl	63cd

Different letters in the same column indicate statistically significant differences according to test Duncan ($p \leq 0.05$)

et al. 2011). These complex relationships explain why there is no recommended threshold value for this parameter. Felts et al. (2019), for example observed differences in consumer acceptance for the different acid type fruits, and indicated no single value to describe the optimum ripeness of peaches and nectarines.

As known, another important quality attribute of peach fruit is juiciness (Orazem et al. 2011). In the present study, this parameter ranged from 25% in the cv. 'Earlygrande' to 81% in the cv. 'Chimarrita' (Table 3). Juiciness is inversely related to the consistency of the fruit (Prinsi et al. 2011), and the great juiciness of white-fleshed cultivars can be attributed to a faster loss of flesh firmness in relation to yellow-fleshed cultivars (Oraze et al. 2011; Prinsi et al. 2011). However, in the present study, juiciness was assessed at the same flesh consistency (20 N) for all cultivars. Under this condition, nine out of 21 yellow-fleshed cultivars can reach 57% of juiciness, which was the lowest value of the white-fleshed cultivars evaluated ('Marfin').

The peach cultivars described both in this work and previously (Giovannelli et al. 2014) allow a long and continuous harvesting period for low-chill peach in the central area of Santa Fe. The harvesting time begins at the end of October and finishes at the end of December, with cultivars that begin their harvest period each week (Giovannelli et al. 2014). Consequently, all the cultivars evaluated are useful to achieve the continuity of harvest and the offer of fresh fruits in the regional market.

The PCA allowed grouping the different genotypes according to their common characteristics (Fig. 5). Most of the nectarines formed one cluster to the bottom right of the biplot graph, characterized by their reddish fruit coloration. 'Rojo dos' was the only peach cultivar grouped together with nectarines. Within this group, the nectarines 'Sunwright' and 'Lara' showed low fruit size, productivity, and juiciness ('Lara'), reasons why they are not recommended for cultivation. In contrast, 'Fla 91-8c', 'Hermosillo' and 'Nect 22' were the three genotypes in which all the attributes of fruit quality were within acceptable ranges of marketing and were grouped to the upper right quadrant of the graph together with 'Flordaking', 'Earlygrande' and 'Nec 29'. These cultivars were grouped by their high fruit set and TA of the juice, and intermediate to high fruit yield.

The genotypes grouped to the bottom left quadrant are characterized by their high fruit TSS content and TSS/TA ratio, juiciness, later maturation and high flower density. The nectarine 'Brasil' was grouped in this quadrant and is not recommended for cultivation because of its low red over-color and fruit size, and inadequate reproductive behavior. The upper left quadrant grouped the genotypes that showed high fruit yield per unit TCSA and fruit size, such as 'Jubileo', 'TropicSnow', 'Flordaprince', 'Opodepe' and 'Fla 1-8bis'. Although 'Don Agustín' and 'Maciel' could not attain the defined crop load (1.5 fruit cm^{-2} of TCSA) they reached intermediate to high fruit yield due to their fruit size.

Together, the results here obtained allow accepting the hypothesis; the description made both here and previously (Giovannelli et al. 2014) and the PCA here performed, which segregated the genotypes based on similar properties, generated enough information so that farmers can choose the better peach and nectarine genotypes for their cultivation in a temperate-subtropical climate transition zone such as the central area of Santa Fe (Argentina). The cultivars that combined the best characteristics of internal and external fruit quality attributes and reproductive behavior of the plant, thus allowing an extended harvesting period for the fresh regional market were 'Fla 91-8c', 'Rojo dos', 'Nect

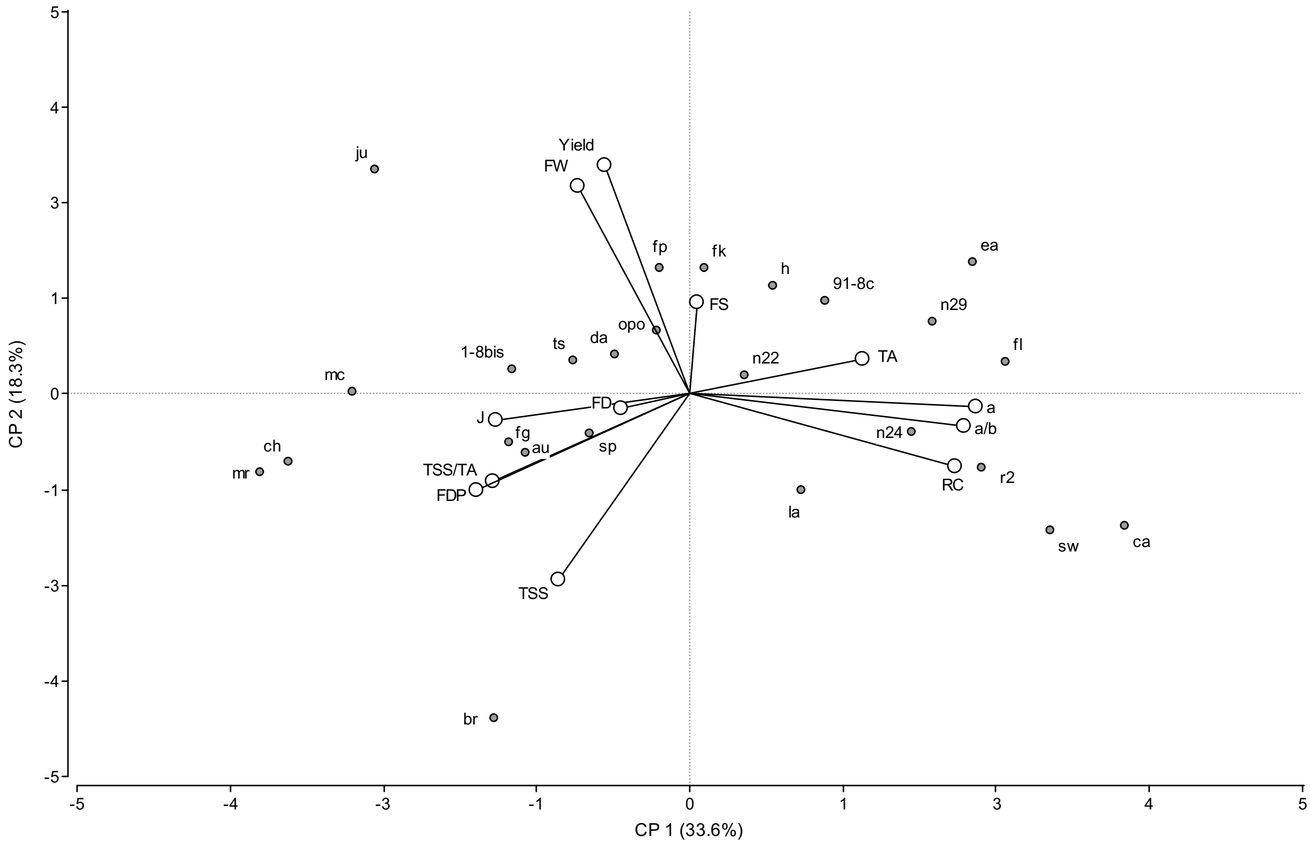

Fig. 5 Two-dimensional positioning of twenty-five low-chill peach and nectarine cultivars and parameters of fruit quality attributes, reproductive characteristics of the tree, fruit development period and fruit yield, determined by the Biplot technique. *RC* percentage of red over-color of the fruit, *FW* fruit weight, *FD* flower density, *FS* fruit set, *TSS* total soluble solid content, *TA* titratable acidity, *TSS/TA* ratio, *J* juiciness, *Yield* fruit yield, *a and a/b* hunter parameters of fruit coloration, *FDP* fruit development period, *Cultivars au* Aurora, *br* brasil (*n*), *ca* Carolina (*n*), *ch* Chimarrita, *da* Don Agustín, *eg* Earlygrande, *fg* Flordagem, *fl* Flordastar, *fk* Floradaking, *fp* Folordaprince, *h* Hermosillo, *ju* Jubileo, *la* Lara (*n*), *mc* Maciel, *mr* Marfin, *n22* Nect 22 (*n*), *n24* Nect 24 (*n*), *n29* Nect 29 (*n*), *opo* Opodepe, *r2* Rojo dos, *sp* San Pedro 1633, *sw* Sunwright (*n*), *ts* TropicSnow, *91-8c* Fla 91-8c, *1-8bis* Fla 1-8bis

22', 'Tropic Snow', 'Hermosillo', 'Jubileo', 'Fla 1-8 bis', and 'Chimarrita'.

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