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Performance profiling of *Prunus persica* (L.) Batsch collection and comprehensive association among fruit quality, agronomic and phenological traits

Evangelina Maulión[a,1], Luis Enrique Arroyo[b], María Elena Daorden[b], Gabriel Hugo Valentini[b,*,1], Gerardo Domingo Lucio Cervigni[a,*]

[a] Centro de Estudios Fotosintéticos y Bioquímicos (CEFOBI), Universidad Nacional de Rosario—CONICET, Suipacha 531, 2000 Rosario, Argentina
[b] Estación Experimental Agropecuaria INTA San Pedro, Ruta 9, km 170, 2930 San Pedro, Argentina

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ABSTRACT

Nowadays, although there are several studies based on peach phenotypic diversity and adaptability, there is no current research regarding associations among characters using multivariate statistical methods which provide more trustable conclusions than bivariate analysis. For this reason, we evaluated not only the adaptability of the accessions but also the relationships among qualitative and quantitative traits applying Multiple Correspondence Analysis and Factor Analysis, respectively. The study was carried out on seventy-seven nectarine and one hundred and thirty-two peach accessions grown in Argentina that were characterized with 35 fruit quality, agronomic and phenological traits during 3 seasons. Multiple Correspondence Analysis revealed that freestone trait would be associated with strong anthocyanin coloration of the flesh around the brown dark stone while semi-freestone trait would be related to weak or no anthocyanin coloration of the flesh around the light brown stone. Then, Factor Analysis enabled us to identify positive relationships between blooming and sprouting date; harvesting period and yield and among fruit development period, harvesting date, fruit weight and soluble solid content. In addition, 'phenology traits', 'productivity' and 'fruit quality and reaping time' would be unrelated to each other. Furthermore, the agglomerative hierarchical cluster analysis grouped the accessions in accordance to their similarities and allowed the identification of the most adapted cultivars. We have demonstrated that this approach is a powerful tool that should be considered for further studies on peach germplasm and it has also the possibility to be applied for other fruit species. Finally, the results of this study provide valuable information for germplasm characterization and for breeding practices aiming to develop accessions adapted to the climatic conditions of the northern of Buenos Aires province.

1. Introduction

Prunus persica (L.) Batsch is one of the most important fruit tree species of the Rosacea family with a worldwide production of nearly 22 million tons of fruits per year. Argentina is the second producer in South America and the ninth in the world with a yearly production of more than 291 thousand tons (FAOSTAT, http://faostat3.fao.org/). Although this specie has been cultivated for proximately 3000 years, it was only during the last 10 decades that breeders began to develop new cultivars according to regional preferences and local adaptability. Breeding programs are led by United States and followed by France and Italy, with a smaller percentage in South Africa, Australia and China (Byrne, 2002; Engel et al., 1988). Most of the cultivars currently planted in Argentina have their origins in private programs such as those of Zaiger Genetics Inc., and N. & L. Bradford (California, USA); Armstrong and Agri Sun Nurseries; Virginia, New Jersey and Louisiana Agricultural Experiment Stations; universities (California, Florida and Texas A&M) and US Department of Agriculture (USDA) in the United States; and Istituto Sperimentale per la Frutticoltura (ISF—Rome) and University of Florence in Italy. Although Argentina's traditional dependence on foreign peach cultivars, the Estación Experimental Agropecuaria INTA San Pedro, started its own programs in 1962. As a result, 'Nectarrojo INTA' nectarine (Torroba and Frangi, 1979) and 'Don Carlos INTA' peach (Valentini and Arroyo, 2007) have been released.

* Corresponding authors at: Suipacha 531, 2000 Rosario, Santa Fe, Argentina.
E-mail addresses: valentini.gabriel@inta.gob.ar (G.H. Valentini), cervigni@cefobi-conicet.gov.ar (G.D.L. Cervigni).
[1] These authors contributed equally to this work.

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Table 1
Origin and pedigree of the accessions evaluated.

Accession	Origin	Pedigree
81.315.009	ITA	Calred op
84.350.001	ITA	María Aurelia x Honey Gold
84.351.029	ITA	Honey Gold x María Aurelia
84.364.060	ITA	Unk
84.364.089	ITA	Unk
86.395.095	ITA	Maria Aurelia x Snow Queen
87.404.243	ITA	Unk
88.412.001	ITA	Unk
89.424.003	ITA	82.320.178 sp
89.424.007	ITA	82.320.178 sp
89.429.003	ITA	82.317.001 sp
89.429.004	ITA	82.317.001 sp
89.431.003	ITA	María Ángela sp
89.435.011	ITA	Unk
111 LB 33	USA	Unk
12 ED 36	USA	Unk
15 GB 23	USA	Unk
150 GD 111	USA	Unk
19 RA 147	USA	Unk
27 GA 575	USA	Unk
30 RA 330	USA	Unk
30 RA 365	USA	Unk
37 G 868	USA	Unk
5 LA 4	USA	Unk
5 RA 135	USA	Unk
55 RA 15	USA	Unk
60 EF 32	USA	Unk
61 RA 208	USA	Unk
Accession	Origin	Pedigree
63 EC 404	USA	Unk
65 EC 72	USA	Unk
72 EC 380	USA	Unk
74 LA 183	USA	Unk
85 GD 20	USA	Unk
95 ED 1	USA	Unk
Angelus	USA	J.H. Hale Op (perhaps x Fortyniner)
Aniversario INTA	ARG	Pelón Tardío x Red June
Appia	ITA	(Southland x Pesco Noce #1) op
August Red	USA	(Red Diamond x Autumn Free)F2
Autumn Prince	USA	O'Henry x BY79P670
Babygold 5	USA	PI35201 x NJ196 [=NJ76925 op (=J.H. Hale x Goldfinch)]
BEA	FRA	Unk
Caldessi 2000	ITA	Stark Redgold x Snow Queen
Caldessi 2010	ITA	Stark Redgold x Snow Queen
Caldessi 2020	ITA	Stark Redgold x Snow Queen
Caldessi 84	ITA	Stark Redgold op
Calred	USA	B4-59 sp (=Fireglobe x 3-4M) 3-4M = 18-9C(=Río Oso Gem x Sunbeam) x Summercrest
Capitán	ARG	Unk
Carolina	USA	Unk
Carolina INTA	ARG	Fairtime x Fantasía
Carolina Red	USA	Nectared 4 sp
Chato Gigante	ARG	Unk
Cotogna del Berti	ITA	Unk
Cotogna del Poggio	ITA	Unk
Cotogna di Rosano	ITA	Unk
Derby	USA	NC7130 (=Haleheaven x Redskin) x Candor
Diamond Princess	USA	Red Diamond x peach sel
Dixiland	USA	FV5-56 (Halehaven sp.) x Dixigem
Don Agustín	ARG-USA	(Sunnyside x Flordawon) x Earlygrande
Don Carlos INTA	ARG	Jerseyqueen x Maravilha
Duchessa D' Este	ITA	(Mayflower x Amsden) op
Dur 94 col chica	ARG	Unk
Dur 95 col chica	ARG	Unk
Dur Amarillo	ARG	Unk
Early Blaze	USA	Unk
Early Diamond	USA	Nect sek x Aurelio Grand
Early Giant	USA	Unk
Early July II	USA	Unk
Early Treat	USA	12ED34 x Sweet Gem (USPP 4064)
Elegant Lady	USA	Early O' Henry x July Lady
Encore	USA	NJ585414 (=NJ32443 op) x Autumnglo; NJ32443 x = x Krasvynos x White Hale
F7 PL 10/12	USA	Unk
F7 PL 52/55	USA	Unk
F8 PL 49	USA	Unk
F8 PL 40-41	USA	Unk
F8 PL 98	USA	Unk

Table 1 (*Continued*)

Accession	Origin	Pedigree
Fairlane	USA	C69-42 op (=Rodeo x Kirkman Gem)
Fantasía	USA	Gold King x P101-24 (Red King op.)
Federica	USA	NJC11 x (NJ13232 x Cherryred), NJ13232 = NJ58127 op (=J.H. Hale x Bolivian Cling)
Firebrite	USA	Flavortop x F66-90 [P100-19 op (Red King op)]
Fireprince	USA	FV6-1130 x FV324-25; FV6-1130 = B7-297 (=Hal Berta Giant x Fireglow) x Redglobe; FV324-25 = FV131-48 op (=Sunhigh x Southland)
Fla 87-4	USA	Unk
Fla 1-8	USA	Unk
Fla 81-17 N	USA	Unk
Accession	Origin	Pedigree
Fla 84-16 N	USA	Unk
Fla 85-6 N	USA	Unk
Fla 9-12 N	USA	Unk
Fla 9-8 N	USA	Unk
Flamecrest	USA	Fayette x P109-96 (=C54-37 x B26-16); C54-37=Southland x FV89-14 (=FV15-48 x Fireglow); B26-16= J.H. Hale x Rio Oso Gem; FV15-48= Rireglow x Hiley
Flameprince	USA	BY68-3877 op (=Summerset x BY4-7364); BY4-7364 = FV6-329 x Merril Fiesta; FV6-329 = V370224 [(=J.H. Hale x Valiant) op] x Redglobe
Flavorcrest	USA	P53-68 (=P110-47 x P109-89) x FV89-14 (=FV15-48 x Fireglow); P100-47 = Kirkman Gem x Dripstone; P109-89 = Kirkman Gem x B27-3 (=J.H. Hale x Rio Oso Gem); FV15-48 = Fireglow x Hiley
Flavortop	USA	Fairtime op
Flordagem	USA	Unk
Flordaglo	USA	Sundowner x Maravilha
Flordaglobe	USA	Redglobe x EarliGrande
Flordaking	USA	Fla 9-67 (=Fla 16-61 x June Gold) x Early Amber; Fla 16-61 = Fla 8B-27 op (=Okinawa x Panamint)
Flordastar	USA	Flordagold x EarliGrande
Forastero	ARG-USA	FV7-873 (=FV131-48 x Coronet) x June Gold; FV131-48 = Sunhigh x Southland
Fred	MEX	Unk
Freedom	USA	Unk
GaLa	USA	Harvester op
Ginart	ARG	Clon de Glohaven; Glohaven = SH20 (=J.H.Hale op) x Kalhaven
Goldprince	USA	Loring x FV3-257 (=FV317-97 x FV9-46); FV317-97= Fairhaven x FV 89-14; FV9-46 = FV89-14 x Duke of Georgia; FV89-14 = FV 15-48 (=Fireglow x Hiley) x Fireglow
Guglielmina	ITA	Unk
Hermosillo	USA	Fla 3-4N (=Fla 15-85W x Columbina) x FLA 5-5 (=Fla 10-48 x Springbrite); Fla 15-85W= Fla Q303-36N x Kaygold; Fla 10-48 = Fla 16-61 x Fla 35-30 (=Fla 3-56 x Earligold); Fla Q303-3N = NJ5107397 x (Paramint x Jewel); Fla 16-61 = Fla 8B-27 op (=Okinawa x Panamint); Fla3-56 = Fla R9T10 x Okinawa; NJ5107397 = [(Candoka x Flaming Gold) x (Garden State x NJ25032) op]; Fla R9T10 = FV244-4 op (=Southland x Hawaiian); NJ25032 = Tenesse Natural op
Iris Rosso	ITA	Unk
July Lady	USA	J.H. Hale x Merril Gem F2
June Crest	USA	Fayette x Mexican Sdlg.
June Glo	USA	Zee Gold x Early Sun Grand
June Gold	CAN	Flamingo x Springtime
June Lady	USA	Fortyniner x Gemfree
June Princess	USA	Unk
June Red	USA	Unk
Kurakata Wase	USA	Unk
L 316	USA	Unk
Lara	ARG-USA	(Fla. 15-85W x Columbia); Fla 15-85 W = Fla Q303-3N x Kaygold; Q303-3N = NJ5107397 x (Panamint x Jewel); NJ5107397 = [(Candoka x Flaming Gold) x (Garden State x NJ25032) op.]; NJ25032 = Tenessee Natural op
Late Dwarf	USA	Unk
Legacy	USA	Unk
Louisiana Peacher	USA	Unk
Louisiana White	USA	L69-66-50 op (=Nectar op.)
LSCr	MEX	Unk
María Angela	ITA	María Delizia x María Bianca
María Anna	ITA	Maria Aurelia x Snow Queen
María Aurelia	ITA	Stark Redgold sp
María Bianca	ITA	Honey Dew Hale x Michelini
María Camila	ITA	Unk
María Carla	ITA	Flavortrop sp
María Cristina	ITA	Honew Dew Hale x Michelini
María Delizia	ITA	Cesarini sp
María Dolce	ITA	Honey Gold x Red Diamond
María Dorata	ITA	Tastyfyee x Maria Serena
María Elisa	ITA	Spring Red sp
María Emilia	ITA	May Grand sp
Maria Grazia	ITA	DOFI 10.V.23 sp
Accession	Origin	Pedigree
María Laura	ITA	Flavortop sp
María Lucía	ITA	María Aurelia x Snow Queen
María Luisa	ITA	Panamint x Fertilia I Morettini
María Marta	ITA	Glohaven sp
María Regina	ITA	Regina di Londa sp
María Rosa	ITA	DOFI 10.V.23 (Morettini 146 x Morettini 1) sp
María Serena	ITA	Babygold 6 sp
May Diamond	USA	Red Diamond op

Table 1 (*Continued*)

Accession	Origin	Pedigree
May Glo	USA	(Fayette x May Grand)F2
Maycrest	USA	Springcrest mutation
Mayred	CAN	Babcook, July Elberta, Swatown, Boston, Goldmine hybrid
Merril Carnival	USA	Rodeo x (July Elberta x Maxine) F2
Merril Gem Free	USA	Unk
Merrill Franciscan	USA	Unk
Michelini	ITA	Unk
Mid Gold	USA	Unk
Milenio INTA	ARG	Rome Star op
Nect 95 col chica	ARG	Unk
Nect Blan	ARG	Unk
Nectarrojo INTA	ARG	Q202-8 op
OH́enry	USA	Merrill Bonanza op
Olympio	FRA	Unk
Pulpa Blanca	ARG	Unk
Queen Giant	USA	Unk
Red Glo	USA	37G870 x (Sun Red x June Glo)
Red Globe	USA	W3-16 (=Admiral Dewey x St. John) x Fireglow
Red Grand	USA	Le Grand x (Kim x Le Grand)
Redcrest	USA	Tennese natural op
Rich Lady	USA	Amparo op
Accession	Origin	Pedigree
Romea	ITA	Catherina op
Rosa del West	ITA	Unk
Roseprincess	USA	BY76N138 op [=F100-62 op (=Red King op)]
Royal Glo	USA	(Dwarf nect x Ruby Gold)op x May Glo
Royal Glory	USA	May Grand op
Ruby May	USA	Springcrest mutation
Rubyprince	USA	Fireprince x (Redgold x Durbin)
San Pedro	ARG-USA	Flordasun x Springtime
SB 40-30 Pie 58	FRA	Unk
Scarletpearl	USA	(Bicoe x Redgold) op
SH 7 D	USA	Unk
SH 1 D	USA	Unk
SH 11 N	USA	Unk
SH 4 D	USA	Unk
SH 5 D	USA	Unk
Sirio	ITA	Unk
Snow Queen	CAN	Unk
Southern Pearl	USA	Roseprincess op
Spring Red	USA	Summer Grand op
Springcrest	USA	FV89-14 (=FV 15-48 x Fireglow) x Springtime; FV 15–48 x = x Fireglow x Hiley
Stark Red Gold	USA	Unk
Starlite	USA	FV89-14 (=FV15-48 x Fireglow) x Springtime; FV15-48 = Fireglow x Hiley
Sugar Lady	USA	(O'Henry x Giant Babckok) x May Grand op.
Summer Lady	USA	O'Henry mutant
Summer Pearl	USA	NJ554039 (=NJ67239 x NJ5107397) x NJ585399 (=NJ32443 op); NJ67239= Candoka x (=Tennessee Natural op), NJ5107397= NJ53739 (=Candoka x Flaming Gold) x NJN17 (=NJN5 op); NJ32443 (=PI119844 x White Hale)
Summer Sweet	USA	[sel x (O'Henry x Giant Babckok)]F2 x [(RedWing x nect)F2]
Summerprince	USA	BY68-3877 op (=Summerset x BY4-7364); BY4-7364= FV6-329 x Merril Fiesta; FV6-329= V370224 [(=J.H. Hale x Valiant) op] x Redglobe
Summerset	USA	June Lady op
Suncrest	USA	Alamar x Gold Dust
Sundollar SH 17 N	USA	Sunlite x Armqueen
Sunprince	USA	Redglobe x FV9-6288 (=Dixiland x FV240-1); FV240-1= FV89-14 x B2832; FV89-14= FV 15-48 (=Fireglow x Hiley) x Fireglow; B2832= Hal - Berta Giant x Eclipse
Sunraycer	USA	Forestgold x Fla 7-3N (=Sungold x Armking)
Sunright	USA	Unk
Sunsplash	USA	Sunlite x Armking
Symphonie	FRA	Early O'Henry op
Tom Grand	USA	Unk
Tropicsnow	USA	Fla 7-11 op [=Fla 5-200 (=Sunnyside x Fordawon)] x Maravilha
TX 2 B 6	USA	Unk
TX 3592/7	USA	Unk
USA CA 1 D	USA	Unk
Valeria	ITA	Unk
Vega	ITA	(Fayette x Stark Redgold)F2
Villa Adriana	ITA	Unk
Villa Doria	ITA	Catherina op
Vivian	USA	(Maxine x Leader) x [(Tuscan x Paloro) x (Paloro x Pratt Low)]
Weinberger	USA	Unk
White Lady	USA	(O'Henry x Giant Babcock) x (May Grand x Sam Houston)

ARG: Argentina, USA: United States of America, CAN: Canada, FRA: France, ITA: Italy, MEX: Mexico, Unk: unknown, sp: self-pollinated, op: open-pollinated.

The introduction of new cultivars on the market is vital for fruit industry to get better products and to attract consumers with innovative fruit types (Infante and Predieri, 2008). Currently, modern breeding programs are focused on satisfying both grower and consumer preferences. Growers require highly productive cultivars with resistance to diseases and diverse harvest dates to prolong the period of fruit production while consumer demands are mainly related to fruit quality (Byrne, 2005). Like other fruit crops, the major traits determining peach and nectarine fruit quality are (1) visible quality such as size and skin appearances, (2) eating quality, usually measured as soluble solids concentration and acid content, and (3) texture quality such as firmness (Byrne et al., 2012; Predieri et al., 2006). Therefore, several parameters should be considered (Génard and Bruchou, 1992) and their associations must be studied to improve fruit evaluation and breeding practice.

Characterization of accessions is vital to avoid the loss of diversity, to preserve potential valuable traits and to identify characters that contribute the most to the total diversity. Additionally, associations among fruit quality, agronomic and phenological traits are important since their recognized significance for improving plant response to agricultural management, and thus for crop breeding in future uncertain climate scenarios (Barrios-Masias and Jackson, 2014). Significant efforts have been made worldwide to test the performance of peach cultivars (Byrne et al., 1991; Cantín et al., 2009; Font i Forcada et al., 2014; Génard et al., 1999; Kwon et al., 2015; Reig et al., 2015). However, no research has comprehensively addressed the relationships among traits by multivariate statistical methods which, as they involve the simultaneous analysis of more than one outcome variable, give a much broader and more accurate picture than looking at just one variable.

The aims of this study were to evaluate the adaptability of seventy-seven nectarine and one hundred and thirty-two peach accessions on the basis of their agronomic performance and fruit quality parameters; to apply multivariate analysis to examine the relationships among fruit quality and agronomic and phenological traits, and to identify the most adapted accessions with potential for exploitation in future breeding programs.

2. Materials and methods

2.1. Plant material

Seventy-seven nectarine and one hundred and thirty-two peach accessions were analyzed at the Estación Experimental Agropecuaria INTA, San Pedro, Argentina (31°41′12°S–60°47′32°W) (Table 1). The station has a temperate climate with brief and irregular winter, loamy–clay soil and a mean annual rainfall of 950 mm. This area is representative of the major peach productive region of the northeastern of Buenos Aires province. Trees were arranged in a completely randomized design with three replications, each of them consisted of three trees planted at 5 × 4 m row spacing. Each year the orchard received standard fungicide and insecticide sprays, pruning and fertilization with urea similar to commercial orchards. No chemical means were used to break dormancy.

2.2. Agro-morphological evaluation

Eight representative fruits were randomly harvested at the physiological maturity stage, on the basis of their skin ground colour, over a period of three consecutive years (2010/11–2012/13). The morphological characterization was accomplished by evaluating each accession against twenty-six qualitative descriptors as suggested by the International Union for the Protection of New Varieties of Plants (Upov, 2010) (Table 2): fruit shape in ventral

Table 2
Qualitative traits and codes used for characterizing Prunus persica (L.) Batsch accessions.

Codes	Traits	Classes
A	Fruit: shape (in ventral view)	1.- Broad oblate 2.- Medium oblate 3.- Crcular 4.- Broad elliptic 5.- Medium elliptic
B	Fruit: size	1.- Very small 3.- Small 5.- Medium 7.- Large 9.- Very large
C	Fruit: shape of pistil end	1.- Prominently pointed 2.- Weakly pointed 3.- Flat 4.- Weakly depressed 5.- Strongly depressed
D	Fruit: mucron tip at pistil end	1.- Absent 9.- Present
E	Fruit: width of stalk cavity	3.- Narrow 5.- Medium 7.- Broad
F	Fruit: depth of stalk cavity	3.- Shallow 5.- Medium 7.- Deep
G	Fruit: prominence of suture	3.- Weak 5.- Medium 7.- Strong
H	Fruit: symmetry (viewed from pistil end)	1.- Symmetric 2.- Moderately asymmetric 3.- Strongly asymmetric
I	Stone: size compared to fruit	3.- Small 5.- Medium 7.- Large
J	Stone: shape (in lateral view)	1.- Oblate 2.- Circular 3.- Elliptic 4.- Obovate
K	Stone: intensity of brown colour	3.- Light 5.- Medium 7.- Dark
L	Stone: relief of surface	1.- Only pits 2.- Predominantly pits 3.- Equally pits and grooves 4.- Predominantly grooves 5.- Only grooves
M	Stone: tendency to split	1.- Absent 3.- Low 5.- Medium 7.- High 7.- Very high
N	Fruit: ground colour of skin	1.- Not visible 2.- Green 3.- Cream green 4.- Greenish white 5.- Cream white 6.- Cream 7.- Pink White 8.- Greenish yellow 9.- Cream yellow 10.- Yellow 11.- Orange yellow
O	Fruit: hue of over colour of skin	1.- Orange red 2.- Pink 3.- Pink red 4.- Light red 5.- Medium red 6.- Dark red 7.- Blackish red

Table 2 (*Continued*)

Codes	Traits	Classes
P	Fruit: pattern of over colour of skin	1.- Solid flush 2.- Mottled 3.- Striped 4.- Marbled
Q	Fruit: relative area of over colour of skin	1.- Absent 3.- Small 5.- Medium 7.- Large 9.- Very large
R	Fruit: pubescence of skin	1.- Absent 9.- Present
S	Fruit: carotenoid coloration of flesh	1.- Greenish white 2.- White 3.- Cream white 4.- Light yellow 5.- Yellow 6.- Orange yellow 7.- Orange
T	Fruit: anthocyanin coloration of flesh around stone	1.- Absent or weak 2.- Medium 3.- Strong
U	Fruit: anthocyanin coloration of flesh next to skin	1.- Absent or very weak 2.- Weak 3.- Strong
V	Fruit: anthocyanin coloration of flesh in central part of flesh	1.- Absent or very weak 2.- Weak 3.- Strong
W	Fruit: acidity	1.- Very low 2.- Low 3.- Medium 4.- High 5.- Very high
X	Fruit: sweetness	1.- Low 2.- Medium 3.- High
Y	Fruit: firmness of flesh	1.- Very soft 3.- Soft 5.- Medium 7.- Firm 9.- Very firm
Z	Stone: degree of adherence to flesh	3.- Weak 5.- Medium 7.- Strong

view (A); fruit size (B); shape of pistil end (C); mucron tip at pistil end (D); width of stalk cavity (E); depth of stalk cavity (F); prominence of suture (G); symmetry viewed from pistil end (H). Stone: size compared to fruit (I); shape in lateral view (J); intensity of brown colour (K); relief of surface (L); tendency to split (M). Skin: ground colour (N); hue of over colour (O); pattern of over colour (P); relative area of over colour (Q); pubescence (R). Carotenoid coloration of flesh (S). Coloration of flesh around stone (T), next to skin (U), in central part of flesh (V). Acidity (W); sweetness (X); firmness of flesh (Y) and degree of adherence of stone to flesh (Z). In addition, three quantitative traits were also recorded: fruit weight (Kg) (AG); size of the stone compared to flesh (%) (AH) and soluble solids content (SSC) (°Brix) (AI). Besides, six agronomic and phenological traits were evaluated: date of anthesis for 50% of the flowers (days from the first of January) (AA); leafing date for 50% of the crown (days from the first of January) (AB); fruit development period (days) (AC); harvesting date (days from the first of January) (AD); harvesting period (days) (AE) and yield (kg/plant) (AF). Yield and fruit weight were obtained by using an electronic sizing and weighing machine (model Calel T2, Sgrilleti S.A., Argentina) and the SSC of the juice was determined with a refractometer (model N1, Atago Co., Japan).

Table 3
Variable levels that contribute the most to dimension 1 (D1) or dimension 2 (D2).

Variable levels	Contribution to D1[a]	Contribution to D2[a]
Z-5	**0.05 (0.43)**	0.00 (0.00)
T-1	**0.05 (0.54)**	0.00 (0.01)
K-3	**0.06 (0.63)**	0.00 (0.00)
Z-3	**0.07 (0.50)**	0.00 (0.03)
T-3	**0.07 (0.59)**	0.00 (0.01)
K-7	**0.07 (0.50)**	0.01 (0.03)
Q-3	0.01 (0.03)	**0.05 (0.18)**
A-2	0.01 (0.06)	**0.05 (0.19)**
C-4	0.02 (0.09)	**0.05 (0.20)**
U-2	0.00 (0.02)	**0.05 (0.21)**
T-2	0.00 (0.00)	**0.06 (0.25)**
S-4	0.00 (0.01)	**0.12 (0.43)**
L-1	0.00 (0.01)	**0.12 (0.43)**

[a] Squared cosine given in parenthesis. Contributions equal to or higher than 0.05 in bold.

2.3. Data analysis

Average and mode values were used for statistical analysis. The collected data was subjected to Factor Analysis (FA) and Multiple Correspondence Analysis (MCA) with the aim of analyzing the pattern of relationships of quantitative and categorical dependent variables, correspondingly. Then, a joint analysis was accomplished with the standardized data in order to identify the most adapted accessions. An agglomerative hierarchical cluster analysis using Ward's method was carried out applying Gower's similarity coefficient (S) (Gower, 1971) and the distance measure was expressed as sqrt(1-S). Analyses were performed with R (R Development Core Team, 2013) and InfoStat (Di Rienzo et al., 2013).

3. Results and discussion

3.1. Analysis of qualitative traits

From the MCA, a two-dimension solution was considered the most adequate. The adjusted inertias of the first and second dimensions are 26.01% and 13.80%, respectively. The contributions of the variable levels and the squared cosines help to interpret the results. Table 3 represents those variable levels whose contributions to dimension 1 (D1) or dimension 2 (D2) are equal to or higher than 0.05. Among them, only those trait classes whose squared cosines are high would be represented in the space with good quality and are shown in Fig. 1. Therefore, D1 could be interpreted as 'flesh around the stone and stone characteristicsí. It is negatively associated with those semi-freestone accessions that have weak or no anthocyanin coloration of the flesh around their light brown stones. In contrast, D1 is positively associated with those freestone accessions that have strong anthocyanin coloration of the flesh around their dark brown stones. On the other hand, only pits on the stone surface and light yellow flesh have the highest squared cosines among those characteristics that contribute the most to D2. However, as these variables levels are not common in the germplasm collection under study, D2 interpretation is not recommended.

Hence, in Fig. 1 the accessions with extreme D1 values are plotted. Michelini and DOFI-84.364.060 have the highest D1 values among the germplasm collection. Thus, they are freestone peach cultivars that have strong anthocyanin coloration of the flesh around their dark brown stones. Otherwise, as the lowest D1 value belongs to FLA 9-1, it is a semi-freestone nectarine cultivar that

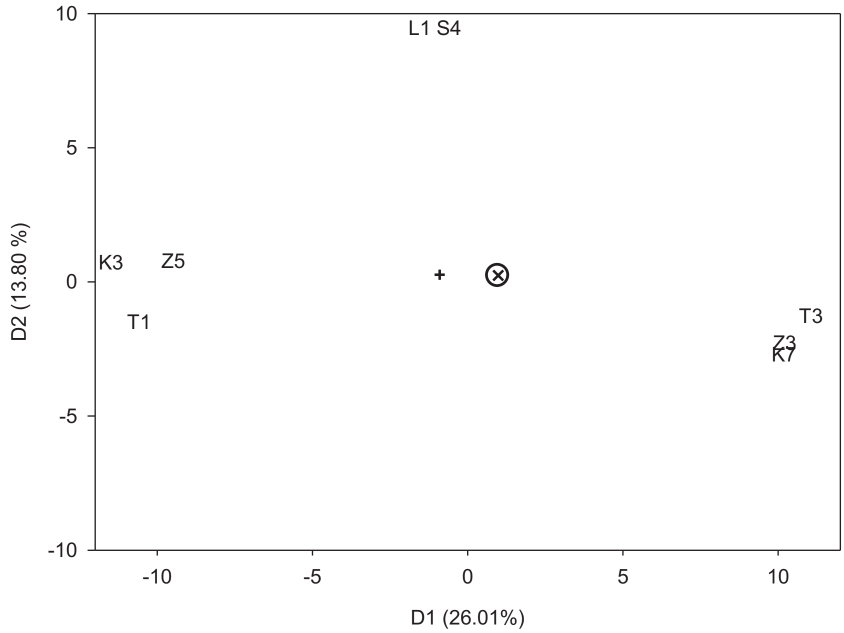

Fig. 1. Multiple Correspondence Analysis. Plot of variable levels that contribute the most to dimension 1 (D1) and dimension 2 (D2). Cultivars with high D1 values are also represented (+: FLA 9-12; O: Michelini and X: DOFI-84.364.060).

has weak or no anthocyanin coloration of the flesh around its light brown stone.

To sum up, given that K-7, T-3 and Z-3, as well as K-3, T-1 and Z-5 are the variable levels that contribute the most to D1, their squared cosines are high and they are close to each other in Fig. 1, freestone accessions would be associated with strong anthocyanin coloration of the flesh around dark brown stone while semi-freestone accessions would be associated with weak or no anthocyanin coloration of the flesh around light brown stone. Taking into account that anthocyanins are very labile and subject to browning in canning operations, this has led to the selection for flesh of canning peaches that is anthocyanin-free (Bassi and Monet, 2008). On the other hand, although the anthocyanin coloration of flesh is not desirable for canned fruit, there are not preferences for fresh fruit consumption in Argentina (Daorden, 2012). Therefore, if the germplasm collection is intended to be used in the production of canned fruit, the associations found by this analysis must be considered.

3.2. Analysis of quantitative traits

Factor analysis after varimax rotation indicates that the first three factors explain 62.17% of total variance. In order to name them properly, factor-loading values are taken into account and those higher than 0.5 are considered significant. Additionally, factor-loading values provide information about the interdependencies between observed variables and these can be considered to reduce the set of variables for future germplasm evaluation. Table 4 shows that the first factor is highly positively related to fruit development period, harvesting date, fruit weight and SSC. The suggested name for the first factor is 'fruit quality and reaping time'. As the second factor is loaded on date of anthesis for 50% of the flowers and leafing date for 50% of the crown, it is called 'phenology traits'. Finally, the third factor is associated with harvesting period and yield, so it is named 'productivity'. Therefore, in the germplasm collection considered in this study, 'fruit quality and ripening time', 'phenology traits' and 'productivity' can be assumed to be unrelated to each other.

The first factor reveals that fruit weight is associated to SSC as was previously reported for peach cultivars by Pearson correlation (Cantín et al., 2009). This result is expected due to the amount of translocated carbohydrates that contributes to SSC determines fruit growth rate (Mounzer et al., 2008). Additionally, fruit size increases sink strength to attract sucrose and sorbitol from the plant sources (Lo Bianco and Rieger, 2006). Although Ruiz and Egea (2007) found out that there is no correlation between these traits in apricot cultivars by univariate analysis, they stated that harvest date correlates significantly with fruit weight in accordance with the association found in our study. On the other hand, De Souza and Taylor (1998) stated that date of ripening does not correlate to blooming date, but it has a strong and positive correlation with FDP and SSC in peach, as the associations reported in our analysis. Moreover, taking into account that late season cultivars have greater capacity to accumulate sugar compared to early season cultivars (Byrne, 2002; Engel et al., 1988), the positive association between harvesting date and SSC is expected. The second factor shows that blooming date is associated to leafing budbreak date which is in accordance with the fact that lateral vegetative and flower buds have similar chilling requirements (Scalabrelli and Couvillon, 1986). Finally, the association between harvesting period and yield is expected. The length of the harvesting period depends on the number of fruits since peaches on the same tree do not ripen at the same time and generally 3–5 pickings are required to complete the harvest. On the other hand, yield is related to the amount of fruits per plant and fruit weight. Therefore, it seems that harvesting period and yield are associated to each other by the amount of fruits.

Currently, the purposes of the breeding program for fresh market are the development of late ripening freestone cultivars whose fruits have bright red skin and early ripening freestone cultivars with late blooming and fruits with large size, firm flesh and bright red skin (Daorden, 2012). Hence, the association between harvesting date and fruit weight, which was revealed by the first factor, would cause difficulties in obtaining early ripening cultivars with large fruit size from the germplasm collection evaluated.

3.2. Joint analysis of qualitative and quantitative traits

Hierarchical agglomerative cluster analysis was performed in order to divide the accessions into groups of increasing dissim-

Table 4
Percentage of variation, percentage of accumulated variation and factor loadings associated to the first three factors after varimax rotation.

	Variation (%)	Accumulated variation (%)	Factor loadings								
			AA	AB	AC	AD	AE	AF	AG	AH	AI
F1	26.65	26.65	0.20	0.15	**0.91**	**0.90**	−0.13	0.04	**0.58**	−0.22	**0.55**
F2	24.80	51.45	**0.97**	**0.96**	−0.18	0.39	−0.08	−0.17	0.24	−0.09	0.30
F3	10.73	62.17	−0.11	−0.12	−0.08	−0.11	**0.55**	**0.66**	0.35	−0.21	−0.14

Bold values indicate factor loading higher than 0.5.

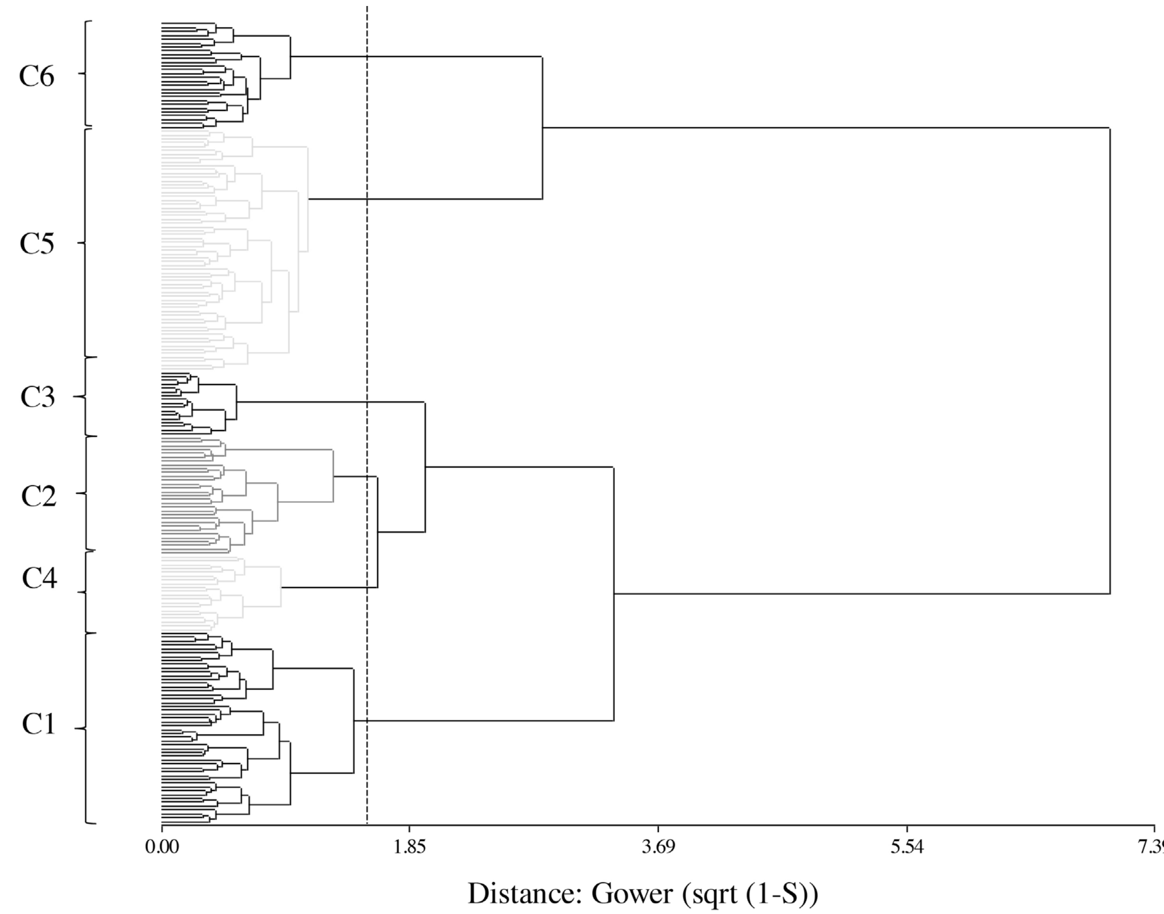

Fig. 2. Dendrogram obtained from agglomerative hierarchical cluster analysis using Ward's method. Gower's similarity coefficient was calculated from mode or average values of agro-morphological traits of 76 nectarine and 133 peach accessions (C1 = cluster 1; C2 = cluster 2; C3 = cluster 3; C4 = cluster 4; C5 = cluster 5; C6 = cluster 6).

ilarity. Ward's minimum variance criterion was applied to the original standardized variables and the dendrogram obtained from the analyses, which is shown Fig. 2, pointed out six main groups. Although the cophenetic correlation coefficient is not high (0.26), as the accessions that belong to each cluster have similarities among them while they differ to the accessions of the other groups, the dendrogram obtained is trustable. Since the distance between SH7 and Flordagem is 0.56, they are the most divergent within the collection. Cluster number three has the most similar varieties: Federica is similar to Cotogna di Rosano ($d = 0.10$) and USA CA1 is similar to Maycrest ($d = 0.10$).

Cluster 1 and 2 consist of accessions whose fruits are characterized by the absence of anthocyanin coloration of the flesh around the stone and SSC lower than 12 °Brix. The first group includes 47 nectarine and 3 peach early ripening accessions whose stones are big compared to flesh. June Glo and Caldessi 2020 are the most similar varieties within this cluster ($d = 0.15$) while Caldessi 2000 is the one that differ the most ($d = 0.50$) (Fig. 3). The second group has 29 peach and 2 nectarine accessions which have short fruit development periods. LSCr and Springcrest are the most similar varieties ($d = 0.27$) whereas 5LA4 is the last to join this cluster (Fig. 4). Clusters 3–6 consist of accessions whose fruits are characterized by the absence of mucron tip at the pistil end. Cluster 3 consists of 17 peach accessions whose semi-freestone fruits are broad elliptic. The skin is predominantly yellow on the ground and the dark red over colour is largely and uniformly distributed. In addition, the small stones have low tendency to split and the firm yellow flesh has medium SSC and acidity but lacks of anthocyanin coloration. The most similar varieties are Federica and Cotogna di Rosano ($d = 0.10$) and USA CA1 and Maycrest ($d = 0.10$) while the last accession to be incorporated is 60EF32 ($d = 0.36$), as shown in Fig. 5. The fourth cluster includes 20 peach varieties developed in United States, whose fruits have low SSC and moderate acidity. Also, since these accessions bloom and leaf budbreak during August and their fruits ripe in November, they are characterized by early phenology. Within this group, TX2B6 and 55RA15 are the most similar ($d = 0.28$) while SH7 and Flordagem are the most divergent ($d = 0.56$) (Fig. 6). Cluster 5 consists of 60 peach and 3 nectarine accessions whose fruits

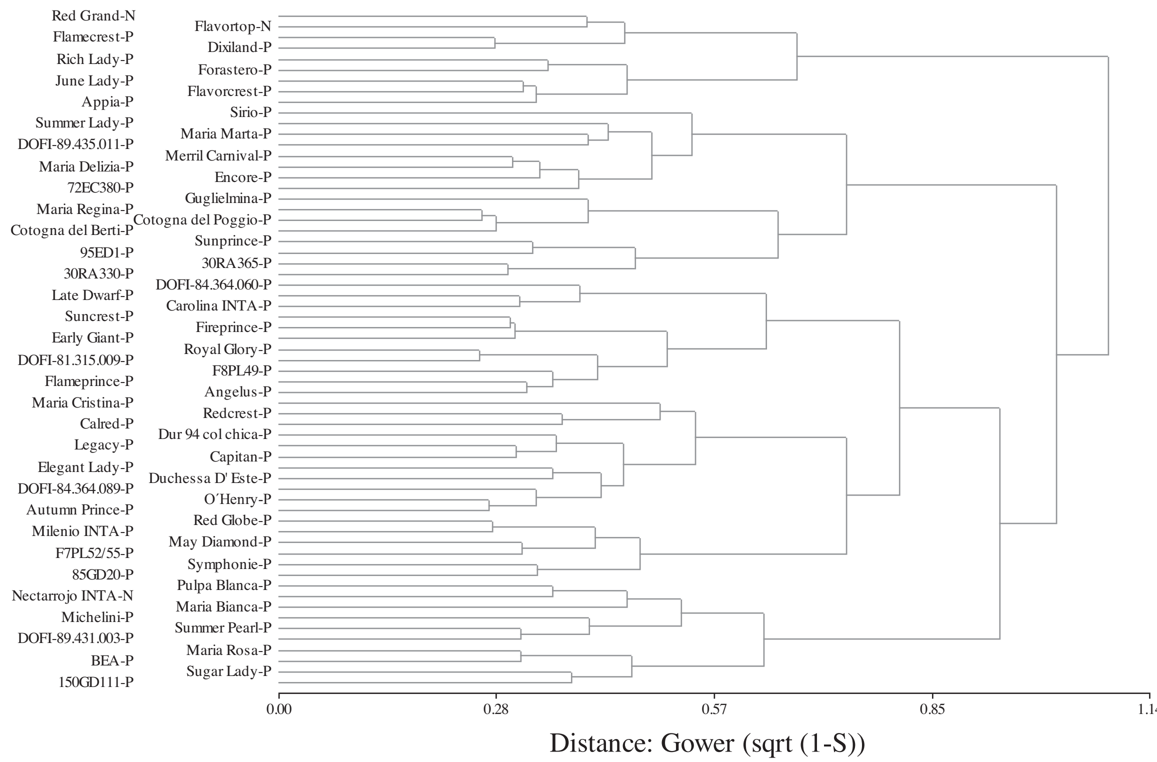

Fig. 3. Cluster 1 obtained from agglomerative hierarchical cluster analysis using Ward's method based on Gower's similarity coefficient (P = peach; N = nectarine).

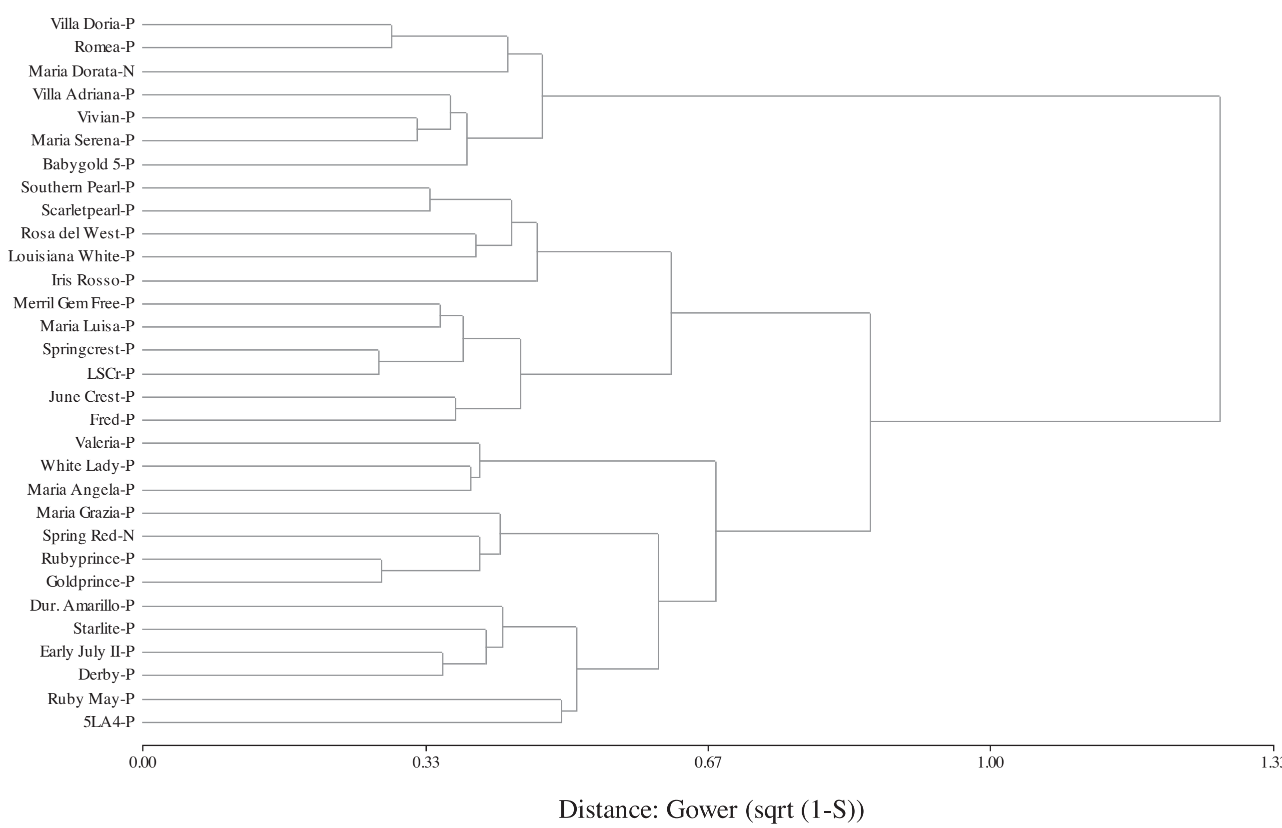

Fig. 4. Cluster 2 obtained from agglomerative hierarchical cluster analysis using Ward's method based on Gower's similarity coefficient (P = peach; N = nectarine).

ripe lately and their stones do not split. The flesh is medium acid, has moderately high SSC and lacks of anthocyanin coloration next to the skin. Royal Glory and DOFI-81.315.009 are the most similar varieties (d = 0.26) whereas Sirio has the lowest similarity (d = 0.53) (Fig. 7). The last cluster includes 25 nectarine and 3 peach freestone accessions that ripe lately. Fruits have moderately high SSC

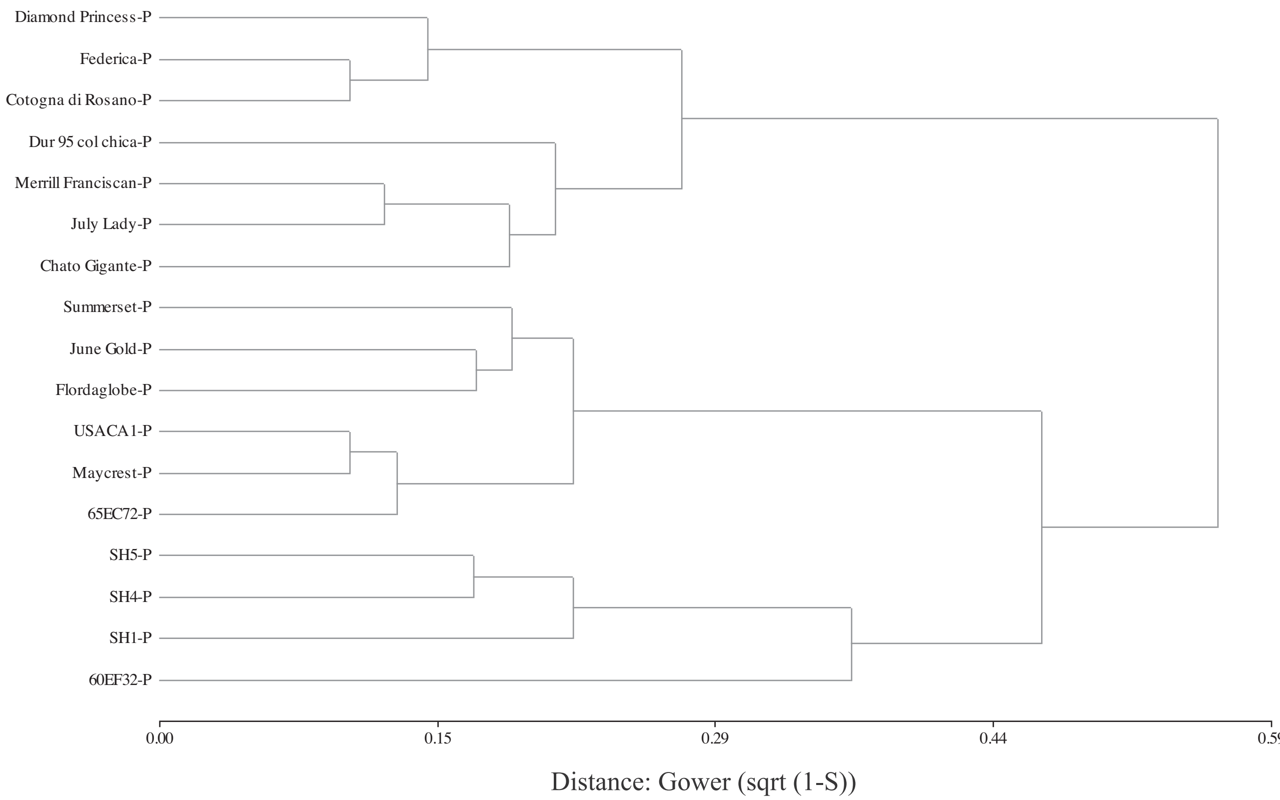

Fig. 5. Cluster 3 obtained from agglomerative hierarchical cluster analysis using Ward's method.

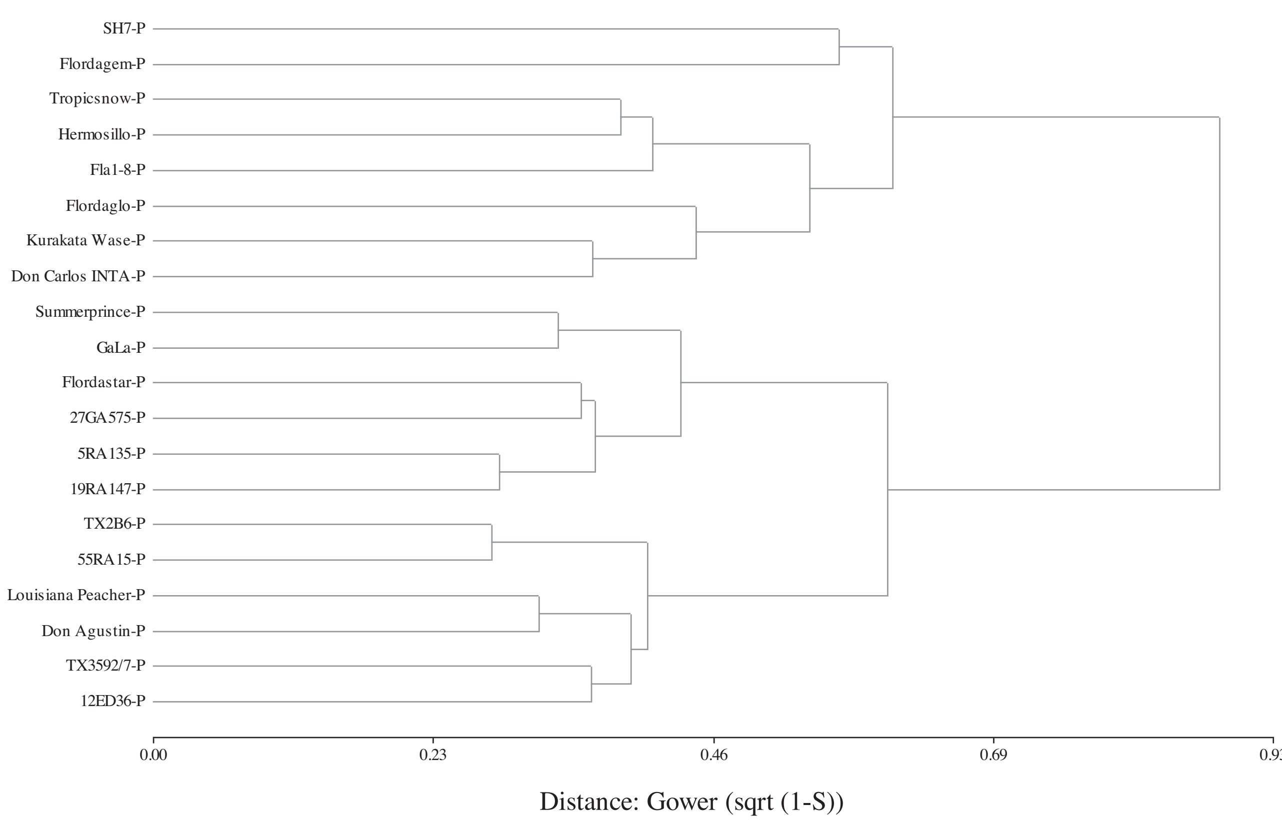

Fig. 6. Cluster 4 obtained from agglomerative hierarchical cluster analysis using Ward's method based on Gower's similarity coefficient (P = peach).

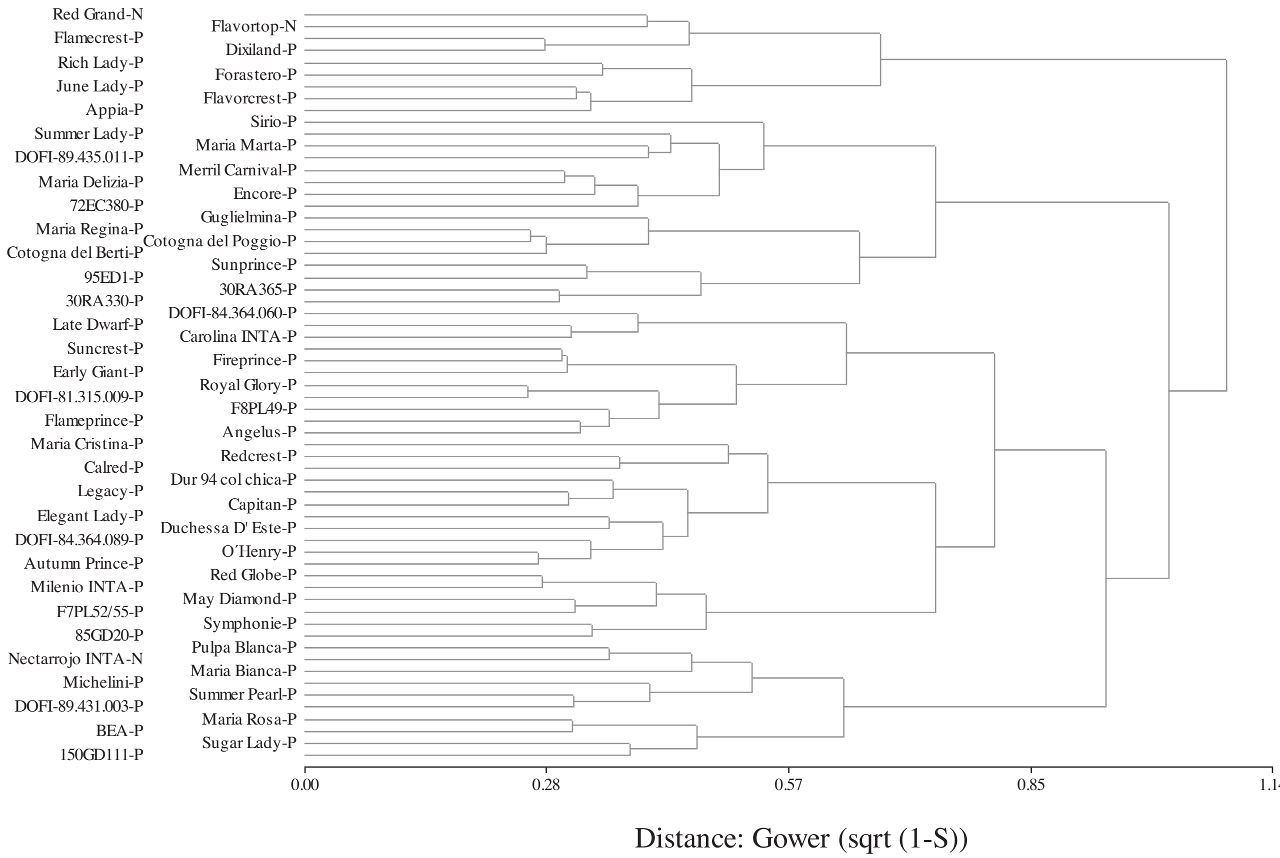

Fig. 7. Cluster 5 obtained from agglomerative hierarchical cluster analysis using Ward's method based on Gower's similarity coefficient (P = peach; N = nectarine).

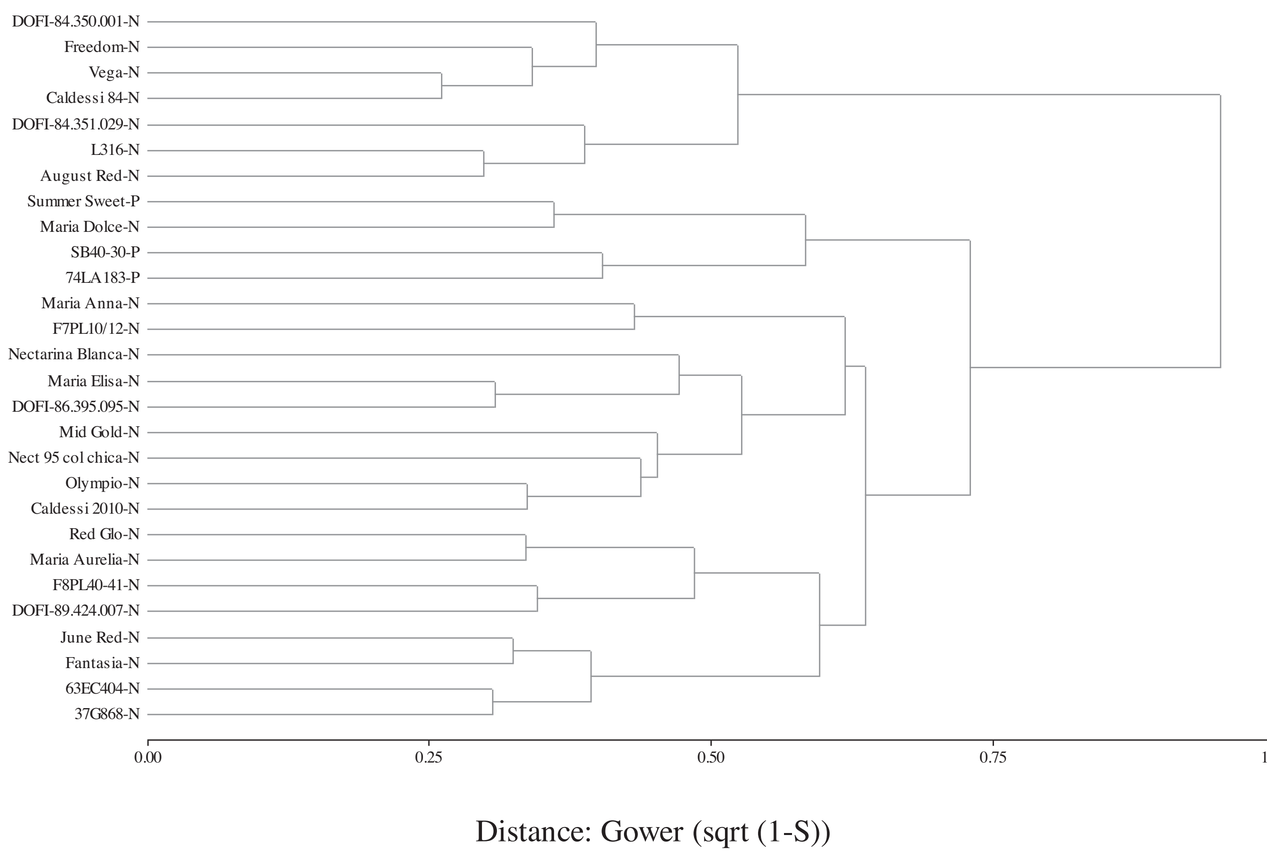

Fig. 8. Cluster 6 obtained from agglomerative hierarchical cluster analysis using Ward's method based on Gower's similarity coefficient (P = peach; N = nectarine).

and their stones do not split. The firm flesh has strong anthocyanin coloration around the stone. Vega and Caldessi 84 have the smallest distance (d = 0.26) while Nectarina Blanca is the least similar (d = 0.47), as shown in Fig. 8.

Peach flavor is quite complex but the major easily measured traits are soluble solids and acid contents. Even though preferred profile varies with regional and personal customs, in general acid and low-acid fruits are expected to have more than 10 and 11 °Brix of soluble solids content (SSC), respectively (Byrne et al., 2012). So, taking into account the current interest in satisfying consumer preferences, the accessions that belong to cluster one, two and four should not be recommended due to their low SSC.

On the other hand, clusters three, five and six are characterized by valuable accessions whose fruits lack of mucron tip at the pistil end and their stones do not split. These characteristics are advantageous since fruit with split pits soften more quickly than intact fruits and are more susceptible to decay (Horton et al., 2008). Moreover, the acute tip present at the apex is undesirable because fruits damage during harvest and handling and also its fragments are difficult to eliminate from processed fruits (Bassi and Monet, 2008; Topp et al., 2008).

Additionally, peach fruits that belong to cluster three take the advantages of having high visible, texture and eating quality since the dark red over colour is widely and uniformy distributed on the skin, the yellow flesh is firm and SSC is comprised between 12 °Brix and 14 °Brix. Furthermore, as the flesh lacks of anthocyanin coloration, these accessions can be destined to canned fruit and fresh fruit consumption. On the contrary, as the last two clusters have accessions whose fruits have anthocyanin coloration in the flesh, they can only be chosen for fresh fruit consumption. Cluster number five is formed by accessions whose peaches have extremely sweet flavor since their SSC are higher than 15 °Brix, while accessions of cluster six have freestone nectarine fruits with firm and sweet flesh. Finally, clusters three, five and six should be considered simultaneously so as to obtain cultivar with wide range of harvest dates.

Since each accession interacts with several climatic variables, differential performance is expected when a genotype has been selected in one environment and is cultivated in another. In this way, the origin of materials becomes an important factor as a possible cause of the phenotypic variability and the relationships among accessions. Nectarine and peach accessions were clearly separated. Nectarines accessions were grouped in cluster 1 and 6. However, San Pedro, Ginart and Flordaking peach genotypes were included in cluster 1, while SB40-30, Summer Sweet and 74 LA 183 peach accessions were associated with nectarines in cluster 6. This ambiguity classification is not expected because the presence and absence pubescence are weighted with very extreme codes (Table 2). However, other characters were clearly more important than pubescence to group the accessions. Although these traits were not identified in our work, the quantitative characters might be the cause of this ambiguity. The genetic basis of these characters consists of many genes, and their expressions are highly influenced by the environment and genotype-by-environment interaction. Fruit yield is one of them, and as demonstrated Maulión et al. (2014) peach and nectarine yield varies significantly from one year to another. Separation established between peach and nectarine in this study is in agreement with Aranzana et al. (2003, 2010). These authors studied the genetic variability and genetic structure of a collection of peach commercial cultivars using simple sequence repeat (SSR). Three main groups were established: peaches, nectarines and non-melting peaches and nectarines, suggesting that crosses between genotypes of different groups have been used less frequently in peach breeding than crosses between members of the same group.

Accession from USA were in all clusters, mainly in cluster 1 and 5, while genotypes from ITA were grouped in clusters 1, 2, 3, 5 and 6. Genotypes from ARG had a lower representation than those from USA and ITA, however, they can be identified in the 4 groups. This reveals that the INTA San Pedro germplasm has a high genetic variability. This variability may be a consequence of the modern selection strategies used in USA and ITA, often based on the selection of individuals from progeny of a cross and where self pollination is occasionally used (Aranzana et al., 2003). Variability of Argentine genotypes is also expected because the selection strategy is similar to the one mentioned above and accessions used in crosses usually come from USA. There are few accessions from MEX, CAN and FRA and, consequently, it is not possible make inference about their variability.

Using classical methods of genetic improvement in peach, the development of new cultivars can take many years. However, this situation has changed in recent years due to its genetic and biological characteristics (small genome size, taxonomic proximity to other important species and short juvenile period), thus peach has become a model plant in genomic research in the Rosaceae family. Recently, the whole genome sequence of peach has been released, including the resequencing data of several peach accessions. It has been possible to estimate the SNP variability of this specie (Aranzana et al., 2012) and a 9k SNP array v1 has been developed by the International Peach SNP Consortium (IPSC). Genotyping-by-sequencing (GBS) (Elshire et al., 2011) is now feasible for diversity, linkage disequilibrium (LD) and association mapping. Previous studies had revealed a high level of LD conservation in peach (Aranzana et al., 2010) and the possibility to apply association mapping using SSR (Cao et al., 2012) or single nucleotide polymorphism (SNP), which allow finer analysis of LD and the whole-genome association analysis considering a set of characters, such as presented in this work. These methodologies open a new era for peach breeding and others fruit crops.

4. Conclusions

The present study revealed considerable phenotypic diversity and associations among traits measured in seventy-six nectarine and one hundred and thirty-three peach accessions grown in the Estación Experimental Agropecuaria INTA San Pedro, Argentina. Multiple correspondence analysis exposed associations among the adherence of the stone to the flesh, the colour of the stone and the anthocyanin coloration of the flesh. Consequently, if the accessions are intended to be used in the production of canned fruit, these findings should be considered. On the other hand, Factor Analysis showed positive relationships between blooming and leafing dates; harvesting period and yield; and among fruit development period, harvesting date, fruit weight and SSC. Therefore, 'phenology traits', 'productivity' and 'fruit quality and reaping time' could be assumed to be unrelated to each other. These results emphasize the possibility to obtain desirable trait combinations in specific cultivars. However, it must be pointed out that the association between harvesting date and fruit weight, which was revealed by the first factor, would cause difficulties in obtaining early ripening cultivars with large fruit size. Finally, the agglomerative hierarchical cluster analysis grouped the accessions according to their similarities and those that belong to clusters three, five and six could be recognized as the most adapted accessions. According to our results, even though the cultivars included in this study had been developed in foreign breeding programs, these accessions might be considered to develop peach and nectarine varieties with high quality fruits with the aim of satisfying regional evolving market and consumer demands. The evaluation of fruit quality, agronomic and phenological traits performed in this study provides valuable information for the development and improvement of adaptability of peach and nectarine cultivars. It is important to highlight that this research gives a broad and accurate idea of traits associations since it is novel in the analysis of the relationships among traits by multivariate analysis. On the other hand, it opens the possibility to apply new methodologies as association mapping and genome-wide selection, with the goal of developing superior genotypes in less time, and contributes to further expansion of -omics science of *Prunus*.

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References

Aranzana, M.J., Carbo, J., Arús, P., 2003. Microsatellite variability in peach [*Prunus persica* (L.) Batsch]: cultivar identification, marker mutation, pedigree inferences and population structure. Theor. Appl. Genet. 106, 1341–1352.
Aranzana, M.J., Abbassi, E., Howad, W., Arús, P., 2010. Genetic variation, population structure and linkage disequilibrium in peach commercial varieties. BMC Genet. 11, 69.
Aranzana, M., Illa, E., Howad, W., Arus, P., 2012. A first insight into peach [*Prunus persica* (L.) Batsch] SNP variability. Tree Genet. Genomes 8 (6), 1359–1369.
Barrios-Masias, F.H., Jackson, L.E., 2014. California processing tomatoes: morphological, physiological and phenological traits associated with crop improvement during the last 80 years. Eur. J. Agron. 53, 45–55, http://dx.doi.org/10.1016/j.eja.2013.11.007.
Bassi, D., Monet, R., 2008. Botany and taxonomy. In: Layne, D.R., Bassi, D. (Eds.), The Peach: Botany, Production and Uses. CABI publishing, Oxfordshire, pp. 1–37.
Byrne, D., Nikolic, A., Burns, E., 1991. Variability in sugars, acids, firmness, and color characteristics of 12 peach genotypes. J. Am. Soc. Hortic. Sci. 116, 1004–1006.
Byrne, D.H., 2002. Peach breeding trends. Acta Hortic. 592, 49–59.
Byrne, D.H., 2005. Trends in stone. Horttechnology 15, 494–500.
Byrne, D.H., Raseira, M.B., Bassi, D., Piagnani, M.C., Gasic, K., Reighard, G.L., Moreno, M.A., Salvador, P., 2012. Peach. In: Badenes, M.L., Byrne, D.H. (Eds.), Fruit Breeding. Springer, New York, pp. 523–536.
Cantín, C.M., Gogorcena, Y., Moreno, M.A., 2009. Phenotypic diversity and relationships of fruit quality traits in peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies. Euphytica 171 (2), 211–226, http://dx.doi.org/10.1007/s10681-009-0023-4.
Cao, K., Wang, L., Zhu, G., Fang, W., Chen, C., Luo, J., 2012. Genetic diversity, linkage disequilibrium, and association mapping analyses of peach (*Prunus persica*) landraces in China Tree. Genet. Genomes, http://dx.doi.org/10.1007/s11295-012-0477-8.
Daorden, M.E., 2012. Comentarios generales sobre el mejoramiento genético en duraznero. In: Valentini, G.H., González, J., Gordo, M. (Eds.), Producción de Duraznero En La Región Pampeana, Argentina. Ediciones INTA, Buenos Aires, pp. 62–70.
De Souza, V.A.B., Taylor, J.F., 1998. Heritability, genetic and phenotipic correlations, and predicted selection response of quantitative traits in peach: II. An analysis of several fruits traits. J. Am. Soc. Hortic. Sci. 123, 604–611.
Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzalez, L., Tablada, M., Robledo, C.W., 2013. InfoStat, versión 2013. In: Grupo InfoStat, FCA. Universidad Nacional de Córdoba, Argentina.
Elshire, R., Glaubitz, J., Sun, Q., Poland, J., Kawamoto, K., Buckler, E., Mitchell, S., 2011. A robust, simple genotyping-by-sequencing (GBS) approach for high diversity species. PLoS One 6, e19379.
Engel, K., Ramming, D., Flath, R., Teranishi, R., 1988. Investigation of volatile constituents in nectarines. 2. Changes in aroma composition during nectarine maturation. J. Agric. Food Chem. 36, 1003–1006.
Font i Forcada, C., Gradziel, T.M., Gogorcena, Y., Moreno, M.Á., 2014. Phenotypic diversity among local Spanish and foreign peach and nectarine [*Prunus persica* (L.) Batsch] accessions. Euphytica 197, 261–277, http://dx.doi.org/10.1007/s10681-014-1065-9.
Génard, M., Bruchou, C., 1992. Multivariate analysis of withintree factors accounting for the variation of peach fruit quality. Sci. Hortic. (Amsterdam) 52, 37–51.
Génard, M., Reich, M., Lobit, P., Besset, J., 1999. Correlations between sugar and acid content and peach growth. J. Hortic. Sci. Biotechnol. 74, 772–776.
Gower, J.C., 1971. A general coefficient of similarity and some of its properties. Biometrics 27, 857–871.
Horton, D.L., Fuest, J., Cravedi, P., 2008. Insects and mites. In: Layne, D.R., Bassi, D. (Eds.), The Peach: Botany, Production and Uses. CABI publishing, Oxfordshire, pp. 467–504.
Infante, R., Predieri, S., 2008. Quality oriented fruit breeding: peach [*Prunus persica* (L.) Batsch]. J. Food Agric. Environ. 6, 342–356.
Kwon, J.H., Jun, J.H., Nam, E.Y., Chung, K.H., Hong, S.S., Yoon, I.K., Yun, S.K., Kwack, Y.B., 2015. Profiling diversity and comparison of Eastern and Western cultivars of *Prunus persica* based on phenotypic traits. Euphytica, http://dx.doi.org/10.1007/s10681-015-1494-0.
Lo Bianco, R., Rieger, M., 2006. Carbohydrate metabolism and sink strength in peach. HortScience 41, 930.
Maulión, E., Valentini, G., Ornella, L., Pairoba, C.F., Daorden, M.E., Cervigni, G.D.L., 2014. Study of statistic stability to select high-yielding and stable peach genotypes. Sci. Hortic. (Amsterdam) 175, 258–268, http://dx.doi.org/10.1016/j.scienta.2014.06.026.
Mounzer, O.H., Conejero, W., Nicolas, E., Abrisqueta, I., Garcia-Orellana, Y.V., Tapia, L.M., Vera, J., Abrisqueta, J.M., Ruiz-Sanchez, M.D.C., 2008. growth pattern and phenological stages of early-maturing peach trees under a mediterranean climate. HortScience 43, 1813–1818.
Predieri, S., Ragazzini, P., Rondelli, R., 2006. Sensory evaluation and peach fruit quality. Acta Hortic. 713, 429–434.
Development Core Team, R., 2013. A language and environment for statistical computing. R Found. Stat. Comput., http://dx.doi.org/10.1007/978-3-540-74686-7.
Reig, G., Alegre, S., Gatius, F., Iglesias, I., 2015. Adaptability of peach cultivars [*Prunus persica* (L.) Batsch] to the climatic conditions of the Ebro Valley, with special focus on fruit quality. Sci. Hortic. (Amsterdam) 190, 149–160, http://dx.doi.org/10.1016/j.scienta.2015.04.019.
Ruiz, D., Egea, J., 2007. Phenotypic diversity and relationships of fruit quality traits in apricot (*Prunus armeniaca* L.) germplasm. Euphytica 163, 143–158, http://dx.doi.org/10.1007/s10681-007-9640-y.
Scalabrelli, G., Couvillon, G., 1986. The effect of temperature and bud type on rest completion and the GDH°C requirement for budbreak in Redhaven peach. J. Am. Soc. Hortic. Sci. 111, 537–540.
Topp, B.L., Sherman, W.B., Raseira, M.C.B., 2008. Low-chill cultivar development. In: Layne, D.R., Bassi, D. (Eds.), The Peach: Botany, Production and Uses. CABI publishing, Oxfordshire, pp. 106–138.
Torroba, C., Frangi, H., 1979. Nectarrojo INTA, a new nectarine cultivar for San PedroBuenos Aires. IDIA, 102–105.
Upov, 2010. Guidelines for the conduct of tests for distinctness, uniformity and stability. Peach. TG/53/7. International Union for the protection of New Varieties of Plants.
Valentini, G.H., Arroyo, L.E., 2007. Don Carlos INTA peach. HortScience 42, 1295–1296.