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Phenotypic diversity and relationships of fruit quality traits in peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies

Celia M. Cantín, Yolanda Gogorcena & María Ángeles Moreno*

Dpto. de Pomología. Estación Experimental de Aula Dei (CSIC). Apdo. 13034, 50080 Zaragoza, Spain

*Corresponding author. Tel: +34 976 71 61 36. Fax: +34 976 71 61 45. E-mail address: mmoreno@eead.csic.es

Abstract

Agronomic and fruit quality traits were evaluated and compared for three consecutive years on 1111 seedlings coming from fifteen peach and nectarine breeding crosses, grown under a Mediterranean climate. Significant differences among and within the different progenies were found for most of the traits analyzed. The breeding population segregated for several Mendelian characters such as peach or nectarine fruit, round or flat fruit, yellow or white flesh and freestone or clingstone. In addition, aborting fruit and flat fruit trees were found in our progeny, and our data seem to support multi-allelic control of both flat shape and aborting fruit. The variation within the progenies of some traits such as blooming and harvesting date, yield, fruit weight and SSC was continuous, suggesting a polygenic inheritance. Relationships between qualitative pomological traits and these agronomic and fruit quality parameters were also found. Valuable correlations among agronomic and fruit quality parameters were found, although coefficients of variation depending on the progeny should be considered. In addition, principal component analysis (PCA) revealed several relationships among quality traits in the evaluated progenies. Based on this evaluation, 26 outstanding genotypes were pre-selected from the initial breeding population for further studies.

Keywords Aborting fruit · Acidity · Fruit shape · Principal component analysis · Sugars · Yield

Introduction

Peach and nectarine [*Prunus persica* (L.) Batsch] are the second most important fruit crop in the European Union (EU) (approx. 4.3 million tons) after apple (FAOSTAT 2007), and the most important within the genus *Prunus*. Spain is the second producer in Europe and the third in the world with a production of more than one million tons (FAOSTAT 2007). Among temperate fruit crops, the peach breeding industry is one of the most dynamic and new cultivars are released every year (Fideghelli et al. 1998, Byrne 2002, Sansavini et al. 2006).

The creation of cultivars through controlled cross pollination in peach was first done by Thomas A. Knight in 1806 (Brown 1975). At present, the most common method for producing new cultivars is via cross of chosen parents. The resulting full-sib families are planted in trials from which the best genotypes, that share the most appropriate combination of traits after evaluation, are selected (Scorza & Sherman 1996, Nicotra et al. 2002, Martínez-Calvo et al. 2006). The selected seedlings are then budded for clonal testing (Brown 1975). This is the method used in the present work that deals with fifteen progenies derived from crosses between commercial and/or pre-selected peach cultivars, reaching up to one thousand seedlings. We search for superior peach and nectarine cultivars for the Spanish industry with good adaptation to Mediterranean conditions when grown in the Ebro Valley, one of the biggest production areas in Europe. Most crosses were aimed at development of improved yellow, melting flesh peaches with emphasis on red skin color, good size and firmness and enhanced flavour. A few crosses in the program were made for development of improved yellow nectarines, white flesh peaches and flat shape fruits (Moreno 2005, Cantín et al. 2006). Besides lowering the production costs and improving pest and disease resistance, breeding objectives of this program also include extension of the harvest season, development of new fruit types for areas with mild-winter climate areas, and improvement of fruit quality (shape, flesh and skin colour, firmness, flavour, etc.). Like other temperate fruits, peach has chilling and heat requirements for flowering. Early flowering is a desirable characteristic in many breeding programs in Mediterranean areas to obtain the earliest yield (George & Nissen 1992) although spring frosts may reduce production in some years. Extension of the harvest season with very early, as well as late-maturing peach genotypes, is of considerable interest for the peach industry in this area, in order to supply the market for a longer period of time (Carusso & Sottile 1999, Byrne 2003, Badenes et al. 2006, Martínez-Calvo et al. 2006).

On the other hand, breeders have traditionally selected primarily for external fruit quality (fruit size and appearance), with organoleptic and nutritional traits being a secondary goal (Byrne 2002, Hilaire 2003). However, nowadays fruit quality is fundamental for the acceptance of peach and nectarine cultivars by consumers, due to the high competition in the market with numerous new released cultivars and other fruit species (Crisosto & Crisosto 2005, Crisosto et al. 2006b, Iglesias & Echeverría 2009). Kramer and Twigg (1966) defined quality as being composed of those chemical and physical characteristics that give a product consumer appeal and acceptability. Skin appearance (colour and freedom from defects), texture, flavour and sugar and acid content are key factors that determine high-quality fresh peaches and nectarines. The shape and proportions of the fruit are also of interest to the consumers (Badenes et al. 2006). All these parameters may not be independent from each other, and therefore, should be studied as a whole and should be considered in breeding programs dealing with fruit quality.

Some important agronomic and fruit quality traits are controlled by major genes transmitted to the offspring over Mendelian inheritance. Some of these traits are peach flesh texture (Bassi & Selli 1990), flesh adhesion (Yamamoto et al. 2001), flesh colour (Connors 1920), skin colour (Yamamoto et al. 2001), non-acid fruit (Monet 1979), skin hairiness (Dirlewanger et al. 1998), and fruit shape (Lesley 1940). However, quantitatively inherited characters constitute the bulk of the variability selected during the breeding process in fruit trees as in most cultivated species. Characters related with plant growth and architecture, yield, blooming and harvesting times, and fruit quality, are usually of quantitative nature (Dirlewanger et al. 1999, Etienne et al. 2002). The quality parameters may not be independent of each other, and therefore, relationships among them should be studied to improve the choice of production objectives. Previous studies carried out in peach (Byrne et al. 1991, Génard et al. 1994, Esti et al. 1997, Génard et al. 1999) have found correlations among some pomological traits related to the fruit quality.

Different studies have investigated the phenotypic diversity and relationships of fruit quality traits in peach and nectarine and other fruits germplasm such as apricot (Byrne et al. 1991, Génard & Bruchou 1992, Brooks et al. 1993, Esti et al. 1997, Ruiz & Egea 2008). However, there is limited information on the global evaluation of fruit quality in breeding progenies and their relationships with pomological traits. In this study, we investigated different agronomic and fruit quality parameters in fifteen peach and nectarine breeding populations over three consecutive years.

The aims of this work were to evaluate the existing phenotypic diversity among and within the breeding progenies, and to study the relationships among agronomic and fruit quality parameters, including qualitative pomological traits linked to the fruit quality. In addition, principal component analysis was carried out to study correlations among variables and to establish relationships among breeding crosses regarding fruit quality attributes. The materials evaluated are representative of the germplasm available for peach breeding in the Mediterranean area. The high number of genotypes, with large genetic variability for many fruit quality traits, will improve the knowledge of the genetic studies on this crop and will constitute a helpful tool to be applied in peach breeding programs.

Material and methods

Plant material

Fifteen controlled biparental crosses between nineteen peach and nectarine cultivars (Table 1) were made during 2000 and 2001 in collaboration with Agromillora Catalana S.A. (Barcelona, Spain). The plant material used as progenitors for the controlled crosses included ten commercial cultivars ('Andross', 'Babygold-9', 'Big Top', 'Calante', 'Crown Princess', 'O'Henry', 'Orion', 'Red Top', 'Rich Lady' and 'Venus') and nine experimental cultivars ('VAC-'). The assayed progenitors belonged to six different categories of fruit type: yellow-fleshed freestone peach, white-fleshed freestone peach, yellow-fleshed clingstone peach, white-fleshed clingstone peach, yellow-fleshed freestone nectarine and white-fleshed freestone nectarine. The resulting seedlings were budded on the same rootstock (GF-677) and established (one tree per genotype) in an experimental orchard at the Experimental Station of Aula Dei-CSIC (northern Spain, Zaragoza) in 2002. Trees were trained to the standard open vase system and planted at a spacing of 4 m x 2.5 m. Hand thinning was carried out to reduce fruit load when required. Trees were grown under standard conditions of irrigation, fertilization and pest and disease control. Vegetative and fruit quality traits have been evaluated in a total of 1111 genotypes over three consecutive years (2005-2007). All traits were measured or scored for each seedling tree separately over the three-year period and means of three years were calculated. Finally, superior genotypes were selected by independent culling of the most important agronomic (harvest date and yield) and fruit quality traits (fruit weight, soluble solids content, acidity, skin blush, endocarp staining and firmness) evaluated.

Fruit Quality Trait Evaluation

During the 2005, 2006 and 2007 seasons, agronomic and fruit quality traits were measured individually in each seedling tree. Blooming date was recorded for each progeny according to Fleckinger (1945), i.e., the average date for bloom beginning (E stage), full bloom (F stage) and bloom end (G stage) was scored in each progeny. The mean harvesting date was also calculated for each progeny. Fruits were considered ripe in the tree when their growth had stopped, they began softening, exhibited yellow or orange ground colour (which is also representative for each cultivar) and were easily detached. Harvesting date ranged from late-May to mid-September, depending on the genotypes.

Yield (kg/tree) was determined for each seedling tree and the total number of fruits was also recorded. From these measurements the total average fruit weight was calculated. For the evaluation of fruit quality parameters a representative sample consisting of 30 fruits per tree was selected. The agronomic characters segregating as simple characters were recorded, i.e. peach or nectarine, yellow or white flesh, round or flat fruit, aborting or non-aborting fruit, and freestone or clingstone. Some other pomological traits such as skin blush, stone adhesion, endocarp staining, or fruit shape (diameters), were scored using the rating scales appropriated for each of them. Skin blush was scored as the percentage of skin surface with red colour. Stone adhesion and endocarp staining (redness around stone) were scored in an increasing arbitrary scale from 1 to 10. We also measured the three dimensions of the whole fruit: height (H), suture diameter (SD) and cheek diameter (CD). From these parameters, sphericity was calculated as H/SD and H/CD. The suture deformation index (SDI) was estimated as SD/CD. The soluble solids content (SSC) of the juice was measured with a temperature compensated refractometer (model ATC-1, Atago Co., Tokyo, Japan); and data are given as ºBrix. The titratable acidity (TA) was determined by titration with NaOH 0.1 N to pH 8.1 (AOAC 1984). Data are given as g malic acid per 100 g fresh weight (FW), since this is the dominant organic acid in peach. Flesh firmness was determined on opposite sides of the equator of each fruit with a penetrometer fitted with an 8-mm diameter probe on five fruits from each tree. The two readings were averaged for each fruit, and data are given in Newtons (N).

Data analysis

All statistical analyses were performed using SPSS 17.0 for Windows (Chicago, IL). To obtain basic statistics for the entire plant material studied, number of observed seedlings, maximum and minimum value, mean, mean standard error and standard deviation for each trait were calculated. Results were analyzed by considering cross and year as fixed factors, and seedling within crosses plus the interaction of seedling with year, as the residual term. Differences between crosses for each trait were analyzed by Duncan's multiple range test ($P \leq 0.05$). When comparing different fruit types (peach or nectarine, round or flat, yellow or white flesh) *t* test ($P \leq 0.05$) was used. Correlation between traits to reveal possible associations was calculated with raw data based on single plant estimates over the three years, using Pearson correlation coefficient at $P \leq 0.05$. Principal components analysis (PCA) was performed with family means to determine the relationships among progenies and to obtain an overview of correlation among fruit quality traits.

Results and discussion

Blooming and harvesting dates

Blooming and harvesting dates for the fifteen breeding progenies averaged over the three years of the study are shown in Fig. 1. Early flowering is a desirable character in Mediterranean areas to obtain earliest yields (George & Nissen 1992, Caruso & Sottile 1999) even though spring frosts may reduce production in some years. Although no significant differences were found among progenies for the beginning of the bloom, higher differences were observed for the full bloom and end of the bloom, due to the existing differences on the length of the blooming period for different progenies. Blooming date is considered as a quantitative trait in peach and other *Prunus* species (Dirlewanger et al. 1999, Vargas & Romero 2001). Thus, the differences for the blooming date observed among the seedlings within any progeny from the fifteen breeding populations studied (data not shown) were somehow expected.

Regarding harvesting time (Fig. 1), significant variations were found in the harvest season among the tested genotypes ranging from late-May to mid-September. The earliest seedlings to be harvested (late-May) belonged to the 'Red Top' x 'VAC-9513' progeny. The latest seedlings were those from the 'Andross' x 'Calante' progeny, which were harvested from mid-August to mid-September. The harvesting time showed a normal distribution within each progeny for all the crosses (data not shown), reflecting a quantitative genetic control. This trait has been established as characteristic of each cultivar, and quantitatively inherited (Dirlewanger et al. 1999, Vargas & Romero 2001). This variability allows selecting the most interesting harvesting date among the genotypes in order to cover market demands (Byrne 2003).

Although blooming and harvesting time may change every year depending on the environmental conditions, especially temperature (Sánchez-Pérez et al. 2007, Mounzer et al. 2008, Ruiz & Egea 2008), the fruit development period (number of days from full bloom to maturity) remained more or less stable for each seedling over the three years of study (data not shown). The peach fruit development period is highly dependent on cultivar (Jackson & Sherman 1980, Muñoz et al. 1986, Cunha et al. 2007, Cheng 2008, Mounzer et al. 2008), however, previous research has shown an influence of spring temperatures on the harvest date of peach cultivars (López & DeJong 2007). Very early-maturing, as well as very late-maturing peach genotypes, are of considerable interest for the peach industry in the Mediterranean area (Caruso & Sottile 1999), and the main difference between these genotypes is the length of their fruit development period (Mounzer et al. 2008). In the present work, the fruit development period ranged from 80 to 130 days for all the progenies, except for 'Andross' x 'Calante' which showed the longest period (approximately 150 days). Consequently, this was the latest progeny to be harvested (Fig. 1). The shortest fruit development period (data not shown), and the earliest harvest season, was found in 'Andross' x 'Crown Princess', 'Red Top' x 'VAC-9513' and 'VAC-9520' x 'VAC-9517' progenies. This interesting trait, among others, was valued in the selection of eleven genotypes from these three progenies.

Cross influence on agronomic and fruit quality traits

Cumulative and annual yield showed a large range of variation among the breeding seedlings (from 0.0 to 137.7 kg for cumulative yield and from 0.0 to 80.8 kg for annual yield). Both of them were significantly different among the fifteen studied progenies (Table 1). 'Andross' x 'VAC-9511' and 'Babygold-9' x 'VAC-9510' showed the significantly highest average cumulative yield (54.4 and 55.6 kg, respectively) and annual yield (18.3 and 18.9 kg, respectively) among the progenies. On the other hand, 'Andross' x 'Calante' showed the lowest cumulative and annual yield (13.5 and 5.8 kg, respectively) without being significantly different from 'Rich Lady' x 'VAC-9511', 'VAC-9512' x 'VAC-9511' and 'Venus' x 'Big Top' progenies. The combination of 'Andross' with 'Crown Princess', 'Rich Lady' and 'VAC-9511' resulted in higher productive progenies whereas yields were dramatically decreased when it was crossed with 'Calante' cultivar. 'O'Henry' performed similarly in terms of yield for any of the three studied crosses, inducing intermediate yields in their seedlings. Significant differences among seedlings within the progenies were also found (data not shown). The observed variability supports the quantitative genetic control of yield previously reported in peach (Dirlewanger et al. 1999, Dirlewanger et al. 2004).

Fruit weight is a major quantitative inherited factor determining yield, fruit quality and consumer acceptability (Dirlewanger et al. 1999). There was more than a 10-fold range (28.9 to 370.3 g) in mean fruit weight among the breeding seedlings, due to the influence of genotype, cultivar and type of fruit (flat and round peach). This agrees with previous reports where high variability in this parameter has been described among peach (Quilot et al. 2004a, Iglesias & Echeverría 2009) and apricot genotypes (Ruiz & Egea 2008). The highest mean fruit weight was found in 'Orion' x 'VAC-9510' progeny (Table 1), in spite of being one of the most productive crosses. 'Babygold-9' seemed to induce large fruits in its offspring, although the two other progenitors, involved in crosses with this cultivar, also showed big fruits in different cross combinations. A tendency of having higher mean fruit weight was found for the latest harvesting crosses, such as 'Orion' x 'VAC-9510', 'Babygold-9' x 'VAC-9510' and 'Andross' x 'Calante' which is in agreement with previous reports for peach and apricot, where a positive correlation between harvesting date and fruit weight has been reported (Dirlewanger et al. 1999, López & DeJong 2007, Ruiz & Egea 2008). Conversely, 'VAC-9520' x 'VAC-9517' showed the lowest fruit weight among the breeding progenies. 'VAC-9517' is a flat peach that segregates in the progeny for the S gene, a dominant gene controlling fruit shape (*S-,* flat or *ss,* round) (Lesley 1940). This low fruit weight average observed in this progeny originated from a flat peach and it agrees with the previous information indicating that reduction of fresh weight and productivity was detected in flat peach seedlings by Lesley (1940). This reduction in fruit weight on flat peach or nectarine can be explained by the proximity of the QTLs for fruit weight and the *S* gene reported by Dirlewanger et al. (1999). Our results are corroborated by the significant difference found when comparing yield and fruit weight between round and flat fruits (Table 2).

The finding of aborting fruits in some flat seedling trees from 'VAC-9520' x 'VAC-9517' progeny is noticeable. From the whole progeny, 52% of the seedlings had non-aborting round fruits, 32% had non-aborting flat fruits, whereas 16% had aborting flat fruits. This aborting fruit character was first reported by Dirlewanger et al. (2006). Aborting fruit trees had flowers, but fruits started to fall 2 months after blooming. Fruits that fell prematurely displayed a crack on the pistilar side, as observed by Dirlewanger et al. (2006). These authors suggested that both characters, *flat fruit* and *aborting fruit*, are controlled by a single gene, and that the protein encoded by this gene modulates fruit development. Therefore, the *s* recessive allele, responsible for the round shape, seems to be a necessary gene for fruit development. However, they did not discard the possibility of two linked genes: the dominant allele of the *S* gene being linked to the recessive allele of the *Af* gene. If *Flat fruit* and *Aborting fruit* were separate loci, some round aborting fruit phenotypes would be expected to occur in our progeny as recombinants between the loci. Thus, our morphological data supports the hypothesis by Dirlewanger et al. (2006) that *S* and *Af* could be at the same locus, with different alleles. However, under their hypothesis, we would have not found aborting fruits, since we do not have homozygous genotypes (SS) for flat locus in our progeny. Therefore, we suggest the introduction of a third null allele (*n*) that has the same effect of the absence of the *s* recessive allele, which is supposed to be necessary for fruit development. The understanding of this trait is crucial since marker assisted selection could be used to identify genotypes which would bear no fruits at maturity. Further investigation is necessary to elucidate the mechanism of this premature fall and its genetic control.

Skin fruit colour has a significant impact on consumer acceptance and sales of peaches and nectarines (Scorza & Sherman 1996, Liverani 2002). The percentage of skin blush on the fruit surface greatly varied among the breeding seedlings (from 8 to 100%) and significant differences were also found among different progenies (Table 1). 'Rich Lady' x 'VAC-9511' and 'VAC-9512' x 'VAC-9511' progenies showed the highest percentage with more than 89% of blush colour on the fruit surface, which positively influences their attractiveness. On the other hand, 'Andross' x 'Calante' showed the lowest percentage with less than 25%, having the least attractive fruit among the crosses, since fruit colour intensity is nowadays positively related to consumer acceptance for fresh market (Iglesias & Echeverría 2009). This unfavorable trait, in combination with low productivity, resulted in no pre-selected genotypes from this progeny.

Significant differences were detected among progenies for soluble solids content (SSC) (Table 1). Even though SSC values ranged from 7.6 to 24.6 ºBrix among the breeding seedlings, most of them had SSC levels greater than 11 ºBrix. The highest value (24.6 ºBrix) was recorded by a seedling derived from the cross between 'Venus' (an acid nectarine) and 'Big Top' (a non-acid nectarine with high SSC). The minimum SSC established by the EU to market peaches and nectarines is 8 ºBrix [Commission Regulation (EC) No. 1861/2004 of 28 October 2004], although SSC below 11 ºBrix are generally unacceptable to consumers (Kader 1994, Hilaire 2003, Crisosto & Crisosto 2005). However, the relationship between SSC and consumer acceptance is cultivar specific, and there is not a single reliable SSC that assures a given percentage of satisfied consumers (Kader 1994, Hilaire 2003, Crisosto & Crisosto 2005). A tendency to show the highest SSC values can be observed in the progenies with the latest harvesting date, such as 'Andross' x 'Calante', 'O'Henry' x 'VAC-9514' and 'O'Henry' x 'VAC-9515' (Table 1), although no significant correlation was found between harvesting time and SSC. A positive correlation between later harvesting date and SSC has been previously reported in peach and apricot (Dirlewanger et al. 1999, Ruiz & Egea 2008). A high variability was also found for the SSC among seedlings within the progenies (Cantín et al. 2006), which can be explained by the quantitative regulation of this quality trait (Dirlewanger et al. 1999, Quilot et al. 2004b). This variability allows selecting the most interesting seedlings in terms of sweetness, as it was the case of some early-selections from 'VAC-9520' x 'VAC-9517' and 'O´Henry' x 'VAC-9514' progenies.

Regarding pH and TA, significant differences were also found among progenies because both are cultivar dependent traits (Table 1). There was a five-hold range in TA (from 0.30 to 1.50 g malic acid per 100 g FW) whereas pH ranged from 2.80 to 5.50. Because of different scales, a small change in pH represented a large change in TA. The mean fruit juice pH of different progenies ranged from 3.32 to 3.63. These values are usual for normal acidity fruit. Even in the progeny derived from a cross between the acid nectarine 'Venus' and the non-acid 'Big Top', the average pH value was common for normal acid fruits. All the mean TA values, except for the 'VAC-9512' x 'VAC-9511' progeny, were lower than 0.9%, which is considered the maximum limit for normal acidity peaches (Hilaire 2003). Due to the strong correlation between TA and the perception of sourness (Crisosto et al. 2006a), fruits from 'VAC-9512' x 'VAC-9511' would be the tartest among all the studied progenies. TA also plays an important role in consumer acceptance for grapes (Nelson et al. 1973), cherries (Crisosto et al. 2003) and kiwifruit (Marsh et al. 2004). However, the perception of acidity in the mouth depends not only on the acid concentration but also on the type of acid (Pangborn 1963) and on the concentration and type of sugars (Bassi & Selli 1990). The high TA, low SSC and consequently low ripening index showed by the 'VAC-9512' x 'VAC-9511' progeny, together with its low yield and fruit weight, resulted in no interesting progeny for the selection of high fruit quality genotypes.

Ripening indexes (RI) ranged from 6.5 to 45.7 among the breeding seedlings, depending on their SSC and TA. The sugar-acid ratio is commonly used as a quality index (Robertson et al. 1989, Bassi & Selli 1990), and higher ratios are usually preferred. Crisosto et al. (1997) reported a closer relationship of RI with eating quality than that of TA or SSC individually, and Harker et al. (2002) reported that RI was the best predictor of apple flavour. The RI also plays an important role in consumer acceptance of some peach, nectarine and plum cultivars (Crisosto et al. 2004, Crisosto & Crisosto 2005, Iglesias & Echeverría 2009). The 'Venus' x 'Big Top' progeny showed the higher RI, being not significantly different from the 'Andross' x 'Calante' progeny (Table 1). As expected, higher RI values were usually found in families with the highest SSC. However, some of the progenies with high SSC had low RI because of their high TA, as shown by the two progenies with 'Rich Lady' as a parent and in 'VAC-9512' x 'VAC-9511'. Nevertheless, optimal sugar and acid contents for peaches and nectarines are not universal criteria and they can change with diverse consumer ethnic groups (Crisosto et al.

2006a). High sugar contents and, to a lower extent, high acid contents seem to be favorable to fruit quality as evaluated by consumers (Crisosto & Crisosto 2005). This equilibrated flavour, combined with other interesting traits, was appreciated in the selection of some genotypes from 'VAC-9520' x 'VAC-9517' and 'Venus' x 'Big Top' progenies. However, in a recent study with nectarines (Iglesias & Echeverría 2009) the consumer acceptance was always greater for non-acid than for acid cultivars, even at early or advanced stages of fruit maturity. Bassi and Selli (1990) also reported that the high acidity explained the unsatisfactory taste of some acid peach cultivars. The phenotypic variation found in our progenies indicates that there is a genetic potential to develop peaches with optimum sugar and acid contents. Due to their organoleptic relevance, these traits were considered in every pre-selected genotype.

Fruit firmness measured on both cheeks of the fruit was highly variable among all the studied seedlings (from 10.5 to 48.6 N). Maximum levels of fruit firmness for marketing fresh peaches and nectarines are set by the EU at 63.7 N with an 8 mm diameter probe [Commission Regulation (EC) No. 1861/2004]. Mean firmness values for all the progenies were in the standard commercial firmness range, and more precisely in the range considered as "ready to buy" (18-35 N) (Crisosto et al. 2001a). These authors segregated peaches and nectarines into different classes by using firmness thresholds indicating critical changes during postharvest ripening and susceptibility to bruising damage. The classification of fresh peaches and nectarines into "ready to eat" and "others" was accomplished by using an 18 N threshold. Fruit between 18 and 35 N was considered "ready to buy", and the 35 N threshold was used to define "mature and immature" fruit. Among the breeding progenies, the highest mean fruit firmness was found in 'Rich Lady' x 'VAC-9511' and 'Venus' x 'Big Top' (31.6 and 31.4 N, respectively) (Table 1), without being significantly different from 'Orion' x 'VAC-9510' and 'VAC-9512' x 'VAC-9511' progenies. It must be noted that the firmest fruit means were found in crosses with nectarines in their progeny, which is corroborated by the significant differences found for firmness between nectarine and peach fruit (Table 2). Such results have already been observed by other authors (Crisosto et al. 2001a, Valero et al. 2007). On the contrary, lower mean fruit firmness was found in 'O'Henry' x 'VAC-9516' although it was not significantly different from 'Andross' x 'Rich Lady', 'Andross' x 'VAC-9511' and 'Red Top' x 'VAC-9513'. Firmness is an important fruit quality trait to consider in a breeding program, since it is directly related to susceptibility to mechanical damage during postharvest (Kunze et al. 1975, Crisosto et al. 2001b). This trait was highlighted for the pre-selection of some genotypes, such as some seedlings from 'Rich Lady' x 'VAC-9511', 'Venus' x 'Big Top' and 'Babygold-9' x 'VAC-9510' progenies.

Significant differences were also found for fruit shape and size among the studied progenies (Table 1). ‘Orion’ x ‘VAC-9510’ showed the largest fruits among the crosses with increased height (H), suture diameter (SD) and cheek diameter (CD), as it was confirmed by its highest mean fruit weight. After ‘Orion’ x ‘VAC-9510’ progeny, the highest fruits were found within ‘Venus’ x ‘Big Top’, ‘Babygold-9’ x ‘VAC-9510’ and ‘O’Henry’ x ‘VAC-9515’ progenies. Global shape of fruit (sphericity) was characterized by calculating H/SD and H/CD (Wert et al. 2007). All the populations showed ratios very close to 1 (except ‘VAC-9520’ x ‘VAC-9517’ progeny, since it has flat fruits among its offspring), which means that fruits were almost spherical. Fruits from ‘Venus’ x ‘Big Top’ and ‘Orion’ x ‘VAC-9510’ progenies were significantly more elongated (H/SD and H/CD greater) than the rest of progenies. Fruit shape is an important fruit quality attribute, since it influences consumer’s acceptance and postharvest handling. In peach and nectarine, round shapes without protruding tips are preferred by consumers (Badenes et al. 2006). In addition, protruding tips and sutures can be bruised during handling and shipping of fruit and are, therefore, undesirable traits for commercial peaches (Kader 2002). Significant differences in suture deformation among crosses were detected by calculating suture deformation indexes (SDI), although values were always close to 1. When the SDI is 1, the shape is considered as globally round. When it is different from 1, the shape is oval, flattened or with protruding sutures. SDI ranged from 1.0 for ‘Rich Lady’ x ‘VAC-9511’ to 0.95 for ‘Andross’ x ‘Crown Princess’ and ‘Venus’ x ‘Big Top’ progenies.

Influence of pomological traits on agronomic and fruit quality traits

Significant differences were found among fruit types for the different agronomic and quality traits evaluated (Table 2). As previously reported, significantly lower fruit weight was observed on flat fruit trees compared to the round fruit ones. As mentioned above, this could be explained by the presence of QTLs for fresh weight and productivity near the gene controlling fruit shape (Lesley 1940, Dirlewanger et al. 1999). On the other hand, nectarine genotypes in our progenies also showed lower yield and fruit weight than peach genotypes, whereas no significant differences were found among yellow and white flesh seedlings.

Nectarines had a higher percentage of skin blush and endocarp staining than peaches, whereas flat fruit showed higher skin blush than round fruit, but lower endocarp staining (Table 2). These differences were probably due to the characteristics of the cultivars involved as progenitors in this breeding program. White flesh fruits showed higher blush percentage than yellow flesh fruits, which agrees with the higher anthocyanin content found in this type of fruits (Cantín et al. 2009b).

Nectarines had significantly higher SSC than peaches (Table 2) as previously observed by other authors (Crisosto et al. 2001a, Wu et al. 2005, Crisosto et al. 2006a, Cantín et al. 2009a). This could be explained by the co-localization of a major QTL for SSC with the morphological marker for peach/nectarine on linkage group 5 (Quilot et al. 2004b). At the same time, flat fruits showed higher SSC than round fruits, which is in agreement with reports where most flat fruit varieties have shown sweeter taste and higher sugar content (Ma et al. 2003). The interest in flat fruit peach cultivars is increasing to a large extent due to their excellent organoleptic characteristics (Nicotra et al. 2002). On the other hand, white flesh fruits showed significantly higher SSC than yellow flesh fruit, in agreement with Robertson et al. (1990) and Cantín et al. (2009a), who reported higher sucrose, glucose, fructose and SSC in white-fleshed than in yellow-fleshed peaches.

Regarding acidity, significantly higher TA (and consequently lower pH) was observed for nectarine compared to peach (Table 2). At the same time, flat fruit showed higher TA than round fruit. However, most flat peach varieties have been reported to have low titratable acidity (Ma et al. 2003). In our work, the higher acidity showed by flat fruit genotypes could be explained by the influence of non-flat progenitors, since this is a continuous trait of quantitative inheritance (Dirlewanger et al. 2006). On the other hand, nectarines showed higher RI than peaches due to their reported higher SSC. Round and yellow flesh fruit showed higher RI than flat and white flesh fruit respectively, due to the higher TA values obtained in the latter.

Firmness was also higher in nectarine than in peach fruits (Table 2), as observed by other authors (Crisosto et al. 2001a, Valero et al. 2007). Additionally, softer fruits were found in white flesh seedlings when compared with yellow flesh ones, which is in agreement with Crisosto et al. (2001a).

Correlation between traits

Table 3 shows the correlations found between the agronomic and fruit quality traits. Most of them appeared significant although no high coefficients were found when all progenies were considered together.

Harvest date was significantly correlated with fruit weight in a way that early harvested seedlings generally had smaller fruits than late ones, as was previously found for different peach and apricot cultivars (Dirlewanger et al. 1999, López & DeJong 2007, Ruiz & Egea 2008). However, correlation coefficients varied depending on the progeny, being higher in specific crosses such as ‘Rich Lady’ x ‘VAC-9511’ ($r = 0.581$, $P \leq 0.01$). On the other hand, it has been reported that medium and late season cultivars have a greater capacity to accumulate sugar compared to early season cultivars due to the non-interruption of the growing process (Engel et al. 1988, Byrne 2002). Although harvest date did not show significant correlation with SSC, a tendency from latest harvesting genotypes, within the same progeny, to have higher SSC was observed, as already mentioned above.

Skin blush was, in general, positively correlated with endocarp staining although coefficients were variable depending on the progeny. Significant correlations ($P \leq 0.01$) were found in 'Andross' x 'Calante' (r = 0.377), 'Babygold-9' x 'Crown Princess' (r = 0.271), 'Red Top' x 'VAC-9513' (r = 0.219) and 'Babygold-9' x 'VAC-9510' (r = 0.184). This correlation is expected since both traits are due to the anthocyanins level in the fruit (Tomás-Barberán et al. 2001). Endocarp staining can be an appreciated trait by specific consumers although a relationship of this trait with postharvest browning has also been reported (Ogundiwin et al. 2009). No relationship between skin colour and firmness was found for any cross which is in agreement with previous work in peach (Génard et al. 1994) and apricot (Ruiz & Egea 2008). In general, fruit weight was positively correlated with annual yield, endocarp staining, pH, RI, firmness and sphericity, and negatively correlated with skin blush and TA. It is worthy to note the significant ($P \leq 0.01$) positive correlation found for annual yield versus fruit weight in some progenies such as 'Red Top' x 'VAC-9513' (r = 0.523), 'VAC-9520' x 'VAC-9517' (r = 0.410), and 'O'Henry' x 'VAC-9514' (r = 0.432), showing that these crosses have a better potential to produce higher yields and larger fruits. However, no significant correlations were found for the highest yielding progenies, such as 'Babygold-9' x 'VAC-9511', 'Andross' x 'Crown Princess' and 'Andross' x 'VAC-9511'. The results suggest that fruit weight increases with annual yield until reaching a value when the tree resources cannot contribute to increasing fruit weight and yield simultaneously. No correlation was found for fruit weight and SSC when all seedlings were considered together. However, a significant positive correlation ($P \leq 0.01$) was observed for some progenies as 'Andross' x 'Rich Lady' (r = 0.508), 'Babygold-9' x 'Crown Princess' (r = 0.481) and 'Red Top' x 'VAC-9513' (r = 0.501) indicating the tendency of larger fruits to have higher sugar contents. This result is expected since amount of translocated carbohydrates contributing to SSC determines fruit growth rate (Mounzer et al. 2008), and at the same time, fruit size increases sink strength to attract sucrose and sorbitol from the plant sources (Lo Bianco & Rieger 2006). Contrary, yield showed a significant negative correlation versus SSC, showing the sink competition among fruits by the assimilate supply (Mounzer et al. 2008). This effect was variable depending on the progeny, and higher coefficients ($P \leq 0.01$) were found in 'Venus' x 'BigTop' (r = -0.460), 'VAC-9520' x 'VAC-9517' (r = -0.560), 'O´Henry' x 'VAC-9514' (r = -0.566) and 'O´Henry' x 'VAC-9515' (r = -0.405) progenies.

As previously reported for peach (Dirlewanger et al. 1999, Wu et al. 2003), a positive significant correlation was observed for SSC versus TA suggesting a dependent genetic control of both traits. The location of QTLs for nearly all the chemical compounds (sucrose, fructose, sorbitol, malic and citric acid) in the linkage groups 5 and 6 (Dirlewanger et al. 1999, Etienne et al. 2002) with possible pleiotropic effect, could partly explain this result. Highest coefficients ($P \leq 0.01$) were found in 'Rich Lady' x 'VAC-9511' (r= 0.812), 'VAC-9520' x 'VAC-9517' (r= 0.722), 'O'Henry' x 'VAC-9514' (r= 0.702) and 'O'Henry' x 'VAC-9515' (r= 0.703) progenies. In general, significant correlation was also found between firmness and other traits such as fruit weight, SSC and TA, which is in agreement with Byrne et al. (1991). A higher correlation between firmness and SSC was found in 'Orion' x 'VAC-9510' (r= 0.634), 'Redtop' x 'VAC-9513' (r= 0.485), 'Andross' x 'Rich Lady' (r= 0.442) and 'O´Henry' x 'VAC-9516' (r= 0.488) progenies, whereas no significant correlation was found in others. A positive relationship between firmness and SSC has also been reported in sweet cherry (Jiménez et al. 2004). This result suggests that, at the same level of ripening, firmer fruits show a tendency to have higher SSC. This correlation is important since selection of high SSC genotypes will aim first at higher firmness, and second at lower susceptibility to mechanical damage during handling and packaging (Crisosto et al. 2001b). The reported genetic correlations are due mainly to pleiotropy, though linkage disequilibrium can be a cause of transient correlation (Falconer & Mackay 1996). The breeding response for one trait depends on genotypic variations of that trait within the breeding population and on genotypic correlations between traits. Thus, phenotypic correlations are important parameters to take into account in breeding programs.

Principal component analysis and grouping of progenies

Principal component analysis (PCA) model was performed to provide an easy visualization of the complete data set in a reduced dimension plot. PCA has been previously used to establish genetic relationships among cultivars and to study correlations among fruit traits within peach (Brovelli et al. 1999, Lavilla et al. 2002, Crisosto et al. 2006a) and apricot genotypes (Badenes et al. 1998, Gurrieri et al. 2001, Ruiz & Egea 2008).

The PCA carried out in this work showed that more than eighty per cent of the observed variance could be explained by the first five components. PC1, PC2 and PC3, respectively, accounted for 34.3%, 26.2% and 10.8% of total variability. Table 4 shows the correlation between the original variables and the first three components: PC1 represents mainly harvest date, fruit weight, percentage of blush, acidity (pH, TA and RI) and esphericity; PC2 explains annual and cumulative yield, sugars (SSC) and firmness; PC3 mainly contributes to annual and cumulative yield, together with PC2, and to endocarp staining.

Component scores for the fifteen studied progenies are shown in Table 4. Positive values for PC1 indicate populations with late harvest date, large fruit sizes, low skin blush and low acidity fruits, in general. Progenies such as ‘Andross’ x ‘Calante’, ‘Andross’ x ‘Crown Princess’, two progenies from ‘Babygold-9’ (‘Babygold-9’ x ‘Crown Princess’ and ‘Babygold-9’ x ‘VAC-9510’) and ‘Venus’ x ‘Big Top’ belong to this group (Fig. 2). The lowest values for PC1 indicate early harvest date progenies with high acidity and small fruit sizes such as ‘Rich Lady’ x ‘VAC-9511’, ‘VAC-9512’ x ‘VAC-9511’ and ‘VAC-9520’ x ‘VAC-9517’. The highest values for PC2 indicate high yield progenies with low firmness, endocarp staining and SSC fruits. Families such as ‘Andross’ x ‘Crown Princess’ and ‘Andross’ x ‘VAC-9511’ belong to this group. On the contrary, families with lowest values for PC2, such as ‘O´Henry’ x ‘VAC-9514’, ‘O´Henry’ x ‘VAC-9515’ and ‘Venus’ x ‘Big Top’, have low yields but high SSC, firmness, blush and endocarp staining fruits.

Conclusions

A high variability has been found in the 1111 peach and nectarine genotypes evaluated for the studied pomological traits related to fruit quality, and significant differences among crosses were observed for all quality attributes, which indicates that there is a genetic potential to develop peaches and nectarines with high quality. The high number of evaluated genotypes, coming from very different genetic origins and with high phenotypic variability, provides valuable information about the peach species, regarding the parameters that influence peach quality. This study shows the existing relationship between different qualitative pomological traits such as peach-nectarine, round-flat shape and yellow-white flesh, and the agronomic and fruit quality attributes. On the other hand, our data support a preliminary hypothesis for the characteristic aborting fruit to be determined by a multi-allelic locus also controlling the flat fruit shape.

The correlations found between some quality attributes such as yield, fruit weight and SSC, SSC vs. TA, and SSC vs. firmness, could be interesting for quality oriented fruit breeding programs. However, the substantial variation in the correlation of coefficients for different cultivars should be taken into account. The study also emphasizes the usefulness of PCA in evaluating the fruit quality of new breeding releases and studying relationships among pomological traits.

Finally, this work enabled the selection of 26 genotypes with the most appropriate combination of agronomic and quality traits within the breeding population. Among the evaluated crosses, ‘Babygold-9’ x ‘Crown Princess’ and ‘Babygold-9’ x ‘VAC-9510’ resulted in the best progenies for selection of new high fruit quality genotypes in the Mediterranean area conditions. ‘O´Henry’ x ‘VAC-9514’, ‘O´Henry’ x ‘VAC-9515’ and ‘Venus’ x ‘BigTop’ crosses showed a good performance regarding fruit quality aspects such as soluble solids content, acidity, fruit weight, firmness and skin blush although productivity should be improved. On the other hand, crosses with ‘Andross’ as progenitor resulted in non-interesting hybrids regarding fruit quality, in spite of having higher yields.

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Tables

Table 1 Agronomic and fruit quality traits for each of the peach and nectarine breeding progenies subjected to assessment. The number of observed seedlings (n) is shown for each progeny

Progeny	n	Cumulative yield (kg)	Annual yield (kg)	Fruit weight (g)	Blush (%)	Endocarp staining[a]	SSC (ºBrix)	pH	TA (g 100 g^{-1} FW)	RI	Firmness (N)	H (mm)	SD (mm)	CD (mm)	H/SD (mm)	H/CD (mm)	SDI (mm)
1 Andross x Calante	118	13.5 h	5.8 g	185.4 cd	24.8 j	1.7 g	12.6 bc	3.63 a	0.55 hi	23.4 ab	27.2 bc	72.3 cde	73.6 cd	77.0 bc	0.98 cde	0.94 cde	0.96 ef
2 Andross x Crown Princess	25	46.3 b	15.4 b	168.8 ef	57.5 fg	2.9 f	10.8 efg	3.59 ab	0.50 i	21.8 bcd	27.1 bc	68.8 f	71.3 de	75.2 c	0.97 cdef	0.92 e	0.95 f
3 Andross x Rich Lady	47	40.6 bc	14.5 b	167.6 ef	65.6 de	3.5 def	10.6 fg	3.53 bcd	0.74 c	14.7 ij	23.8 de	70.7 def	74.2 bc	77.1 bc	0.95 def	0.92 e	0.96 cdef
4 Andross x VAC-9511	25	54.4 a	18.3 a	173.8 de	69.6 d	2.6 fg	11.3 def	3.46 def	0.61 fgh	18.6 fg	23.6 de	70.5 ef	73.8 c	77.0 bc	0.96 cdef	0.92 e	0.96 def
5 Babygold-9 x Crown Princess	102	31.4 d	11.1 cd	187.6 bcd	37.6 i	3.3 ef	10.2 g	3.58 abc	0.52 i	20.0 def	24.0 d	72.5 cde	73.5 cd	75.9 c	0.99 bc	0.96 abcd	0.97 cde
6 Babygold-9 x VAC-9510	130	55.6 a	18.9 a	203.0 b	51.6 h	4.9 bc	11.1 defg	3.63 a	0.59 gh	19.4 ef	28.7 b	75.0 bc	76.2 ab	79.2 ab	0.98 cd	0.95 bcde	0.96 def
7 O´Henry x VAC-9514	159	24.0 efg	9.2 de	187.0 bcd	71.2 cd	6.3 a	14.2 a	3.53 bcd	0.67 cdef	22.2 bc	27.3 bc	70.2 ef	73.7 cd	75.0 c	0.95 def	0.94 cde	0.98 b
8 O´Henry x VAC-9515	75	26.3 def	10.4 d	195.9 bc	70.7 d	6.6 a	13.9 a	3.48 def	0.69 cde	21.0 cde	27.6 bc	73.5 bcd	74.4 bc	76.2 c	0.99 bc	0.97 abc	0.98 bc
9 O´Henry x VAC-9516	99	38.7 c	13.1 bc	154.8 fg	54.8 gh	4.2 cde	11.8 cd	3.48 def	0.63 efg	19.1 efg	21.2 e	64.6 g	68.2 f	69.9 d	0.95 ef	0.92 de	0.98 bcd
10 Orion x VAC-9510	15	41.8 bc	14.1 b	223.7 a	62.2 ef	5.9 ab	11.3 def	3.42 ef	0.73 cd	15.6 hij	29.3 ab	78.9 a	77.6 a	81.0 a	1.02 ab	0.97 ab	0.96 def
11 Red Top x VAC-9513	100	22.8 fg	8.6 def	119.7 i	67.8 de	4.9 bc	10.7 efg	3.46 def	0.63 efg	17.5 gh	22.5 de	62.7 g	64.4 g	67.4 e	0.98 cde	0.93 cde	0.96 ef
12 Rich Lady x VAC-9511	25	19.6 gh	7.7 efg	128.1 hi	90.4 a	3.6 def	11.0 defg	3.32 g	0.82 b	13.7 jk	31.6 a	65.2 g	69.7 ef	69.8 de	0.94 f	0.94 cde	1.00 a
13 VAC-9512 x VAC-9511	40	19.9 fgh	8.8 def	141.0 gh	89.5 a	4.6 cd	11.6 de	3.40 fg	0.96 a	12.3 k	29.3 ab	65.0 g	68.3 f	70.2 d	0.95 def	0.93 de	0.97 bcd
14 VAC-9520 x VAC-9517	76	30.1 de	10.6 d	97.3 j	76.7 c	3.2 ef	12.9 b	3.34 g	0.83 b	16.0 hi	25.1 cd	49.0 h	61.7 h	64.3 f	0.79 g	0.76 f	0.96 def
15 Venus x Big Top	75	18.1 gh	6.6 fg	190.6 bc	83.3 b	4.3 cde	14.6 a	3.50 cde	0.66 def	25.3 a	31.4 a	75.5 b	73.0 cd	76.9 bc	1.03 a	0.98 a	0.95 f

Mean separation within columns by Duncan´s test ($P \leq 0.05$). In each column, values with the same letter are not significantly different. *Abbreviations:* SSC: soluble solids content; TA: titratable acidity; RI: ripening index (SSC/TA); H: height; SD: suture diameter; CD: cheek diameter; SDI: suture deformation index

[a] Endocarp staining was scored in an increasing arbitrary scale from 1 to 10

Table 2 Influence of pomological traits on agronomic and fruit quality characteristics of a peach and nectarine breeding population. The number of observed seedlings (n) is shown for each fruit type

Fruit type	n	Annual yield (kg)	Fruit weight (g)	Blush (%)	Endocarp staining[a]	SSC (ºBrix)	pH	TA (g 100g^{-1} FW)	RI	Firmness (N)
Peach	934	11.8 a	172.5 a	57.4 b	4.2 b	11.6 b	3.54 a	0.61 b	19.6 b	25.6 b
Nectarine	177	6.4 b	156.3 b	75.4 a	4.8 a	15.8 a	3.43 b	0.86 a	20.6 a	30.4 a
Round	1075	11.1 a	172.8 a	59.8 b	7.7 a	12.1 b	3.53 a	0.64 b	19.9 a	26.3 a
Flat	36	8.4 b	84.7 b	69.6 a	5.3 b	14.4 a	3.33 b	0.93 a	16.0 b	27.8 a
Yellow	980	11.0 a	174.3 a	59.5 b	4.3 a	12.1 b	3.54 a	0.64 b	19.9 a	26.6 a
White	131	11.0 a	137.5 b	64.9 a	4.4 a	13.2 a	3.43 b	0.73 a	18.6 b	23.7 b

Mean separation within trait columns by *t* test ($P \leq 0.05$). In each trait column (Peach and Nectarine; Round and Flat; Yellow and White), values with the same letter are not significantly different.

Abbreviations: SSC: soluble solids content; TA: titratable acidity; RI: ripening index (SSC/TA)

[a] Endocarp staining was scored in an increasing arbitrary scale from 1 to 10

Table 3 Correlation coefficients between agronomic and fruit quality traits in fifteen nectarine and peach breeding progenies. Correlation coefficients were calculated based on single plant estimates

Trait	Annual yield	Fruit weight	Skin blush	Endocarp staining	SSC	pH	TA	RI	Firmness	Esfericity	SDI
Harvest date	0.060 *	0.091 **	NS	NS	NS	NS	NS	NS	NS	-0.177 **	NS
Annual yield		0.205 **	NS	NS	-0.349 **	NS	-0.148 **	-0.149 **	NS	NS	NS
Fruit weight			-0.218 **	0.255 **	NS	0.330 **	-0.330 **	0.363 **	0.202 **	0.333 **	NS
Skin blush				0.270 **	0.112 **	-0.313 **	0.299 **	-0.164 **	NS	-0.106 **	0.105 **
Endocarp staining					0.260 **	NS	0.127 **	NS	0.255 **	NS	0.168 **
SSC						NS	0.393 **	0.363 **	0.294 **	-0.153 **	0.117 **
pH							-0.436 **	0.444 **	NS	0.127 **	NS
TA								-0.656 **	-0.258 **	-0.293 **	0.176 **
RI									NS	0.180 **	-0.105 **
Firmness										NS	NS
Sphericity											-0.169 **

*, ** Correlations significant at $P \leq 0.05$ and $P \leq 0.01$, respectively; - non significant. *Abbreviations:* SSC: soluble solids content; TA: titratable acidity; RI: ripening index (SSC/TA); SDI: suture deformation index

Table 4 Component loadings for quality variables and component scores for fifteen peach and nectarine breeding progenies

Variable/factor	Component loadings			Progeny	Component scores		
	PC1, λ=34.30 %	PC2, λ=26.20 %	PC3, λ=10.79 %		PC1	PC2	PC3
Harvest date	0.67	-0.59	0.00	Andross x Calante	1.54	-0.34	-2.22
Annual yield	0.17	0.76	0.53	Andross x Crown Princess	0.91	1.43	-0.28
Cumulative yield	0.06	0.71	0.58	Andross x Rich Lady	-0.35	0.11	-0.35
Fruit weight	0.79	-0.22	0.41	Andross x VAC-9511	0.12	1.46	0.84
% Blush	-0.62	-0.46	0.27	Babygold-9 x Crown Princess	1.10	0.71	-0.40
Endocarp staining	-0.17	-0.49	0.56	Babygold-9 x VAC-9510	0.85	0.61	1.74
SSC	0.25	-0.78	0.03	O´Henry x VAC-9514	0.29	-1.28	0.92
pH	0.93	0.12	-0.01	O´Henry x VAC-9515	0.32	-1.37	1.09
TA	-0.81	-0.44	0.17	O´Henry x VAC-9516	0.09	0.83	0.49
RI	0.86	-0.18	-0.04	Orion x VAC-9510	-0.61	-0.50	1.25
Sphericity	0.72	-0.29	0.17	Red Top x VAC-9513	-0.32	0.46	-0.83
SDI	-0.32	-0.37	0.41	Rich Lady x VAC-9511	-1.95	-0.68	-0.37
Firmness	-0.02	-0.64	0.04	VAC-9512 x VAC-9511	-1.12	0.05	-0.40
				VAC-9520 x VAC-9517	-1.79	0.58	-0.90
				Venus x Big Top	0.90	-2.08	-0.59

Abbreviations: PC: principal component; SSC: soluble solids content; TA: titratable acidity; RI: ripening index (SSC/TA); SDI: suture deformation index

Figures

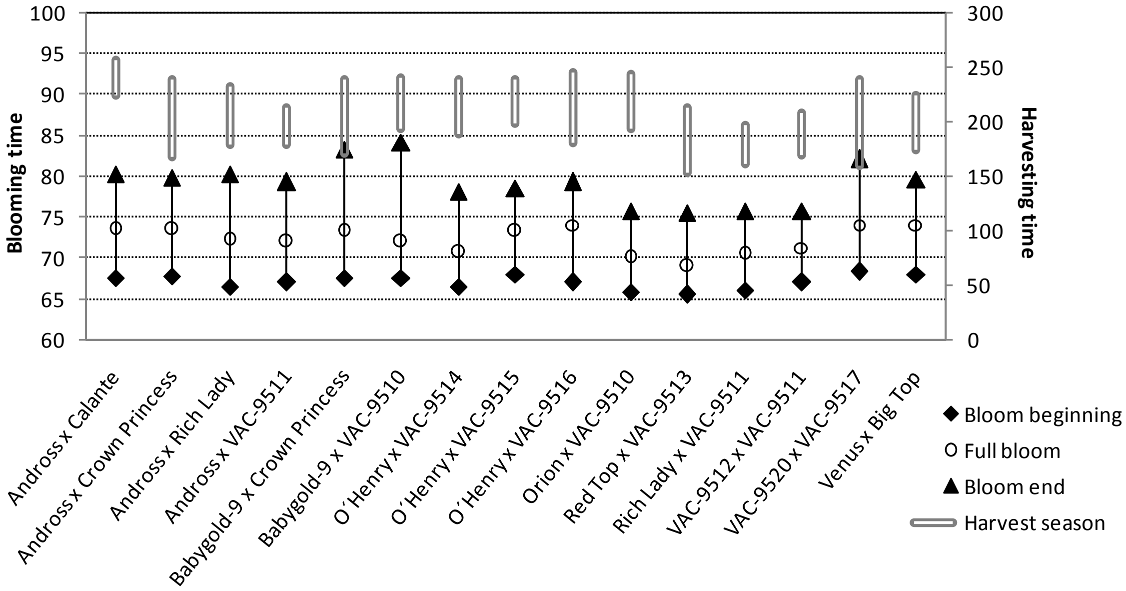

Fig. 1 Blooming and harvesting time (in Julian days) for the fifteen peach and nectarine breeding progenies. Bloom beginning (E stage), full bloom (F stage) and bloom end (G stage) dates, determined according to Fleckinger (1945). Data are means of three consecutive years for each peach and nectarine breeding progeny

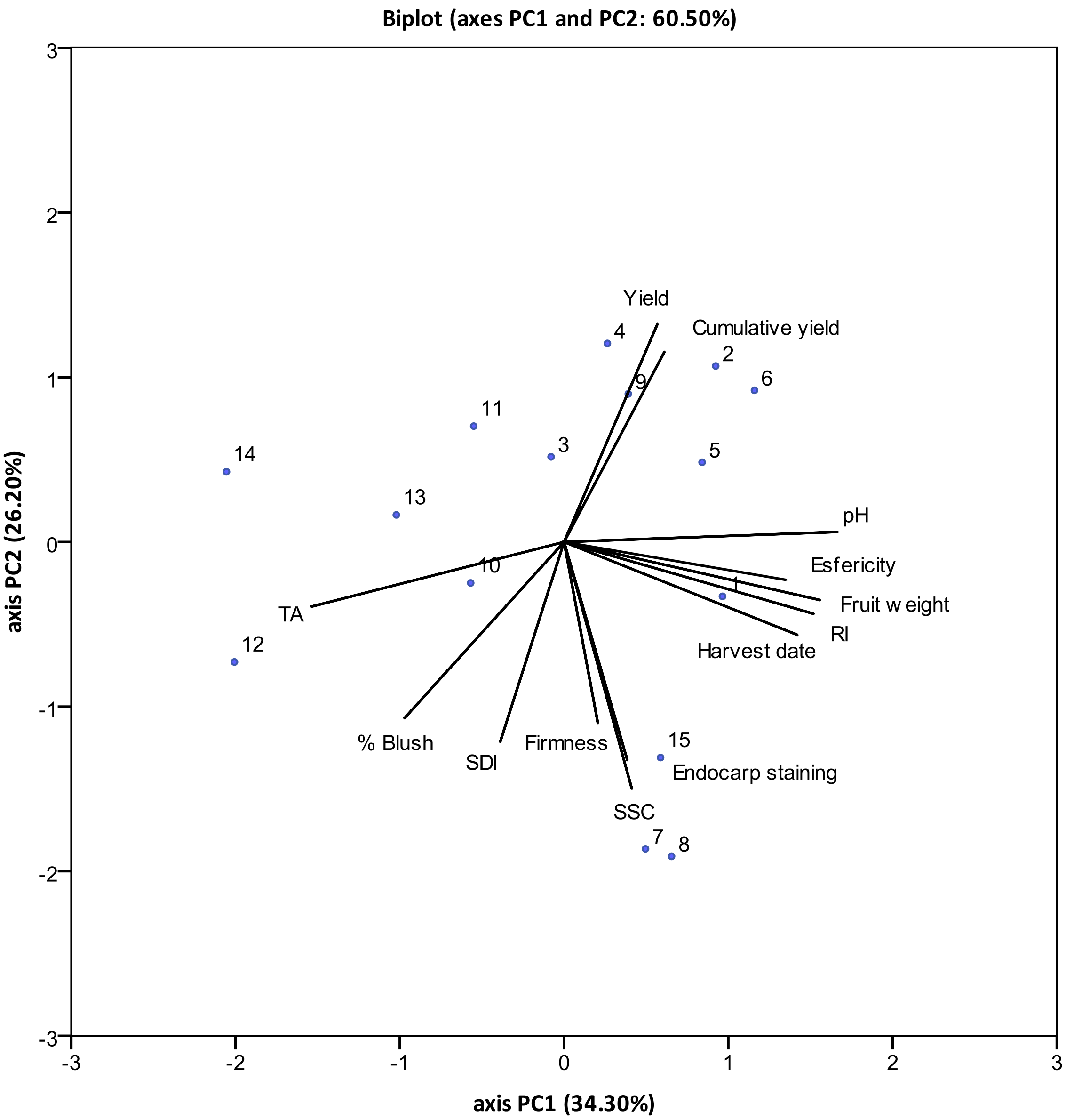

Fig. 2 Segregation of the fifteen peach and nectarine breeding progenies according to their agronomic and fruit quality characteristics determined by principal component analysis (PCA). Vectors represent the loadings of agronomic and quality traits data along with the principal component scores. Numbers represent peach and nectarine progenies (numbers shown in Tables 2 and 3): 1, 'Andross' x 'Calante'; 2, 'Andross' x 'Crown Princess'; 3, 'Andross' x 'Rich Lady'; 4, 'Andross' x 'VAC-9511'; 5, 'Babygold-9' x 'Crown Princess'; 6, 'Babygold-9' x 'VAC-9510'; 7, 'O´Henry' x 'VAC-9514'; 8, 'O´Henry' x 'VAC-9515'; 9, 'O´Henry' x 'VAC-9516'; 10, 'Orion' x 'VAC-9510'; 11, 'Red Top' x 'VAC-9513'; 12, 'Rich Lady' x 'VAC-9511'; 13, 'VAC-9512' x 'VAC-9511'; 14, 'VAC-9520' x 'VAC-9517'; 15, 'Venus x Big Top'. *Abbreviations*: PC: principal component; RI: ripening index (SSC/TA); SDI: suture deformation index; SSC: soluble solids content; TA: titratable acidity