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Adaptability of peach cultivars [*Prunus persica* (L.) Batsch] to the climatic conditions of the Ebro Valley, with special focus on fruit quality

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ABSTRACT

Adaptability of 89 peach cultivars of distinct origin to climatic conditions of the Ebro Valley at the IRTA-Experimental Station of Lleida (Lleida, northern Spain) over three consecutive years (2009–2011) was studied. For this purpose, several agronomic, morphological and internal quality traits of the fruits were evaluated. Agronomic traits included bloom and harvest dates, yield, and yield efficiency, while morphological traits encompassed fruit shape and size, percentage of red skin, and an appearance quality index. The latter was established to facilitate the assessment of each cultivar on the basis of fruit appearance. Internal quality parameters included flesh firmness, soluble solids content, titratable acidity, sensory attributes, and relative antioxidant capacity. Under the climatic conditions of the Ebro Valley, extensive variability was observed for most quantitative and qualitative (breeding program, fruit type and flesh color) traits. In terms of agronomic performance and fruit quality (fruit appearance included), we considered that a well-adapted cultivar for a given area should achieve the following characteristics: high yield efficiency, high appearance index quality, high relative antioxidant capacity, strong flavor, and medium to high ripening index. However, according to the different breeding programs, fruit types, and flesh colors evaluated in this study, none of them simultaneously showed these characteristics. However, some achieved a number of the desired traits. A principal component analysis for melting peach, nectarine, non-melting peach and flat peach cultivars revealed the best ones for each fruit type. The results showed that cultivars do not combine all the desired traits. Nevertheless, these findings are valuable for breeding strategies aiming to achieve cultivars with better adaptation to the climatic conditions of the Ebro Valley.

1. Introduction

In the last two decades, many new cultivars from breeding programs worldwide have been introduced into the Spanish peach production system. The use of such cultivars has allowed a longer harvest season (from mid-April to the end of October), improved agronomic performance, and enhanced fruit appearance and quality (Iglesias and Echeverría, 2009; Reig et al., 2012, 2013b). The adoption of the new cultivars, together with the consistent improvement in irrigation, fertilization, crop protection, postharvest technology, and certification and traceability techniques, has allowed Spanish growers to increase in competitiveness, in particular with respect to export markets. Indeed, Spain is the third largest peach producer worldwide, surpassed only by China and Italy, the second largest producer in the European Union, and the leader of exports in Europe (FAOSTAT, 2014). The main peach-producing area in Spain lies in the Ebro Valley – which includes regions of Catalonia and Aragon – and accounts for 63% of the total production of this crop in this country (Iglesias et al., 2012).

Peach breeding programs aim to improve agronomic performance, external fruit quality (size and appearance), postharvest life, and organoleptic and nutritional traits (Font i Forcada et al., 2014a; Kader, 2002; Monet and Bassi, 2008). However, in recent decades, the adaptability (good agronomic performance, fruit appearance and internal fruit quality) of newly released peach cultivars to different climatic conditions from their country of origin has not been a selection criterion considered by the main breeding programs.

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Significant efforts have been made to test the performance of the new released worldwide peach cultivars in the main peach-producing areas of Europe (Berra et al., 2011; Hilaire, 2003; Hilarie and Giauque, 2003; Iglesias et al., 2012). The knowledge gathered from such research is essential for commercial peach production, as well as for future breeding programs. Indeed, it is vital to characterize the properties of peaches and to quantitatively assess variability among cultivars in order to achieve improved discrimination, enhanced processing efficiency for the peach industry, and assured high quality. However, the collection of precise information about the agronomic performance, appearance, and internal quality traits of fruit is a time-consuming process. Few authors studied some of these traits in several commercial and traditional peach cultivars (Cevallos-Casals et al., 2006; Chalak et al., 2006; Font i Forcada et al., 2014a; Legua et al., 2011; Reig et al., 2013a,b) and in *Prunus persica* breeding progenies (Abidi et al., 2011; Cantín et al., 2009a,b, 2010). However, no study has simultaneously addressed the variations in the three main characteristics of peach cultivars (agronomic performance, fruit appearance and internal fruit quality) when grown under different climatic conditions to those of their country of origin. Nor has a multidimensional dataset been used to establish a phenotypic relationship among cultivars or variables.

In particular, there is a knowledge gap concerning the nature of the relationships between agronomic, morphological, and internal fruit quality traits for peach cultivars. The differences and similarities of these traits depend on the breeding program from which the cultivars derive and the influence of growing conditions. Plant growth and architecture, yield, blooming and harvest time, fruit shape, flesh texture, and flesh color and acidity levels are genetically controlled in breeding programs (Dirlewanger et al., 1999; Infante et al., 2008; Lester et al., 1996; Martínez-García et al., 2013). However, attributes like fruit size, mass, sugar content, and phytochemical content are significantly affected by the growth environment, seasonal factors, and rootstocks (Cantín et al., 2009a; Font i Forcada et al., 2014b; Génard et al., 1994; Schnabel and Crisosto, 2008). To enable comparisons of traits, here we evaluated various peach cultivars grown in the same season and the same region in northern Spain.

The aims of this work were: (1) study the adaptability of various peach cultivars by characterizing them on the basis of agronomic performance, fruit appearance, and internal fruit quality traits; (2) examine the effect of origin and pomological characteristics on these traits; (3) apply multivariate analysis to identify the cultivars best adapted to the climatic conditions of the Ebro Valley.

2. Materials and methods

2.1. Plant material

Eighty-nine peach cultivars representing a wide range of breeding programs were grown at the IRTA-Experimental Station (Lleida, northern Spain) and subjected to evaluation in the seasons of 2009–2011 (Table 1). In order to simplify identification, the flat peach and flat nectarine cultivars will henceforth be referred to as flat peach cultivars.

The four year old trees were grafted onto INRA®GF-677 rootstocks, spaced 4.5 m × 2.5 m and trained to central axis system (893 trees ha^{-1}). With this training system the full yield is achieved for most of the cultivars at the fourth year. Each cultivar was replicated on three trees. The rows were oriented from NE to SW. The trees were trickle-irrigated using drip irrigation, with two drips per tree, delivering 4 l of water per hour. Standard commercial management practices recommended for the area were followed; these included fertilization and the control of pests and plant diseases following the guidelines established for integrated fruit production. The weather conditions for the period 2009–2011 were usual for this continental Mediterranean area: with daily maximum summer temperatures of >30 °C and accumulated annual rainfall of around 370 mm. Hand thinning was carried out in early May in each growing season using similar criteria for all the cultivars in order to obtain similar crop loads.

The traits of interest were measured and scored for each cultivar separately over the 3-year period and means of the three years were calculated. The mean value and standard error of each trait for each cultivar are shown in Electronic Supplementary Material (ESM 1–ESM 3).

2.2. Agronomic performance

At the end of each season (November), the trunk girth of each tree was measured 20 cm above the graft union. The trunk cross-sectional area (TCSA) (cm^2) was then calculated. Full bloom date (FB) (in Julian days) was recorded following Baggiolini (1952). The harvest date of each cultivar was determined on the basis of flesh firmness, which ranged from 39 N to 49 N. In this study, the harvest season spanned from June to September, covering market demands. Therefore, peach cultivars were classified in three harvest seasons (Table 1): early, mid and late. Fruits from each tree were harvested in a single pick, weighed, and then graded using an electronic grading calibration manager (SAMMO s.r.l., Model S2010, Cesena, Italy) to obtain yield (Y) (kg $tree^{-1}$). Afterwards, yield efficiency (kg cm^{-2}) was calculated on the basis of the TCSA obtained for each cultivar and season.

2.3. Fruit appearance

Six representative fruits (2 fruits × tree) per cultivar were evaluated and scored according to UPOV (2010) descriptors for *Prunus persica* L. with slight modifications.

Peach dimensions, such as cheek diameter (*D*), height (*H*), and suture diameter (W), were measured using a digital caliper (Mitutoyo's digimatic calliper, Japan) with an accuracy of 0.1 mm. Fruit shape or sphericity was then calculated as H/D and H/W (Cantín et al., 2010; Wert et al., 2007). This trait was not evaluated in flat peaches due to their particular shape. When the ratios were 1, the shape was considered round. Red skin (SC) was visually scored as a percentage of red surface. This trait was not, however, evaluated in non-melting peaches. Symmetry (SY) was calculated as the difference in *H* between the two cheeks. Stones were characterized by measuring the two principal dimensions of each stone, namely length (SL) and width (SW).

Five qualitative traits were recorded. The shape of the pistil end or fruit tip (SPE) was represented by four categories: 1 = pointed, 2 = slightly pointed, 3 = flat, and 4 = depressed. Prominence of suture (POS): 1 = not visible, 2 = weak, 3 = medium, and 4 = strong. Presence of lenticels (POL): 1 = not visible, 2 = slightly visible, 3 = visible, and 4 = highly visible. Stone adherence: 1 = freestone within the space between the mesocarp and endocarp (FEW), 2 = freestone with no space between the mesocarp and endocarp (FEO), 3 = semi-clingstone (SCL), and 4 = clingstone (CL). Flesh color: 1 = yellow (YL), 2 = yellow-red (YR), 3 = white (WH), and 4 = white-red (WR). SPE was not evaluated in flat peaches, and POS was evaluated only in nectarines.

Appearance is the trait that most attracts consumers when purchasing fruit. Markets, and therefore fruit growers, need to achieve cultivars with optimum performance in terms of fruit appearance: round shapes without protruding tips and/or sutures, and without or with only slightly visible lenticels on the skin surface (Badenes et al., 2006; Byrne et al., 2012; Topp et al., 2008; Wert et al., 2007). Therefore, here we developed a new quality index named