Universitat de Lleida

Selección de nuevas variedades de melocotón [*Prunus persica* (L.) Batsch] en función de caracteres agronómicos, morfológicos, de calidad y de conservación del fruto

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Tesis Doctoral

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Memoria presentada por **Gemma Reig Córdoba**,

Ingeniera Agrónoma, para optar al grado de Doctora

por la Universitat de Lleida

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Lleida, 2013

El presente documento, que lleva por título "**Selección de nuevas variedades de melocotón [*Prunus persica* (L.) Batsch] en función de caracteres agronómicos, morfológicos, de calidad y de conservación del fruto**" constituye la memoria de **Gemma Reig Córdoba**, estudiante del programa de doctorado "Ciencia y Tecnología Agraria y Alimentaria" de la Universitat de Lleida, para optar al grado de Doctor. La parte experimental se ha realizado en la Estación Experimental de Lleida del Instituto de Investigación y Tecnología Agroalimentaria (IRTA) bajo la dirección del **Dr. Simó Alegre Castellví** y el **Dr. Ignasi Iglesias Castellarnau**. Ambos autorizan la presentación de dicha memoria de tesis al reunir las condiciones necesarias para su defensa.

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RESUMEN

España es el cuarto productor mundial de melocotón [*Prunus persica* (L.) Batsch] y el segundo a escala europea, con una producción anual de más de un millón de toneladas. Las variedades comercializadas proceden en su mayoría de programas de mejora genética de Estados Unidos, Italia y Francia, lo que ha provocado una excesiva dependencia de los obtentores extranjeros, y ha dado lugar a la aparición de diferentes programas nacionales de mejora y selección de nuevas variedades adaptadas a las condiciones edafo-climáticas de las principales áreas de cultivo.

La actual dependencia juntamente con la falta de adaptabilidad de muchas variedades extranjeras cuando éstas son cultivadas en zonas de cultivo diferentes de donde han sido obtenidas, y la inmediatez requerida por los agricultores y técnicos de campo para obtener datos sobre su comportamiento agronómico y cualitativo, ha dado lugar a la necesidad de obtener esta información, y es lo que el IRTA-Estación Experimental de Lleida está llevando a cabo en sus parcelas de experimentación desde 1994, marco de esta Tesis Doctoral.

El objetivo general de este estudio es la caracterización agronómica, morfológica y cualitativa de variedades comerciales de melocotón, nectarina, pavía, melocotón plano y nectarina plana cultivadas en la zona del Valle del Ebro, con el fin de profundizar en el conocimiento de aquellos factores que puedan afectar a una buena elección por parte de los agricultores, técnicos, y comerciales. Además, se ha estudiado la evolución de la maduración y de la calidad en campo, así como el comportamiento en poscosecha de diferentes variedades de nectarina cultivadas en parcelas comerciales.

Por todo ello, en este trabajo se ha evaluado el comportamiento agronómico de 112 variedades procedentes de diferentes programas de mejora. Las evaluaciones llevadas a cabo mostraron una amplia variabilidad agronómica para todos los parámetros evaluados en función de la tipología de fruto, programa de mejora y variedad. El análisis de componentes principales permitió la agrupación de las distintas variedades, de cada tipología de fruto, de acuerdo a las características agronómicas más relevantes. Este estudio facilitó la selección de aquellas variedades con mejor comportamiento agronómico.

La zona del Valle del Ebro se encuentra frecuentemente expuesta a heladas primaverales. Por ello, y porque la resistencia a heladas no es un objetivo prioritario de los programas de mejora, se evaluó la tolerancia a estas de 56 variedades procedentes de diferentes programas de mejora. Los resultados mostraron más o menos variabilidad en la intensidad y la severidad del daño dependiendo de la época de floración, tipología de fruto, programa de mejora y variedad. Además, se obtuvieron las temperaturas críticas (LT_{10}, LT_{50} y LT_{90}) de 15 de las 56 variedades de melocotón, que corroboraron la gran variabilidad observada entre las variedades evaluadas.

La apariencia del fruto ha recibido un papel muy importante en los programas de mejora, ya que es lo primero que percibe el consumidor cuando éste realiza su compra. Para ello, se analizaron distintos caracteres morfológicos de 119 variedades procedentes de diferentes programas de mejora, y se creó un índice de evaluación de la apariencia del fruto. Se observó variabilidad en el estudio de los distintos caracteres morfológicos y el índice de apariencia en función de la tipología del fruto y de los programas de mejora. El análisis por componentes principales para cada tipología de fruto permitió la agrupación de las distintas variedades, de acuerdo a los caracteres morfológicos comunes, y conocer cuáles de ellas se pueden adecuar o no a los criterios requeridos por el mercado.

Actualmente la calidad del fruto y sus propiedades beneficiosas para la salud estan adquiriendo mucha importancia en los programas de mejora, ya que éstas junto con la presentación del fruto también condicionan la aceptación del consumidor. Por lo tanto, se analizó la calidad, la capacidad antioxidante y el contenido de antocianinas y de nutrientes de 106 variedades procedentes de diferentes programas de mejora. Los resultados mostraron una gran variabilidad entre las variedades y un efecto significativo del programa de mejora y de los caracteres pomológicos cualitativos (tipología del fruto, color de la pulpa, forma y contenido de acidez) sobre todos los parámetros de calidad evaluados, muchos de los cuáles se correlacionaron significativamente entre sí. El análisis de componentes principales permitió la agrupación de las distintas variedades, según la tipología de fruto, de acuerdo a los parámetros comunes.

Finalmente, la necesidad por parte de los productores y los comerciales de fruta por conocer el comportamiento varietal tanto en campo como en poscosecha dio origen al estudio de cinética de maduración de 11 variedades de nectarina tanto nuevas como tradicionales, en campo y su comportamiento en cámara frigorífica por un período determinado de tiempo. Se evaluó el crecimiento relativo del fruto, el porcentaje de color rojo en la piel, la pérdida de firmeza, la degradación de la clorofila de la pulpa y la producción de etileno durante 5 fechas de recolección (2 realizadas antes y 2 después de la cosecha comercial). Se encontró un efecto de la variedad y de la época de recolección en la pérdida de firmeza tanto en el campo como en cámara frigorífica, siendo las variedades de recolección temprana las que más rápido perdieron firmeza, y en el estudio de la degradación de clorofila. Sin embargo, no se encontró una muy buena correlación entre la pérdida de firmeza y la degradación de la clorofila. La producción de etileno no ayudó a explicar el diferente comportamiento varietal en campo en cuanto a la pérdida de firmeza. Por otro lado, al comparar variedades nuevas con tradicionales, no se encontraron diferencias significativas en los distintos parámetros evaluados.

SUMMARY

Spain is the fourth largest peach crop [*Prunus persica* (L.) Batsch] producer in the world and the second producer in the European Union with an annual production more than one million tons. The commercialized cultivars have their origin in different breeding programs, mainly from USA, Italy and France breeding programs. This has produced an excessive and not desirable dependency on the foreign breeders, and boost to the development of different national breeding and selection programs for the selection of new cultivars well-adapted to the main growing areas climatic conditions.

Nevertheless, this current dependency together with the lack of adaptation of some of these cultivars when they are grown under climatic conditions different from those where they were originally developed, the immediacy required by growers and technicians to establish an experimental trial to provide data about agronomic and qualitative performance, has led to the need to obtain this information. This is what IRTA-Experimental Station of Lleida is carrying on its experimental fields since 1994, framework of this Thesis.

The general objective of the study was the agronomical, morphological and qualitative characterization of commercial melting peach, nectarine, nonmelting peach, flat peach and flat nectarine cultivars grown in the Ebro Valle area, in order to gain a better understanding of which factors can contribute to growers, technicians and retailers to make a good choice. Another objective has been the study of ripening and quality evolution in the field, as well as postharvest performance of different nectarine cultivars from commercial orchards.

Because of that, in this work the agronomic performance of 112 cultivars from different breeding programs was evaluated. These evaluations showed a great agronomical variability for all the studied traits. Principal components analysis allowed the grouping of the different cultivars, from each fruit type, according to the most relevant agronomic traits. This study assisted the selection of cultivars with the most interesting agronomic performance.

The Ebro Valley area is frequently exposed to spring frost. For this, and because tolerance to spring frost has not a general priority from breeding programs, tolerance to spring frost of 56 cultivars from different breeding programs was evaluated. The results showed more or less variability on intensity and severity of the damage depending on blooming time, fruit type, breeding program and cultivar. Moreover, three lethal temperatures (LT_{10}, LT_{50} and LT_{90}) were obtained from 15 of 56 cultivars, which confirmed the great variability observed among cultivars evaluated.

Fruit appearance is one of the main breeding programs goals, due to fruit appearance is the first thing that consumer see when buy fruits. For this, morphological traits of 119 cultivars from different breeding programs were evaluated, and appearance quality index was developed. Variability was observed among morphological traits according to fruit type and breeding program. The principal component analysis led to group different cultivars according similar morphological traits, and to know which of them matched or unmatched market requirements.

Currently fruit quality and health-promoting properties has become an interesting target of breeding programs, since it together with fruit appearance determines the acceptance of the cultivars by the consumers. Therefore, quality, antioxidant capacity, and nutrients and anthocyanins content were evaluated on 106 cultivars from different breeding programs. The results showed great variability among cultivars and a significant

effect of breeding program and qualitative pomological traits (fruit type, flesh colour, fruit shape and acidity content) on the all quality traits evaluated most of them were significantly correlated. Principal component analysis allowed the grouping of the different cultivars, from each fruit type, according to the similar traits.

Finally, growers and retailers needs to know cultivar performance on the field and postharvest gave way to tree-ripening kinetics study of 11 nectarines, and their postharvest behavior. Relative growth rate, percentage of red skin color, firmness loss, chlorophyll degradation, ethylene production over 5 harvest (2 before and 2 later commercial harvest). Cultivar and maturity season effects were found in flesh firmness loss during ripening and postharvest softening. Early maturing cultivars loosed firmness faster than mid and late maturing ones. Cultivar and maturity season effects were also found in chlorophyll degradation study. Nevertheless, loss of flesh firmness and chlorophyll degradation were not well correlated. Ethylene production did not help to explain different cultivar performances in flesh firmness loss. On the other side, comparing traditional to new cultivars no differences were observed in all parameters evaluated.

RESUM

Espanya és el quart productor de préssec [*Prunus persica* (L.) Batsch] i el segon a escala europea, amb una producció anual de més d'un milió de tones. La majoria de les varietats comercialitzades provenen de programes de millora genètica d'Estats Units, Itàlia i França, la qual cosa ha provocat una gran dependència dels obtentors estrangers i ha donat lloc a l'aparició de diferents programes nacionals de millora i selecció de noves varietats adaptades a les condicions edafo-climàtiques de les principals zones de cultiu.

No obstant, aquesta actual dependència juntament amb la falta d'adaptabilitat de moltes de les varietats quan aquestes són cultivades en zones de condicions climàtiques diferents a les que han estat obtingudes, la necessitat requerida pels agricultors i tècnics de camp a obtenir dades sobre el seu comportament agronòmic i qualitatiu ha donat lloc a la necessitat d'obtenir aquesta informació, que és el que l'IRTA-Estació Experimental de Lleida està duent a terme en les seves parcel·les experimentals des de 1994, marc d'aquesta Tesis Doctoral.

L'objectiu general d'aquest estudi és la caracterització agronòmica, morfològica i qualitativa de varietats comercials de préssec, nectarina, pavia, préssec pla i nectarina plana cultivades a la zona de la Vall de l'Ebre, amb la finalitat d'aprofundir en el coneixement d'aquells factors que poden afectar a una bona elecció per part dels agricultors, tècnics i comercials. A més, s'ha estudiat l'evolució de la maduració i la qualitat en camp, així com el comportament en postcollita de diferents varietats de nectarina cultivades en parcel·les comercials.

Per tot això, en aquest treball s'ha avaluat el comportament agronòmic de 112 varietats procedents de diferents programes de millora. Les avaluacions realitzades han mostrat un àmplia variabilitat per a tot els paràmetres avaluats. L'anàlisi de components principals ha permès l'agrupació de les diferents varietats, de cada tipologia de fruit, d'acord a les característiques agronòmiques més rellevants. Aquest estudi ha facilitat la selecció d'aquelles varietats que han presentat un millor comportament agronòmic.

La zona de la Vall de l'Ebre es troba exposada freqüentment a gelades primaverals. Per això, i perquè la resistència a aquestes no és un objectiu prioritari dels programes de millora, s'ha avaluat la tolerància a gelades primaverals de 56 varietats procedents de diferents programes de millora. Els resultats han mostrat més o menys variabilitat en la intensitat i severitat del dany depenent de l'època de floració, tipologia del fruit, programa de millora i de la varietat. A més a més, s'han obtingut les temperatures crítiques (LT_{10}, LT_{50} y LT_{90}) de 15 de les 56 varietats, que corroboren la gran variabilitat observada entre les varietats avaluades.

L'aparença del fruit ha rebut un paper molt important en els programes de millora, ja que és el que primer percep el consumidor quan aquest realitza la compra. Per això, es van analitzar diferents caràcters morfològics de 119 varietats procedents de diferents programes de millora. S'ha observat variabilitat en l'estudi dels diferents caràcters morfològics en funció de la tipologia de fruit i dels programes de millora. L'anàlisi per components principals de cada tipologia de fruit va permetre l'agrupació de les diferents varietats d'acord els caràcters morfològics comuns, i saber quina d'elles s'adeqüen o no als criteris requerits pel mercat.

Actualment la qualitat del fruit i les seves propietats beneficioses per la salut estan adquirint molta importància en els programes de millora, ja que juntament amb la presentació del fruit també condicionen l'acceptació del consumidor. Per tant, es va

analitzar la qualitat, la capacitat antioxidant i els continguts d'antocians i nutrients de 106 varietats procedents de diferents programes de millora. Els resultats han mostrat una gran variabilitat entre les varietats i un efecte significatiu del programa de millora i dels caràcters pomològics qualitatius (tipologia de fruit, color polpa, forma i contingut d'acidesa) sobre tots els paràmetres avaluats, molts dels quals s'han correlacionat significativament entre si. L'anàlisi per components principals ha permès l'agrupació de varietats, segons la tipologia de fruit, d'acord als paràmetres comuns.

Finalment, la necessitat per part dels productors i dels comercials de fruita per conèixer el comportament varietal tant en camp com en postcollita va donar lloc a l'estudi de la cinètica de maduració de 11 varietats de nectarina en camp, i el seu comportament en cambra frigorífica per un període determinat de temps. Es va avaluar el creixement relatiu del fruit, el percentatge de color vermell en la pell, la pèrdua de fermesa, la degradació de clorofil·la en la polpa i la producció d'etilè en 5 dates de recol·lecció (2 realitzades abans i 2 després de la collita comercial). Es va trobar un efecte de la varietat i de l'època de maduració tant en camp com en cambra frigorífica, essent les varietats primerenques les que van perdre més ràpid la fermesa, i també en l'estudi de la degradació de clorofil·la. No obstant, no es va trobar una molt bona relació entre la pèrdua de fermesa i la degradació de clorofil·la. La producció d'etilè no va ajudar a explicar el diferent comportament varietal observat a camp respecte a la pèrdua de fermesa. D'altra banda, en la comparació entre varietats noves i tradicionals no es van trobar diferències significatives en els diferents paràmetres avaluats.

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Abreviaturas

AM	Ambra
AQI	appearance quality index
ANTHOCYA	anthocyanin content
AU	August Red
BB	Big Bang
BD	blooming density
BN	Big Nectared
BT	Big Top
CL	crop load
C3G	cyanidin-3-glucoside
DA	diameter
E	early maturity season
EB	the date of the end of the bloom
EU	European Union
F	flat shape
FB	the date of full bloom
FD	flower density/proportion of damaged flowers
FF	flesh firmness
FN	fruit number
FP	flat peach
FS	fruit size
FSE	fruit set percentage
FT	frost temperature (capítulo 2), fruit type (capítulo 3)
FW	fruit weight (capítulo 1), fresh weight (capítulo 4)
ANOVA	análisis de varianza
H1	harvest 15 days before commercial harvest
H2	harvest 7 days before commercial harvest
H3	commercial harvest
H4	harvest 7 days later commercial harvest
H5	harvest 15 days later commercial harvest
h	heterogeneity
H	height
HD	harvest date
HN	Honey Royale
HSD	Tukey’s honest significant difference
I_{AD}	index of asorbace difference
IPGI	international peach genome initiative
IPGRI	international plant genetic resources institute
L	late maturity season
LOQ	instrumental limit of quantification
LSMEANS	least square means
M	mid maturity season
MP	melting peach (capítulo 2)
N	newton

NE	nectarine (capítulos 3, 4, 5 y 6), northern east (capítulo 3), Nectareine (capítulo 7)
NMP	nonmelting peach
NS	non-showy (capítulo 2), no significativo (capítulo 3), Nectaross (capítulo 7)
NY	Nectalady
PCA	principal component analysis
PE	melting peach (capítulo 1), peach (capítulo 3 y 4)
PM	presence of powdery mildew
POL	presence of lenticels
POS	prominence of suture
QTLs	quantitative trait loci
R	round shape
RAC	relative antioxidant capacity
RI	relative increase in trunk cross-sectional area (capítulo 1), ripening index (capítulo 4 y 5)
RJ	Red Jim
RR	resistance ratio
S1	proportion of flowers with the first frost symptom
S2	proportion of flowers with the second frost symptom
S3	proportion of flowers with the third frost symptom
S4	proportion of flowers with the fourth frost symptom
S	showy
SA	stone adherence
SB	the date of start of bloom
SC	red skin color
SPE	shape of pistil end
SW	southern west
SY	symmetry
TCSA	trunk cross-sectional area
TFN	tree fruit number
THR	thinning requirement
UPOV	International Union for the Protection of New Varieties of Plants
USA	United States of America
VE	Venus
W	suture diameter (capítulo 3), white (capítulo 4)
WFP	white flat peach
WNE	white nectarine
WPE	white melting peach
WR	white-red
Y	yield (capítulo 1), year (capítulo 3), yellow (capítulo 4)
YE	yield efficiency
YFP	yellow flat peach
YNE	yellow nectarine
YPE	yellow melting peach
YR	yellow-red

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1.1. Origen y fuentes de variabilidad del melocotonero

El melocotonero tiene su origen en el oeste de China, donde podría haberse cultivado desde hace 4000 años (Scorza y Okie, 1990). Desde China, el melocotonero se extendió hasta Persia (actual Irán) por la ruta de la Seda, y desde allí se introdujo en Grecia, entre los años 400 y 300 a.C. Posteriormente, en los siglos I y II d.C, este cultivo se extendió por todo el Imperio Romano (Hancock y col., 2008) y llegó a España. Durante su difusión se fueron seleccionando poblaciones locales por su productividad y adaptabilidad a las diferentes condiciones ambientales. En el siglo XVI los españoles y portugueses introdujeron el cultivo del melocotón en Florida, México y Sur América, donde fue rápidamente adoptado y extendido por toda Norte América (Scorza y Okie, 1990).

La propagación de semillas fue la principal fuente de obtención de este cultivo hasta la mitad del siglo XIX en los Estados Unidos (EUA) y Europa, y hasta mediados del siglo XX para América Central y América del Sur. Por lo tanto, existen muchas variedades de melocotón que han sido objeto de varios siglos de selección en cuanto a la adaptación, entre otras características, en toda Europa, América del Norte, América del Sur y Asia (Byrne y col., 2000; Bouhadida y col.l, 2007; Pérez, 1989; Pérez y col., 1993). La expansión de los frutales a zonas del sur de China, Taiwán y Tailandia dió origen a germoplasma menos exigente en frío y adaptado a zonas con inviernos suaves. Este germoplasma se difundió a través de Florida por los Estados Unidos y a las zonas productoras del sur de Europa, Norte de África y América del Sur en los años 70 (Badenes y col., 2006; Iglesias y Casals, 2011).

Actualmente, China es el país del mundo con una mayor riqueza en germoplasma de la especie (Badenes y col., 2006). Las mayores colecciones de melocotón se encuentran en Nanjing, Zhengzhou y Beijing (Wang y col., 2002b). En algunas áreas de este país se encuentran todavía melocotoneros silvestres conocidos como “Maotao” (melocotón peludo) o “Yitao” (melocotón silvestre), que se utilizan como patrones para los cultivares mejorados (Scorza y Okie, 1990).

1.2. Taxonomía del melocotonero

El melocotonero es una planta *Dicotyledoneae*, que pertenece a la familia de las *Rosaceaes*, subfamilia *Prunoideae*, género *Prunus* (L.), subgénero *Amygdalus*, sección

Euamygdalus. Existen 5 especies distintas de melocotonero, todas procedentes de China: *P. persica* (L.) Batsch, *P. davidiana* (Carr.) Franch, *P. mira* Koehne, *P. kansuensis* Rehd. y *P. ferganensis* (Kost. & Rjab) kov. & kost (Hancock y col., 2008).

Las variedades comerciales pertenecen a la especie *Prunus persica* (L.) Batsch, especie diploide con un número de cromosomas 2n=2x=16, la cual está dividida habitualmente por los botánicos en diferentes variedades botánicas (Fuente: IOPI, http:/www.iopi.org):

- ✓ Melocotón: *Prunus persica* (L.) Batsch var. *persica*. Incluye las variedades de melocotón ya sean de carne amarilla o blanca, de hueso libre o adherente. Dentro de este grupo, algunos autores denominan *pavía* al melocotón de hueso adherente. Este grupo de frutos también recibe la denominación de *duraznos*.
- ✓ Nectarina de hueso libre: *Prunus persica* (L.) Batsch var. *nectarina* (Aiton) Maxim. Incluye las nectarinas bien sean de carne blanca o amarilla.
- ✓ Nectarina de hueso adherente: *Prunus persica* (L.) Batsch var. *nucipersica* (Borkh.) Schneider. Incluye las nectarinas bien sean de carne blanca o amarilla.
- ✓ Melocotón plano o Paraguayo: *Prunus persica* (L.) Batsch var. *platycarpa* L.H. Bailey. Incluye las variedades de forma plana o achatada, bien sean con piel de melocotón o nectarina, de carne blanca o amarilla.

El fruto del melocotonero botánicamente se define como drupa (Brady, 1993). Es un fruto de gran tamaño, de forma más o menos globosa, con una línea de sutura en su epidermis delgada (piel), un mesocarpio carnoso (pulpa), un endocarpio (hueso) que contiene la semilla y una cavidad alrededor del pedúnculo (MARM, 2013).

1.3. Importancia económica del melocotonero

1.3.1. Importancia del melocotonero a nivel mundial

El melocotonero es la tercera especie frutal más producida en el mundo, detrás del manzano y del peral (Byrne y col., 2012). En los últimos 15 años, la producción del melocotonero se ha duplicado como consecuencia del uso de técnicas de cultivo más eficientes, de la introducción de nuevas variedades y de patrones mejor adaptados (Llácer, 2005; Iglesias, 2013), pasando de 11,4 millones de toneladas en 1995 a 20,5 millones de toneladas en 2010 (FAOSTAT, 2012). Asia es el continente de mayor producción (12,9 millones de toneladas en 2010), seguido por el continente europeo (4 millones de toneladas en 2010) y Estados Unidos (1,3 millones de toneladas en 2010) como segunda y tercera área geográfica en importancia. Le siguen América del Sur (1,1 millones de toneladas en 2010), África (0,8 millones de toneladas en 2010) y Oceanía (0,1 millones de toneladas en 2010) (FAOSTAT, 2012).

1.3.2. Importancia del melocotonero en la Unión Europea

El melocotonero ocupa un segundo lugar en la Unión Europea en cuanto a importancia después del manzano, con una producción de 3.736 miles de toneladas (Europêch, 2012). El principal productor de melocotón es Italia con un 42% de la producción total, seguido por España con un 30% de la producción, Grecia con un 20% de la producción y Francia con un 8% de la producción (Europêch, 2012).

En cuanto a las tipologías de fruto o subespecies de melocotón, el melocotón rojo (melocotón plano incluido) y la nectarina son las que más se producen, con 39,6% y un 40,3% respectivamente de la producción total. Le sigue la pavía con un 20% de la producción total. La evolución según tipología de fruto en el período 1991-2012 (Figura 1.1), muestra un notable incremento de la producción de nectarina, un aumento moderado de la del melocotón, debido principalmente al incremento del melocotón plano, y un descenso muy significativo de la producción de durazno o pavía que en 1992 representaba el 67% de la producción total.

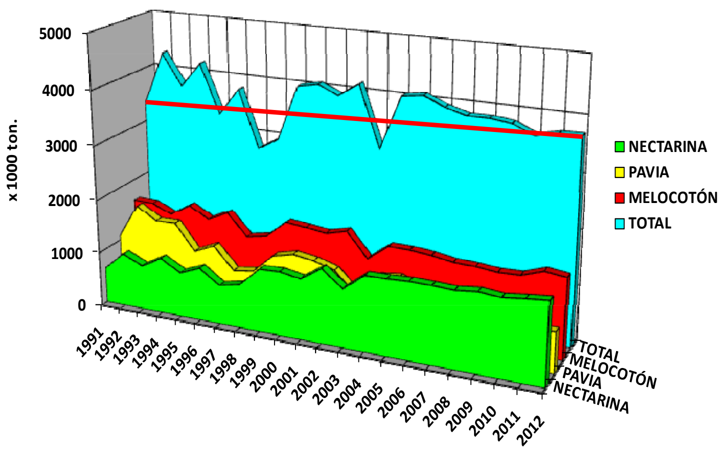

Figura 1.1. Evolución de la producción de los principales grupos varietales en Europa en el período 1991-2012 (Europêch, 2012).

1.3.3. Importancia del melocotonero en España

En España la producción anual media de melocotón es de alrededor del millón de toneladas, lo que la convierte en la especie de fruta dulce más producida, seguida por el manzano y el peral (FAOSTAT, 2012). Según datos del 2010, la superficie del melocotonero consta de 78.000 ha y una producción de 1.091.000 toneladas (Iglesias y col., 2012).

Se localiza principalmente en las regiones del arco mediterráneo, siendo Cataluña, Aragón y Murcia las más importantes, y ocupando un lugar destacable Extremadura y Andalucía, tal como se observa en la Figura 1.2. El melocotonero, en particular, es una especie frutal bien adaptada a zonas calurosas con escasas precipitaciones, lo que reduce la incidencia de enfermedades si se compara con otros países como Italia y Francia (Llácer y col., 2009a,b; Iglesias, 2010) y no afecta negativamente en la calidad del fruto. Pero no todo son ventajas, por su floración precoz, el riesgo de heladas es mayor que en el manzano, peral o cerezo, por lo que no es una especie adaptada a todas las zonas de producción. A pesar de ello, al igual que ha ocurrido en Italia en las dos últimas décadas, su cultivo se ha meridionalizado, es decir, se ha ido desplazando hacia el sur, buscando la precocidad o extraprecocidad de la recolección, lo cual ha sido posible gracias a la disponibilidad de numerosas variedades de bajo reposo invernal (*low chilling*) (Iglesias y Casals, 2011; Iglesias, 2013).

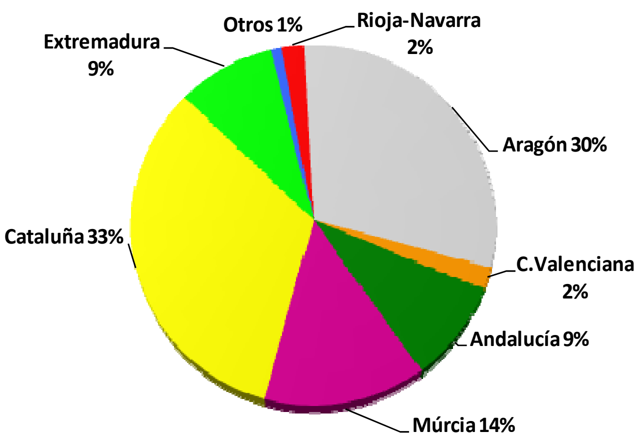

Figura 1.2. Producción de melocotonero en España por comunidades autónomas en 2010 (MARM, 2012).

La superficie de cultivo del melocotonero en España ha aumentado casi un 200% desde 1980 hasta 2011. Desde el año 1990 hasta el 2001, la superficie de cultivo osciló en torno a las 75.000 ha, aumentando sustancialmente en los últimos años (Figura 1.3). Por otra parte, la producción aumentó un 315% desde 1980 hasta 2011, con descensos puntuales debidos a fuertes heladas o descensos térmicos acusados en las primaveras de algunos años (FAOSTAT, 2012; Europêch, 2012). Además de su buena adaptación, la mejora tecnológica, como por ejemplo el *vaso catalán* (sistema de formación muy bien adaptado en España) (Montserrat e Iglesias, 2011) y la renovación varietal, como la introducción de nuevas variedades de melocotón, nectarina y melocotón plano, de programas de mejora de todo el mundo, con un amplio rango de maduración (desde mediados de Abril hasta finales de Octubre), de tamaños, sabores y apariencias diversas (Iglesias y col., 2005, 2010) han propiciado un incremento progresivo y mayor de las producciones que de las superficies durante los últimos quince años, lo que supone una eficiencia tecnológica cada vez mayor. La importante renovación varietal realizada ha permitido incrementar y diversificar notablemente la oferta.

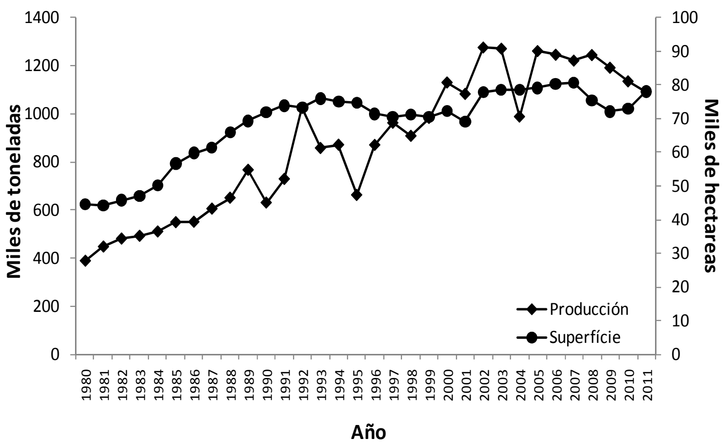

Figura 1.3. Evolución de la superficie cultivada y de la producción de melocotonero en España (FAOSTAT, 2012; Europêch, 2012).

Uno de los aspectos que caracterizan el sector del melocotón en España es su creciente competitividad en los mercados internacionales. Ello es debido a su capacidad para ofrecer un producto de elevada calidad y colocarlo en los mercados de destino a precios inferiores (menores costes de producción) a los de otros países competidores como Italia o Francia (Iglesias y Casals, 2011). Desde 2006 (Figura 1.4), debido a un incremento anual en la producción de más de 30%, España se ha convertido en el primer exportador de Europa tanto a países intra como extracomunitarios, seguido de Italia, Grecia y Francia. Esta exportación ha representado en los últimos años alrededor del 55% de la producción y se ha basado en el melocotón, la nectarina y el melocotón plano. La pavía producida en España se ha destinado casi exclusivamente a mercado nacional, tanto para consumo en fresco como para la transformación. Los principales países importadores han sido Alemania, Francia, Italia, Polonia, Portugal, Reino Unido y Rusia en el caso del melocotón, y Alemania, Bélgica, Francia, Países Bajos, Polonia, Reino Unido y Rusia en el caso de la nectarina (Iglesias y Casals, 2013).

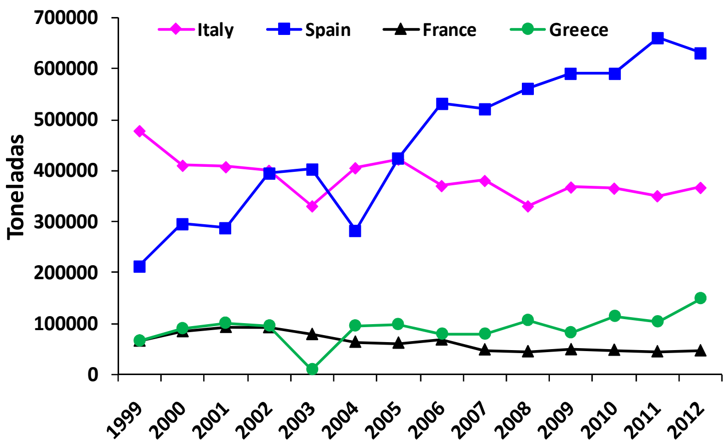

Figura 1.4. Evolución de la exportación de melocotón de los principales países productores de la Unión Europea (DAAM, 2012).

La evolución en España de las producciones según tipología de fruto, en el período 1991-2012, muestra un notable incremento de la producción de nectarina, un aumento moderado del melocotón rojo (melocotón plano incluido) y un descenso muy significativo de la producción de pavía (Figura 1.5). En 2012, la nectarina ha aportado el 41% de la producción total, el melocotón rojo el 35% y la pavía el 24% (Europêch, 2012). En un futuro, los grupos que seguirán incrementando su producción serán la nectarina y el melocotón plano, ambos de amplia aceptación en los mercados de exportación, en detrimento del melocotón rojo y principalmente de las pavías (Iglesias y Casals, 2013).

Desde hace unos 10 años, el melocotón plano ha ido adquiriendo mucha importancia en España, hasta el punto de ser actualmente el único país productor a nivel mundial de éste a gran escala (Iglesias, 2013). La principal zona productora es Cataluña, con 48.000 toneladas de las 97.400 toneladas que se produjeron en España en el 2011, seguida por Murcia y Aragón (Iglesias y col., 2010; Europêch, 2012). El 62% de su producción total se destina a exportación, sobre todo a Alemania, Reino Unido, Bélgica, Noruega, Polonia y Rusia (Iglesias, 2013). El resto es destinado a consumo en fresco, ya que es un fruto muy apreciado por su sabor dulce y aromático (Sorrenti y col., 2010; Reig y col., 2012). Por otra parte, la nectarina plana o platerina todavía es menos conocida por los agricultores y los consumidores españoles. Su producción supone tan solo el 13% de la producción total de frutos planos en España (Iglesias, 2013).

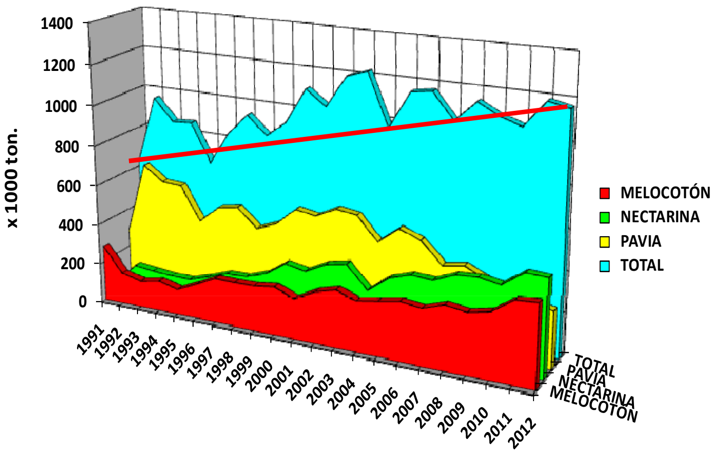

Figura 1.5. Evolución de la producción de los principales grupos varietales en España en el período 1991-2011 (Europêch, 2012).

Los hogares españoles realizan sus compras de melocotón y nectarina en un 40% de las ocasiones en tiendas tradicionales y en un 28% en supermercados e hipermercados, por lo tanto son las tiendas de proximidad y de pequeña o mediana superficie las más importantes para la venta de este tipo de fruta.

La importante innovación varietal junto a la reconversión de plantaciones realizada en España en las dos últimas décadas no se ha traducido en un incremento del consumo interno, el cual en los últimos años se ha atascado en los 4,3 kg/habitante y año (Figura 1.6), muy inferior al de Grecia (23), Italia (21) o Francia (6), también productores de melocotón (Iglesias y Casals, 2013). Los consumidores españoles mencionan como causa principal de este bajo consumo la falta de calidad del producto (Iglesias y col., 2012). Esto se traduce en frutos con falta de sabor y excesiva firmeza, debido fundamentalmente a su recolección anticipada para evitar mermas en el proceso de comercialización (Llácer y col., 2009c). También la calidad variable e inconstante y la falta de identificación del tipo de sabor (Iglesias y col., 2012) son causas del bajo consumo. Esta misma tendencia se ha dado también en otros países o Estados, como Italia o Francia (Clareton, 2000; Della Strada y Fideghelli, 2003) o California (EUA), donde el porcentaje de consumidores no satisfechos llegó a alcanzar el 80% (Crisosto, 2002).

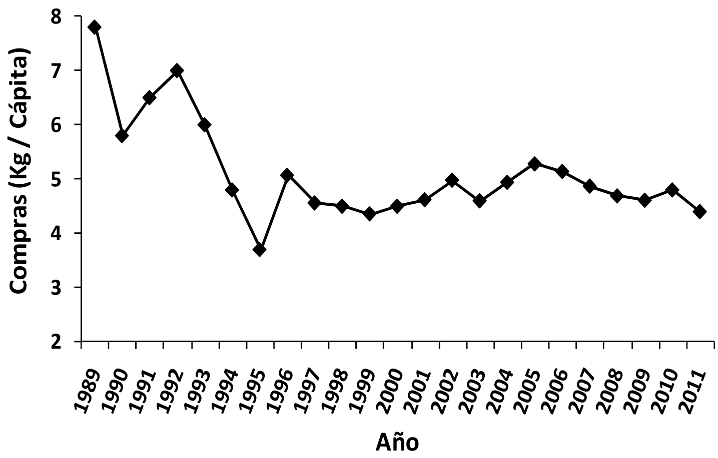

Figura 1.6. Evolución del consumo de melocotón en los hogares españoles en el período 1989-2011 (Fuente: MARM, 2012).

1.3.4. Importancia del melocotonero en Cataluña

El melocotonero es la principal especie de fruta dulce cultivada en Cataluña, seguida del manzano y del peral. En 2011, su superficie total plantada era de 21.675 ha con una producción de 397.730 toneladas. Esta cantidad representó el 7% de la producción final agraria catalana (DAAM, 2012).

Lleida es la principal provincia productora de Cataluña, con un 87,5% de la producción total, seguida de Tarragona, con un 9,9%, Barcelona, con un 1,5% y Girona, con un 1,1% (DAAM, 2012).

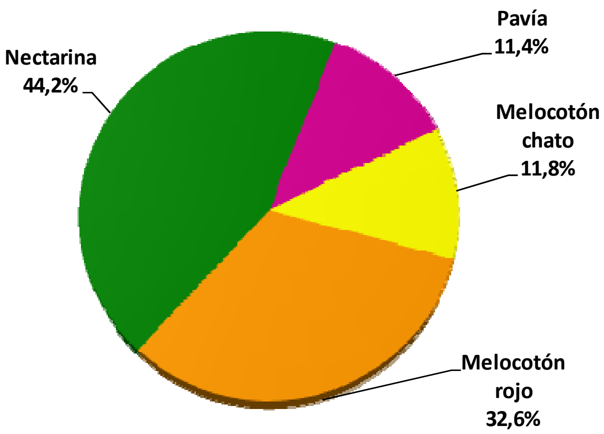

Figura 1.7. Distribución de la producción de melocotón en Cataluña (DAAM, 2012).

En cuanto a la tipología de fruto (Figura 1.7) en 2011, la mayor producción fue para la nectarina, seguida del melocotón rojo, el melocotón plano y pavía.

1.4. Mejora genética en el melocotonero

La mejora genética de los frutales de hueso abarca tanto la mejora de variedades como la mejora de portainjertos. No obstante, en esta tesis se hablará solamente de la mejora varietal.

El melocotonero es una de las especies con mayor gama de variedades disponibles entre los frutales caducifolios. A escala mundial, más de un millar de variedades de melocotón han sido licenciadas entre 1970 y 2011, y en los últimos 10 años se han licenciado por año una media de 100 variedades (Badenes y col., 2006). Sin embargo, la mayoría de ellas tiene un origen común a partir de un reducido número de variedades comerciales, si se compara con la gran diversidad genética existente. A partir de unas pocas introducciones de China y de Asia Central se desarrollaron las variedades europeas que posteriormente fueron fuente de germoplasma para otras zonas productoras como América del Norte y del Sur, Sudáfrica, Australia y Nueva Zelanda (Llácer y col., 2009c). Estas variedades se han adaptado al consumidor occidental, consiguiendo unos frutos uniformes y de óptimo calibre, con buena apariencia y con más acidez que las variedades asiáticas.

Actualmente existen en el mundo más de 70 programas de mejora genética (Tabla 1.1), liderados por Estados Unidos, de donde proceden el 52% de las nuevas variedades difundidas en el mundo, mientras que el 30% proceden de Europa (principalmente de Italia y Francia, y en menor medida de España) y el resto de Sudáfrica, Australia, China, Japón, Méjico y Brasil (Byrne, 2002).

1.4.1. Objetivos de la mejora genética

Los primeros programas de mejora básicamente dedicaron sus esfuerzos hacia la mejora de las características comerciales del fruto tales como el color, la firmeza y su apariencia, sin apenas incidencia en la resistencia o su adaptación al entorno, ni en sistemas de producción económicamente eficientes (Monet y Bassi, 2008b). Pero, en las últimas décadas esto ha ido cambiando. Se están dirigiendo importantes esfuerzos hacia variedades de producción elevada y constante, de buena calidad y atractivas para el mercado, la cual cosa implica una combinación perfecta entre adaptación, manejo del árbol y características del fruto para así satisfacer tanto al productor como al consumidor y facilitar su manejo poscosecha (Byrne y col., 2012). Para ello, los mejoradores están dedicando actualmente sus esfuerzos en múltiples objetivos como son: la *adaptabilidad climática, resistencia a plagas y enfermedades*, *resistencia a factores abióticos*, *hábitos de crecimientos del árbol*, *características del fruto*, *ampliación del calendario de recolección* y *efectos beneficiosos para la salud*.

Tabla 1.1. Programas de mejora genética activos en el mundo para la obtención de nuevas variedades (Badenes y col., 2006; Bellini y col., 2004a; Fideghelli y Della Strada, 2008; Iglesias y col., 2012; Liverani y col., 2005; Okie y col., 2008; Topp y col., 2008).

Programa	País	Financiación
ALM-Frutaria *Planasa* *PSB Producción Vegetal* *Proseplan* *Provedo*	España	Privada
Estación Experimental de Aula Dei (EEAD-CSIC) *Centro de Investigación y Tecnología de Aragón (CITA)* *Instituto Agrario de Investigaciones Agrarias*		Pública
Imida-Novamed *IRTA-ASF (Fruit Futur)*		Privada y Pública
A&L Maillard-ASF *Europépinières* *Star Fruits–AC*	Francia	Privada
INRA		Pública
A. Minguzzi *CAV* *CIV* *Vivai G. Battistini* *V. Ossani*	Italia	Privada
CRA: FRU Roma + FRU Forlí *DCA-Universidad de Bolonia* *Universidad de Florencia* *Universidad de Pisa*		Pública
Universidad de Milán–New Plant		Privada y pública
Univ. Of Western Sydney	Australia	Pública
EMBRAPA *Instituto Agronómico*	Brasil	Pública

Tabla 1.1. Continuación.

Programa	País	Financiación
Agricultural Research Institute *Beijing Institute of Pomology* *Forestry and Fruit Research Institute* *Zhengzou Fruit Research Institute* *Horticultural Research Institute (HRI)*	China	Pública
Burchell Nursery *G. Merrill* *Bradford Farm & B Q Genetics* *P.J. Friday* *Sun World International, Inc.* *Zaiger's Inc.*	Estados Unidos de América	Privada
Arkansas University *California University* *Clemson University* *Florida University* *Michigan University* *North Carolina University* *Rutgers University* *USDA-ARS* *Texas A & M University*		Pública
Universidad de Budapest. Facultad Agraria de Corvinus	Hungría	Pública
Centro de Fruticultura, Colegio de Universidad Autónoma de Queretaro	Méjico	Pública
Plant Food Research	Nueva Zelanda	Pública
Research Institute of Pomology and Floriculture	Polonia	Pública
SCPP Fruit Research Station	Romania	Pública
ARC-Infrutec	Sudáfrica	Pública
Royal Project Fundation *Royal Agricultura Station*	Tailandia	-
Taiwan Agricultural Research Institute	Taiwan	Pública

La adaptabilidad climática es la clave para obtener variedades con alto y constante rendimiento productivo (Byrne y col., 2012). Ésta depende básicamente de las necesidades de frío y calor, las cuales regulan la época de floración y maduración, y la tolerancia al frío y al calor (Liverani, 2008). Esta adaptación ha implicado mucho esfuerzo en desarrollar y seleccionar variedades con bajas necesidades de frío (*low- chilling requirement*), las cuáles han permitido extender este cultivo a zonas tropicales y sub-tropicales (Liverani, 2008); variedades low-chilling tolerantes a altas temperaturas durante la floración para mejorar la producción en zonas muy cálidas (Byrne, 2012); variedades tolerantes al frío en zonas donde las heladas primaverales producen pérdidas en la producción durante la floración (Byrne y col., 2012); variedades tolerantes al frío del invierno para zonas frías del hemisferio norte (Byrne y col., 2012); y variedades de maduración temprana en zonas donde el cultivo de melocotón se ha meridionalizado para así extender el calendario de maduración y ampliar la cuota de mercado (Byrne, 2012).

Debido a la creciente preocupación de los consumidores por la presencia de residuos químicos en las frutas y verduras, y dado que numeras plagas y enfermedades atacan al melocotón, especialmente en zonas de cultivo húmedas, los mejoradores de todo el mundo han dedicado esfuerzos en obtener variedades resistentes o tolerantes a los principales organismos que las producen (Byrne y col., 2012; Liverani, 2008), como son: *Monilinia fructicola* (Wint.) Honey y *Monilinia laxa* (Aderhn & Rull) Honey; *Xhanthomonas arboricola* pv. *pruni*; *Taphrina deformans* (Berk.) Tul.; *Transchelia discolor* (*Fuckel.*) *Transchel & Litv*; *Sphaeroteca pannosa* (Wall. FR. Lev.); *Podosphaera pannosa* (Wallr.:Fr.) Braun & Takamatsu; *Potyvirus*; *Meloidogyne* spp.; *Armillaria mellea* (Vahl: Fr.) P. Kumm. y *Armillaria tabescens* (Scop.); y *Myzus persicae*.

El hábito de crecimiento típico del melocotonero corresponde a un árbol robusto, de copa ovalada y de altura media entre 4-6 m. Próximo a este hábito de crecimiento, llamado estándar, se conocen otras formas de crecimiento como son el porte pendular, el porte erecto o el carácter enanizante (Bassi y Monet, 2008; Liverani, 2008). Los programas de mejora están evaluando dichos hábitos de crecimiento del árbol para así obtener nuevas variedades que requieran menos aclareo, menos tiempo de manejo y que sean más eficientes en la producción de frutos de calidad (Byrne 2005; Byrne, y col., 2012; Sansavini y col., 2006).

Los hábitos de los consumidores están cambiando, especialmente en países desarrollados, en cuanto a salud y comodidad (Hankock y col., 2008). Por ello, los programas de mejora en estos últimos años han ido diversificando su oferta varietal, con una amplia gama de colores, tanto en la piel como en la pulpa, de texturas y grados de ablandamiento, formas, tamaños y sabores (Byrne y col., 2012), y cada vez están teniendo más en cuenta los aspectos de calidad del fruto como factor diferencial (Martínez-Calvo y col., 2006), ya que es una de las quejas más comunes en los consumidores (Byrne, 2005;

Iglesias, 2013). Para ello, los esfuerzos en la mejora genética se han focalizado principalmente en obtener:

✓ Frutos con un buen tamaño (calibre y peso), y especialmente en aquellas zonas donde la temperatura es muy cálida durante el período de desarrollo del fruto (FDP) y en variedades de corto FDP (Byrne y col., 2012).

✓ Frutos con una buena firmeza, ya que es esencial para un buen manejo en cosecha y en poscosecha (Byrne y col., 2012), debido a que los mercados están cada vez más globalizados. La mayoría de los melocotones para el consumo en fresco son *melting flesh* o *pulpa fundente* (Infante y col., 2008). Esta textura muestra un importante reblandecimiento del fruto en su último estadio de maduración. Ello es debido fundamentalmente a la solubilización enzimática de las pectinas insolubles de la pared celular por la enzima endopolygalacturonasa (endoPGase), que provoca una reducción de la cohesión celular y con ello el ablandamiento del tejido (Redgwell y Fischer, 2002). En el estadio final de la maduración, esta textura produce una elevada cantidad de etileno. Recientemente, algunos programas de mejora han focalizado su atención en obtener variedades para el consumo con otro tipo de texturas, *nonmelting* o *pulpa no fundente* y *stony hard* (Byrne y col., 2012; Liverani, 2008). La textura *nonmelting* o *pulpa no fundente*, confiere a los frutos una buena firmeza en estados más avanzados de la maduración, obteniendo frutos con una mayor calidad y tamaño (Byrne y col., 2012). Se caracteriza por tener una textura firme cuando el fruto está totalmente maduro, ablandándose poco a poco cuando está sobremaduro, pero nunca llega a tener una textura fundente (Bassi y Monet, 2008). Esto es debido a la falta de la enzima responsable de la destrucción de las pectinas en la pared celular en los frutos de textura *melting*, la endopolygalacturonasa (endoPGase) (Lester y col., 1996). En el estadio final de la maduración, esta textura produce una elevada cantidad de etileno. La textura *stony hard* confiere a los frutos una elevada firmeza y crocanticidad. Los frutos con esta textura maduran muy lentamente, ya que no producen etileno y nunca se ablandan cuando están maduros (Byrne y col., 2012; Topp y col., 2008). Estas características hacen que los frutos puedan tener una larga vida poscosecha (Byrne, 2012). Dentro de la textura *melting* se encuentra un fenotipo muy interesante, parecido al *stony hard* en firmeza y crocanticidad, pero que se convierte en *melting* solo cuando alcanza la plena maduración, mostrando un retraso en el ablandamiento del fruto y la producción de etileno. Este fenotipo queda clasificado dentro de la Tabla 1.2, como *melting very, very firm*. Diferentes variedades comerciales (‘Big Top’, ‘Rich Lady’ o ‘Diamond Princess’) actualmente producidas presentan este tipo de textura (Byrne y col., 2012), pero sin lugar a dudas ‘Big Top’ es la más importante y la que en los últimos 15 años ha supuesto la mayor innovación, debido a sus características de textura, pero también a su elevada coloración y calibre y a su sabor dulce. Es por ello que esta variedad se ha utilizado ampliamente como parental en numerosos programas de mejora genética (Bassi y col., 2008).

Tabla 1.2. Clasificación provisional de las texturas del melocotón (Bassi y col., 1998; Haji y col., 2005; Mignani y col., 2006; Yoshiba, 1976).

		Pectinas			
Textura	**Firmeza**	**Soluble**	**Insoluble**	**Calcio**[a]	**Etileno**[b]
Melting					
Soft	Baja	+++	+	++	++
Firm	Alta	+++	++	+++	++
Very, very firm	Muy alta	++	++	++	+
Stony hard	Muy alta	+	+++	++	-/(+)
Nonmelting	Muy alta	+++	+++	+++	+++

El símbolo de + representa el contenido relativo por cada columna respectivamente; - significa ausencia; (+) significa presencia.
[a] Contenido en pulpa; sin límite contundente entre los distintos fenotipos.
[b] Cantidad producida por el fruto entero.

✓ Frutos con pulpas blancas, tanto en melocotón como en nectarina, altamente aromáticas y sabrosas y con buen comportamiento en poscosecha (Conte y col., 2010; Infante y col., 2008) para el mercado Americano y Europeo (Byrne y col., 2012).

✓ Frutos con pulpas de color naranja o rojo, con buen sabor (Byrne, 2005; Sloan, 2008) por su innovación y beneficios para la salud debido a su elevado contenido en polifenoles (Conte y col., 2010; Byrne y col., 2012).

✓ Frutos con una elevada e intensa coloración roja en la piel, especialmente en nectarinas (Bellini y col., 2004b; Carbó y Iglesias, 2002; Iglesias, 2013; Liverani, 2008; Scorza y Sherman, 1996).

✓ Frutos con pulpas y pieles sin antocianos o “deantociánicas” (Conte y col., 2010; Infante y col., 2008).

✓ Frutos de forma perfecta, esférica, sin protuberancias en la sutura ni en la cavidad pistilar para su óptimo manejo tanto en la recolección como en la poscosecha (Byrne y col., 2012). Principalmente forma redonda en melocotones y redonda-alargada para nectarinas (Liverani, 2008).

- ✓ Frutos de forma plana (Liverani, 2008). Estudios de consumo realizados recientemente en España han demostrado que son más fáciles de consumir que el melocotón y la nectarina (Iglesias y Carbó, 2009), por lo que aportan una mayor comodidad de consumo, y en particular las nectarinas planas por no poseer vellosidad.
- ✓ Frutos con una amplia gama de sabores, desde sub-ácidos (elevado contenido en azúcares y bajo contenido en acidez), dulces, equilibrados hasta muy ácidos (Byrne y col., 2012; Conte y col., 2010; Iglesias y col., 2010; Liverani, 2008).

La obtención de variedades extra–tempranas y tardías de elevada calidad, han permitido al agricultor ampliar su período de recolección, obteniendo nuevas cotas de mercado (Byrne, 2012; Byrne y col., 2012; Liverani, 2008). También la comodidad de consumo, en el caso de los melocotones planos, y su sabor dulce han sido muy bien valorados por los consumidores con un incremento notable de la oferta y la demanda en los últimos años en España (Iglesias, 2013).

1.4.2. Situación de la mejora vegetal en España

Al igual que otros países productores, la excesiva dependencia de variedades obtenidas en programas de mejora extranjeros por parte de los productores españoles, principalmente de Estados Unidos, Italia y Francia, la falta de adaptación de éstas a las condiciones agroclimáticas de nuestro país, el acceso limitado a muchas variedades y a las condiciones económicas impuestas por los obtentores, editores y/o multiplicadores (pago de *royalties*), han promovido la aparición a partir de la década de los años 90 de varios programas de mejora genética en España (Iglesias y col., 2010; Llácer y col., 2009c).

Actualmente hay más de 10 programas de mejora (Tabla 1.1). Sus objetivos de mejora varían según la zona donde se ubican y el tipo de financiación del programa. En España, los programas de mejora genética privados básicamente buscan la obtención de variedades de características mejores o similares a los mejores cultivares extranjeros para evitar la dependencia de los programas foráneos (Llácer y col., 2009c). Para ello se recurre a combinar por hibridación un cierto número de variedades disponibles, la mayoría obtenidas en California y Florida, pero también a su vez, en algunos programas con material chino para ampliar la base genética, que en la actualidad es muy reducida (Aranzana y col., 2003).

En cambio, los programas de mejora genética públicos se plantean objetivos a corto plazo y largo plazo, buscando no sólo la independencia de programas extranjeros, sino que también la adaptación climática, la calidad interna y nutricional del fruto, la resistencia a plagas y enfermedades y la disminución de los costes de producción (Llácer y col., 2009c). Por ejemplo, los diversos programas públicos (IVIA, CITA, etc.) se han centrado en la obtención de variedades mejoradas combinando germoplasma autóctono, básicamente de pavías, con variedades de melocotón y nectarina dulces altamente coloreadas para la obtención de variedades de baja necesidad de frío que se adapten bien en las regiones del sur de España (Badenes y col., 2006; Batlle y col., 2012; Fideghelli y Della Strada, 2008), y en menor escala en la mejora del melocotón plano (Iglesias y Carbó, 2009).

Hoy en día es todavía muy elevado el número de variedades cultivadas en la zona de Valle del Ebro que se han obtenido en condiciones climáticas distintas a las de ésta. Esto hace que en muchas ocasiones ocurra lo que se ha denominado técnicamente el "coeficiente sorpresa" de una variedad (Berra y col., 2011; Iglesias y col., 2010; Reig y col., 2013). Es decir, que el comportamiento agronómico, y por lo tanto, el comportamiento cualitativo de una variedad es incierto cuando ésta es cultivada en condiciones climatológicamente diferentes de donde fue seleccionada, debido a que la adaptabilidad de las nuevas variedades a diferentes condiciones climáticas no ha sido uno de los principales objetivos de mejora en las últimas décadas (Iglesias, 2013). Si a este hecho se le añade el gran dinamismo varietal que caracteriza esta especie de *Prunus*, se hace casi imposible saber por parte de los investigadores, técnicos y agricultores qué variedad se comporta mejor que otra. En este trabajo se han caracterizado más de 100 variedades comerciales de melocotón en función de aspectos agronómicos, morfológicos y cualitativos con el fin de proporcionar esta información tan necesaria para el sector, pero siendo conscientes de que muchas de estas variedades quizás se quedaran obsoletas durante el proceso de evaluación y nunca se introduzcan a escala comercial.

1.5. Caracterización agronómica del melocotonero

La adaptación de una variedad en la zona donde debe ser cultiva incluye una serie de caracteres agronómicos propios de la variedad, como el vigor, época de floración, tipo de flor, fenología, densidad de floración o floribundidad, cuajado, susceptibilidad a heladas primaverales, intensidad de aclareo, carga frutal y eficiencia productiva, como se describen en los Capítulos 3 y 4 de esta tesis doctoral, y de factores externos como el riego, la poda y la fertilización, que no han sido objeto de estudio en este trabajo. Estos caracteres agronómicos posteriormente se reflejan en la productividad (Fideghelli y Sansavini, 2005), en los costes de producción (Monet y Bassi, 2008; Iglesias, 2013) y en la calidad final del fruto en unas determinadas condiciones ambientales. Es decir, el objetivo final que se persigue es la selección de variedades con una elevada productividad al mínimo coste posible y con una excelente calidad en el fruto. Ello pasa por su adaptación a las diferentes zonas de cultivo.

El melocotonero es un árbol robusto, es decir en general vigoroso, de copa ovalada y con una vida útil económica de 12-15 años como máximo. Su tamaño está influenciado por el vigor conferido principalmente por el portainjerto, por las condiciones edafo-climáticas y por el porte o hábito de crecimiento de éste.

La época de floración es de gran importancia en esta especie, dado que es más precoz que otras especies frutales como el manzano, el peral o el cerezo, lo que supone un mayor riesgo frente a heladas primaverales en muchas zonas de cultivo en España. La época de floración está influenciada por dos mecanismos complementarios: la acción del frío invernal (acumulación de horas de frío o *chilling units*) necesario para romper el estado de reposo de las yemas y la acción de las temperaturas cálidas de primavera sobre las yemas receptivas por la acumulación de las horas de frío (inferior a 7ºC) propias de cada variedad. Así pues, la época de floración de una variedad se puede retrasar por no haber acumulado un total de horas de frío suficiente o porque las temperaturas de primavera no sean suficientemente elevadas. También se puede adelantar si ha cubierto las horas de frío, lo que suele pasar cuando se cultivan variedades *mid* o *low chilling* en zonas con buena disponibilidad de horas de frío, como el Valle del Ebro. Normalmente, se consideran tres niveles de expresión: *floración temprana*, cuando las horas de frío acumuladas son inferiores a 600; *floración media*, cuando las horas de frío acumuladas varían entre 600 y 900; y *floración tardía*, cuando éstas son superiores a 900 (Bassi y Piagnani, 2008; MARM, 2013). En España la disponibilidad de horas de frío es muy amplia según sea la zona de producción y oscila entre 200 horas en el sur (Andalucía, Murcia) y 1100 en las zonas tardías del Valle del Ebro (Llácer y col., 2009c; Iglesias, 2013).

La fenología del melocotonero, descrita por Baggiolini (1952), condiciona su tolerancia a heladas primaverales, dado que la tolerancia está fuertemente relacionada con el estado fenológico de la variedad en cuestión, pero también de la época de floración. De hecho, se han registrado diferencias entre variedades de hasta 20 días. Las heladas primaverales pueden ocurrir desde la hinchazón de la yema floral (principios de marzo) hasta la formación de los pequeños frutos (mediados de abril), que es cuando la resistencia al frío de la yema floral va disminuyendo progresivamente (Miranda y col., 2005; Moure, 1995), siendo las variedades de floración temprana las más sensibles (Aygün y San, 2005; Okie y col., 1998).

El síntoma inicial más característico de una helada es el cambio de color y su manifestación se muestra habitualmente como oscurecimiento de la parte dañada que, posteriormente puede extenderse o no al resto del órgano. No obstante y según el estado fenológico de la yema de flor, cada una de sus partes tiene diferente sensibilidad a las bajas temperaturas, tal y como describen Royo y col. (1998) para frutales de hueso (melocotonero, almendro y cerezo) y pepita (manzano y peral). Las partes más frecuentemente dañadas se consideran las más sensibles. Cuando se observa que una helada solo ha afectado a las partes más sensibles se puede deducir que fue muy ligera y, por tanto, no afectaría más que a una pequeña proporción de flores (o frutos). Por el contrario, si afecta a las partes más resistentes se puede deducir lo contrario: habrá sido muy intensa y, por tanto habrá afectado a una gran parte de los órganos reproductores (Royo y col., 1998), traduciéndose en una pérdida importante de producción, y por lo tanto, en pérdidas económicas. No obstante, es difícil fijar umbrales de resistencia al frío, al haber importantes diferencias intervarietales, como se describe en el Capítulo 4 de esta tesis doctoral.

Tabla 1.3. LT_{10} y LT_{90} medias para cada estado fenológico del melocotón.

Estado fenológico	**LT_{10}**	**LT_{90}**
B	-6.6	-15.4
C	-8.0	-13.8
D	-4.7	-9.9
F	-2.0	-6.6
G	-2.6	-4.4
H	-2.3	-3.6
I	-1.7	-3.6

En la Tabla 1.3 se observan las temperaturas críticas (LT_{10} y LT_{90}), temperaturas en las que el 10% y el 90% de las flores han sido afectadas por la helada, de cada uno de los estadios fenológicos del melocotón en general, excepto A y E, según un estudio realizado por Miranda y col. (2005) en varias especies del género *Prunus*. En otro estudio realizado por Osaer y col. (1998), los valores de las LTs fueron similares a las obtenidas por Miranda y col. (2005).

Según el vigor y la distribución de la yemas de flor, el melocotonero puede florecer y fructificar en ramas mixtas, ramas de dos años, chifonas o en ramilletes de mayo (Bassi y Monet, 2008; Bassi y Piagnani, 2008; MARM, 2013), dando una flor perigenea y hermafrodita, con un solo pistilo, de 20 a 30 estambres, y normalmente con un solo ovario (Bassi y Monet, 2008; MARM, 2013). La forma de la corola, compuesta de cinco pétalos, clasifica las flores del melocotón en dos grupos: *Rosacea* o *showy*, cuando los pétalos son largos y de color rosa más o menos claro; y *Campanulacea* o *non-showy*, cuando los pétalos son pequeños, de color rosa intenso y se observan claramente las anteras entre los pétalos (Bassi y Monet, 2008; Bassi y Piagnani, 2008; MARM, 2013; UPOV, 1995).

En plena floración, no todas las variedades presentan la misma densidad de floración o floribundidad (número de flores por metro lineal de rama mixta) (Lombard y col., 1988) entre ellas (Marini y Reighard, 2008; Reig y col., 2013). La tendencia de determinadas variedades a producir más yemas de flor, les confieren una mayor capacidad de estas a sobrevivir en invierno y a hacer frente a las heladas primaverales (Marini y Reighard, 2008). Se pueden clasificar en: *floribundidad baja*, cuándo tienen menos de 20 flores por metro lineal de rama mixta (por ejemplo la variedad 'Big Top'); *floribundidad media* cuando tienen entre 20 y 40 flores por metro lineal de rama mixta; y *floribundidad alta* cuando tienen más de 40 flores por metro lineal de rama mixta.

Normalmente, entre un 30-35% de las flores formadas acaba siendo un fruto maduro (Agustí, 2004). El número de pequeños frutos o de frutos jóvenes por metro lineal de rama mixta que cuajan correctamente depende, entre otros factores, de la temperatura durante el proceso de cuajado y de la densidad de floración de la variedad. En la zona del Valle del Ebro es típico realizar el aclareo de forma manual cuando los frutos están formados. Según sea la variedad, la época de maduración y el tamaño final del fruto esta operación se realiza con más o menos intensidad, dependiendo del número de frutos cuajados y del número de frutos deseables a dejar en las ramas mixtas para obtener una óptima carga frutal y una óptima producción (Marini y Reighard, 2008). El aclareo manual representa como media el 18% de los costes totales de producción (Iglesias, 2013), pudiéndose reducir o aumentar dependiendo de la variedad, de ahí la importancia de una buena elección. En zonas con bajo riesgo o sin riesgo de heladas y con variedades de floribundidad media–alta y recolección precoz es del todo imprescindible el aclareo en flor. Ello permite reducir hasta un 40% el coste de producción y mejorar el calibre de los frutos.

1.5.1. Crecimiento, desarrollo y maduración del fruto.

El crecimiento del fruto del melocotonero sigue una curva del tipo doble sigmoide (Conners, 1994). En ella se distinguen 3 fases, tal y como se observa en la Figura 1.8 (Agustí, 2004; Bassi y Piagnani, 2008; Marini y Reighard, 2008).

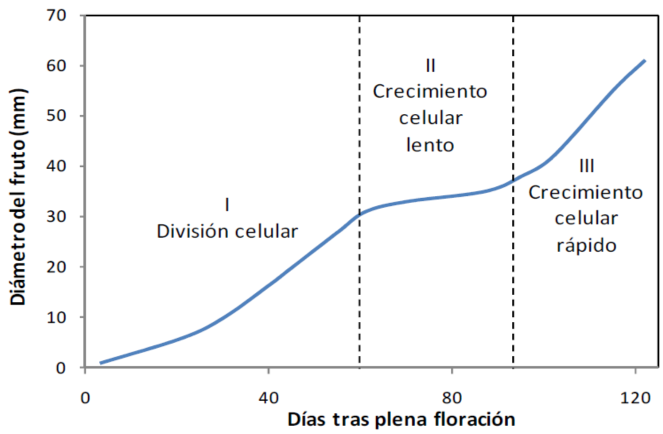

Figura 1.8. Curva de crecimiento (tipo doble sigmoide) del fruto del melocotonero (Conners, 1994).

- *Fase I*: Empieza en plena floración hasta 50 días después de floración, dependiendo de la temperatura y la variedad. Se caracteriza por su división celular y el desarrollo del endocarpio (hueso).
- *Fase II*: Crecimiento muy lento y lignificación o endurecimiento del endocarpio (hueso). La duración de esta fase depende de la época de maduración de la variedad. En variedades de recolección temprana, esta fase es muy reducida y muchas veces el cierre del endocarpio no se completa (Brady, 1993). De ahí, que muchas de éstas presenten un desorden fisiológico comúnmente llamado *hueso abierto* (*Split pit*).
- *Fase III*: También llamada '*final swell*'. Ocurre en las últimas semanas antes de la recolección. Se caracteriza por un rápido crecimiento del fruto debido a la expansión celular

del mesocarpio (pulpa) hasta que este alcanza prácticamente su tamaño final, y es cuando en el mesocarpio del fruto acumula sus reservas de agua, azúcares y ácidos.

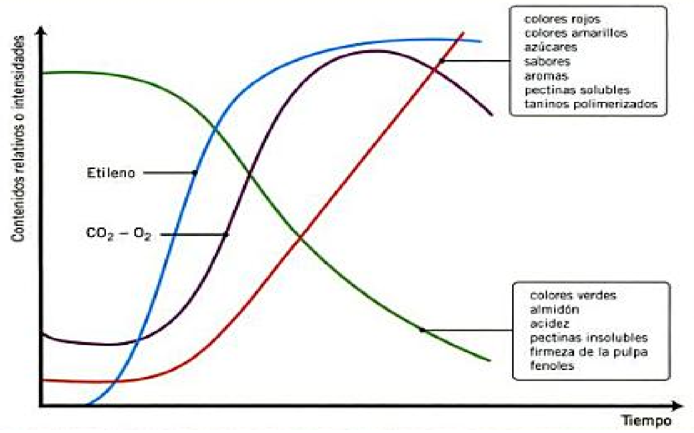

Figura 1.9. Efecto de la maduración sobre los compuestos de las frutas (Gil, 2010).

Sin embargo, para que un fruto adquiera el color, el sabor y la textura aptos para ser consumido se tienen que producir una serie de cambios físicos y químicos importantes (Figura 1.9). Estos cambios se producen durante el proceso de *maduración* del fruto, en el que se pueden distinguir tres clases de madurez del fruto (Coleto, 1995):

- *Maduración fisiológica* (*maturity*): Se produce en la fase III de crecimiento del fruto, cuando todas sus partes han alcanzado un estado de desarrollo suficiente para que, después de la cosecha y periodo poscosecha, su calidad sea, al menos, la mínima aceptable para el consumidor final (Crisosto y col., 1995).
- *Madurez de cosecha o madurez comercial*: Es cuando el fruto, dependiendo de la variedad, ha alcanzado su madurez fisiológica, y por lo tanto, ha llegado a su momento óptimo de recolección. Este estado de madurez influye enormemente en el sabor, en la vida útil y en la calidad del fruto, ya que el proceso de maduración del fruto controla los componentes del sabor y del aroma, los problemas de deterioro fisiológico, la susceptibilidad a daños mecánicos, la resistencia a la pérdida de humedad, la susceptibilidad a podredumbres, la vida útil y la habilidad a adquirir la madurez de consumo (Crisosto, 1994; Crisosto y col., 1995).
- *Madurez de consumo (ripening*): El fruto ha alcanzado sus mejores características organolépticas y nutricionales y es apto para el consumo directo.

Los cambios transcurridos durante el proceso de maduración del fruto están básicamente controlados por la respiración y la producción de etileno. El melocotón, como *fruto climatérico* que es, evoluciona una vez separado del árbol hasta adquirir la madurez óptima de consumo, siempre y cuando éste haya sido recolectado en un estado adecuado de madurez fisiológica. Tanto su actividad respiratoria como su producción de etileno aumentan, llegando a un pico máximo denominado *pico climatérico*, que normalmente está ligado al final de la madurez de consumo (Tonutti y col., 1991).

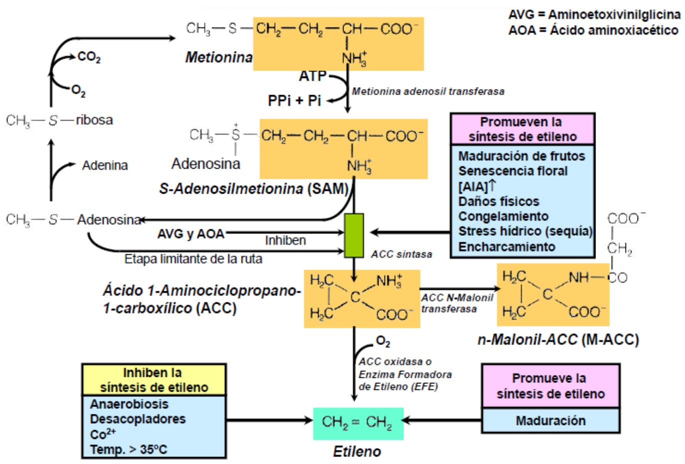

Figura 1.10. Ruta biosintética del etileno (Adaptada, Wang y col., 2002a).

El etileno es la principal hormona responsable de la maduración, del envejecimiento del fruto y de su absición (Gil, 2010). El etileno desencadena la actividad de diversas enzimas responsables del ablandamiento del fruto (solubilización de celulosa y pectinas, degradación del almidón), de la tasa de maduración, del color (pérdida de clorofila, acumulación de carotenoides y síntesis de pigmentos antociánicos), del contenido en azúcares y ácidos orgánicos, entre otros (Bonghi y col., 1998; Downs y col., 1992; Tonutti y col., 1991; Zanchin y col., 1994). Su ruta metabólica, conocida como el ciclo de la metionina o de Yang (Figura 1.10), ha sido muy estudiada en el melocotón (Ramina y col., 2008). Muchos tratamientos poscosecha se han focalizado en la reducción del nivel de etileno al que los frutos están expuestos como también en la reducción de la respuesta de los frutos al etileno como protocolo para alargar la vida útil del fruto (Byrne, 2012), mediante inhibidores de su síntesis (Aminoetoxivinilglicina, *AVG*, 1-metilciclopropeno, *1–MCP*) y/o almacenamiento de los frutos en atmósferas controladas (baja concentración de O_2 y alta concentración de CO_2).

Una vez que el fruto ha adquirido su madurez de consumo empieza la *senescencia*, donde los cambios físicos y químicos del fruto se traducen en un ablandamiento de la pulpa, en la pérdida de aromas deseables y en una completa descomposición del fruto (Kader y Mitchell, 1989).

1.5.2. Momento óptimo de recolección

Recolectar el fruto en un punto óptimo de madurez es esencial para la conservación y comercialización de frutos de hueso en buen estado, ya que el grado de madurez condiciona el almacenamiento y la calidad final de los melocotones. Frecuentemente, los melocotones se recolectan habiendo alcanzado la madurez fisiológica, pero sin haber alcanzado la madurez de consumo, y por ello nunca llegan a alcanzar su sabor y aroma potencial (Crisosto y Costa, 2008), debido a que su vida útil después de la cosecha es muy corta. Últimamente, las principales áreas de producción de melocotón en Europa están perdiendo mercado y consumidores porque recolectan los frutos en estadios de desarrollo demasiado inmaduros (Crisosto y Costa, 2008), ya que no es lo mismo recolectar frutos para el mercado local que para mercados más lejanos. Además, la globalización progresiva de los mercados implica que los frutos deban viajar cada vez más a mayores distancias, por lo que una buena calidad en destino es cada vez más difícil. Es por ello, que en diferentes países (Estados Unidos, Chile) se han desarrollado en los últimos años diferentes técnicas que mejoran la calidad gustativa del fruto cuando éste llega a su destino, una de ellas es el pre-acondicionado (Infante y col., 2009).

Para determinar el momento óptimo de recolección se utilizan medidas objetivas como los índices de madurez (Kader y col., 1989). Éstos han de ser sencillos, fáciles de realizar durante la manipulación, medibles con equipos relativamente baratos que den unos resultados objetivos, y preferiblemente no destructivos. Los más utilizados actualmente para determinar la recolección del melocotón son el color de la piel, el tamaño y la forma, la firmeza, el contenido en sólidos solubles, la acidez, la relación entre sólidos solubles y acidez, la actividad respiratoria y la emisión de etileno (Crisosto, 1994). No obstante, estos índices de madurez, no reflejan otros aspectos fundamentales de la calidad como son la capacidad antioxidante, la emisión de aromas, el sabor y el contenido de azúcares y ácidos orgánicos, la determinación de los cuáles se realiza en laboratorios muy bien equipados con personal muy especializado, que hace que no sean muy utilizados para este fin (Crisosto y Costa, 2008).

En los últimos años se han desarrollado otras técnicas para la determinación de la calidad interna en el momento de la recolección (Crisosto y Costa, 2008). Éstas, además de no requerir la destrucción del fruto , se caracterizan por poder evaluar un elevado número de muestras, repetir el análisis en las mismas muestras y conseguir información a tiempo real en varios parámetros de calidad al mismo tiempo (Abbott, 1999). Entre ellas cabe mencionar las técnicas NIRS (*Near Infrared Spectroscopy)* y AD (*Absorbance difference*). La primera permite determinar indirectamente (cuando el equipo está calibrado) los diferentes parámetros: la firmeza, los sólidos solubles, la acidez y la concentración de los principales azúcares y ácidos orgánicos. La segunda es una técnica utilizada básicamente para la determinación de la fecha de recolección y para agrupar frutos recolectados en clases homogéneas que muestran diferentes tasas de maduración durante su vida útil (Costa y col., 2006).

Sin embargo, en la mayoría de los casos, la fecha de recolección del melocotón se determina mediante la combinación de varios de estos índices de madurez a la vez (Crisosto, 1994), teniendo en cuenta siempre que no todas las variedades evolucionan del mismo modo en el árbol. Debido a que uno de los objetivos de la mejora es obtener variedades con un 100% de coloración roja en la piel, estas muchas veces llegan a su plena coloración antes de estar maduras, y por lo tanto, requieren de la utilización de otros índices de maduración, como por ejemplo, la firmeza o el DA, para la determinación de su óptima recolección. Los criterios de recolección utilizados en este trabajo varían según el capítulo y el objetivo a determinar.

Cabe mencionar también que el período de recolección de la especie *Prunus persica* es muy amplio, y para ello es necesario establecer una clasificación de las variedades típicas de la zona en función de su fecha de recolección: *recolección temprana* (principios de junio hasta el 10 de julio), *recolección media* (del 10 de julio hasta el 20 de agosto), y *recolección tardía* (del 20 de agosto hasta el 30 de septiembre) (Bassi y Piagnani, 2008; UPOV, 1995).

1.6. Caracterización morfológica del fruto

Los caracteres morfológicos establecidos para la caracterización de especies del género *Prunus* están estandarizadas principalmente por la UPOV a partir de una serie de características fenotípicas recogida para la especie considerada (UPOV, 1995). En él hay establecidas las directrices para la realización de las observaciones necesarias para determinar las características de las variedades de cada especie.

En base a estas directrices y con algunas modificaciones, en este trabajo se han estudiado los caracteres de mayor importancia de cara a la comercialización y el consumo fresco del fruto del melocotón, cuando éste ha llegado a su plena madurez fisiológica, y hacen referencia principalmente a su presentación o apariencia. Tales caracteres son la tipología del fruto (melocotón, nectarina, pavía y melocotón y nectarina planos), el porcentaje de color rojo de la piel, el color de la pulpa, la prominencia de la sutura y de la cavidad pistilar, la adherencia del hueso, la presencia de lenticelas, el peso y el tamaño del fruto (Figura 1.11). Los criterios y la metodología utilizados en este trabajo son bastante similares a los establecidos por Frett y col. (2012), los cuales recomiendan y ponen a punto una metodología estandarizada que permite una recopilación de datos de forma coherente y comparable, así como una eficiente transferencia y comparación de los mismos.

Figura 1.11. Frutos con diferentes caracteres morfológicos en variedades de la colección de melocotón, nectarina, pavía, y melocotón y nectarina planos del IRTA-Estación Experimental de Lleida.

El término tipología de fruto es muy amplio y básicamente está condicionado a la vellosidad de la piel y a la forma del fruto. El fruto es un melocotón cuando presenta vellosidad en la piel y tiene una forma globular, y es una nectarina cuando no presenta vellosidad y también tiene una forma globular. En el caso del melocotón y la nectarina plana, ambos presentan una forma plana o achatada, pero el primero presenta vellosidad y el segundo no. No obstante, los términos globular y plano son muy amplios, y los frutos según su longitud y anchura presentan formas diversas (MARM, 2013; UPOV, 1995), tales como muy achatado, ligeramente achatado, redondeado, ovalado y oblongo. La forma de fruto (más o menos achatada o alargada) está controlada genéticamente, pero condiciones climáticas adversas durante el otoño y el invierno, así como las condiciones climáticas propias de la zona de cultivo (horas de frío disponibles, temperatura, etc.) pueden producir variaciones en la presentación de los frutos (Infante y col., 2008).

El color de la superficie del fruto tiene un impacto muy importante en la aceptación del consumidor y en su comercialización (Badenes y col., 2006). Sin embargo, el reglamento (CE) No. 1861/2004 de la Comisión, que establece la norma de comercialización del melocotón y la nectarina, no establece un criterio claro en cuanto a este aspecto morfológico, mientras sí lo hace en el caso de las manzanas. Tan solo menciona que la coloración de la piel debe ser la correspondiente a cada variedad. En general se prefiere que más del 80% de la superficie esté coloreada (Espada y col., 2009). Por este motivo la necesidad de definir la proporción de superficie de fruto pigmentada de rojo es necesaria. A excepción del pavía (piel de color amarillo o chapada hasta un 50% de la superficie de la piel) típica de la zona del Valle del Ebro (Espada y col., 2009), el resto de tipologías de fruto (melocotón, nectarina, melocotón y nectarina plana) presentan más o menos porcentajes de color rojo en la superficie, y por lo tanto, este parámetro se ha dividido en 4 niveles de expresión: 1: 0-25 % de color rojo en la piel; 2: 25-50 % de color rojo en la piel; 3: entre 50-75% de color rojo en la piel y 4: 75-100 % de color rojo en la piel.

El color de la pulpa en melocotón va del blanco pasando por el amarillo hasta el rojo oscuro, con variaciones en sus tonalidades (Vizzotto y col., 2007). El color sanguíneo en la pulpa tanto en melocotón como en nectarina es actualmente una característica objeto de selección en diferentes programas de mejora de Francia, EUA, China, Italia y España por su novedad y sus beneficios potenciales para la salud debido a su elevado contenido de polifenoles (Byrne y col., 2012). Para definir el color de la pulpa en este trabajo se han seguido los criterios establecidos por la UPOV (1995) con algunas modificaciones, quedando así 6 colores: amarillo, amarillo verdoso, amarillo con estrías rojizas, blanco, blanco con estrías rojizas y blanco rosado.

La sutura prominente es un carácter morfológico no deseado en melocotones comerciales, ya que da problemas de magulladuras durante la manipulación y transporte del fruto (Kader, 2002), y hacen la presentación del fruto menos atractiva. Para evaluar la incidencia de este aspecto es necesario clasificar las variedades en función de este carácter en una escala (del 1 al 4) basada en las directrices establecidas por la UPOV (1995): 1: Inapreciable; 2: Visible; 3: Marcada y 4: Muy marcada.

Los dos hemisferios que separa la línea de sutura determinan en la zona opuesta a la peduncular la cavidad pistilar. Al igual que en la sutura prominente, formas de pistilo mucronadas o prominentes no son deseables en los melocotones, ya que suelen originar problemas de magulladuras durante la manipulación y el transporte (Kader, 2002), resultando además los frutos menos atractivos. Por este motivo y para clasificar las distintas variedades de melocotón, se ha dividido la forma del pistilo en cuatro categorías: 1. Mucronada; 2. Redonda; 3. Plana y 4. Deprimida. Otro problema de la cavidad pistilar, aunque no haya sido objetivo de esta tesis (pero merece la pena mencionar) es su mal cierre, principalmente en los melocotones planos, debido a la propia variedad o a condiciones climatológicas adversas (pluviometría, humedad) durante el cuajado del fruto. Muchos son los esfuerzos dedicados por los programas de mejora a resolver este problema, y en la actualidad ya se dispone de variedades con cierre pistilar perfecto (Iglesias y col., 2010; Iglesias, 2013; Sorrenti y col., 2011).

Para la determinación de la adherencia del hueso a la carne, se secciona el fruto por la línea de sutura y se someten ambas unidades a un movimiento de torsión. Principalmente hay tres clases de adherencia al hueso: hueso libre (*freestone*), cuando no hay adherencia entre la pulpa y el hueso-, hueso semi-adherido (*semi-clingstone*), cuando la adherencia entre la pulpa al hueso es media; y hueso adherido (*clingstone)*, cuando hay una fuerte adherencia de la pulpa al hueso. Sin embargo, hay algunas variedades de melocotón de hueso libre que presentan una cavidad entre el hueso y la pulpa, característica indeseable que afecta a la calidad del melocotón y a su vida en poscosecha (Infante y col., 2008). Esto ha hecho que en nuestro protocolo de caracterización morfológica hayamos divido la clase de hueso libre en dos: hueso libre con espacio entre la pulpa y el hueso y hueso libre sin espacio entre la pulpa y el hueso.

La presencia de defectos en la epidermis del fruto es un criterio de clasificación del melocotón para su comercialización (reglamento (CE) No. 1861/2004 de la Comisión). La presencia de lenticelas en la piel es considerada como un defecto, y básicamente solo se encuentra en nectarinas. Para poder clasificar las variedades según este carácter morfológico, se han establecido 4 clases: 1: Lenticelas no visibles; 2: Lenticelas ligeramente visibles; 3: Lenticelas visibles y 4: Lenticelas muy visibles y/o formando placas en la piel. Esta última categoría hace que el fruto sea menos atractivo, mientras que las categorías 2 y 3 se relacionan generalmente con frutos de sabor más dulce.

El peso del fruto es un carácter morfológico muy importante ya que está directamente relacionado con la producción. Cuando las condiciones de cultivo son las adecuadas y tiendo en cuenta que las variedades precoces dan un fruto más pequeño que las de estación media o tardía, el peso del fruto puede variar desde valores de 75 g o menos hasta valores mayores de 180 g (MARM, 2013).

El tamaño del fruto, que incluye tanto el diámetro como la altura, está directamente influenciado por la carga frutal y la genética de la variedad, y se mide mediante un pie de rey (Gasic y col., 2010). El diámetro o calibre del melocotón se mide tanto entre las suturas del fruto como entre las dos caras. Según el reglamento (CE) No. 1861/2004 de la Comisión, que establece la norma de comercialización del melocotón y la nectarina, el diámetro del fruto (diámetro entre las dos caras del fruto) debe ser codificado por categorías, quedando de la siguiente manera: AAAA ($\geq$ 90 mm); AAA (80 mm $\leq$ 90 mm); AA (73 mm $\leq$ 80 mm); A (67 mm $\leq$ 73 mm); B (61 mm $\leq$ 67 mm); C (56 mm $\leq$ 61 mm); y D (51 mm $\leq$ 56 mm). Estas categorías están directamente relacionadas con los precios percibidos por el agricultor. Es por ello que el calibre del fruto es el atributo de mayor importancia.

1.7. La calidad del fruto

Se considera un fruto con una buena calidad cuando tiene una buena apariencia (forma, tamaño, color, carencia de defectos), una buena calidad interna (sabor, aroma y textura) y un óptimo grado de madurez y firmeza para una mayor vida poscosecha, seguridad alimentaria y valor nutritivo y nutracéutico (Crisosto y Costa, 2008; Llácer, 2009). La calidad del melocotón viene determinada por distintos factores precosecha y poscosecha (Lee y Kader, 2000), y entre ellos el factor variedad es el más importante. La percepción de la calidad por los diferentes agentes participantes de la cadena productiva y comercial es distinta (Crisosto y Costa, 2008). No obstante, todos ellos deberían tener como objetivo final la satisfacción del consumidor (Pecore y Kellen, 2002).

1.7.1. Calidad sensorial

La calidad sensorial es un concepto difícil de definir, el cual cubre, no sólo los atributos intrínsecos del fruto, sino también la interacción entre el fruto y el consumidor. Esta interacción contiene numerosos factores relativos a las características del fruto (composición química, estructura y propiedades físicas), a las características del consumidor (genéticas, fisiológicas y sociales) y a las del entorno (geografía, cultura, gastronomía, religión, educación, etc.). Es además necesario establecer una relación entre la composición físico-química del fruto y sus atributos organolépticos, como la forma, el color, la firmeza, el aroma (compuestos volátiles) y el sabor (dulce, ácido) y también entre las percepciones sensoriales y la aceptabilidad final del consumidor.

La evaluación sensorial mediante paneles entrenados, a pesar de ser costosa, ofrece la posibilidad de obtener la descripción de un perfil completo de la fruta, siendo este a su vez válido para la comparación de variedades, la vigilancia de la vida útil y la predicción por parte del consumidor. Este perfil sensorial está definido por una serie de atributos identificables (Tabla 1.4). Las diferencias perceptibles entre las muestras se deben a la mayor o menor intensidad de dichos atributos en cada uno de ellas.

Tabla 1.4. Atributos sensoriales utilizados en la evaluación del melocotón. Definiciones y referencias de cada atributo (López y col., 2011).

Atributo	Definición	Referencia estándar
Dulzor	Característico del azúcar	Zumo de melocotón comercial diluido al 50% con agua filtrada
Acidez	Característico del ácido	Zumo de melocotón comercial diluido al 50% con agua filtrada
Crocanticidad	La cantidad y el tono del sonido cuando la muestra es mordida por los dientes delanteros	Banana y apio
Firmeza	La fuerza requerida al comprimir la muestra con los dientes posteriores	Melocotón en conserva y manzana
Jugosidad	La cantidad de jugo liberada al masticar con los dientes posteriores	Banana y sandía
Facilidad de romper	La cantidad de masticación requerida para romper la muestra y que pueda ser tragada	Albaricoque seco y puré de melocotón en conserva
Fibrosidad	Presencia de estructuras fibrosas en la boca durante la masticación	Yogurt y piña
Sabor	Característico del sabor	Puré de melocotón enlatado

El dulzor es uno de los atributos sensoriales más importantes en la calidad del melocotón. Su percepción está relacionada más con la relación sólidos solubles y acidez (Infante y col., 2008) que con los sólidos solubles a solas (Moreau-Rio y col., 1995), pero también con algunos compuestos volátiles (Ortiz y col., 2009). Altos contenidos de azúcares no son sinónimo de frutos más dulces debido a que el contenido de ácidos orgánicos en el equilibrio del fruto es muy importante en la percepción final que se tenga de éste (Iglesias y Echeverría, 2009). El sabor engloba componentes como el olor y el gusto. En el caso del melocotón y la nectarina, el olor viene dado por los compuestos volátiles aromáticos, y los gustos dulce y ácido vienen dados principalmente por los contenidos de azúcares y ácidos orgánicos, así como del contenido en compuestos astringentes (algunos compuestos fenólicos) (Gil, 2003).

El análisis sensorial, juntamente con el test para consumidores (por ejemplo la escala hedónica) son herramientas imprescindibles al servicio de la mejora genética y utilizadas ampliamente en la evaluación de nuevas variedades de melocotón, identificando las características peculiares de cada variedad (perfil sensorial), pudiendo así orientar cada una de éstas a un tipo determinado de consumidor (Infante y col., 2008).

1.7.2. Calidad físico-química del fruto

La evaluación sensorial de una variedad de melocotón siempre debe estar complementada por un análisis físico-químico de los parámetros de calidad relacionados con los parámetros sensoriales, si el objetivo es conseguir una caracterización detallada del fruto (Pardo y col., 2000). Varios han sido los estudios que han correlacionado los diferentes atributos sensoriales con los atributos físico-químicos del fruto (Colaric y col., 2005; Crisosto y Crisosto, 2005; Crisosto y col., 2006; Esti y col., 1997).

1.7.2.1. La firmeza

La firmeza, además de ser un referente del momento adecuado para la recolección (Infante y col., 2008) y de fácil determinación, es un atributo que condiciona la posterior conservación de la fruta (Kader, 1999), ya que influye directamente en la susceptibilidad a los daños mecánicos durante el manejo poscosecha (Badenes y col., 2006). No obstante, no siempre es el más adecuado ya que varía según el tamaño del fruto, las condiciones climáticas o las prácticas culturales (Crisosto, 1994).

Existen varios métodos para la evaluación de la firmeza, como los métodos destructivos (penetromía) y los no destructivos (durómetro, NIRS o el método acústico) (Infante y col., 2008).

1.7.2.2. Contenido de sólidos solubles

El contenido en sólidos solubles (SSC) es un criterio fundamental y determinante en la calidad y está bastante relacionado con la percepción del dulzor. Muchas de las nuevas variedades hoy plantadas se caracterizan por presentar un amplio rango en SSC cuando alcanzan su momento óptimo de recolección (Crisosto y Crisosto, 2005). No obstante, deben tener un contenido mínimo de SSC para ser cosechadas y posteriormente comercializadas. El reglamento (CE) No. 1861/2004 de la Comisión para la comercialización del melocotón y la nectarina dice que el SSC debe ser superior o igual a 8 ºBrix. El SSC puede medirse también mediante métodos destructivos (refractometría) o no destructivos (NIRS) (Lu, 2004; Bureau y col., 2009).

1.7.2.3. Acidez

La acidez del melocotón está controlada por varios factores tales como la variedad, condiciones ambientales, posición del fruto en el árbol, carga frutal, estado de madurez (Crisosto y col., 1997) y el patrón (DeJong y col., 2002). La acidez puede medirse mediante una sencilla valoración ácido-base (TA, *titratable acidity*) o mediante NIR (Bureau y col., 2009). En este trabajo se ha utilizado el TA para clasificar las variedades según los criterios establecidos por Iglesias y Echeverría (2009): variedades sub-ácidas (<3,3 g ácido málico L^{-1}); variedades dulces (3,3-6 g ácido málico L^{-1}); variedades equilibradas (6-8 g ácido málico L^{-1}); variedades ácidas (8-10 g ácido málico L^{-1}); variedades muy ácidas (>10 g ácido málico L^{-1}).

1.7.2.4. Relación contenido sólidos solubles y acidez

También llamado *índice de madurez* o *ripening index* (RI). En frutas como el melocotón, se utiliza como índice de calidad (Bassi y Selli, 1990) debido a que está muy relacionado con la percepción del sabor (Byrne y col., 1991; Robertson y col., 1988). Es un indicador potencial del dulzor (Crisosto y col., 2006; Di Miceli y col., 2010) y juega un papel muy importante en la aceptación por parte del consumidor (Crisosto y Crisosto, 2005). Dado que tanto las variedades de sabor dulce como las de sabor ácido presentan valores similares en contenido de sólidos solubles, la diferencia en los valores de acidez (menores) hace que el RI sea en general 2 ó 3 veces mayor en variedades de sabor dulce (Iglesias y Echeverría, 2009).

1.7.3. Calidad nutricional

La calidad nutricional es aquella relacionada con la capacidad de los alimentos de proporcionar los elementos nutritivos que favorezcan una buena salud y eviten la aparición de enfermedades (Cámara, 2006). A veces este concepto suele incluir a la calidad nutracéutica, que se refiere a la presencia de sustancias antioxidantes que actúan como protectoras frente al cáncer y enfermedades cardiovasculares (Lee, 2007; Lule y Xia, 2005; Smith-Warner y col., 2002).

Es conocido, que el consumo de frutas tiene un efecto positivo en la salud humana, ya que desde el punto de vista nutritivo, las frutas poseen un alto contenido de agua y carbohidratos, fibras de alto valor alimentario, proteínas y lípidos, y son en general, una buena fuente de minerales y vitaminas (Knee, 2002). No obstante, también contienen una gran variedad de metabolitos secundarios (Gil, 2010), entre los cuales se encuentran los carotenoides, los compuestos fenólicos, como los ácidos fenólicos, los flavonoides (flavonas, flavonoles, flavononas, isoflavonas y antocianinas), los isoflavonoides, los proantocianidinos y los taninos (Dalla Valle y col., 2007; Pan y col., 2008; Vicente y col., 2011), el ácido ascórbico (Robards y col., 2003) y la vitamina E (Vicente y col. 2011). Aunque estén en concentraciones relativamente pequeñas, tienen un papel importante en la calidad final del fruto (percepción sensorial), ya que son una buena fuente de antioxidantes (Ramina y col., 2008), y muchos de ellos determinan el color y el sabor del fruto (Vicente y col., 2011).

Algunos de estos compuestos juegan un papel importante contra enfermedades humanas (Ames y col., 1993; Olsson y col., 2004; Rice-Evans y Miller, 1996). A estos compuestos se les llama compuestos nutracéuticos (Vicente y col., 2011). Estudios experimentales, epidemiológicos y clínicos han demostrado ampliamente los efectos positivos del consumo de melocotón. Por ejemplo, se ha demostrado que los compuesto fenólicos del melocotón inhiben el crecimiento y la inducción a la diferenciación de las células del cáncer de colon (Lea y col., 2008). Sin embargo, todavía queda mucho trabajo por hacer, ya que la cantidad y la calidad de todos estos compuestos depende, entre otros factores, de la variedad en cuestión.

1.7.3.1. Composición del fruto y su capacidad antioxidante

El agua es el componente mayoritario del fruto en el caso del melocotón, llegando a alcanzar el 87% del peso total. El segundo tipo de compuestos en importancia incluye a los carbohidratos (7-18% del peso total) (Wills y col., 1983), y el tercero a los ácidos orgánicos (0,4-1,2% del peso total). Además, hay pequeñas cantidades de pigmentos, fenoles, vitaminas, compuestos volátiles, antioxidantes, proteínas y lípidos (Crisosto y Valero, 2008; USDA, 2003). Sin embargo, en este trabajo los objetivos de estudio han sido el contenido en carbohidratos, en ácidos orgánicos, en antocianinas y la capacidad antioxidante relativa de más de 100 variedades comerciales de melocotón.

1.7.3.1.1. Carbohidratos

El contenido en azúcares puede variar considerablemente según la variedad, el estado de madurez y las condiciones ambientales (Crisosto y col., 1997). Conforme el fruto madura, el contenido de azúcares totales aumenta. La última etapa de crecimiento celular (Fase III) se caracteriza por la expansión celular y la acumulación de carbohidratos en el mesocarpio del fruto (Lo Bianco y Rieger, 2002).

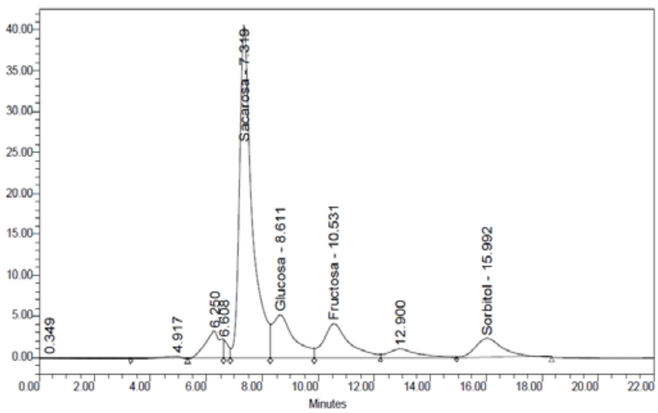

Figura 1.12. Perfil de azúcares de una muestra de zumo de melocotón analizada por HPLC.

Los carbohidratos más abundantes en melocotón maduro son la sacarosa, seguida por los azúcares reductores (glucosa y fructosa) y el sorbitol en pequeñas cantidades (Moriguchi y col., 1990; Robertson y col., 1990) (Figura 1.12). Los carbohidratos juegan un papel importante en la calidad organoléptica y nutricional del melocotón (Colaric y col., 2005; Crisosto y Crisosto, 2005; Esti y col., 1997; Génard y col., 1994; Versari y col., 2002), además de la textura. Los polisacáridos estructurales forman parte de las paredes celulares y tienen un papel decisivo en el ablandamiento de la pulpa debido a la solubilización, despolimerización, desesterificación y pérdida de azúcares neutros de las cadenas laterales (Seymour y Gross, 1996). Por su gran importancia nutricional, son numerosos los autores que han estudiado el nivel de carbohidratos existes en diversas variedades de melocotón (Brooks y col., 1993; Byrne y col., 1991; Cantín y col., 2009b; Colaric y col., 2005; Dirlewanger y col., 1999; Esti y col., 1997; Montevecchi y col., 2012; Abidi y col., 2011; Wu y col., 2003; Wu y col., 2005).

El análisis individualizado de los azúcares de la fruta requiere de la utilización de la cromatografía líquida de alta resolución (HPLC) (método utilizado en este trabajo) o de la cromatografía de gases (GC), mediante la obtención previa de derivados volátiles. En función de la capacidad endulzante o endulcorante los carbohidratos se clasifican en el siguiente orden: fructosa (1.75) > sacarosa (1) > glucosa (0.75) > sorbitol (0.6) (Kader, 2008; Pangborn, 1963; Schiweck y Ziesenitz, 1996). Dado que existe una buena correlación entre SSC y el contenido en azúcares totales (Dirlewager y col., 1999), SSC es una medida utilizada por los programas de mejora, por los técnicos y por las centrales frutícolas para estimar el contenido de azúcares de una variedad, que además es de muy fácil determinación.

1.7.3.1.2. Ácidos orgánicos

Al igual que el contenido en azúcares, la acidez del fruto viene determinada por la composición de los diferentes ácidos orgánicos (Colaric y col., 2005; Esti y col., 1997), que junto con los azúcares y los aromas, contribuyen de una forma importante en la calidad organoléptica (sabor y aroma) del melocotón (Wu y col., 2012) y por lo tanto, en la aceptación por parte del consumidor (Colaric y col., 2005; Crisosto y Crisosto, 2005; Esti y col., 1997; Harker y col., 2002; Kader, 1999). Los tres ácidos orgánicos mayoritarios en melocotón son el málico, el cítrico y el quínico (Wu y col., 2002). Cantidades muy pequeñas de succínico, shikímico, ascórbico y ácido oxálico también han sido encontradas por varios autores (Chapman y Hovart, 1990; Liverani y Cangini, 1991; Selli y Sansavini, 1995; Sweeney y col., 1970; Wu y col., 2005). La acidez alcanza un máximo durante el desarrollo del melocotón y luego disminuye con la maduración y el período de cosecha.

1.7.3.1.3. Capacidad antioxidante relativa (RAC)

El consumo de elevadas cantidades de antioxidantes está siendo muy promocionado por su efecto beneficioso en la salud a corto y largo plazo, debido a la reducción general del estrés oxidativo dentro del cuerpo originado por la presencia de radicales libres .Muchos son los autores que se han interesado en la evaluación de los niveles de antioxidantes o de la capacidad antioxidante de los frutos (Wargovich y col., 2012). En el caso del melocotón varios autores han descrito la capacidad antioxidante del melocotón (Abidi y col., 2011; Byrne y col., 2009; Cevallos-Casals, 2006; Cantín y col., 2009ª; Gil y col., 2002; Legua y col.; 2011; Vizzotto y col., 2007;), y se ha observado que ésta varía ampliamente según la variedad. No obstante, su evaluación no es una tarea fácil, ya que muchos métodos (ABTS, DPPH, FRAP y ORAC) se pueden utilizar para determinarla, y los sustratos, las condiciones, los métodos analíticos y las concentraciones pueden afectar a la actividad estimada (Frankel y Meyer, 2000). En este trabajo se ha utilizado el método DPPH, adaptado de Brand-Willians y col. (1995), que evalúa la capacidad de destrucción del radical libre 2,2-dipheniyl-1-picrylhydrazyl.

1.7.3.1.4. Antocianinas

Las antocianinas, juntamente con las flavonas, flavonoles, flavononas y las isoflavononas, forman parte de un grupo dentro de los compuestos fenólicos llamado flavonoides (Wargovich y col., 2012). Son colorantes naturales, solubles en agua, que se encuentran ampliamente distribuidos en flores, frutos y vegetales (Andersen y Jordheim, 2006; Hu y Xu, 2011). Dentro del grupo de las antocianinas se han identificado más de 400 compuestos (Mazza y Miniati, 1993). Sin embargo, las antocianinas predominantes en el melocotón son la cianidin-3-glucósido y la cianidin-3-rutinosido (Tomás-Barberán y col., 2001; Vasco y col., 2009; Wu y col., 2005).

Los frutos de color rojo o púrpura tanto en la piel como en la pulpa, como las bayas, uvas, ciruelas y cerezas, son ricos en antocianinas (Hu y Xu, 2011; Wargovich y col., 2012; Wu y col., 2006). Sin embargo, existen otras especies frutales, como la manzana, el melocotón y el kiwi, donde el contenido en antocianinas es bajo en la pulpa, ya que mayoritariamente se encuentran en la piel (Wargovich y col., 2012), es decir, la parte del fruto que muchas veces se elimina con su pelado cuando se quiere consumir. Por este motivo, se han desarrollado variedades que contienen importantes cantidades de antocianinas en la pulpa (Cevallos-Casals; 2006; Jaeger y Harker, 2005; Vizzotto y col., 2007; Voltz y col., 2009), confiriéndoles el color rojo característico y diferencial al resto de variedades. Muchos han sido los estudios que han caracterizado el contenido de antocianinas en distintas variedades comerciales y selecciones de melocotón (Abidi y col., 2011; Byrne y col., 2009; Cantín y col., 2009a; Cevallos-Casals; 2006; Tomás-Barberán y col., 2001; Vizzotto y col., 2007).

Las antocianinas tienen un especial interés, por parte de los programas de mejora y los consumidores, debido a su amplia gama de colores (desde color salmón pasando por el rojo y el violeta hasta el azul oscuro), su inocuidad y sus beneficios para la salud. También tienen una elevada capacidad antioxidante, y ayudan a la prevención de enfermedades cardiovasculares (Bertelli y Das, 2009) y diabetes (Martineau y col., 2006), entre otras. En la presente tesis se han determinado en pulpa con el método de Fuleki y Francis (1968).

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Capítulo 2

Objetivos

Como se ha comentado anteriormente, la innovación varietal está aportando un gran número de variedades al mercado. Estas variedades pueden diferir sustancialmente en su comportamiento agronómico y cualitativo y dicha información, siendo vital para el agricultor, no está suficientemente disponible en el momento de dicidir su elección. Por lo tanto, los objetivos generales de esta Tesis Doctoral son la caracterización agronómica, morfológica y cualitativa de variedades comerciales de melocotonero y el estudio de la maduración en campo y el ablandamiendo del fruto en poscosecha de diferentes variedades de nectarina. Dentro de los objetivos generales, los objetivos específicos son los siguientes:

1. La evaluación de las características agronómicas de diferentes variedades de melocotón y el estudio de las relaciones existentes entre los parámetros agronómicos y la tipología de fruto y el origen de la variedad (continente y programa de mejora) (**Capítulo 3**).
2. El estudio de la sensibilidad de las flores del melocotonero a heladas primaverales, así como de las relaciones existentes entre la sensibilidad a heladas y la época de floración, la tipología del fruto, el programa de mejora y la variedad. Como parte de la metodología se desea estudiar las posibles diferencias varietales en cuanto a las temperaturas letales en melocotón (**Capítulo 4**).
3. La evaluación de las características morfológicas del fruto de diversas variedades de melocotonero, así como la influencia de la tipología del fruto y el programa de mejora sobre las características morfológicas y la clasificación de variedades en función de su morfología (**Capítulo 5**).
4. El análisis de los parámetros de calidad, del perfil sensorial, del perfil de azúcares y ácidos orgánicos, del contenido en antocianinas totales y de la capacidad antioxidante de diversas variedades de melocotón. Evaluación de la variabilidad fenotípica y de las diferencias existentes entre tipologías de fruto, programas de mejora y variedades. Estudio de las relaciones existentes entre los distintos parámetros evaluados (**Capítulo 6**).
5. Estudio del comportamiento de 11 variedades de nectarina comerciales durante su proceso de maduración en campo y en poscosecha (**Capítulo 7**).

Capítulo 3

Agronomical performance under Mediterranean climatic conditions among peach[*Prunus persica* (L.) Batsch] cultivars originated from different breeding programmes

3.1. Abstract

Nowadays more than 70 active peach breeding programmes are developed around the world, all of them, regardless of country, with their specific objectives. Nevertheless, there is no currently available information comparing different peach cultivars based in their origin in terms of agronomic performance and fruit quality under Mediterranean climatic conditions. For this reason, we evaluated the influence of fruit type, origin (continent and breeding program) and cultivar on adaptability, production and susceptibility to powdery mildew. A study was carried out on 112 cultivars at the IRTA-Experimental Station of Lleida (Spain) during the 2009 and 2011 seasons in which melting peach cultivars presented better agronomical performance than nectarine, nonmelting peach and flat peach cultivars. Comparing continents, USA *versus* Europe, in terms of fruit type, melting peach and nectarine cultivars from Europe were best adapted to Mediterranean conditions. According to origin by fruit type, melting peach cultivars from Monteaux-Caillet, ASF, Zaiger and Minguzzi showed the best agronomical performance. In the case of nectarine, the ASF, PSB and Bradford breeding programmes provided the most interesting cultivars. The fact that there are only a few breeding programmes for flat peaches makes them all the more interesting to producers. In most of the traits studied important variability among cultivars was recorded, either within the same breeding program. In spite of these results, the cultivars in each breeding program were clearly different; this explains why producers tend to adopt the strategy of choosing cultivars from different breeding programmes.

3.2. Introduction

The peach [*Prunus persica* (L.) Batch.] is the third most important deciduous fruit crop in the world (Llácer et al., 2009c) and the second most important in the European Union (EU), after the apple. Spain is the second larger producer in the EU, after Italy, with 29% of the total production (Europêch, 2011). In Spain, peach production is mainly located in the Mediterranean area, with the Ebro Valley (Catalonia and Aragon) being the most important production area, followed by Murcia, Extremadura and Andalucía (Iglesias and Casals, 2007; Llácer et al., 2009a). Most of these regions are characterized by warm summers and cold winters. In contrast, Andalucía has warm summers and mild winters, and produces only low-chilling cultivars. Spain's climatic diversity allows it to produce a large range of cultivars, ranging from very early harvest (mid-April) to very late harvest (late October) (Llácer et al., 2009b).

The peach is the most dynamic of deciduous fruit species grown in the world. About 100 new peach and nectarine cultivars have been introduced per year over the last 10 years (Badenes et al., 2006; Byrne, 2002; Byrne, 2005; Fideghelli et al., 1998; Sansavini et al., 2006b). For this reason, there are more than 70 active breeding programmes around the world, led by the United States and followed by Europe, and particularly France and Italy, with a smaller percentage in South Africa, Australia, China, Japan, Mexico and Brazil (Byrne, 2002). The new cultivars currently planted in Spain are mainly in the Ebro Valley and have their origins in private programmes such as those of: Zaiger Genetics Inc. and N. & L. Bradford (California, USA) and universities (Davis and Michigan) in the United States; the DCA-Università di Bologna, University of Pisa and University of Florence in Italy; public institutes (such as INRA in France, CRA-Roma and Forlí in Italy); and public or private breeding programmes like CIV, CAV, A. Minguzzi, Martorano in Italy and AgroSelection Fruits (ASF), Europépinières and R. Monteux Caillet-Star Fruits in France (Iglesias et al., 2012). Due to its traditional dependence on foreign peach cultivars, Spain only started its own programmes about 12 years ago. This has involved several breeding programmes. These have been mainly private (Provedo, Frutaria-ALM, Planasa and PSB), public (CITA and IVIA) or with mixed public and private participation (IMIDA-NOVAMED, ASF-IRTA-Fruit Futur, etc.) in order to reduce the cost of royalties and to guarantee adaptation to local growing conditions (Llácer et al., 2009c). This large number of improvement programmes has provided a very large and varied offer of peach varieties, but has left little time for evaluating their behaviour. The main objectives of all of these programmes were to improve fruit quality and agronomical performance by modifying tree size, simplifying training techniques (Byrne, 2002) and offering a range of cultivars capable of covering the whole harvest season and that are well-adapted to the local conditions for which they were selected (Batlle et al., 2012).

The recent discovery of the *Prunus* genome sequence (IPGI) and, as a consequence, the knowledge of which genes and quantitative trait loci (QTLs) are related to agronomical characters (flower colour, ripening time, blooming time, powdery mildew resistance, etc.) is providing new tools to help select varieties for the global market, along with long shelf life and good handling resistance (Cantín et al., 2006; Martínez-Calvo et al., 2006). Recent studies have demonstrated the low level of genetic variation among peach cultivars from breeding programmes in Europe and North America (Aranzana et al., 2010). For example, Monet detected an index of consanguinity of up to 0.80 in Californian varieties obtained by Anderson and Bradford (Sansavini et al., 2006b). This could lead people to think that there would not be any significant differences between varieties from different breeding programmes because of high-levels of inbreeding of quantitative traits. However, fruit growers say that they have clear evidence of the different productive behaviour of different cultivars. For this reason, the main objectives of this study were to ascertain whether or not the low genetic variation between varieties from different breeding programmes is relevant for agronomical performance and, at the same time, which of the tested origins offers the best adaptation to the Mediterranean conditions of the Ebro Valley.

3.3. Material and Methods

One hundred and twelve varieties of peach and nectarine were tested over two seasons. Their origin, fruit type, harvest date and shape are described in Table 3.1. The study included: 30 melting peach cultivars, of which 19 had yellow flesh and 11 had white flesh; 54 nectarine cultivars, of which 40 had yellow flesh and 14 had white flesh; 9 nonmelting peach cultivars; 14 flat peach cultivars; and 5 flat nectarine cultivars. In order to simplify the analysis, the flat nectarine cultivars were analyzed together with the flat peach cultivars. Most of these cultivars came from different breeding programmes in the United States of America (California) and Europe (France, Italy and Spain).

Table 3.1. Breeding programme, origin (continent and country), fruit type, harvest date and fruit shape of the cultivars evaluated.

Cultivar	Breeding Programme	Continent	Country	Maturity Season	Shape	Fruit Type
African Bonnigold	ARC	Africa	South Africa	E	R	NMP
Alice	Martorano	Europe	Italy	E	R	NE
Amiga	Minguzzi	Europe	Italy	M	R	NE
ASF 05-25	ASF	Europe	France	M	R	NE
ASF 05-93	ASF	Europe	France	M	F	FP
ASF 06-07	ASF	Europe	France	M	R	NE
ASF 06-88	ASF	Europe	France	L	F	FP
ASF 06-90	ASF	Europe	France	M	F	FP
August Red	Bradford	North America	USA	L	R	NE
Azurite	Monteaux	Europe	France	M	R	PE
Big Bel	Zaiger	North America	USA	M	R	NE
Big Nectared	ASF	Europe	France	L	R	NE
Big Top	Zaiger	North America	USA	E	R	NE
Catherina	L.Houg	North America	USA	M	R	NMP
Country Sweet	Zaiger	North America	USA	M	R	PE
Crimson Lady	Bradford	North America	USA	E	R	PE
Diamond Bright	Bradford	North America	USA	E	R	NE
Diamond Ray	Bradford	North America	USA	M	R	NE
Donutnice	ASF	Europe	France	M	F	FP
Early Rich	Zaiger	North America	USA	E	R	PE
Early Top	Zaiger	North America	USA	E	R	NE
Endogust	ASF	Europe	France	L	R	NE
Extreme July	Provedo	Europe	Spain	M	R	PE
Extreme Red	Provedo	Europe	Spain	M	R	NE
Extreme Sweet	Provedo	Europe	Spain	M	R	PE
Fairlane	U.S.D.A	North America	USA	L	R	NE
Feraude	INRA	Europe	France	M	R	NMP
Fercluse	INRA	Europe	France	M	R	NMP
Ferlot	INRA	Europe	France	L	R	NMP
Fire Top	Zaiger	North America	USA	M	R	NE
Flataugust	ASF	Europe	France	M	F	FP
Flatpretty	ASF	Europe	France	M	F	FP
Flatprincess	ASF	Europe	France	L	F	FP
Flatqueen	ASF	Europe	France	L	F	FP
Fullred	ASF	Europe	France	M	R	PE
Garaco	PSB	Europe	Spain	E	R	NE
Garcica	PSB	Europe	Spain	M	R	NE
Gardeta	PSB	Europe	Spain	E	R	NE
Gartairo	PSB	Europe	Spain	E	R	NE
Grenat	Monteaux	Europe	France	M	R	PE
Hesse	U.California	North America	USA	L	R	NMP
Honey Blaze	Zaiger	North America	USA	M	R	NE
Honey Fire	Zaiger	North America	USA	M	R	NE
Honey Glo	Zaiger	North America	USA	M	R	NE
Honey Kist	Zaiger	North America	USA	M	R	NE
Honey Royale	Zaiger	North America	USA	M	R	NE
IFF 1182	CRA	Europe	Italy	M	R	NE
IFF 1190	CRA	Europe	Italy	M	R	PE
IFF 1230	CRA	Europe	Italy	E	R	PE
IFF 1233	CRA	Europe	Italy	E	R	PE
IFF 331	CRA	Europe	Italy	M	R	PE
IFF 800	CRA	Europe	Italy	E	R	NE
IFF 813	CRA	Europe	Italy	M	R	NE
IFF 962	CRA	Europe	Italy	M	R	PE
Julienice	ASF	Europe	Italy	L	R	PE
Kewina	Zaiger	North America	USA	L	R	PE

Tabla 3.1. Continued

Cultivar	Breeding Programme	Continent	Country	Maturity Season	Shape	Fruit Type
Lady Erica	Martorano	Europe	Italy	L	R	NE
Luciana	PSB	Europe	Spain	M	R	NE
Mesembrine	INRA	Europe	France	M	F	FP
Nectabang	ASF	Europe	France	E	R	NE
Nectabelle	ASF	Europe	France	E	R	NE
Nectabigfer	ASF	Europe	France	M	R	NE
Nectadiva	ASF	Europe	France	L	R	NE
Nectaearly	ASF	Europe	France	E	R	NE
Nectafine	ASF	Europe	France	L	R	NE
Nectagala	ASF	Europe	France	M	R	NE
Nectalady	ASF	Europe	France	L	R	NE
Nectapi	ASF	Europe	France	L	R	NE
Nectapink	ASF	Europe	France	M	R	NE
Nectaprima	ASF	Europe	France	E	R	NE
Nectareine	ASF	Europe	France	M	R	NE
Nectarjewel	ASF	Europe	France	M	R	NE
Nectarjune	ASF	Europe	France	E	R	NE
Nectarlight	ASF	Europe	France	L	R	NE
Nectarmagie	ASF	Europe	France	M	R	NE
Nectaroyal	ASF	Europe	France	L	R	NE
Nectarperla	ASF	Europe	France	M	R	NE
Nectarreve	ASF	Europe	France	M	R	NE
NectaTop	ASF	Europe	France	M	R	NE
Nectavanpi	ASF	Europe	France	L	R	NE
NG 187	Minguzzi	Europe	Italy	M	R	NE
NG 4/720	Minguzzi	Europe	Italy	E	R	NE
Noracila	PSB	Europe	Spain	E	R	NE
O'Henry	G.Merril	North America	USA	L	R	PE
Onyx	Monteaux	Europe	France	E	R	PE
Oriola	INRA	Europe	France	M	F	FP
PG 3/1312	Minguzzi	Europe	Italy	M	R	PE
PG 3/138	Minguzzi	Europe	Italy	M	R	PE
PG 3/719	Minguzzi	Europe	Italy	M	R	PE
PI 2/84	Minguzzi	Europe	Italy	M	R	NMP
Pink Ring	CRA	Europe	Italy	M	F	FP
Platibelle	INRA	Europe	France	M	F	FP
Platifirst	INRA	Europe	France	E	F	FP
Platifun	INRA	Europe	France	M	F	FP
Rich lady	Zaiger	North America	USA	M	R	PE
Romea	CRA	Europe	Italy	M	R	NMP
Rose Diamond	Bradford	North America	USA	E	R	NE
Subirana	Agromillora	Europe	Spain	M	F	FP
Summersun	ARC	Africa	South Africa	M	R	NMP
SummerSweet	Zaiger	North America	USA	M	R	PE
Surprise	INRA	Europe	France	M	R	PE
Sweet Dream	Zaiger	North America	USA	M	R	PE
Sweetbella	ASF	Europe	France	M	R	PE
SweetLove	ASF	Europe	France	M	R	PE
SweetMoon	ASF	Europe	France	M	R	PE
Sweetprim	ASF	Europe	France	E	R	PE
SweetStar	ASF	Europe	France	L	R	PE
UFO 3	CRA	Europe	Italy	E	F	FP
UFO 4	CRA	Europe	Italy	E	F	FP
UFO 7	CRA	Europe	Italy	M	F	FP
UFO 8	CRA	Europe	Italy	L	F	FP
Zee Lady	Zaiger	North America	USA	M	R	PE

Abbreviations: E, early (1st June-10th June); M, mid (10th June-20th August); L, late (20th August-30th September); R, round; F, flat; PE, melting peach; NE, nectarine; NMP, nonmelting peach; FP, flat peach.

Data for the different cultivars were recorded in 2009 and 2011. In 2010, a frost during the period 7th–10th March (–6 ºC) differentially affected cultivar yields, so these data were not considered. The different varieties were planted on an experimental collection plot located at the IRTA-Experimental Station of Lleida, located in Mollerussa (Catalonia, Spain). The experimental orchard contained three trees per cultivar which were planted in a single block and grafted onto INRA® GF-677 rootstock. The trees were at full production in 2009. They were trained using a central axis system, with a 4.5 m × 2.5 m spacing, and with the rows oriented from NE to SW. The trees were irrigated using two drippers per tree, delivering 4 litres per hour. Standard commercial management practices recommended for the area were followed including: fertilization, plant disease and pest control, using guidelines 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 ºC and accumulated annual rainfall of around 370 mm. In each season, hand thinning was carried out in early May, using similar criteria for all cultivars in order to obtain similar crop loads.

The trunk perimeter of each tree was measured at the end of the season (in November 2009 and 2011) at a point 20 cm above the graft union. The trunk cross sectional area (TCSA) (cm^2) was then calculated for each cultivar and season. Tree vigour was assessed based on the relative increase in TCSA (RI) (cm^2), because not all the cultivars were planted in the same year.

3.3.1. Blooming date, flower density, fruit set and thinning requirements

The blooming period was recorded for both seasons for all the cultivars, according to Baggiolini (1952). Records were taken on three dates per cultivar and year: the date of the start of bloom (SB) (2% of flowers open), full bloom (FB) (70-80% of flowers open) and the end of bloom (EB) (beginning of stage G, last flowers on the tree). Periodic controls were carried out at the experimental orchard for this purpose. From each one of the three trees, we chose two homogeneous one-year-old shoots of similar height but with different orientations; these were marked and their length was measured at full bloom. The number of flowers on each shoot was counted to obtain the flower density (FD) which was expressed as the number of flower buds per linear metre of branch (Lombard et al., 1988). Each season, one month after blooming, and before thinning (end of April), we counted the number of fruitlets on each shoot to determine the fruit set percentage (FSE). Thinning requirements (THR) were evaluated according on a scale from 0 to 4: (0) No thinning; (1) Light thinning; (2) Normal thinning; (3) Intense thinning; (4) Very intense thinning (Iglesias and Carbó, 2009).

3.3.2. Sensitivity to diseases: powdery mildew

In order to test the sensibility of the cultivars to powdery mildew, from mid-August we did not apply any fungicide treatments on the testing plot. Then, at the end of September, we evaluated the presence of powdery mildew (PM). We then recorded the presence or absence of powdery mildew on 10 shoots from each of three trees of each cultivar. Cultivar sensitivity to powdery mildew was assessed on the basis of 5 categories organized by the percentage of mildew infection: (0) No sensitivity: 0% of shoots with the presence of powdery mildew; (1) Low sensitivity: 0-25% of shoots with the presence of powdery mildew; (2) Medium sensitivity: 25-50% of shoots with the presence of powdery mildew; (3) High sensitivity: 50-75% of shoots with the presence of powdery mildew; (4) Maximum sensitivity: 75-100% of shoots with the presence of powdery mildew.

3.3.3. Yield parameters

The value of firmness established to determine the harvest date was around 45 N. This parameter was determined using a penetrometer (Penefel, Copa technologie, St-Etienne du Gres, France) mounted on a laboratory bench an 8 mm diameter plunger tip. At harvest time, all the 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}), fruit size (FS) (mm), fruit weight (FW) (g) and fruit number (FN). Afterwards, crop load (CL) (no. fruits cm^{-2}) and yield efficiency (kg cm^{-2}) were calculated according to the TCSA obtained for each cultivar and season.

3.3.4. Data analysis

All the parameters evaluated were separately determined for each of the three trees per cultivar and season. The results were analyzed considering fixed factors such as the origin of the cultivar (Table 3.1), fruit type (melting peach, nectarine, nonmelting peach and flat peach) and season and with the cultivar as the residual term. All the data were tested using analysis of variance (GLM procedure) with the SAS program package (SAS, 1997). Differences between origin (breeding programme and continent) and fruit type for each parameter were then analyzed based on the mean square error for each season and parameter. Lsmeans were compared with Tukey's honestly significant difference (HSD) test at the $P \leq 0.05$ level of significance. TCSA was used as a covariate of yield efficiency, crop load and fruit number. Crop load was used as a covariate of fruit size and fruit weight. A principal component analysis (PCA) was performed to analyze existing correlations among agronomical traits.

3.4. Results and Discussion

3.4.1. Differences between fruit types

The analysis of agronomical traits showed significant differences among fruit types (Table 3.2). In the case of the date of the beginning of bloom (BB), nonmelting peaches generally started to bloom later than melting peaches or flat peaches, while nectarine cultivars tended to enter bloom first. The longest blooming period (BP) was recorded for flat peach and nectarine, and the shortest was recorded with melting and nonmelting peaches. The range of values for these two agronomical traits showed important differences among cultivars. The BBs of the different cultivars ranged from the 58th Julian day to the 76th and the BPs ranged from 11 to 23 days. For this reason, these two agronomical traits could be considered cultivar dependent, with coefficients of variation of 0.05 and 0.11, respectively. These two variables (BB and BP) could also be said to be dependent on fruit typology and that each fruit typology presents a different degree of heterogeneity (data not shown). The fact that the nectarines had the lowest BB value and one of the highest BP values was only due to the high degree of variability between its varieties; it exhibited the highest coefficient of variation for BB (0.04) and the second highest for BP (0.08) when we compared it with the other fruit types. The same was observed with nonmelting peaches in terms of BB and BP, but in reverse, with a high level of BB, which could have been due to more homogenous values between cultivars, and a low value of BP, which could have been due to a high coefficient of variation (0.12) in comparison with the other types of fruit.

Table 3.2. Mean values (2009 and 2011 seasons) of agronomic traits by fruit type. The number of observed cultivars tested (n) is shown for each fruit type.

Trait	Melting peach	Nectarine	Nonmelting peach	Flat peach
n	30	54	9	19
BB (Julian days)	67.5 b	65.7 c	69.7 a	67.2 b
BP (Julian days)	16.9 b	18.0 a	16.8 b	18.4 a
FD (nº flowers m^{-1})	27.8	25.0	24.6	26.9
FSE (%)	48.8 a	46.1 ab	48.6 ab	41.3 b
THR	1.70	1.44	1.77	1.6
PM (%)	39.0	39.7	49.4	44.4
HD (Julian days)	197.5 b	197.2 b	204.4 ab	205.2 a
FS* (mm)	74.5 a	71.6 b	70.91 b	71.9 b
FW* (g)	194.9 a	194.2 a	168.9 b	119.7 c
TFN* (fruits $tree^{-1}$)	187.1 b	156.7 c	209.3 b	294.1 a
CL* (nº fruits cm^{-2})	1.76 b	1.46 c	1.75 bc	2.57 a
Y (kg $tree^{-1}$)	35.0 a	28.7 b	32.4 ab	28.9 b
YE* (kg cm^{-2} of TCSA)	0.32 a	0.27 b	0.26 ab	0.24 b
RI (cm^2)	74.4 ab	76.3 a	87.0 a	53.4 b

Mean separation within rows by Tukey's test ($P \leq 0.05$). In each row by fruit type, values with the same letter are not significantly different. *Abbreviations*: BB, date of beginning of bloom; BP, blooming period; FD, flower density; FSE, fruit set percentage; THR, thinning requirement; PM, powdery mildew percentage; HD, harvest date; FS*, fruit size with crop load as a covariable; FW*, fruit fresh weight with crop load as a covariable; TFN*, tree fruit number with TCSA as a covariable; Y, yield; YE*, yield efficiency with TCSA as a covariable; CL*, crop load with TCSA as a covariable; RI, relative increase in trunk cross-sectional area.

Many authors have reported that the number of flower buds, or flower density, is genotype-dependent (Bellini and Gianelli, 1975; Okie and Werner, 1996). In our study, although no significant differences in flower density were found between fruit types, differences between cultivars of the same fruit type were observed (Figure 3.1), which could imply different thinning requirements.

An analysis of the fruit set percentage (FSE) for different fruit types indicated high values in melting peach cultivars. Nectarine and nonmelting peach cultivars showed similar values to melting peaches, while flat peach cultivars presented the lowest FSEs. Despite these differences, melting peach cultivars generally had only 15% greater FSEs than flat peach cultivars. This trait is affected by weather conditions at full bloom (temperatures, rainfall, etc.) and can also have a substantial influence on fruit growth rate and final fruit size (Berman et al., 1998; Grossman and Dejong, 1995b).

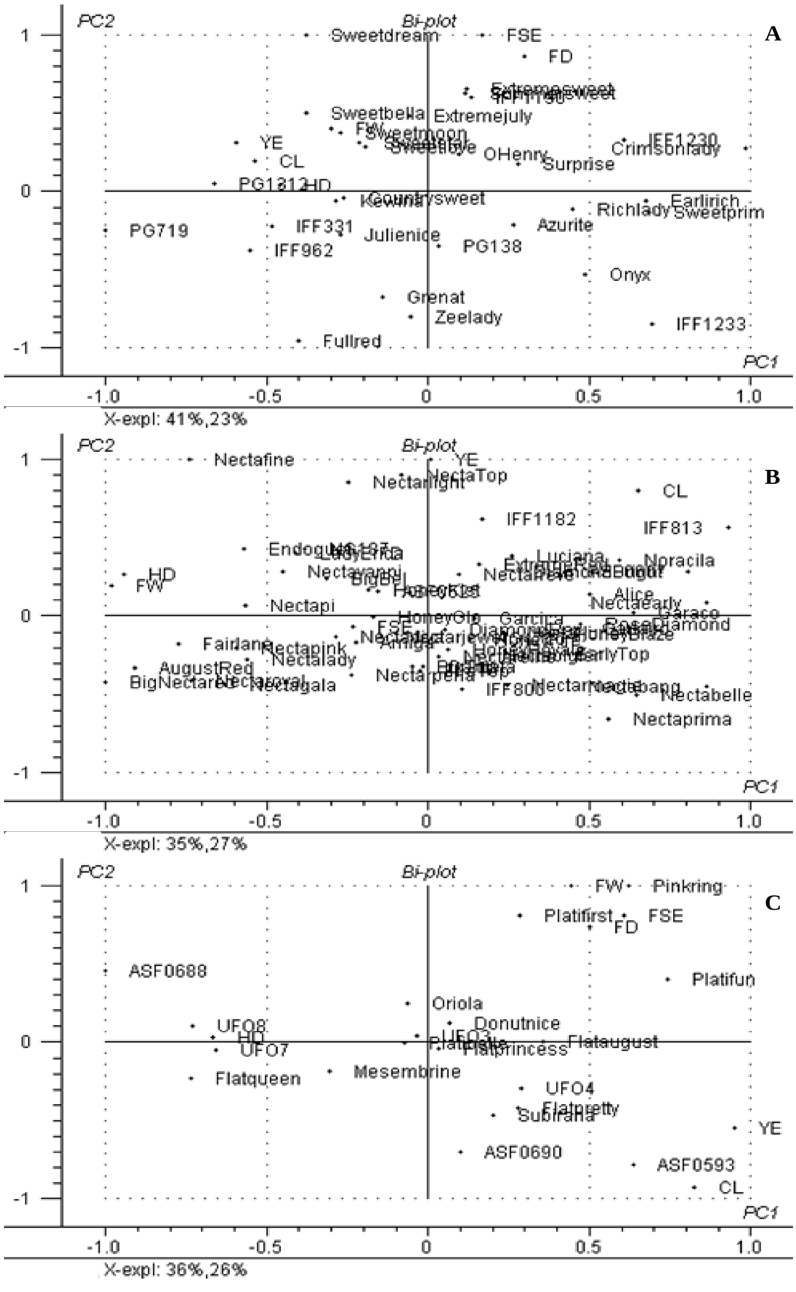

Figure 3.1. Segregation of the 112 peach cultivars, divided by fruit type: (A) melting peach, (B) nectarine and (C) flat peach, according to their most important agronomical traits determined by principal component analysis (PCA). *Abbreviations*: YE, yield efficiency; CL, crop load; FW, fruit fresh weight; FD, flower density; FSE, fruit set percentage; HD, harvest date.

No differences were observed among fruit types, either in terms of thinning requirements (THR) or in the percentage of shoots affected by powdery mildew (PM).

Nevertheless, significant differences in harvest date (HD) were observed. In general, flat peach and nonmelting peach cultivars were harvested later than melting peach and nectarine cultivars. As with BB and BP, HD could be considered cultivar dependent due to the fact that it started at the end of May and finished at the end of September for all fruit types. Moreover, despite the results obtained, each fruit type presented a different coefficient of variation (data not shown), with the nectarine being the group that showed the greatest variability.

Melting peach cultivars presented the highest fruit size (FS): 74.5 mm, with the rest of the fruit types exhibiting similar values. The difference between the maximum and minimum values was only 5%. Regarding fruit weight (FW), the melting peach and nectarine cultivars showed the highest values, 149.9 g and 194.2 g, respectively, followed by nonmelting peach and flat peach cultivars. The fact that the melting peach and nectarine cultivars showed similar FWs but different FSs could be explained by the fact that nectarine cultivars tend to be more oblate in shape than melting peach cultivars. In the case of flat peach cultivars, similar FS values were observed to those of nonmelting peach and nectarine cultivars, though this did not mean similar FWs, due to their flat fruit shape.

Regarding tree fruit numbers (TFN), flat peach cultivars showed the highest value (294.1 fruits), followed by nonmelting peach, melting peach and nectarine cultivars. Comparing fruit types, we noted a huge difference (46%) between the maximum (294.1) and minimum (156.7) values of TFN. This suggests that this trait could be fruit-type dependent. Nevertheless and as previously mentioned for other traits, a high degree of variability was found among cultivars of the same fruit type (data not shown).

The crop load (CL) trait is directly related to TFN. The results obtained were therefore similar to those obtained for TFN. Flat peach cultivars showed the highest values compared to the rest of the fruit types, followed by nonmelting peach, melting peach and, finally, nectarine cultivars. In our study, as in those reported by many other authors (Acevedo, 1991; Forshey and Elfving, 1977; Reginato et al., 1995), we generally observed an inverse relationship between crop load and fruit weight. A high CL (2.57 fruits cm^{-2}) tended to mean a low FW (119.7 g.), and vice versa. An exception to this general tendency was observed for melting peach cultivars. Although most melting peach cultivars showed similar CLs to nonmelting peach cultivars, their FWs tended to be greater than that obtained for nonmelting peach cultivars. This suggests that FW could be genotype dependent.

Considering productive parameters such as yield (Y) and yield efficiency (YE), the mean Y of the melting peach cultivars in both years of the study was 35 kg per tree; this was 18% higher than the mean nectarine and flat peach yield and was quite similar to the 32.4 kg per tree of the nonmelting peach cultivars. These differences could be related to lower selection pressure in the case of nectarines and flat peaches because the main breeding programmes originally focussed on peach. Even so, in recent decades, there has been great selection pressure for nectarines and very recently for flat peaches too. This is something that can be observed in the YE, where the melting peach cultivars had a high value, around 0.32 kg cm^{-2}, which was greater than for nectarines and flat peaches and similar to that of nonmelting peaches. These results suggest that nectarine and flat peach cultivars should be planted and carefully managed, from a technical point of view: optimizing plot rootstock location, planting distance, pruning, etc., in order to optimize yields.

Finally, the nectarine and nonmelting peach cultivars showed the highest relative increases in trunk cross sectional area (RI) compared to flat peach cultivars, while intermediate values were obtained for melting peach.

3.4.2. Origin: continent

A general comparison was carried out between US and European breeding programmes for the most important agronomical traits (Table 3.3). Under the climatic conditions found in the Ebro Valley, the mean values for all the different varieties from the different continents showed some relevant differences.

Continent had no effect on the BB and BP of melting peaches and nectarines, reflecting the fact that both continents had released new cultivars with similar genetics in terms of blooming.

Most of the US cultivars tested came from Modesto and Le Grand (California). The climatic conditions in California differed from those of the main production areas of Europe (Italy, France and Spain) and, in particular, from those of the Ebro Valley, where spring damage and cold springs are common. Werner et al. (1988) reported that peach cultivars from California had lower flower densities than those used in Eastern US programmes, where the risk of freeze damage is clearly higher. Nevertheless, in the Ebro Valley, US melting peach and nectarine cultivars exhibited higher FD values than those from Europe. More specifically, FD was 20% higher for melting peach and 17% higher for nectarine cultivars. FD must be taken into consideration when selecting new cultivars (Batlle et al., 2012), because spring frost damage for similar dates of blooming is influenced by flower density (Okie and Werner, 1996). Marini and Reighard (2008) demonstrated that peach cultivars tend to produce flower buds and, consequently, flower densities tend to depend on the ability of a given cultivar to survive winter. However, this difference in FD was not reflected in FSE. This could mean that the spring frost affected more US peach and nectarine cultivars or, on the other hand, that more FD did not necessarily mean more FSE. In our study, FSE was similar for cultivars of both fruit types from the two continents. This could be explained by the important degree of cultivar variability found among fruit types within cultivars from the same continent (Figure 3.1).

More THR was recorded on US melting peach and nectarine cultivars than on the corresponding European cultivars. In general, US cultivars exhibited about 20% more FD than European cultivars. This means that the cost of thinning was higher for US than European cultivars because this cost mainly depends on the flower density of a specific cultivar (Iglesias, 2010).

No differences in PM were observed between continents for the different fruit types, suggesting that this trait was highly cultivar dependent, with a coefficient of variation of 0.8. Moreover, no differences in HD were found either; this was probably due to the fact that the cultivars from the two continents were spread throughout the harvest season (Figure 3.1).

In terms of FS, only the nectarines showed differences between continents, with the European ones exhibiting the highest value (72.7 g). This could have been due to European nectarines exhibiting less FD than US nectarines. However, this trend was not observed in European melting peaches, which exhibited similar FS values to US melting peaches. As a consequence of these results, significant differences in FW were only found in nectarine cultivars. In general, European nectarines exhibited higher FW values than US nectarine cultivars. More specifically, FW values for European nectarines were around 10% higher than for US nectarines.

With regard to TFN, we only found significant differences between continents for melting peach cultivars. Within the same continent, a number of different origins were evaluated which involved cultivars with different harvest maturities. The fact that US melting peaches needed more THR than European melting peaches was a consequence of the fact that the first US melting peaches were low in TFN compared to European ones. This could have been due to most of the cultivars from the USA being early and mid maturity season, while most of the European ones were mid and late maturity season cultivars. Thus, according to these results, only the melting peach cultivars showed significant differences.

European melting peach cultivars exhibited the highest CLs (1.90 fruits·cm^{-2}). However, comparing CLs between fruit types, we observed that although melting peaches exhibited different CLs, the corresponding FS values were similar for different continents. The opposite was observed for nectarines, with similar CLs for the different continents producing different FS values.

Table 3.3. Mean values of agronomical traits (2009 and 2011 seasons) by continent for melting peach and nectarine. The number of observed cultivars (n) is shown for each fruit type.

Trait	Melting peach		Nectarine		Round Fruits	
	Europe	USA	Europe	USA	Europe	USA
n	21	9	40	14	61	23
BB (Julian days)	67.7	67.0	65.7	65.7	66.4	66.2
BP (Julian days)	16.9	17.0	18.0	18.1	17.6	17.7
FD (nº flowers m^{-1})	25.8 b	32.4 a	23.7 b	28.5 a	24.5 b	30.0 a
FSE (%)	49.0	48.5	46.9	43.9	47.6	45.7
THR	1.59 b	1.94 a	1.36 b	1.64 a	1.44 b	1.76 a
PM (%)	39.7	37.4	40.8	36.6	40.4	36.9
HD (Julian days)	196.4	198.5	196.9	198.0	196.7	198.2
FS* (mm)	74.3	74.7	72.7 a	70.1 b	73.2 a	71.9 b
FW* (g)	190.1	204.9	201.8 a	182.9 b	198.0 a	190.9 b
TFN* (fruits tree^{-1})	194.0 a	161.7 b	159.3	164.3	171.2	163.5
CL* (nº fruits cm^{-2})	1.90 a	1.57 b	1.42	1.31	1.59	1.40
Y (kg tree^{-1})	36.4	31.8	28.6	28.8	31.3	30.0
YE* (kg cm^{-2} of TCSA)	0.35	0.30	0.26 a	0.22 b	0.29 a	0.25 b
RI (cm^{2})	65.5	63.4	72.6	81.0	127.9 b	149.1 a

Mean separation within rows by Tukey's test ($P \leq 0.05$). In each row by fruit type, values with the same letter are not significantly different. *Abbreviations*: BB, date of beginning of bloom; BP, blooming period; FD, flower density; FSE, fruit set percentage; THR, thinning requirement; PM, powdery mildew percentage; HD, harvest date; FS*, fruit size with crop load as a covariable; FW*, fruit fresh weight with crop load as a covariable; TFN*, tree fruit number with TCSA as a covariable; Y, yield; YE*, yield efficiency with TCSA as a covariable; CL*, crop load with TCSA as a covariable; RI, relative increase in trunk cross-sectional area.

Continent had no effect on the RI or Y of melting peaches or nectarines, suggesting that the cultivars from the two continents had similar genetics in terms of vegetative growth and absolute yield. In this case, differences in FD did not result in differences in Y in the two fruit types on these two continents. Nevertheless, although no differences between continents were observed for YE in melting peach cultivars, in the case of nectarines, the European varieties showed higher YE values than American ones, with around 15% greater YE. As mentioned previously, more variability was observed within each fruit type than between different fruit types.

The main goals of breeding programmes differ from one continent to the other due to their specific climatic conditions and market requirements. American breeding programmes have developed white and yellow-fleshed, low-acidity and medium-to-low chilling cultivars and high red-colour and round fruit with medium-to-high fruit size (Okie et al., 2008). Breeding programmes in France, Italy and Spain – the most important producing countries in Europe – share the condition of having late harvest dates. This allows them to obtain cultivars that are well-adapted to their areas of production and can give high fruit quality and good colour and size (Cantín et al., 2006; Llácer et al., 2009c; Martínez-Calvo et al., 2006). In general, the adaptability of new peach cultivars to different climatic conditions has not been a selection criteria in the main breeding programmes developed in recent decades. For this reason, the agronomic response of some new varieties is uncertain when they are grown under climatic conditions that are different from those where they were originally developed (Berra et al., 2011). As a result, European cultivars tended to show better agronomic behaviour than American cultivars due to the similarity in climatic conditions.

3.4.3. Origin: breeding programme

A comparison between breeding programmes for a given fruit type (melting peach, nectarine and flat peach) was carried out for the most important agronomical traits (Table 3.4). In general, different results were obtained when we compared fruit types for all the different agronomical traits. Breeding programme had no noticeable effect on BB for melting peaches. However, significant differences were found for nectarine and flat peach cultivars. With regard to nectarine CRA, A. Minguzzi and ASF produced the highest values, followed by Zaiger, Bradford and then PSB. All the PSB cultivars started to bloom earlier than the other cultivars because the PSB breeding programme is interested in obtaining mid- and low-chilling cultivars (Liverani, 2008) in order to advance the harvest date in areas of early fruit production. Early flowering is a desirable character in many breeding programmes in Mediterranean areas because it is related to early harvest and large fruit size for similar harvest dates. This is what largely determines price, although spring frost may affect yields in some years (Cantín et al., 2010). Nevertheless, ASF was the breeding programme whose cultivars tended to start bloom later than the others.

In terms of BP, breeding programme had no effect on the behaviour of flat peach cultivars. However, very significant differences were observed in melting peaches and nectarines. This could mean that BP was breeding programme dependent in these two fruit types; differences of around 15% were observed between the maximum and minimum values of BP for these two fruit types.

Differences in FD were found between breeding programmes for melting peach and nectarine cultivars, although most of them presented similar values. In the case of melting peaches, Zaiger with 30 flowers·m^{-1} and A. Minguzzi with 20.4 flowers·m^{-1} exhibited extreme values. Among the nectarines, 'Big Top' was considered the reference cultivar because of its low flower density (20 flower·m^{-1}) (Iglesias, 2010). The rest of the breeding programmes showed similar values. The same trend was observed in nectarines, with Bradford exhibiting the highest value (31.3 flowers·m^{-1}) and ASF showing the lowest (23.2 flowers·m^{-1}). Even so, significant differences were observed between cultivars within the same breeding programmes (Figure 3.1), with a range of from low to medium and to high flower density (Bassi and Monet, 2008).

In the case of FSE, no differences were found between melting peach and nectarine cultivars, suggesting that the breeding programmes for both peach and nectarine that exhibit most FD are also the ones that produce the largest fruit set. Instead, differences in FSE were observed in flat peaches, with INRA and CRA presenting the highest values. In this case, the difference between the maximum and minimum values of FSE was about 40%.

Different results relating to THR were obtained from different breeding programmes according to fruit type. This trait is directly related to FD and fruit set. The fact that no statistically significant differences were found in the case of melting peaches suggested the existence of greater variability between different breeding programmes in terms of fruit set, with a coefficient of variation of 0.26. This means that THR should not be used as a criterion when selecting new melting peach cultivars. A different trend was observed among nectarine breeding programmes; differences in THR were observed that were more

Table 3.4. Mean values (2009 and 2011 seasons) of agronomical traits by origin for each fruit type, except nonmelting peach type. The number of cultivars (n) tested is shown for each origin.

Trait	Melting peach					Nectarine						Flat peach		
	Minguzzi	ASF	CRA	Monteaux	Zaiger	Minguzzi	ASF	Bradford	CRA	PSB	Zaiger	ASF	CRA	INRA
n	3	7	5	3	7	3	25	4	3	6	9	8	5	5
BB (Julian days)	66.8	67.8	67.8	67.3	66.8	66.6 a	66.2 a	64.6 b	67.6 a	61.4 c	66.0 ab	68.2 a	65.9 b	66.7 b
BP (Julian days)	18.3 a	17.7 ab	16.3 c	15.7 c	16.8 bc	18.5 ab	18.2 ab	19.1 a	18.0 ab	17.2 b	17.6 b	18.5	18.5	18.3
FD (nº flowers m⁻¹)	20.4 b	26.2 ab	27.6 ab	22.8 ab	30.0 a	28.3 ab	23.2 b	31.3 a	23.1 ab	23.2 ab	27.2 ab	25.7	25.6	28.6
FSE (%)	40.9	49.8	47.8	40.0	47.9	53.1	46.8	45.4	34.8	51.5	40.9	32.0 b	45.7 a	54.1 a
THR	1.2	1.8	1.4	1.2	1.8	2.00 a	1.39 ab	1.87 a	1.16 ab	1.00 b	1.31 ab	1.56 ab	1.20 b	2.10 a
PM (%)	43.3 ab	28.0 b	54.3 a	42.8 ab	34.7 b	37.2	39.9	27.7	26.6	43.3	41.6	53.7 a	33.3 b	34.3 b
HD (Julian days)	193.7 ab	207.2 a	192.6 b	185.2 b	200.0 ab	195.0 abc	204.0 a	191.2 abc	182.8 bc	175.8 c	192.2 b	214.5 a	196.1 b	198.0 b
FS* (mm)	78.6 a	74.3 b	73.2 b	73.3 b	75.5 ab	74.4 a	73.0 a	68.3 c	72.0 abc	70.5 abc	70.1 bc	71.7 a	69.3 b	72.3 a
FW* (g)	210.9 a	199.5 a	173.9 b	188.9 ab	212.8 a	214.2 a	207.8 a	176.5 b	190.6 ab	174.2 b	176.7 b	114.0	112.9	116.5
TFN* (fruits tree⁻¹)	205.7 ab	175.3 b	146.8 b	283.2 a	168.3 b	126.8 b	156.4 b	221.7 a	166.7 ab	172.2 ab	147.8 b	306.7	269.8	274.4
CL* (nº fruits cm⁻²)	2.3 a	1.70 b	1.50 b	2.62 a	1.63 b	1.04	1.34	1.57	1.78	1.5	1.2	2.8	2.4	2.5
Y (kg tree⁻¹)	45.9 a	34.7 ab	29.2 b	45.5 a	33.6 ab	26.1	29.0	34.6	23.4	27.5	26.7	27.9	29.4	30.6
YE* (kg cm⁻² of TCSA)	0.46 a	0.3 b	0.3 b	0.5 a	0.3 b	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.3
RI (cm²)	115.3	64.0	71.7	81.0	63.0	71.8	70.4	66.5	81.8	100.6	74.8	64.6	38.1	56.5

n: number of cultivars tested. Mean separation within rows by Tukey's test ($P \leq 0.05$). In each row by fruit type, values with the same letter are not significantly different. *Abbreviations*: BB, date of beginning of bloom; BP, blooming period; FD, flower density; FSE, fruit set percentage; THR, thinning requirement; PM, powdery mildew percentage; HD, harvest date; FS*, fruit size with crop load as a covariable; FW*, fruit fresh weight with crop load as a covariable; TFN*, tree fruit number with TCSA as a covariable; Y, yield; YE*, yield efficiency with TCSA as a covariable; CL*, crop load with TCSA as a covariable; RI, relative increase in trunk cross-sectional area.

closely associated with FD than THR, in spite of no differences were observed in FSE**.** In contrast, differences in THR were observed in flat peaches. Similar FDs with different FSEs involved different THRs suggesting that variability among breeding programmes, with a coefficient of variation of 0.40, was greater than variability within the same breeding programme, with coefficients of variation of 0.29, 0.39 and 0.30 for ASF, INRA and CRA, respectively.

PM sensibility was only affected by breeding programme in the case of melting peaches and flat peaches. In melting peach CRA presented the highest value (54.3%) and ASF the lowest (28%). On the contrary to melting peach, ASF exhibited its highest value (53.7%) in flat peach. This is one of the most important diseases present in the main peach producing areas of Southern Europe (Foulongne et al., 2003) and in particular in those with low rainfall in spring. There was a more than 80–fold range (1.0-86.7 %) in PM sensibility among cultivars and breeding programmes. This trait could therefore be cultivar and origin dependent.

Origin had an effect on HD for different fruit types. In general, melting peach cultivars from CRA and Monteaux-Callet were harvested earlier in the season than those from other breeding programmes and cultivars from ASF were harvested later. Fruits from the rest of the breeding programmes were harvested between these dates. This could be explained by the fact that the percentages of early cultivars from CRA, Monteuax-Callet and ASF were 33, 20 and 14, respectively. Similar trends were also observed for nectarines and flat peaches. In the case of nectarines, ASF presented the latest HD (204th Julian day), with only 20% of early cultivars, and PSB the earliest HD (175.8th Julian day). As previously mentioned, most of the cultivars from PSB are low or medium chilling, and in our study 66% of the cultivars evaluated were associated with both early bloom and early maturity. Just as with melting peaches and nectarines, ASF in flat peaches was associated with later HDs than other breeding programmes. In all the fruit types, ASF was least associated with early season cultivars.

In the case of FS, significant differences were found between breeding programmes for each fruit type. A. Minguzzi melting peaches exhibited the highest value, though Zaiger presented similar values to A. Minguzzi. The lowest values were for ASF, CRA and Monteaux-Callet. In the case of nectarine, A. Minguzzi and ASF presented the highest FS values and Bradford the lowest; this was because 50% of the Bradford cultivars were characterized by early-season maturity. The small fruit size associated with early-season cultivars is due to small cell numbers and the short duration of the fruit growing period (Marini and Reighard, 2008). However, a difference of only 10% was observed between the maximum and minimum values. With respect to flat peaches, ASF and INRA produced larger fruit sizes, 71.7 and 72.3 mm, respectively. In the case of ASF cultivars, the high FS values could have been due to the fact that most of the cultivars were late harvest varieties.

FW is an important inherited quantitative factor that determines yield, fruit quality and consumer acceptability (Dirlewanger et al., 1999). High FWs were observed in A. Minguzzi, ASF and Zaiger melting peaches. In general, larger fruits were heavier than smaller ones. One exception was ASF, probably because ASF cultivars were more oblate than A. Minguzzi and Zaiger cultivars. In the case of nectarines, the breeding programmes which produced high FSs also exhibited high FWs; these were Minguzzi and ASF. There was a difference of about 19% between the maximum and minimum values observed in both melting peach and nectarine fruits. Nevertheless, despite the existence of significant differences in origin with respect to FW in nectarine cultivars, no relationship was found between breeding programmes for differences between CL and FW (Figure 3.2). Finally, no differences in FW were observed in flat peaches. This could be explained by fruit shape, but similar FWs tended to be associated with similar CLs (Figure 3.3).

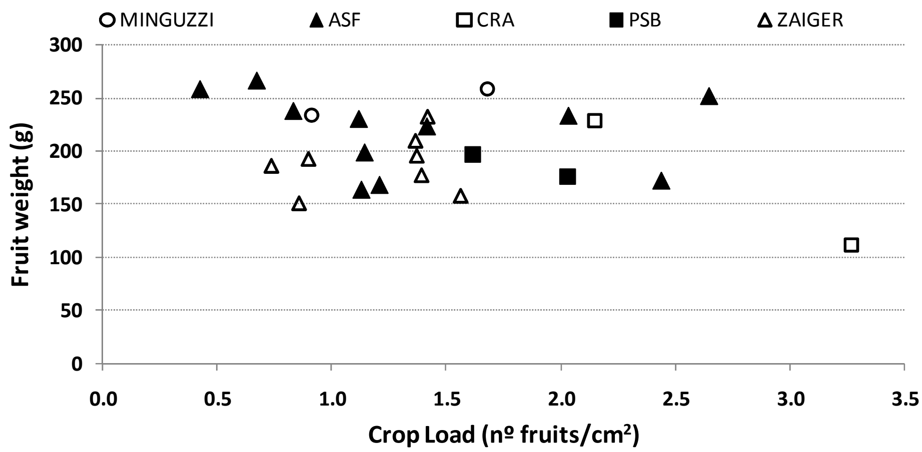

Figure 3.2. Distribution of agronomic traits of different mid-season nectarine cultivars averaged over the two years of the study, according to their origin.

The breeding programme used only had a significant effect on FN in the cases of melting peaches and nectarines. Monteaux-Callet showed the highest values followed by A.

Minguzzi, with 205.7 and 283.2, respectively; in contrast, the other melting peach breeding programmes all presented similar values. The Monteaux-Callet programme established hardiness as one of the main cultivar selection criteria. For this reason, Monteaux-Callet cultivars performed very well in frosty areas of the Ebro Valley. For nectarines, Bradford (221.7) and PSB (172.2) produced the highest TFN values; this was due to most of their cultivars being early-season maturity and early-season blooming. A. Minguzzi (126.8), ASF (156.4) and Zaiger (147.8) had the lowest TFN values. Comparing the same breeding programme for both fruit types, for example A. Minguzzi and Zaiger, the FN values were higher in melting peaches than in nectarines in both cases. This suggests that, from the point of view of yield, the melting peaches performed better than the nectarine cultivars. On the other hand, for CL, which is directly related to FN, only melting peach breeding programmes exhibited statistically significant differences. In this case, breeding programmes with high FN values presented high CL values. However, higher CL values should mean lower FW values. This is a general rule applicable for the different breeding programmes for each fruit type; with Minguzzi melting peaches breeding programme as the only exception (Figure 3.3).

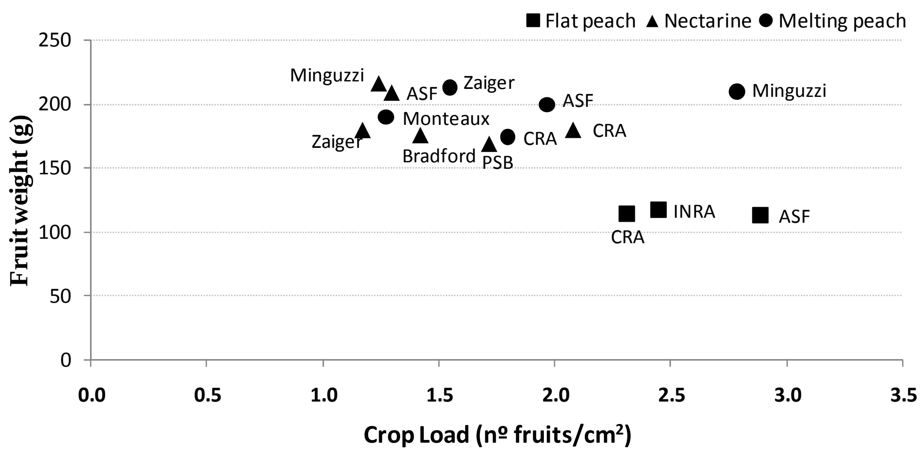

Figure 3.3. Distribution of agronomic traits of different melting peach, nectarine and flat peach cultivars averaged over the two years of the study according to their origin. Each point is the mean of all the cultivars evaluated within the same breeding program.

In terms of productive parameters, different results were obtained with different breeding programmes according to fruit type. Only melting peaches showed statistically differences between breeding programmes for Y and YE. A. Minguzzi and Monteaux-Callet showed high Y and YE values despite presenting the highest CL and FN values.

Finally, in the case of RI, the breeding programme for each fruit type did not have any direct effect due to the huge variability between cultivars and within those of the same origin. Differences of 70, 78, 73 and 73% were observed between maximum and minimum values of RI for melting peach, nectarine, nonmelting peach and flat peach cultivars, respectively.

Each breeding programme focuses on developing the cultivars best adapted to its particular climatic conditions and consumer demand. However, not all breeding programmes seek the same objectives and not all objectives, which can include: good productivity, hardiness, improved fruit size and/or tolerance to powdery mildew (Bassi et al., 2010; Fideghelli and Della Strada, 2009; Okie et al., 2008), can be achieved when cultivars are grown in different areas from where they were first developed, and particularly in the Ebro Valley.

3.4.4. Cultivars

A principal component analysis (PCA) was performed in order to evaluate the most important agronomical traits considered (yield efficiency, crop load, fruit weight, flower density, fruit set percentage and commercial harvest) (Figure 3.1). Three PCA models were developed for melting peach, nectarine and flat peach cultivars, respectively, to know which the best cultivars for each fruit type were. Both samples and variables were presented together and projected onto the biplot plane defined by the first two principal components. The range of values for each agronomical variable was very wide between different cultivars. Crop load values ranged between 0.3 and 4.1 fruit·cm^{-2}. Yield efficiency included values from 0.1 to 0.8 kg·cm^{-2}. There was a more than three-fold range (80.8–290.5 g) in mean fruit weight between cultivars due to genotype and fruit type (nectarine, melting peach, clingstone and flat peach). There was a more than 15–fold range in mean flower density between cultivars, with values ranging from 4 (very low) to 67 (very high density). Finally, the commercial harvest date ranged from the end of May to the end of September (152nd – 251st Julian day).

The results for melting peach cultivars are presented in Figure 3.1A. The variances explained by the first two PCs were 41% and 23%, respectively. The biplot for melting peach cultivars revealed a strong correlation for yield efficiency, crop load and harvest date. Fruit set percentage and flower density also presented a strong relationship. Cultivars like 'Early Rich', 'Sweetprim' and 'Crimson Lady', which are all early-season harvest cultivars showed low yield efficiency, low crop load and low fruit weight. 'Zee Lady', 'Grenat', 'Fullred', 'Onyx' and 'IFF 1233', which are from different breeding programmes, showed low flower density values and the lowest fruit set percentage. Nevertheless, the most productive peach cultivars were 'Sweetbella', 'PG 3/1312', 'Sweetstar', 'IFF 331', 'IFF 962', 'Fullred' and 'Sweet Dream'. These were all from different breeding programmes and continents (US or Europe) and for this reason exhibited different flower densities and different fruit set percentages.

For nectarine cultivars, we observed different trends to melting peach cultivars. The variances explained by the first two PCs were 35% and 27%, respectively. In Figure 3.1B, it is possible to observe a strong relationship between harvest date and fruit weight (Okie et al., 2008). Early harvest nectarine cultivars exhibited lower fruit weights, but not all nectarine cultivars with low yield efficiencies had low fruit weights; for example, 'Nectaperla', 'Nectamagie' and 'IFF 800', which had similar low yield efficiencies, had different fruit weights. In this case, the most productive nectarine cultivars were 'Nectatop', 'Nectarlight' and 'Nectafine', all of which differ in their other agronomic traits, but which share a common breeding programme: ASF.

As expected, flat peach cultivars showed different behaviour from melting peach and nectarine cultivars (Figure 3.1C), but a similar total variance percentage was obtained (62%). Late harvest date flat peach cultivars such as 'ASF 06-88', 'UFO 8', 'UFO 7' and 'Flatqueen' were less productive. In contrast, as with melting peach and nectarine cultivars, fruit weight in flat peaches showed a strong relationship with flower density and fruit set percentage. In general, greater fruit weight was related to low fruit set percentage and to low flower density values. In cultivars such as 'UFO-3' and 'UFO-4', high flower density values were related to high fruit set percentages and lower fruit sizes if the level of fruit thinning applied was not the adequate (Iglesias and Carbó, 2009). Nevertheless, cultivars like 'Pink Ring', 'Platifirst' and 'Platifun' proved an exception to this rule. On the other hand, high flower density, which is genetically dependent (Werner et al., 1988; Okie and Werner, 1996; Burgos et al., 2004), resulted in high fruit set and high yield but 'ASF 05-93' exhibited low flower density and high yield efficiency. Despite these differences, the most productive flat peach cultivars were therefore ‘UFO-4’, ‘ASF 05-93’, ‘Pink Ring’ and ‘Platifun’. The large number of floral biology factors affecting the final fruiting and the influence of climatic conditions could explain the differences observed between cultivars and the year-by-year variation in fruit production and fruit set (Ruiz and Egea, 2008).

3.5. Conclusion

The low degree of genetic variability among peach cultivars reported by many authors did not mean low variability in terms of agronomical performance. Our study shows a strong relationship between different traits such as fruit type, continent, origin and cultivar, within the agronomic attributes and agronomical performance associated with the Ebro Valley.

This work enabled us to select the most interesting cultivars from a plot mix of 112 cultivars which was based on the most appropriate combination of several agronomical traits and fruit sizes. Among the origins evaluated by fruit type, the melting peach cultivars from Monteaux-Callet and A. Minguzzi were the most productive. ASF melting peach cultivars were also interesting on account of their high fruit weight and low incidence of powdery mildew. All of these origins are European. In the case of nectarines, the Bradford cultivars were the best from the point of view of yield. The PSB origin was characterized by early season harvest and also exhibited good yield efficiency and crop load. The ASF origin exhibited good performance with respect to fruit size and fruit weight, although yield efficiency needed to be improved in some cultivars. Although the reduced number of flat peach breeding programmes evaluated in our study, all of them showed good yields; even so, the ASF cultivars proved the most susceptible to powdery mildew.

The large number of cultivars tested, which was from different origins, could provide Spanish growers with valuable information about the agronomical performance of melting peach, nectarine and flat peach cultivars in the Ebro Valley. According to our results, the most melting peach productive cultivars were ‘PG 3/1312’, ‘IFF 962’, ‘IFF 331’. In nectarines, they were ‘Nectatop’, ‘Nectarlight’, ‘Nectafine’ and ‘ASF 05-93’, and ‘Platifun’ and ‘Pink Ring’ for flat peaches.

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Capítulo 4

How does simulated frost treatment affect peach [*Prunus persica* (L.)] flowers of different cultivars from worldwide breeding programmes?

4.1. Abstract

The proportion of frost damaged flowers (FD) and frost symptoms (S1, S2, S3 and S4) was evaluated on 56 peach cultivars from several breeding programmes during 2010 and 2011 seasons in order to understand the tolerance of peach cultivars to low temperature and the susceptibility of their pistils to frost damage. The cultivars were tested at full bloom ('F') under simulated frost treatment. Fifteen of these cultivars were also selected in 2012 to calculate frost temperatures (FT_{10}, FT_{50} and FT_{90}) and their relationship to pistil dry matter. Mid blooming cultivars showed lower tolerances to low temperature than late and early blooming cultivars. Their pistils were also more susceptible to low temperature, showing a higher proportion of more severe symptoms. Blooming time did not affect the degree of pistil susceptibility. Fruit type or peach subspecies (peach, nectarine and flat peach) showed similar susceptibilities to low temperatures; this was not, however, the case for pistils. Significant differences in FD were found for nectarine breeding programmes, but not for peach breeding programmes. The PSB nectarine breeding programme included most of the hardiest cultivars. The susceptibility of pistils to frost damage varied according to breeding programme. Great variability and significant differences were observed between cultivars with regard to FD and frost symptoms. The three frost temperatures considered in this study (FT_{10}, FT_{50} and FT_{90}) corroborated this variability, mainly because significant differences between cultivars were found within each frost temperature. Nevertheless, no significant relationship was found between them and pistil dry matter. These results provide growers with important information to help them when selecting cultivars for new orchards.

4.2. Introduction

Spain is the second largest peach producer in the European Union (EU), accounting for 29% of total production; it is also the fourth largest producer in the world (FAOSTAT, 2012; Iglesias, 2010). In Spain, peach production is mainly located in the Mediterranean areas, with Catalonia and Aragon being the most important producing areas (Iglesias, 2010). This specie is the main deciduous fruit crop, providing 33% of total fruit production. The climate conditions of the Ebro Valley are characterized by warm and hot summers and cold winters, with the latter being sufficient to cover chilling requirements. The average annual rainfall is 375 mm with peaks in spring and autumn. Nevertheless, the main peach producing areas in Spain, and particularly in the Ebro Valley, are frequently exposed to severe spring frosts during the blooming and fruit set periods (March and April). This climatic event frequently leads to important frost damage injury and can be a limiting factor in terms of obtaining optimal agronomical and economic performance (Kalberer et al., 2006).

Many authors (Ballard et al., 1999; Miranda et al., 2005; Osaer et al., 1998; Proebsting and Mills, 1978) have contributed to the literature on several frost temperatures (FT_{10}, FT_{50} and FT_{90}) for different species of Prunus. These FT indexes show the temperatures at which 10%, 50% and 90% of peach flowers are damaged. FTs are commonly used to determine the temperatures at which injury occurs and how many flower buds can survive (Faust, 1989). The temperatures at which fruit buds are injured primarily depend on their stage of development. When buds begin to swell and expand into blossoms, they become less resistant to freeze injury (Miranda et al., 2005). The sequence of the appearance of frost symptoms at full bloom, and therefore the degree of pistil susceptibility (and the severity of damage) is as follows (Royo et al., 1998): the first frost symptoms appear at the base of the style; this is followed by browning on the inside of the ovary, which later progresses from the inside towards the apex and basal zones and then to the other side of the ovary; the next tissue to be affected is the seminal primordium (future seed), first on its bottom and then spreading throughout it; and finally the most severe symptoms appear on the external side of the ovary. Whenever the whole ovule is affected, the embryo aborts and the fruit abscises (Rodrigo, 2000). However, when only the integuments are affected, the fruit may continue to develop in spite of the abortion of the embryo (Saunier, 1960). The survival of flowers or fruits following frost damage therefore depends upon the amount of damage to vital tissues, the capacity of the remaining intact cells to continue growth and also the subsequent environmental conditions, and particularly the risk of tissue desiccation (Modlibowska, 1962).

Many factors have been widely reported to play a part in the vulnerability or resistance of flowers to spring frost. The most important of these are genotype (Westwood, 1993), ice formation, moisture content, flower sugar and starch content (Ercisli, 2003; Levitt, 1980) and the nutritive status of the pistil (Rodrigo, 2000). Other factors, like the intensity and duration of the low temperatures, the rate of temperature decrease, the temperatures during the previous days, short-term temperature variations and climatic conditions (wind speed, relative humidity and cloud cover), influence the extent of frost damage (Rodrigo, 2000). On the other hand, according to Pakkish et al. (2011), in *Prunus sp*. there are three field parameters associated with spring frost injury avoidance: high flower bud set (or bud density), long blooming period and late bloom.

In the Ebro Valley, as in most of the peach-producing areas in the world, a wide variety of cultivars are grown. These cultivars differ in blooming time (early, mid and late) and blooming density (from less than 10 to more than 40 flowers per metre of shoot), among other characteristics. They have mainly their origins in the USA and Europe. These breeding programmes all involve the selection of improved cultivars for better fruit quality and agronomical performance (Byrne, 2002; Iglesias and Echeverría, 2009), adapted to the local conditions for which they were selected (Batlle et al., 2012) and to cover the whole harvest season (Sansavini et al., 2006). Nevertheless, the selection of new cultivars with tolerance to spring frost has not been a general priority. In the period 1999–2008, only 4.4% of new cultivars were selected according to their resistance to spring frost (Fideghelli and Della Strada, 2009). To the best of our knowledge, no lab or field studies have been carried out with the aim of determining the damage caused to the flowers of different cultivars at the same phenological stage (full bloom). This information could help us to discover and characterize the performance of new cultivars against frost damage for the first time. Thereby it could also allow growers to reduce the further risk of low yields.

Due to the difficulty in comparing information on lethal temperatures that is available in the literature and relating to the influence of cultivar on bud frost hardiness, an homogeneous laboratory methodology was developed under controlled conditions to: (1)

find out how blooming time, fruit type, breeding programme and cultivar influence frost tolerance, (2) evaluate the tolerance of 56 peach cultivars to a given frost temperature, (3) examine the relationship between blooming density and tolerance to frost damage, (4) determine the 3 frost temperatures (FT_{10}, FT_{50} and FT_{90}) for 15 peach cultivars, and (5) examine the relationship between pistil dry matter and lethal temperatures in order to provide useful information for peach breeding programmes.

4.3. Materials and methods

4.3.1. 2010 and 2011 seasons

4.3.1.1. Plant Material

Fifty–six peach cultivars were evaluated during the 2010 and 2011 seasons on an experimental collection plot located at the IRTA Experimental Station (Lleida, Northern Spain). Their main characteristics (country, breeding programme, fruit type, blooming time and flower type) are presented in Table 4.1. These cultivars corresponded to 15 melting peaches, 26 nectarines, 5 nonmelting peaches, 7 flat peaches and 3 flat nectarines. The experimental orchard contained three trees per cultivar, planted in a single block, grafted onto INRA®GF-677 rootstock and trained on a central axis system with a 4.5 m × 2.5 m plant spacing. The trees were irrigated using two drippers per tree, delivering 4 l/h. The standard commercial management practices recommended for the area were followed, including for fertilization and the control of pests and plant disease. The weather conditions for the period 2010–2011 were usual for this continental Mediterranean area, with daily maximum summer temperatures of >30 ºC and accumulated annual rainfall of around 370 mm.

4.3.1.2. Simulated frost treatment

The trial was based on the methodology reported by Miranda et al. (2005) and involved the use of shoots with flowers in phenological stage F (Baggiolini, 1952). One tree per cultivar was assessed when more than 60% of its flower buds had reached the desired stage. Fifteen one-year-old shoots per cultivar, of the desired phenological stage, were selected from different sides of the tree at a height of about 1.5 m above the ground. These shoots were then sampled, placed in an insulated container, and then immediately taken to the lab. Shoots were put into plastic bags (5 shoots per bag) and placed inside a programmable 432 L chamber (ASLA Aparatos Científicos, Madrid, Spain). The chamber was equipped with a heat-cold unit, working over the range of -20ºC to 30ºC, equipped with three trays into which the plastic bags were placed together with three Testo 117-H1 dataloggers (Testo AG, Germany) in order to record the air temperature and frost temperature. The running procedure of the programmable chamber has been described by Miranda et al. (2005). Frost temperature was chosen according to Miranda et al. (2005) and Osaer et al. (1998) and some previous tests were carried out before the first trial. The reference temperature for 2010 and 2011 was established at –5.5 ºC, but the real temperature was calculated as the mean of the temperatures recorded by the 3 dataloggers (one for each tray) during the 30 min before the minimum temperature recorded for each tray. The temperature was programmed to decline by 2 ºC h^{-1} until the desired frost temperature was reached. Once the 30 minutes at minimum temperature had passed, it was increased by 3 ºC h^{-1} to 7 ºC.

After the frozen simulation had been completed, the samples were placed in a dark chamber and kept at 6 ºC for another 48 h before visual examination. Then, after the flowers had been detached from the spurs, their pistils had been individually examined under a microscope and the frost symptoms suggested by Royo et al. (1998) were identified. This methodology considered any brownish floral structure to reflect frost damage and also established a scale of frost sensitivity within flower and fruit tissues. The sensitivity order of the tissues at full bloom stage, from most to least sensitive, is as follows: S1: base of the style, S2: internal side of the ovary, S3: seminal primordium, S4: external side of the ovary. In all cases, the damaged flower will be effectively “dead”, i.e., unable to yield fruit. However, the identification of those symptoms allows better identifying and ranking of cultivar tolerance to frost treatments, because after the same frost treatment, the hardiest cultivars will have lower proportion of damaged flowers and also of symptoms in the hardiest tissues.

In order to evaluate the resistance or susceptibility of peach cultivars to low temperature the proportion of frost damaged flowers (FD) and of each frost symptom (S1, S2, S3, S4) were calculated.

Table 4.1. Description of 56 peach cultivars according to country of origin, breeding programme, fruit type, blooming time and flower type.

Cultivar	Country	Breeding programme	Fruit Type	Blooming Time[a]	Flower Type[b]
African Bonnigold	South Africa	ARC	NMP	Mid	NS
Alice	Italy	Martorano di Cesena	NE	Mid	S
ASF 06-88	France	ASF	FP	Mid	S
Belbinette	France	ASF	MP	Late	S
Big Bang	France	ASF	NE	Mid	S
Big Bel	USA	Zaiger	NE	Mid	S
Big Sun	France	Europepinieres	MP	Mid	S
Big Top	USA	Zaiger	NE	Mid	S
Catherina	USA	L. Hough	NMP	Late	S
Extreme Sweet	Spain	Provedo	MP	Late	S
Extreme White	Spain	Provedo	NE	Late	S
Feraude	France	INRA	NMP	Late	S
Fire Top	USA	Zaiger	NE	Mid	S
Flatqueen	France	ASF	FP	Late	S
Garcica	Spain	PSB	NE	Early	S
Hesse	USA	U. California	NMP	Late	S
Honey Blaze	USA	Zaiger	NE	Late	S
Honey Fire	USA	Zaiger	NE	Early	S
Honey Glo	USA	Zaiger	NE	Late	S
IFF 331	Italy	CRA	MP	Late	S
IFF 691	Italy	CRA	MP	Mid	S
IFF 962	Italy	CRA	MP	Mid	NS
Lady Erica	Italy	Martorano di Cesena	NE	Late	S
Latefair	USA	Zaiger	NE	Mid	NS
Luciana	Spain	PSB	NE	Early	S
Magique	France	Europepinieres	NE	Mid	NS
Mesembrine	France	INRA	FP	Mid	S
Nectabelle	France	ASF	NE	Mid	NS
Nectabigfer	France	ASF	NE	Mid	S
Nectagala	France	ASF	NE	Late	S
Nectapi	France	ASF	NE	Mid	S
Nectatop	France	ASF	NE	Mid	S
Nectavanpi	France	ASF	NE	Mid	S
NG-4/720	Italy	A. Minguzzi	NE	Mid	S
Noracila	Spain	PSB	NE	Early	S
O'Henry	USA	G. Merrill	MP	Mid	S
Oriola	France	INRA	FP	Late	S
PG 3/138	Italy	A. Minguzzi	MP	Mid	NS
Pink Ring	Italy	CRA	FP	Mid	S
Platibelle	France	INRA	FP	Mid	S
Platifirst	France	INRA	FP	Mid	S
Rich Lady	USA	Zaiger	MP	Mid	S
Romea	Italy	CRA	NMP	Late	S
Rose Diamond	USA	Bradford	NE	Early	S
Snow Queen	USA	D.L. Armstrong	NE	Late	S
SummerSweet	USA	Zaiger	MP	Mid	S
Sweet Dream	USA	Zaiger	MP	Mid	S
Sweetbella	France	ASF	MP	Mid	NS
Sweetprim	France	ASF	MP	Mid	S
UFO 4	Italy	CRA	FP	Mid	S
UFO 8	Italy	CRA	FP	Late	S
UFO 9	Italy	CRA	FP	Late	S
Venus	Italy	CRA	NE	Late	S
Very Good	France	Europepinieres	MP	Late	S
X-5517	Spain	PSB	NE	Early	S
Zee Lady	USA	Zaiger	MP	Mid	NS

Abbreviations: MP, melting peach; NE, nectarine; NMP, nonmelting peach; FNE, flat nectarine; FP, flat peach; E, early (12th March-15th March); M, mid (16th March-20th March); L, late (21st March-25th March); NS, non-showy; S, showy.

[a] At full bloom stage.

[b] According to UPOV (1995).

4.3.1.3. Blooming density

The number of flowers on each shoot was counted to obtain the blooming density (BD); this was expressed as the number of flowers per length of shoot (m) (Lombard et al., 1988).

4.3.2. 2012 season

4.3.2.1. Plant Material

Based on the results for the 2010 and 2011 seasons, 15 of the 56 peach cultivars previously reported in Table 4.1 where chosen. This second study included 10 nectarines, 1 nonmelting peaches, 1 flat nectarine and 3 flat peaches. These 15 cultivars covered the whole blooming time and the whole range of frost susceptibility.

4.3.2.2. Simulated frost treatment

In order to determine the temperature in which 10%, 50% and 90% of the flower buds are frost damaged (designated FT_{10}, FT_{50} and FT_{90}, respectively), the same methodology was previously described for the 2010 and 2011 was used in 2012, but with slight modifications. We choose several reference temperatures (–2.5 ºC, –4 ºC, –5.5 ºC, –7 ºC and –8.5 ºC), but the real temperature was calculated as the mean of the values recorded by the 3 dataloggers (one for each tray) during the 30 min before each of them recorded the minimum temperature.

4.3.2.3. Pistil dry matter

Pistils from 12 peach cultivars were isolated from 3 x 10–flower replicates per cultivar for dry matter analysis. Flowers were from different parts of the shoot. They were weighed before and after drying in a chamber (Dryglass, JP Selecta S.A., Barcelona, Spain) at a temperature of 70 ºC until a constant weight in order to obtain their dry matter percentage. Due to external causes, the pistils from 3 of the cultivars were lost.

4.3.3. Data analysis

The influence of blooming time, fruit type, breeding programme and cultivar on FD and the severity of each incidence of frost damage was tested by analysis of variance (GLM-ANOVA) using the SAS program package (SAS, 1997). In the case of blooming time, fruit type and breeding programme, *n* was the number of cultivars tested and represented the mean for all the flowers evaluated. When statistically significant differences ($P \leq 0.05$) were found using this analysis, LSMEANS were calculated and mean separation was performed using the Tukey test at the $P \leq 0.05$ level of significance. The proportions of frost damage and the severity of each incidence of frost damage were then arc–sin transformed.

The relationship between frost temperature (dependent variable) and the mean proportion of frost damage (independent variable) for each of the fifteen cultivars was described using a sigmoid curve. This was fitted using probit analysis (Finney, 1971) with the application of PoloPlus software by LeOra (Robertson et al., 2002) to obtain linear regressions for flower damaged probit–temperature. Lethal temperatures (FT_{10}, FT_{50} and FT_{90}) and 95% confidence limits were also calculated. 95% confidence limits were compared to evaluate equality hypotheses between the frost temperatures for the different cultivars. When limits overlapped, critical temperatures were considered not to differ significantly, except under unusual circumstances (Robertson and Preisler, 1992).

4.4. Results and discussion

4.4.1. The 2010 and 2011 seasons

4.4.1.1. Blooming time

Significant effects were found between blooming time (early, mid and late) and FD when all the cultivars were evaluated at full bloom (Table 4.2). Early blooming cultivars were the least damaged: 32% less than mid blooming cultivars. There was a good relationship between frost damage intensity and the appearance of frost–related symptoms in hardier flower tissues. For all the blooming times (early, mid and late), the S1 values were similar. However, the greater the frost damage, the greater was the proportion of flowers exhibiting symptoms in hardier tissues (S2, S3 and S4). Indeed, the differences between early and mid blooming cultivars were 40% for S2 and 35% for S4. Late blooming cultivars produced significantly different results from the other cultivars. However, the differences between late and mid blooming cultivars were smaller, 4% for S2 and 13% for S4. These results suggested that the low temperature used in this study severely affected the pistil, but that blooming time had no effect on flower frost sensitivity.

Several field studies carried out on *Prunus persica* have shown that early blooming cultivars are susceptible to spring frost damage in regions where frost is common (Aygün and San, 2005; Okie et al., 1998). When frost occurs early in the spring and kills some of the reproductive organs, may be some compensation by trees in the form of reduced fruit-abortion at a later stage (Thompson, 1996). Topp et al. (2008) suggest that breeders may wish to select late blooming cultivars in order to reduce the risk of spring frost damage. Because it seems that flower buds that initiate later on 1–year–old shoots tend to be hardier (Shengrui, 2011). However, in our study, which was carried out in a lab under controlled conditions, we were able to compare all the cultivars at the same phenological stage (stage F); this is something which is not possible under field conditions.

Table 4.2. Mean values (2010 and 2011) of frost damaged flowers (%) and the severity of each incidence of frost damage (%) depending on the blooming time.

Trait	**n**	**FD**	**S1**	**S2**	**S3**	**S4**
Early blooming	6	40.5 c	6.2	6.1 b	9.5 b	18.7 c
Mid blooming	31	59.3 a	6.7	10.2 a	14.0 a	28.3 a
Late blooming	19	55.8 b	8.0	9.8 a	13.4 ab	24.6 b
P value		*<0.0001*	*0.4400*	*0.0268*	*0.0245*	*0.0093*

n: number of cultivars tested. Means separation within columns by Tukey's honestly significant difference test ($P \leq 0.05$). In each column, values with the same letter are not significantly different. *Abbreviations*: BD, blooming density; FD, proportion of frost damaged flowers; S1, proportion of flowers with the first frost symptom; S2, proportion of flowers with the second frost symptom; S3, proportion of flowers with the third frost symptom; S4, proportion of flowers with the fourth frost symptom.

Regarding flower type (showy and non-showy), our results (data not shown) agreed with those reported by Hilaire and Giauque (2003), who reported that showy, or rosacea, flowers were more resistant to low temperatures than non–showy, or campanulacea, flowers.

4.4.1.2. Fruit type

For this analysis, three types of fruit were considered: peach, nectarine and flat peach. Flat nectarines were not considered due to their low number. Melting peaches and nonmelting peaches were both included in the peach fruit type. Fruit type had no significant effect on response to injury (FD) (Table 4.3) due to the great variability found within each fruit type (46, 50 and 44% were the values of the respective coefficients of variation for peach, nectarine and flat peach). Nevertheless, fruit type had a significant effect on the severity of frost damage. There was a good relationship between frost damage intensity and the appearance of frost-related symptoms in hardier flower tissues in the case of peach and nectarine cultivars, but not in flat peach cultivars. The greater the frost damage the greater was the proportion of flowers exhibiting symptoms in hardier tissues (S2, S3 and S4), but this was not the case in flat peach cultivars. We could say that the low temperature used in this study severely affected the pistil given the high mean values observed in S4 and the low values observed in S1. But, the degree of pistil susceptibility varied according to fruit type. Pistils from flat peaches tended to be less affected than those from peach and nectarine cultivars.

Table 4.3. Mean values (2010 and 2011) of frost damaged flowers (%) and the severity of each incidence of frost damage (%) depending on fruit type.

Trait	n	FD	S1	S2	S3	S4
Peach	20	56.4	5.4 b	7.1 c	11.3 b	32.7 a
Nectarine	26	55.8	7.6 a	9.5 b	12.8 b	25.9 a
Flat peach	7	56.5	5.5 ab	13.9 a	21.6 a	15.4 b
P value		*0.9297*	*0.0067*	*0.0005*	*0.0010*	*0.0009*

n: number of cultivars tested. Means separation within columns by Tukey's honestly significant difference test ($P \leq 0.05$). In each column, values with the same letter are not significantly different. *Abbreviations*: BD, blooming density; FD, proportion of frost damaged flowers; S1, proportion of flowers with the first frost symptom; S2, proportion of flowers with the second frost symptom; S3, proportion of flowers with the third frost symptom; S4, proportion of flowers with the fourth frost symptom.

4.4.1.3. Origin: Breeding programme

Most of the cultivars evaluated in our trial originated from breeding programmes conducted in the USA (mainly in California) and Europe (France, Italy and Spain). The climatic conditions of California differ from those of the main production areas of Europe (Italy, France and Spain) and, in particular, from those of the Ebro Valley. These differences in climatic conditions influenced the criteria for selecting new cultivars and also the characteristics of the cultivars selected. The effect of origin (breeding programme) on the frost tolerance of the most important fruit types (peach and nectarine) was studied and the results are presented in Table 4. Melting peaches and nonmelting peaches were both included in the peach fruit type.

Different peach breeding programmes did not produce significant differences in FD (Table 4.4). Nevertheless, in all the peach breeding programmes there was a good relationship between frost damage intensity and the appearance of frost-related symptoms in hardier flower tissues. The greater the frost damage the greater was the proportion of flowers showing symptoms in hardier tissues (S2, S3 and S4). Although no significant differences were found in S1 and S4, our results suggest that ASF cultivars were the most susceptible to frost damage, mainly because 70% of the damaged flowers from ASF showed S4, followed by Zaiger (54%) and CRA (49%). On the other hand, breeding programme did have a significant effect on FD in the case of nectarines (Table 4.4). Although great variability was found within this fruit group (a coefficient of variation of more than 30% for all of these breeding programmes), ASF and Zaiger showed the highest FD and PSB exhibited the lowest. PSB is working for obtaining mid- and low- chilling cultivars in order to advance harvest in areas of early fruit production (Liverani, 2008). In our study, PSB cultivars were all early blooming cultivars. As in peach breeding programmes, there was a good relationship between frost damage intensity and the appearance of frost-related symptoms in hardier flower tissues. However, no differences were found between breeding programmes for S1 and S3. Pistils from PSB tended to be less susceptible to frost than those from other breeding programmes. The differences between PSB and ASF were 16% in S2 and 52% in S4, and those between PSB and CRA were 32% in S2 and 18% in S4.

Table 4.4. Mean values (2010 and 2011) of frost damaged flowers (%) and the severity of each incidence of frost damage (%) depending on breeding programmes for each fruit type (peach and nectarine).

Trait	Peach				Nectarine			
	ASF (3)[1]	CRA (4)	Zaiger (4)	*P value*	ASF (7)	PSB (4)	Zaiger (7)	*P value*
DF	55.9	55.7	54.3	*0.8566*	62.4 a	41.5 b	55.2 a	*0.0036*
S2	5.6	5.5	4.4	*0.7114*	5.8	7.5	7.5	*0.7129*
S3	5.8 b	12.0 a	6.8 ab	*0.0083*	8.6 ab	7.2 b	10.5 a	*0.0473*
S4	4.9 b	11.7 a	13.7 a	*0.0006*	11.0	8.9	15.4	*0.1793*
S5	39.6	27.3	29.4	*0.1096*	36.9 a	17.9 b	21.7 ab	*0.0276*

[1] Number of cultivars tested per breeding programme and fruit type. Means separation within files by Tukey's honestly significant difference test ($P \leq 0.05$). In each file, values with the same letter are not significantly different. *Abbreviations*: BD, blooming density; FD, proportion of frost damaged flowers; S1, proportion of flowers with the first frost symptom; S2, proportion of flowers with the second frost symptom; S3, proportion of flowers with the third frost symptom; S4, proportion of flowers with the fourth frost symptom.

4.4.1.4. Cultivars

When the response of flowers from 56 peach cultivars to low temperature under lab–simulated frost conditions was evaluated, great variability and significant differences were observed (Table 4.5). FD showed great variability among cultivars, ranging from 25.8% ('Rose Diamond') to 90.1% ('African Bonnigold'). With regard to the appearance of frost-

Tabla 4.5. Mean values (2010 and 2011) of frost damaged flowers (%) and the severity of each incidence of frost damage (%) in 56 peach cultivars.

Cultivar	n	BD	FD		S1		S2		S3		S4	
Rose Diamond	468	39.4	**25.8**	**k**	2.6	bcd	**2.0**	**d**	**5.3**	**d**	15.3	defg
Big Bel	254	30.2	29.4	jk	3.1	bcd	4.4	cd	**5.5**	**d**	16.1	defg
UFO 8	365	38.2	34.3	ijk	8.9	abcd	10.3	abcd	12.4	abcd	**2.7**	**g**
Garcica	262	21.0	34.5	hijk	5.6	abcd	6.3	bcd	6.4	bcd	16.2	cdefg
Sweetbella	314	28.5	35.0	hijk	2.9	bcd	**2.4**	**d**	**3.6**	**d**	26.0	bcdefg
Honey Glo	378	34.2	35.9	ghijk	6.8	abcd	5.5	bcd	9.2	bcd	14.2	defg
Very Good	300	32.4	37.7	ghijk	2.2	bcd	**1.3**	**d**	**5.9**	**d**	28.0	bcdefg
Flamina	409	38.2	38.2	ghijk	13.8	abcd	10.5	abcd	7.2	bcd	6.8	efg
Nectatop	400	31.6	39.2	fghijk	4.0	abcd	6.4	abcd	8.4	bcd	20.8	bcdefg
SummerSweet	173	28.3	41.1	efghijk	4.9	abcd	8.3	abcd	8.5	bcd	18.8	bcdefg
Fire Top	290	28.8	41.8	efghijk	10.1	abcd	11.3	abcd	7.1	bcd	14.1	efg
O'Henry	279	22.7	42.3	efghijk	3.8	bcd	3.1	cd	10.3	abcd	25.4	bcdefg
Noracila	268	21.1	42.5	efghijk	9.8	abcd	8.3	abcd	12.3	abcd	12.0	efg
Oriola	407	34.1	44.7	efghijk	**21.7**	**a**	12.2	abcd	6.8	bcd	3.9	fg
Extreme White	255	27.2	45.4	defghijk	10.2	abcd	7.9	abcd	6.1	cd	21.6	bcdefg
Catherina	425	43.1	46.7	defghijk	4.7	abcd	7.3	abcd	15.9	abcd	19.6	bcdefg
Lady Erica	295	28.8	47.4	defghijk	9.0	abcd	7.4	abcd	13.0	abcd	17.7	cdefg
Snow Queen	283	30.9	47.4	defghijk	11.3	abcd	12.2	abcd	9.7	abcd	14.8	defg
Sweet Dream	352	33.6	47.5	cdefghijk	2.3	bcd	4.0	cd	11.0	abcd	30.7	bcdefg
Luciana	377	31.8	51.1	cdefghijk	**0.8**	**d**	3.8	cd	10.0	abcd	35.6	abcdefg
Honey Fire	382	33.4	51.6	cdefghijk	3.9	bcd	6.0	bcd	15.7	abcd	25.6	bcdefg
Flatqueen	296	25.7	52.1	bcdefghijk	2.9	bcd	11.1	abcd	19.9	abcd	18.0	cdefg
Big Sun	229	25.8	53.1	bcdefghijk	13.1	abcd	13.4	abcd	7.7	bcd	19.2	bcdefg
Nectavanpi	305	36.5	54.3	bcdefghijk	4.4	abcd	11.8	abcd	9.8	abcd	28.2	bcdefg
Romea	397	35.2	54.4	bcdefghijk	15.3	abcd	16.5	abcd	6.2	cd	17.3	cdefg
IFF 691	325	43.2	54.5	bcdefghijk	3.0	bcd	6.4	abcd	9.3	bcd	35.9	abcdefg
Zee Lady	243	28.2	56.3	bcdefghijk	1.9	cd	5.4	bcd	18.2	abcd	31.0	bcdefg
IFF 331	486	52.3	56.5	bcdefghijk	**1.0**	**d**	4.7	bcd	17.7	abcd	32.4	bcdefg
Nectapi	293	30.3	56.5	bcdefghijk	7.4	abcd	10.8	abcd	8.3	bcd	29.8	bcdefg
Platifirst	395	30.9	56.7	bcdefghijk	8.0	abcd	16.3	abcd	21.7	abcd	11.1	efg
Alice	350	36.8	57.0	bcdefghijk	5.8	abcd	10.3	abcd	16.5	abcd	24.4	bcdefg
UFO 4	439	39.4	57.3	abcdefghijk	3.6	bcd	14.8	abcd	21.2	abcd	17.4	cdefg
Platibelle	259	18.8	57.5	abcdefghij	2.3	bcd	6.5	abcd	15.1	abcd	33.5	abcdefg
ASF 06-88	332	37.6	60.3	abcdefghij	16.5	abcd	21.8	abc	17.0	abcd	5.4	efg
IFF 962	218	32.2	60.7	abcdefghij	3.4	bcd	20.6	abcd	12.0	abcd	24.7	bcdefg
Extreme Sweet	247	20.2	60.9	abcdefghij	5.3	abcd	3.7	cd	12.3	abcd	39.9	abcdefg
Nectabigfer	304	27.7	61.5	abcdefghij	4.4	abcd	19.8	abcd	11.8	abcd	25.9	bcdefg
Big Bang	252	24.7	61.9	abcdefghij	16.9	abcd	6.3	bcd	**1.8**	**d**	37.7	abcdefg
Mesembrine	248	29.3	62.0	abcdefghij	17.4	abc	20.2	abcd	11.6	abcd	12.9	efg
Hesse	383	39.2	63.9	abcdefghi	5.4	abcd	6.5	abcd	13.3	abcd	38.5	abcdefg
Feraude	418	30.4	65.3	abcdefghi	3.4	bcd	3.5	cd	17.7	abcd	40.9	abcdef
Sweetprim	231	21.7	66.6	abcdefghi	**1.0**	**d**	3.3	cd	6.4	cd	55.7	abcd
Pink Ring	429	43.9	67.2	abcdefgh	5.1	abcd	13.1	abcd	**33.6**	**a**	14.9	defg
Rich Lady	287	25.8	67.4	abcdefgh	9.5	abcd	9.3	abcd	16.2	abcd	32.6	abcdefg
NG-4/720	261	28.4	70.1	abcdefgh	11.3	abcd	11.8	abcd	11.4	abcd	35.7	abcdefg
Belbinette	256	36.2	72.1	abcdefgh	12.3	abcd	11.6	abcd	**4.4**	**d**	43.9	abcdef
PG 3/138	274	32.6	72.3	abcdefg	6.1	abcd	6.5	abcd	19.2	abcd	40.6	abcdef
UFO 9	444	39.4	72.6	abcdef	6.5	abcd	**26.0**	**a**	28.2	abc	11.3	efg
Big Top	207	12.7	73.7	abcde	**0.7**	**d**	12.2	abcd	31.5	ab	29.1	bcdefg
Honey Blaze	186	24.3	75.7	abcde	9.3	abcd	13.6	abcd	8.6	bcd	44.0	abcde
Venus	243	23.0	78.9	abcd	16.1	abcd	24.8	ab	24.2	abcd	14.1	efg
Nectagala	272	21.9	80.7	abcd	2.0	bcd	3.3	cd	19.0	abcd	56.6	abc
Nectabelle	308	27.7	80.9	abc	2.7	bcd	**2.7**	**d**	16.0	abcd	59.3	ab
Magique	169	13.0	81.5	ab	11.1	abcd	6.7	abcd	20.0	abcd	43.8	abcdef
Latefair	310	30.9	83.4	ab	18.0	ab	21.3	abc	28.7	abc	15.1	defg
African Bonnigold	185	16.3	**90.1**	**a**	**1.1**	**d**	3.8	cd	9.9	abcd	**75.0**	**a**
P value			< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001	

n: number of flowers tested. Means separation within columns by Tukey's honestly significant difference test ($P \leq 0.05$). In each column, values with the same letter are not significantly different. *Abbreviations*: BD, blooming density; FD, proportion of frost damaged flowers; S1, proportion of flowers with the first frost symptom; S2, proportion of flowers with the second frost symptom; S3, proportion of flowers with the third frost symptom; S4, proportion of flowers with the fourth frost symptom.

related symptoms in hardier flower tissues, the range of values varied widely between cultivars. S1 included values ranging from 0.7 % ('Sweetprim') to 21.7 % ('Oriola'). There was a more than 20-fold difference in S2 (from 1.3 % for 'Very Good' to 26.0 % for 'UFO 9') and S3 (1.8 % for 'Big Bang' to 33.6 % for 'Pink Ring') values. Finally, S4 values ranged from 2.7 % ('UFO 8') to 75.0 % ('African Bonnigold'). 'African Bonnigold' was the most damaged cultivar, with 83% of its flowers exhibiting S4. In contrast, 'Rose Diamond' was the most resistant cultivar, despite 60% of its flowers showing S4. Our results were in line with those of other authors (Pfammatter and Evequoz, 1975; Proebsting and Mills, 1978). They showed the significance of cultivar for frost resistance and suggested that the resistance to sub-zero conditions of buds of different cultivars but from the same species may be even greater than that among different species.

There was no clear relationship between frost damage intensity and frost damaged tissues. In general, the greater the frost damage the greater was the proportion of flowers exhibiting symptoms of severe frost damage (S2, S3 and S4). However, many cultivars such as 'Flamina', 'Fire Top', 'Oriola', 'Extreme White', 'Lady Erica', 'Flatqueen' and 'Big Sun', among others, did not follow this trend.

In general, cultivars with similar FDs did not exhibit similar mean S1, S2, S3 and S4 values, such as 'IFF 331' and 'Nectapi' cultivars. This could be explained by the fact that, under simulated conditions and at similar blooming stages, flowers from the same cultivar, and even from the same shoot, often presented different responses to low temperature (Miranda et al., 2005). This was because flower bud development is a continuous process associated with progressive vulnerability of the pistil to low temperatures (Proebsting and Mills, 1961) and to the fact that pistil development is not strictly linked to changes in external flower appearance (Miranda et al., 2005). This seems to point to an internal attribute that makes some flowers hardier than others (Wisniewski et al., 1997).

4.4.2. The 2012 season

4.4.2.1. Lethal temperatures and pistil dry matter

Due to the great variability observed among the cultivars tested in 2010 and 2011 at the reference temperature (–5.5 ºC), we carried out a supplementary experiment in 2012 involving 15 peach cultivars. In this case, the goal was to observe whether there was different cultivars exhibited different behaviour when subjected to frost treatment. This was done by applying three frost temperatures (FT_{10}, FT_{50} and FT_{90}) obtained using a probit model. All the cultivars fitted well to the probit model, with heterogeneity values (h) similar to or below 1, and showed great variability in each of the three FTs calculated (Table 4.6).

The lowest FT_{10} values were observed for 'Noracila', 'Garcica', 'Luciana', 'UFO 8' and 'Magique'. On the other hand, 'Honey Blaze', 'ASF 06-88' and 'Nectabigfer' were the most sensitive cultivars at FT_{10}. In the case of FT_{50}, the lowest values were obtained for 'UFO 8' and 'Luciana'. These two cultivars were significantly different from 'Honey Blaze', 'ASF 06-88' and 'Nectabigfer', which exhibited the highest FT_{50} values. At FT_{90}, the highest values were obtained for 'Honey Blaze', 'ASF 06-88' and 'Nectabigfer', while the lowest ones were for 'UFO 8' and 'Platibelle'. We can therefore conclude that the lethal temperatures that cause damage to the reproductive organs of plants differ from cultivar to cultivar. This could constitute a basis to increase the efficiency of selection for frost resistance identifying and isolating candidate genes linked to quantitative trait loci (QTL) as they are generally recognized by comparing the degree of covariation for polymorphic molecular marker and phenotypic trait measurements (Martínez-Gomez et al., 2003).

In a study of the *Prunus* species, Miranda et al. (2005) reported that greater hardiness tended to be translated into steeper slopes. Moreover, the difference between hardy and tender species seemed to be due to the latter having less distance between the temperatures at which certain injuries occur (FT_{10}) and those at which only a few buds survive (FT_{90}). However, this general rule was not entirely verified in the case of cultivars from the same species. In our study the cultivars with steep slopes, such as 'Honey Blaze' (11.6), 'Platibelle' (13.0), 'Venus' (13.6), 'UFO 8' (13.8) and 'Honey Glo' (14.3), were not the ones that showed the greatest hardiness. Similarly, cultivars like 'Noracila' (35.6) and 'Garcica' (27.7) were not the most susceptible either. On the contrary, 'Honey Blaze' was the most susceptible to all of the frost temperatures. As a result, different qualitative responses were observed between cultivars. In this case, slope cannot be used as an indicator of frost tolerance because the resistance of the flowers of different cultivars of the same specie (*Prunus persica*) may be even greater than that between different *Prunus* species.

Tabla 4.6. Sensitivity of 15 peach cultivars to low temperatures at full bloom under controlled lab conditions in 2012 season.

Cultivar	n	h[a]	LT_{10}[b]	LT_{50}[b]	LT_{90}[b]	Slope $\pm$ S.E.	RR[c]
African Bonnigold	756	0.9	-4.5 c	-5.3 c	-6.2 c	19.0 $\pm$ 1.6	1.2
ASF 06-88	657	0.8	-3.7 ab	-4.5 ab	-5.4 a	16.2 $\pm$ 1.3	1.0
Big Bang	737	1.0	-4.5 c	-5.3 c	-6.1 bc	20.2 + 2.2	1.2
Garcica	535	0.9	-5.0 d	-5.6 d	-6.2 c	27.7 $\pm$ 3.3	1.2
Honey Blaze	776	1.0	-3.4 a	-4.4 a	-5.7 ab	11.6 $\pm$ 0.8	1.0
Honey Glo	696	0.8	-3.9 b	-4.8 b	-5.9 bc	14.3 $\pm$ 1.2	1.1
Luciana	952	0.9	-5.9 d	-5.8 e	-6.9 d	17.9 $\pm$ 1.4	1.3
Magique	934	1.0	-4.7 cd	-5.5 d	-6.3 c	19.8 $\pm$ 1.6	1.2
Nectabelle	923	1.0	-4.5 c	-5.1 c	-5.8 b	24.0 + 2.2	1.2
Nectabigfer	702	0.8	-3.9 ab	-4.7 a	-5.6 ab	15.5 $\pm$ 1.4	1.1
Noracila	493	0.6	-5.1 d	-5.5 d	-6.0 bc	35.6 + 5.5	1.2
Platibelle	630	0.7	-4.5 c	-5.6 d	-7.1 de	13.0 $\pm$ 1.0	1.3
Platifirst	818	1.0	-4.3 bc	-5.1 c	-6.1 bc	16.7 $\pm$ 1.5	1.1
UFO 8	591	0.9	-4.9 d	-6.1 e	-7.6 e	13.8 $\pm$ 1.2	1.4
Venus	652	0.9	-4.1 bc	-5.1 bc	-6.4 c	13.6 $\pm$ 1.4	1.2

n: number of flowers tested per cultivar.

[a] Heterogeneity (chi–square value/degree of freedom). Values between 0 and 1 indicate a good fit to the data probit model (Finney, 1971).

[b] Mean separations by Tukey's honestly significant difference test ($P \leq 0.05$). Values with the same letter are not significantly different due to 95% confidence limits overlapping.

[c] RR: FT_{50} cultivar / FT_{50} cultivar less tolerant.

The resistance ratio (RR) was calculated (Table 4.6) to explain the difference between the minimum and maximum FT_{50} values. The maximum RR values were 1.3 (for 'UFO 8' and 'Luciana') and the minimum was 1 (for 'Honey Blaze'). 'Honey Blaze' was the most susceptible cultivar. This could mean that the difference between the minimum and maximum FT_{50} values was not so high (–1.7 ºC) and that most of the cultivar values were closer to the mean FT_{50} value (–5.2 ºC).

Finally, in the case of peach, many authors reported that differences between cultivars in terms of cold hardiness have been associated with differences in the sugar contents (Durner and Gianfagna, 1991), proteins and amino acids in flower buds (Lasheen and Chaplin, 1971). In our study, in order to make a preliminary screening, the relationship between pistil dry matter and FT was evaluated in 12 peach cultivars (Figure 4.1). Even though significant differences in pistil dry matter pistil were found among cultivars (data not shown), no relationship was observed between pistil dry matter and FT (R^2 was below 0.2 in all three cases). These results suggest that to understand why different peach cultivars exhibit different FTs and, as a consequence, different reactions to low temperatures, it is important to know the sugar, protein and amino acids contents of each cultivar.

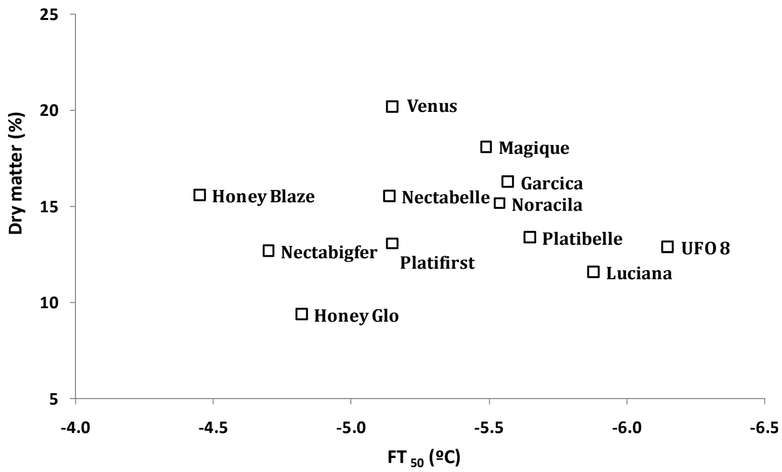

Figure 4.1. Pistil dry matter percentage vs FT_{50}

4.5. Conclusions

This study of 56 peach cultivars, which was conducted under controlled conditions and over a period of two years, has given us a preliminary insight into how factors such as blooming time, fruit type and breeding programme may influence the great variability observed on the response of a cultivar to low temperature. Moreover, due to the great variability observed among cultivars, our results could constitute also a basis for the research of molecular markers (QTL and associated genes) related to the frost tolerance.

The fact that some of our results relating to blooming time did not confirm those cited in the literature, does not make them any less important. These results should be taken into account when: (1) more than one spring frost occurs at similar temperatures, (2) cultivars with different blooming times are at the same phenological stage (F) when spring frosts occur.

The study of the effects of three frost temperatures (FT_{10}, FT_{50} and FT_{90}) on 15 cultivars in 2012 confirmed that great variability exists within the *Prunus persica* species, although the reason for this variability was not clear from this study. We found that pistil dry matter did not offer anything useful to help understand this different in behaviour between different peach cultivars. It would therefore be interesting for further studies to determine sugar, protein and amino acids contents from the pistil in order to characterize different peach cultivars.

The methodology presented here and the results obtained could be useful to growers selecting new cultivars. Our results give an indication of the potential damage that each cultivar could suffer based on the weather conditions that precede bloom in geographic areas similar to those of the Ebro Valley.

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Capítulo 5

Morphological diversity study and establishment of a criteria to select peach cultivars [*Prunus persica* (L.) Batsch] from different breeding programs

5.1. Abstract

Eight morphological traits were recorded in 119 peach cultivars during the 2009 and 2010 harvesting seasons at an orchard placed in IRTA-Estació Experimental de Lleida. An appearance quality index (AQI) was established and calculated in order to give a score to each cultivar. The results revealed significant differences between fruit types (melting peaches, nectarines, nonmelting peaches and flat peaches) for all the morphological traits evaluated and the AQI values. For each fruit type, high variability was also found within the same breeding program, depending on the trait evaluated. Fruit type and breeding program influence gave a general idea of the respective differences and/or similarities and revealed whether the fruits met EU requirements. A PCA analysis for each fruit type made possible to distinguish the most relevant traits and cultivar groups and to detect which cultivars unmatched EU market requirements and which showed the highest and lowest AQI values. Therefore, this study provides relevant information to breeders - to help them improve their new cultivars - and also to growers, technicians, markets and retailers in Spain.

5.2. Introduction

At the present time, the peach crop leads deciduous fruit production in Spain to the detriment of apple and pear; this is mainly due to its better adaptation to the hot, dry climate of the Mediterranean (Iglesias et al., 2010). The Ebro Valley, an area that includes the regions of Catalonia and Aragon, is one of the main peach producing areas in Spain; together with Murcia, Valencia, Andalucía and Extremadura. It accounts for 88% of the country's total production (Iglesias et al., 2012; Iglesias and Casals, 2013).

There are more than 70 active (public and private) peach breeding programs in the world (Byrne, 2002). Their main objective, in terms of fruit appearance, is to select improved cultivars with a full, intense, red color, even at early stages of maturity. This is particularly important in the case of nectarine production (Bellini et al., 2004; Carbó and Iglesias, 2002; Scorza and Sherman, 1996). Another important objective is to select cultivars with a good and homogeneous fruit size. Fruits should be regular and symmetric in shape, with peaches preferably being mainly round or round-oblate and nectarines being round-elongated (Liverani, 2008). These are the optimum characteristics for handling during harvest and postharvest (Kader, 2002). One example of a successful cultivar that exhibits these characteristics is 'Big Top'. This is the indisputable reference and the most highly valued and widespread cultivar in the European Union (Berra et al., 2011; Hilaire and Giauque, 2003; Iglesias, 2010) for both national and international markets (Iglesias and Casals, 2013).

Over the last ten years, a large number (over 100) of new cultivars has been released every year and nectarine type of fruit has undergone a major degree of cultivar renewal (Byrne, 2002). This has, however, made it difficult for growers and technicians in Spain to know whether the newly released cultivars have the characteristics demanded by the markets and retailers (Konopacka et al., 2010) when they are grown in specific cultivation areas. It often takes a long time to establish experimental trials which can provide fruit growers with useful data about the morphological characteristics of new cultivars. As a result, some new cultivars are currently grown in areas without any prior experimental trials. Their performance is therefore sometimes unexpected (Berra et al., 2011; Reig et al., 2013) and they may exhibit poor adaptation, agronomical performance and external and internal quality.

In this study, the morphological traits of 119 commercial cultivars grown under Mediterranean climatic conditions were determined and evaluated in order to provide relevant information to breeders - to help them improve their new cultivars - and also to growers, technicians, markets and retailers in Spain. An appearance quality index was also created to provide a methodology capable of quickly classifying peach cultivars using an overall score (from 1 to 10).

5.3. Material and methods

5.3.1. Plant material

The study was carried out during the 2009 and 2010 seasons and included 119 peach cultivars grown on 3 to 7 year-old trees trained to a central axis (Table 5.1). The cultivars were grafted onto INRA® GF-677 rootstock and grown at an experimental orchard belonging to the IRTA-Estació Experimental de Lleida, located at Mollerussa (Catalonia, Spain). In order to simplify denomination, the flat peach and flat nectarine cultivars will henceforth be referred to as flat peach cultivars. The experimental orchard contained three trees per cultivar; these were randomly planted in three blocks, spaced 4.5 m × 2.5 m and drip irrigated. The rows were oriented from NE to SW. The trees were trickle-irrigated using drip irrigation, with two drips per tree, delivering 4 litres 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 2009-2010 were usual for this warm Mediterranean area, with high summer temperatures (>30 ºC) and low rainfall (379 mm per season). Hand thinning was carried out in early May in each growing season using similar criteria for all of the cultivars in order to obtain similar crop loads.

5.3.2. Morphological traits and appearance quality index (AQI)

All the cultivars were evaluated according to a number of different morphological traits. Most of the traits evaluated have been described by UPOV (1995) and the International Plant Genetic Resources Institute (IPGRI, 1984) for *Prunus persica* L., with slight modifications. The evaluation tests were conducted on 30 representative fruits, taking 10 fruits per tree for each cultivar and season at the harvest date, which was established when fruit firmness ranged from 39 to 49 N. Three dimensions of the whole fruit: cheek diameter (DA), height (H), and suture diameter (W), were measured to an accuracy of 0.01 mm, using a digital calliper (Mitutoyo's digimatic calliper, Japan). Sphericity, considered as fruit shape, was then calculated as H/DA and H/W. When the ratios were 1, the shape was considered globally round. Instead of considering sphericity in flat peaches, this work studied their height. This trait was used to express the convenience of consumption of this particular fruit type (Iglesias and Carbó, 2009). Red skin color was visually scored as a percentage of the red colored skin surface. This trait was not, however, evaluated in nonmelting peaches. Symmetry was calculated as the difference in height between the two cheeks of the fruit. Symmetry was also measured using a digital calliper.

Four qualitative traits were recorded for each cultivar and season: the shape of the pistil end or fruit tip (SPE), 1 = pointed tip, 2 = slightly pointed tip, 3 = flat tip, 4 = depressed tip; prominence of suture (POS), 1 = non-visible suture, 2 = weak suture, 3 = medium suture, 4 = strong suture; presence of lenticels (POL), 1 = absence of lenticels, 2 = slightly visible lenticels, 3 = visible lenticels, 4 = highly visible lenticels; and stone adhesion (SA), 1 = freestone within space between the mesocarp and endocarp, 2 = freestone without any space between the mesocarp and endocarp, 3 = semi-clingstone, 4 = clingstone. SPE was not evaluated in flat peaches and POS was only evaluated in nectarines.

Markets, and therefore fruit growers, need to provide varieties with the best performance in terms of fruit appearance because this is what most attracts consumers when they make their first purchases. An overall score is useful for the purposes of comparison and the appearance quality index (AQI) was defined and developed with this in mind. This index was obtained by giving greater or lesser importance to the different morphological traits evaluated for each fruit type in line with their respective scores and weights (Table 5.2). These scores were defined based on our own experience and that of some of the leading fruit-trading companies in Spain. The maximum possible AQI score for a given cultivar was 10 points.

Table 5.1. Breeding program, origin (country), maturity season and fruit type of the cultivars evaluated over 2009 and 2010 seasons.

Cultivar	Unscrambler code	Breeding program	Country	Maturity Season	Fruit Type
Amiga	3	A. Minguzzi	Italy	M	NE
NG 187	87	A. Minguzzi	Italy	M	NE
NG 4/720	88	A. Minguzzi	Italy	E	NE
PG 3/1312	93	A. Minguzzi	Italy	M	PE
PG 3/138	94	A. Minguzzi	Italy	M	PE
PG 3/719	95	A. Minguzzi	Italy	M	PE
PI 2/84	96	A. Minguzzi	Italy	M	NMP
Subirana	104	Agromillora	Spain	M	FP
A. Bonnigold	1	ARC	South Africa	E	NMP
Summersun	105	ARC	South Africa	M	NMP
ASF 04-71	4	ASF	France	M	FP
ASF 05-25	5	ASF	France	M	NE
ASF 05-93	6	ASF	France	M	FP
ASF 06-07	7	ASF	France	M	NE
ASF 06-88	8	ASF	France	L	FP
ASF 06-90	9	ASF	France	M	FP
Big Nectared	13	ASF	France	L	NE
Donutnice	21	ASF	France	M	FP
Endogust	24	ASF	France	L	NE
Flataugust	33	ASF	France	M	FP
Flatlate	34	ASF	France	L	FP
Flatpretty	35	ASF	France	M	FP
Flatprincess	36	ASF	France	L	FP
Flatqueen	37	ASF	France	L	FP
Fullred	38	ASF	France	M	PE
Julienice	58	ASF	France	L	PE
Nectabang	65	ASF	France	E	NE
Nectabelle	66	ASF	France	E	NE
Nectabigfer	67	ASF	France	M	NE
Nectadiva	68	ASF	France	L	NE
Nectaearly	69	ASF	France	E	NE
Nectafine	70	ASF	France	L	NE
Nectagala	71	ASF	France	M	NE
Nectajewel	72	ASF	France	M	NE
Nectalady	73	ASF	France	L	NE
Nectapi	74	ASF	France	L	NE
Nectapink	75	ASF	France	M	NE
Nectaprima	76	ASF	France	E	NE
Nectareine	77	ASF	France	M	NE
Nectariane	78	ASF	France	M	NE
Nectarjune	79	ASF	France	E	NE
Nectarlight	80	ASF	France	L	NE
Nectarmagie	81	ASF	France	M	NE
Nectaroyal	82	ASF	France	L	NE
Nectarperla	83	ASF	France	M	NE
Nectarreve	84	ASF	France	M	NE
NectaTop	85	ASF	France	M	NE
Nectavanpi	86	ASF	France	L	NE
Sweetbella	108	ASF	France	M	PE
SweetLove	110	ASF	France	M	PE
SweetMoon	111	ASF	France	M	PE
Sweetprim	112	ASF	France	E	PE
SweetStar	113	ASF	France	L	PE
Very Good	118	ASF	France	L	PE
August Red	10	Bradford	USA	L	NE
Crimson Lady	18	Bradford	USA	E	PE
Diamond Bright	19	Bradford	USA	E	NE
Diamond Ray	20	Bradford	USA	M	NE
Rose Diamond	103	Bradford	USA	E	NE

Table 5.1. Continued

Cultivar	Unscrambler code	Breeding program	Country	Maturity Season	Fruit Type
IFF 1182	50	CRA	Italy	M	NE
IFF 1190	51	CRA	Italy	M	PE
IFF 1230	52	CRA	Italy	E	PE
IFF 1233	53	CRA	Italy	E	PE
IFF 331	54	CRA	Italy	M	PE
IFF 800	55	CRA	Italy	E	NE
IFF 813	56	CRA	Italy	M	NE
IFF 962	57	CRA	Italy	M	PE
Pink Ring	97	CRA	Italy	M	FP
Romea	102	CRA	Italy	M	NMP
UFO 3	114	CRA	Italy	E	FP
UFO 4	115	CRA	Italy	E	FP
UFO 7	116	CRA	Italy	M	FP
UFO 8	117	CRA	Italy	L	FP
Big Sun	14	Europepinieres	France	L	PE
Magique	63	Europepinieres	France	M	NE
O'Henry	90	G. Merrill	USA	L	PE
Feraude	29	INRA	France	M	NMP
Fercluse	30	INRA	France	M	NMP
Ferlot	31	INRA	France	L	NMP
Mesembrine	64	INRA	France	M	FP
Oriola	92	INRA	France	M	FP
Platibelle	98	INRA	France	M	FP
Platifirst	99	INRA	France	E	FP
Platifun	100	INRA	France	M	FP
Surprise	107	INRA	France	M	PE
Catherina	16	L. Houg	USA	M	NMP
Alice	2	Martorano di Cesena	Italy	E	NE
Lady Erica	60	Martorano di Cesena	Italy	L	NE
Azurite	11	Monteaux - Callet	France	M	PE
Grenat	43	Monteaux - Callet	France	M	PE
Onyx	91	Monteaux - Callet	France	E	PE
Extreme July	25	Provedo	Spain	M	PE
Extreme Red	26	Provedo	Spain	M	NE
Extreme Sweet	27	Provedo	Spain	M	PE
Garaco	39	PSB	Spain	E	NE
Garcica	40	PSB	Spain	M	NE
Gardeta	41	PSB	Spain	E	NE
Gartairo	42	PSB	Spain	E	NE
Luciana	62	PSB	Spain	M	NE
Noracila	89	PSB	Spain	E	NE
Hesse	44	U.California	USA	L	NMP
Fairlane	28	U.S.D.A	USA	L	NE
Big Bel	12	Zaiger	USA	M	NE
Big Top	15	Zaiger	USA	M	NE
Country Sweet	17	Zaiger	USA	M	PE
Early Rich	22	Zaiger	USA	E	PE
Early Top	23	Zaiger	USA	E	NE
Fire Top	32	Zaiger	USA	M	NE
Honey Blaze	45	Zaiger	USA	M	NE
Honey Fire	46	Zaiger	USA	M	NE
Honey Glo	47	Zaiger	USA	M	NE
Honey Kist	48	Zaiger	USA	M	NE
Honey Royale	49	Zaiger	USA	M	NE
Kewina	59	Zaiger	USA	L	PE
Latefair	61	Zaiger	USA	L	NE
Rich lady	101	Zaiger	USA	M	PE
SummerSweet	106	Zaiger	USA	M	PE
Sweet Dream	109	Zaiger	USA	M	PE
Zee Lady	119	Zaiger	USA	M	PE

Abbreviations, E, Early (1st June-10th June); M, Mid (10th June-20th August); L, Late (20th August-30th September); R, Round; F, Flat; PE, melting peach; NE, nectarine; NMP, nonmelting peach; FP, flat peach.

Table 5.2. Description of fruit traits considered and their value to obtain the appearance quality index (AQI) according to fruit type.

Trait description		Score	Trait weight			
			Melting peach	**Nectarine**	**Nonmelting peach**	**Flat peach**
D (mm)[a]						
90 or +	AAAA	0.0				
80/90	AAA	0.7				
73/80	AA	1.0				
67/73	A	0.9	**3.4**	**3.0**	**5.5**	**3.8**
61/67	B	0.4				
56/61	C	0.2				
51/56	D	0.0				
SC (%)						
0-25		0.0				
25-50		0.2	**3.4**	**3.0**	**-**	**3.8**
50-75		0.6				
75-100		1.0				
H/D (cm)						
1.1-1.2		0.5				
0.9-1.1		1.0	**0.5**	**0.4**	**0.7**	**-**
0.8-0.9		0.5				
<0.8		0.0				
H/W (cm)						
1.1-1.2		0.5				
0.9-1.1		1.0	**0.5**	**0.4**	**0.7**	**-**
0.8-0.9		0.5				
<0.8		0.0				
SPE						
Pointed		0.0				
Weakly pointed		0.3	**0.9**	**0.8**	**1.4**	**-**
Flat		0.7				
Depressed		1.0				
POS						
Non-visible		1.0				
Weak		0.7	**0.6**	**0.5**	**0.9**	**0.6**
Medium		0.3				
Strong		0.0				
SY (mm)						
0 - 5		1.0				
5 - 10		0.5	**0.6**	**5.0**	**9.1**	**0.6**
> 10		0.0				
POL						
Non presence		1.0				
Slightly visible		1.0	**-**	**1.5**	**-**	**-**
Visible		0.5				
Highly visible		0.0				
H (mm)						
35-44		1.0				
44-50		0.5	**-**	**-**	**-**	**1.2**
>50		0.0				

Abbreviations: DA, diameter; SC, skin color; H/DA and H/W, sphericity; SPE, shape of pistil end; POS, ‘rominence of suture; SY, symmetry; POL, presence of lenticels; H, height.

[a] Based on Commission Regulation (EC) No. 1861/2004 for first class category.

5.3.3. Statistical Analysis

Three replications for each of the parameters evaluated were used for each cultivar and season. All the data were analysed using both the analysis of variance and multivariate projection techniques. Analysis of variance (GLM procedure) was applied using the JMP®8 program package (SAS, 2010). LSMeans were compared using Tukey's honestly significant difference (HSD) test at the $P \leq 0.05$ significance level. We relied on a study by Gaaliche et al. (2012) to analyse the qualitative morphological variables because this work used qualitative traits to evaluate fig morphology. A Principal Component Analysis (PCA) was performed using the Unscrambler 7.6 program package (CamoAsa, 2001).

5.4. Results

Given the lack of significance of fruit type (FT) and year (Y) and between breeding program (BP) and year (Y) for the different fruit traits, the data from 2009 and 2010 season were analyzed together.

Table 5.3. Mean values over 2009 and 2010 seasons of morphological traits and appearance quality index (AQI) estimated for each fruit type subjected to assessment. The number of observed commercial cultivars (n) is shown for each fruit type.

					Significance level[1], Pr > F		
Fruit type	Melting peach	Nectarine	Nonmelting peach	Flat peach	*Fruit type (FT)*	*Year (Y)*	*FT × Y*
n	32	57	9	21			
DA (mm)	77.0 a	75.1 ab	74.5 b	76.3 ab	**	*	*ns*
SC (%)	86.7 a	82.4 b	-	78.6 c	***	***	*ns*
H/DA (mm)	0.8 b	0.9 a	0.8 b	-	**	*	*ns*
H/W (mm)	0.8 b	0.9 a	0.8 b	-	***	*ns*	*ns*
SY (mm)	11.1 a	11.1 a	9.0 b	6.9 c	***	*	*ns*
H (mm)	-	-	-	40.1	-	*ns*	-
SPE	3.6 a	3.5 b	3.6 ab	-	*	**	*ns*
POS	2.6 b	2.5 b	2.7 ab	2.8 a	***	*ns*	*ns*
POL	-	2.7	-	-	-	*ns*	-
SA	3.5 b	3.8 a	4.0 a	3.8 a	***	*ns*	*ns*
AQI	7.6 a	6.9 b	7.2 ab	6.9 b	***	*ns*	*ns*

Mean separation within rows by Tukey's test ($P \leq 0.05$). In each row values with the same letter are not significantly different. *Abbreviations*: DA, diameter; SC, skin color; H/DA and H/W, sphericity; SY, symmetry; H, height; SPE, shape of pistil end; POS, prominence of suture; POL, presence of lenticels; SA, stone adherence; AQI, appearance quality index.

[1] Data were evaluated by two-way variance (ANOVA): *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$; ns, not significant.

Fruit type (melting peach, nectarine, nonmelting peach and flat peach) had a significant effect on the different peach fruit traits (Table 5.3). The melting peach had the largest DA, highest SC and best AQI. On the other hand, the nectarine was the most spherical and it jointly with the melting peach were less symmetrical than the other fruit types. Significant differences were observed between fruit types in terms of such qualitative traits as SPE, POS, and SA, although all the different fruit types exhibited mean values which fell between two consecutive categories. The SPE values obtained generally ranged between flat and depressed, the POS values ranged between medium and strong and the SA values ranged between semi-clingstone and clingstone.

Table 5.4. Mean values over 2009 and 2010 seasons of morphological traits and appearance quality index (AQI) estimated by origin for each fruit type subjected to assessment, except nonmelting peach type. The number of observed commercial cultivars (n) is shown for each fruit type.

Fruit Traits	n	DA (mm)	SC (%)	H/DA (mm)	H/W (mm)	SY (mm)	H (mm)	SPE	POS	POL	SA	AQI
Melting peach												
A. Minguzzi	3	78.7	87.5 c	0.91 a	0.9	18.8 a	-	3.0 c	2.6	-	4.0 a	7.4 bc
ASF	8	77.2	87.5 c	0.86 b	0.8	11.0 ab	-	3.8 a	2.5	-	4.0 a	7.5 bc
CRA	5	76.2	72.5 d	0.90 a	0.8	11.7 ab	-	3.4 b	2.4	-	3.1 b	7.0 c
Monteaux-Callet	3	76.5	95.8 ab	0.88 ab	0.8	9.69 b	-	4.0 a	2.5	-	4.0 a	8.6 a
Zaiger	7	78.5	96.4 a	0.87 b	0.8	11.6 ab	-	3.4 b	2.4	-	3.3 b	7.9 ab
Significance level[1]: Pr > F												
Breeding program (BP)		ns	***	***	ns	*	-	***	ns	-	***	***
Year (Y)		***	*	ns	ns	ns	-	ns	ns	-	ns	ns
BP × Y		ns	ns	ns	ns	ns	-	ns	ns	-	ns	ns
Nectarine												
A. Minguzzi	3	79.4 a	75.0 bc	0.9	0.9 a	12.2 a	-	3.0 c	2.5 bc	2.3 bcd	3.0 b	6.5 bc
ASF	26	76.0 ab	83.6 b	0.9	0.8 b	11.2 a	-	3.5 ab	2.3 c	2.8 ab	4.0 a	6.8 bc
Bradford	4	75.0 abc	81.2 b	0.9	0.8 ab	10.6 ab	-	3.7 a	2.7 b	2.3 cd	4.0 a	7.2 ab
CRA	3	70.4 c	70.8 c	0.9	0.8 ab	9.1 b	-	2.4 d	2.6 b	2.0 d	4.0 a	6.1 c
PSB	6	70.7 c	81.2 b	0.9	0.8 b	9.2 b	-	3.6 a	3.0 a	3.0 a	4.0 a	6.7 bc
Zaiger	10	74.1 bc	93.7 a	0.9	0.8 ab	11.3 a	-	3.3 bc	2.5 bc	2.6 abc	3.3 b	7.8 a
Significance level[1]: Pr > F												
Breeding program (BP)		***	***	ns	*	***	-	***	***	***	***	***
Year (Y)		***	**	ns	ns	**	-	**	*	ns	ns	ns
BP × Y		ns	ns	ns	ns	ns	-	ns	ns	ns	ns	ns
Flat peach												
ASF	10	77.7	81.2 a	-	-	7.6 a	40.7 a	-	2.7 b	-	3.8 a	6.9 ab
CRA	5	76.9	67.5 b	-	-	6.6 ab	38.0 b	-	2.9 ab	-	4.0 a	6.4 b
INRA	5	74.6	85.0 a	-	-	6.3 b	41.3 a	-	3.0 a	-	3.6 b	7.2 a
Significance level[1]: Pr > F												
Breeding program (BP)		ns	***	**	**	*	**	-	*	**	**	*
Year (Y)		***	*	*	**	ns	*	-	ns	*	ns	*
BP × Y		ns	ns	ns	ns	ns	ns	-	ns	ns	ns	ns

[1] Data were evaluated by two-way variance (ANOVA): *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$; ns, not significant. Mean separation within columns by Tukey's test ($P \leq 0.05$). In each column values with the same letter are not significantly different. *Abbreviations*: DA, diameter; SC, skin color; H/DA and H/W, sphericity; H, height; SY, symmetry; SPE, shape of pistil end; POS, prominence of suture; POL, presence of lenticels; SA, stone adherence; AQI, appearance quality index.

Studying the influence of the breeding program on each fruit type (melting peach, nectarine and flat peach) allowed us to differentiate between them based on fruit morphology (Table 5.4). The nonmelting peach type was not included in this section of the study due to its limited number of breeding programs; a minimum of 3 cultivars were required for statistical comparisons to be possible. DA was similar for the different melting peach breeding programs. A. Minguzzi and CRA produced the most spherical fruits despite their fruits being generally quite asymmetrical. The Mounteaux-Callet cultivars were the best rated (AQI = 8.56), while the Zaiger cultivars produced the most red-colored fruits. In the case of the nectarine breeding programs, A. Minguzzi exhibited the highest DA values and also, together with ASF, the least symmetrical fruits. Bradford was the best rated breeding program (AQI = 7.20). The comparison between the flat peach breeding programs showed that ASF and INRA had similar SC and H values, with INRA being the best rated (AQI = 7.25). Significant differences were observed between breeding programs for each fruit type in terms of qualitative traits. As mentioned above, all of the fruit types exhibited mean values that fell between two consecutive categories. SPE was between flat and depressed, POS fell between medium and strong, POL was between slightly visible and visible, and SA was between semi-clingstone and clingstone (Table 5.4).

The PCA model revealed the most important variables for describing the variability of the cultivars studied for each fruit type and the possible associations between the original variables.

The model obtained for melting peach data with three Principal Components provided a good summary of the data, explaining 53% of the total variability contained in the 15 original variables of the data set with only 3 PCs. The positive values for PC1 referred to semi-clingstone (SA3) melting peach cultivars with high DA, flat tips (SPE3) and weak sutures (POS2). At the same time, PC2 was highly and positively correlated with sphericity (H/DA and H/W), slightly pointed fruit tips (SPE2), clingstone (SA4) and non-visible sutures (POS 1). In contrast, looking at the third Component (results which have not been presented graphically), it was found that positive values for PC3 were associated with clingstone cultivars. Projecting the melting peach cultivars onto the 1–2 plot highlighted a number of cultivars with very specific traits, such as 'Crimson Lady' (18), 'Extreme July' (25), 'Onyx' (91), 'PG 3/1312' (93), 'Summersweet' (106), and 'Sweet Dream' (109), and others which were closely grouped and exhibited similar characteristics, such as 'Kewina' (59), 'PG

3/138' (94), 'Sweetbella' (108), and 'Sweetstar' (113), and 'Azurite' (11), 'Early Rich' (22), 'Fullred' (38), and 'Rich Lady' (101) (Figure 5.1).

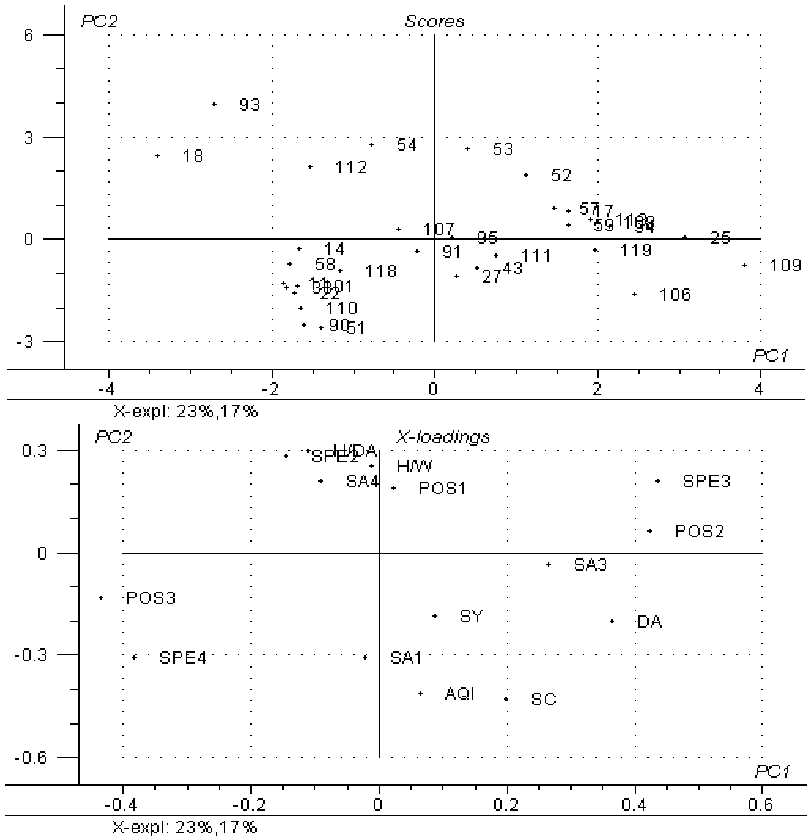

Figure 5.1. Representation of melting peach cultivars according to the most relevant traits. *Abbreviations:* AQI, appearance index quality; DA, diameter; H/DA and H/W, sphericity; POS1, non-visible suture; POS2, weak suture; POS3, medium suture; SA1, freestone within space; SA3, semi–clingstone; SA4, clingstone; SC, red skin color; SPE2, slightly pointed tip; SPE3, flat tip; SPE4, depressed tip; SY, symmetry.

In the case of the model calculated for the nectarine cultivars, three PCs explained 43% of the total variability of the data set. 18% of that variability was associated with PC1, which was positively associated with SC, AQI, depressed tips (SPE4), medium sutures (POS3), and SA4, and negatively associated with DA, SY, flat tips (SPE3), freestones within space (SA1), and weak sutures (POS2). PC2, with 13% of the total variability, exhibited positive values for SC, SPE4, and highly visible lenticels (POL4), but negative values for H/DA, H/W, pointed tips (SPE1) and slightly visible lenticels (POL2). PC3, with 12% of the total variability, showed positive values for SA4 and POS3 (Figure 5.2).

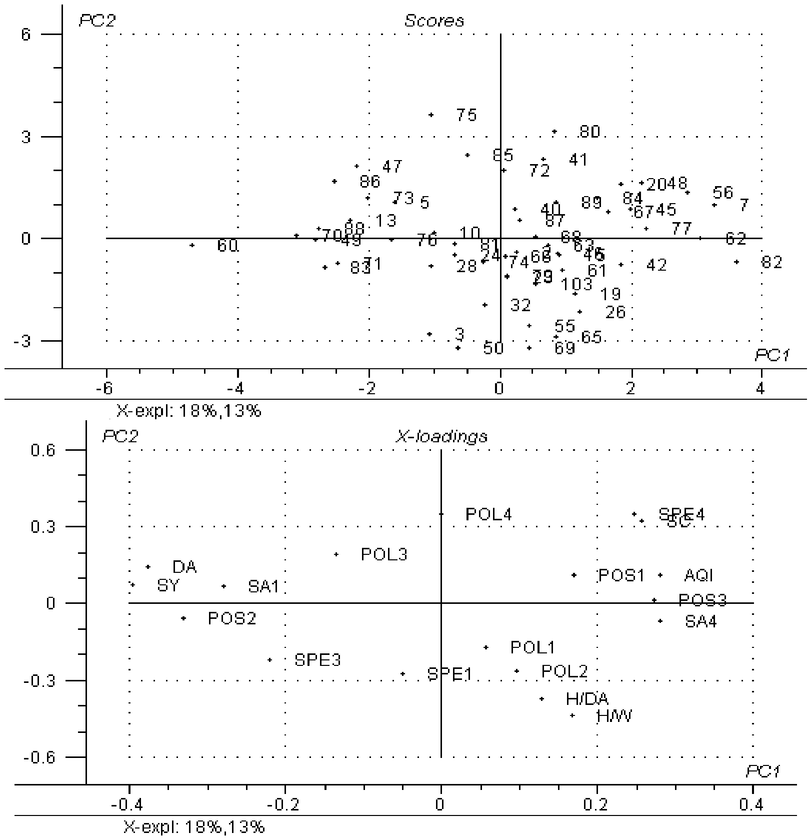

Figure 5.2: Representation of nectarine cultivars according to the most relevant traits. *Abbreviations:* AQI, appearance index quality; DA, diameter; H/DA and H/W, sphericity; POL1, non–visible lenticels; POL2, slightly visible lenticels; POL3, visible lenticels; POL4, highly visible lenticels; POS1, non-visible suture; POS2, weak suture; POS3, medium suture; SA1, freestone within space; SA3, semi-clingstone; SA4, clingstone; SC, red skin colour; SPE1, pointed tip; SPE3, flat tip; SPE4, depressed tip; SY, symmetry.

The PCA model for nonmelting peaches showed that 74% of the total variability in the data could be explained using only the two first Principal Components: 53% by PC1 and 21% by PC2 (Figure 5.3). An examination of the PC1 loadings suggested that, on the positive side, the cultivars were less spherical and more symmetrical, whereas on the negative side, these cultivars exhibited depressed tips and medium sutures. The cultivars on the PC2 loadings suggested that the separation of this component was mainly due to DA, AQI and weakly pointed tips (SPE2). 'Ferlot' (31) and 'Hesse' (44) exhibited high DA, while 'PI 2/84 (96) and 'Catherina' (16) exhibited high sphericity and low symmetry (Figure 5.3).

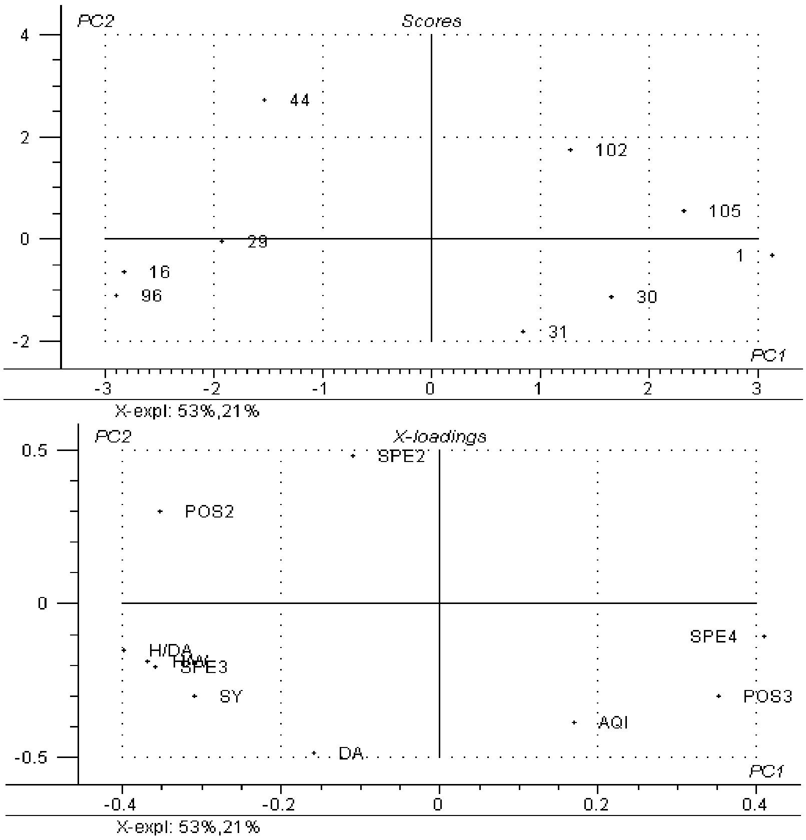

Figure 5.3: Representation of nonmelting peach cultivars according to the most relevant traits. *Abbreviations*: AQI, appearance index quality; DA, diameter; POS2, weak suture; POS3, medium suture; H/DA and H/W, sphericity; SPE2, slightly pointed tip; SPE3, flat tip; SPE4, depressed tip; SY, symmetry.

Finally, in flat peaches, the first three PCs accounted for 66% of total variability (27%, 22% and 18%, respectively). Positive values in PC1 were observed for H/DA, H/W, and freestone without space (SA2), while in PC2, they were registered for DA and H. SY and weak suture (POS2) were the most important in PC3. The projection of flat peach cultivars in the 1-2 plot highlighted the existence of a number of cultivars with particular traits, such as ‘ASF 05-93’ (6), ‘ASF 06-90’ (9), ‘Mesembrine’ (64), Oriola’ (92), ‘Platifun’ (100), and ‘UFO 4’ (115) (Figure 5.4).

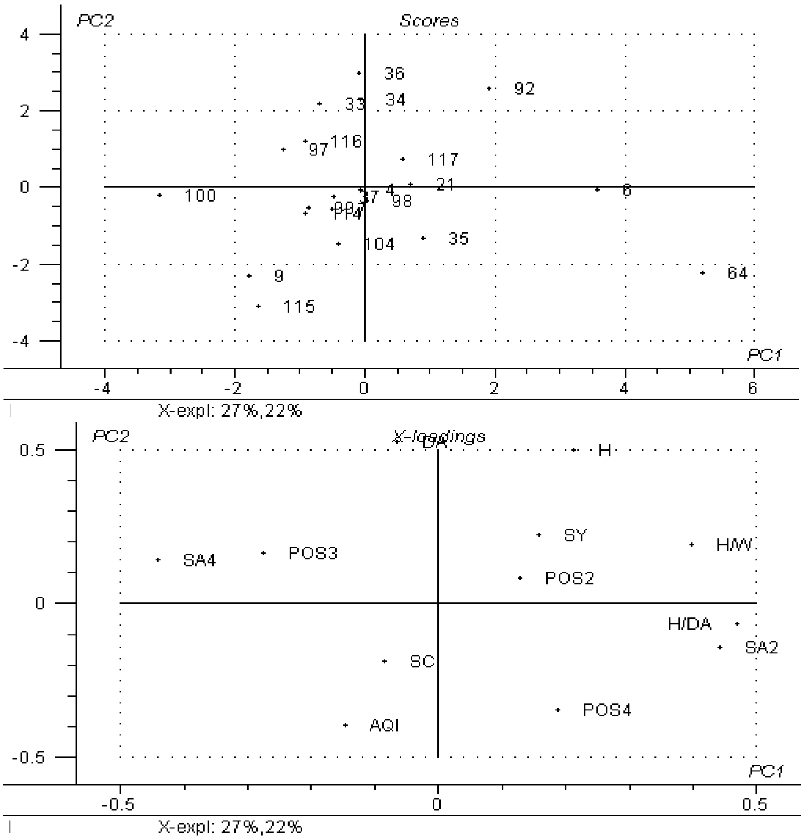

Figure 5.4: Representation of flat peach cultivars according to the most relevant traits. *Abbreviatio*ns: AQI, appearance index quality; DA, diameter; H, height; H/DA and H/W, sphericity; POS2, weak suture; POS3, medium suture; POS4, strong suture; SA2, freestone without space; SA3, semi–clingstone; SA4, clingstone; SY, symmetry.

5.5. Discussion

Before deciding to plant a new cultivar, growers and technicians normally consider many different crop characteristics, such as agronomic performance, fruit appearance and fruit quality, which must also be related to current market requirements. Nevertheless, it is the group of parameters that affect fruit appearance (DA, SC, H/DA, H/W, SY, H, SPE, POS and POL) that has the most significant impact on postharvest handling (Byrne et al., 2012) and, together with fruit quality, which ultimately determines consumer acceptance, sales (Liverani et al., 2002) and postharvest performance (Liverani et al., 2002; Liverani, 2008).

In order to regulate the EU peach and nectarine market in terms of fruit quality, regulation RCE No. 1861/2004 established a classification based on DA and three categories (extra, I and II), in which DA was divided into 7 different categories, with each category having its own particular characteristics. Our study focused on the “extra” category; we therefore gave importance to the typical coloring of the cultivar and the fact that there were no defects on the skin surface, as these could affect quality, postharvest performance and/or presentation when packaged. The market requirements as far as fruit DA was concerned varied according to the final destination (fresh market or otherwise), maturity season (early, mid and late) and/or country of destination. SC was usually above 80% on highly coloured fruit surfaces (Espada et al., 2009) because consumes associate high fruit color with better appearance and quality (Byrne et al., 2012; Iglesias and Echeverría, 2009).

Markets also prefer a round shape without protruding tips and/or sutures in the case of melting peaches, nectarines and nonmelting peaches, because they can otherwise be bruised during postharvest handling and shipping. They also prefer nectarines without, or with only slightly visible, lenticels on their skin surfaces (Badenes et al., 2006; Bellini et al., 2004; Byrne et al., 2012; Kader, 2002; Liverani, 2008; Topp et al., 2008; Wert et al., 2007). These requirements mean that breeding programs must improve the appearance of new cultivars. On the other hand, although SA and H were not considered by RCE No. 1861/2004, this did not make them any less important and they were still considered by breeders selecting new cultivars during the last decade. H values between 35 and 44 mm in flat peaches, which is the size of the normal human mouth opening (García and Rodriguez, 2008), make them easier to eat (Iglesias and Carbó, 2009; Nicotra et al., 2002; Sorrenti et al., 2010). Most freshly consumed fruit tends to be of the freestone melting flesh or clingstone melting flesh types (Peace et al., 2005). Even so, many breeders are currently looking for new cultivars with adhering endocarps because this trait is related to better postharvest performance and therefore longer shelf life (Liverani, 2008).

Morphological trait and AQI values were both influenced by fruit type and origin (breeding program), although considerable variability was found within each program. They gave a general idea of the differences and/or similarities within each fruit type and breeding program and revealed whether the requirements established for EU markets were being met or not. The A. Minguzzi and CRA nectarine breeding programs and the CRA flat peach breeding program did not achieve the high fruit color demanded by these markets (SC > 80%) (Espada et al., 2009) (Table 5.4). Even so, within each fruit type and breeding program there was a high level of variability among cultivars. Therefore, growers should not base their strategy exclusively on the choice of fruit type and breeding program.

The results from the PCA models obtained in this work showed that the variables with the greatest discriminating levels depended on the fruit type evaluated and that these variables proved powerful for studying the genetic diversity of each fruit type under Mediterranean conditions. The PCA also showed great variability among *Prunus persica* cultivars, even when they were very similar in terms of their genetic profiles. As previously reported by Aranzana et al. (2010), this could be attributed to the fact that most of the new cultivars released in the last decade have common founders. The PCA also allowed us to establish which cultivars had similar attributes, which met the requirements of the EU market, and which had the best and worst AQI values. Nevertheless, many cultivars of each fruit type exhibited either one or several morphological traits which made them less appropriate to the market.

On the basis of this study, many of the cultivars of each of the fruit types evaluated should be considered when targeting the EU market. The cultivars to consider would be: melting peaches with either a large DA (more than 80 mm), such as 'Sweet Dream' (109), or a small DA (less than 67 mm), such as 'Crimson Lady' (18) and 'Sweetprim' (112); those with slightly pointed tips (SPE2), such as 'PG 3/1312' (93); those with medium suture (POS3), such as 'Azurite' (11), 'Crimson Lady' (18), 'Early Rich' (22), 'Rich Lady' (101), 'Big Sun' (14), 'PG 3/719' (95), 'Fullred' (38), 'Very Good' (118), 'Julienice' (589, 'IFF 331' (54), 'IFF 1990' (51), 'O Henry' (90), 'Sweetlove' (110), and 'PG 3/1312' (93); those with freestones with space (SA1), such as 'IFF 1190' (51), 'O Henry (90), and 'Sweetlove' (110); and those with quite an asymmetrical form (high SY), such as 'IFF 331' (54). 'Crimson Lady' (18), an early maturity cultivar (Iglesias et al., 2012), had a small DA and poor red coloring on its skin surface (less than 50%) and was the worst rated cultivar (AQI = 4.75). 'Sweet Dream' (109) is the most planted mid-season harvest cultivar in the USA, but its large fruit size is a limiting factor for most European markets and also for other overseas markets (Iglesias, 2010). On the other hand, considering all the traits together with the exception of AQI our results were similar to those reported by many other authors (Cano-Salazar et al., 2012; Foschi et al., 2011; Hilaire and Giauque, 1994; Hilaire and Giauque, 2003; Iglesias et al., 2012; Mennone and Colombo, 2011) for cultivars such as 'Azurite'(11), 'Crimson Lady' (18), 'IFF 331' (54), 'Onyx' (91), 'O Henry' (90), 'Rich Lady'(101), and 'Sweet Dream' (109) (Figure 5.1). The development of protruding tips (SP1) has been attributed to inadequate chilling or prolonged dormancy (Rouse and Sherman, 2002), but this could also be attributed to the cultivar itself, as in the 'IFF 1182' (50), 'Fire Top' (32), and 'Amiga' (3) nectarine cultivars during the two years of this study. This trait, together with that of highly visible lenticels (POL4), was regarded as undesirable by the market for nectarine cultivars. 'Gardeta' (41), 'Nectapi' (75), 'Nectarjune' (80), and 'Nectatop' (85) exhibited POL4 throughout the two years of the study. In contrast, nectarine cultivars with visible lenticels (POL3), medium sutures (POS3), freestones with space (SA1) and either a small (less than 67 mm) or large (more than 80 mm) DA should not be considered interesting. However, the worst rated nectarine cultivars were 'Garaco' (39), 'Nectatop' (85) and 'Nectafine' (70), with respective AQI values of 3.97, 4.62 and 4.95 (Figure 5.2). Among the nonmelting peaches evaluated, 'Hesse' (44) exhibited slightly pointed tips (SPE2) and 'African Bonnigold' (1), 'Fercluse' (30), 'Ferlot' (31), and 'Summersun' (105) all exhibited medium prominence sutures (POS3), while 'Ferlot' (31) was the least symmetrical nonmelting peach cultivar (Figure 5.3). Finally, the main flat peaches that should be considered by markets are 'Flatpretty' (35), 'Mesembrine' (64), and 'UFO 4' (115) because they exhibited strong suture prominence (POS4) and 'Erlataugust' (33), 'Flatlate' (34), 'Flatprincess' (36), and 'Oriola' (92) because they exhibited DAs over 80 mm, while the worst AQI (close to 5) was associated with 'ASF 05-93' (6) due to its height (H), which was greater than 44 mm (Figure 5.4).

5.6. References

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Capítulo 6

Antioxidant capacity, quality, and anthochyanins and nutrient contents of several peach cultivars [*Prunus persica* (L.) Batsch] grown in Spain

6.1. Abstract

Fruit quality, sensory evaluation, nutrient and anthocyanin contents and antioxidant capacity of 106 peach cultivars from different breeding programs were evaluated at Estació Experimental de Lleida, IRTA (Catalonia Spain) during two growing seasons (2010 and 2011). High variability was found among cultivars within each quality trait, where different cultivars were scored as the best and the worst. For example, a 5–fold range (2.17–12.07 g of malic acid L^{-1}), 6–fold range (144.20–711.73 µg of Trolox g^{-1} of FW) and 11–fold range (0.70–11.43 mg of cyaniding-3-glucoside kg^{-1} of FW) were observed in titratable acidity, relative antioxidant capacity and anthocyanin content, respectively. The breeding program within each fruit type (melting peach, nectarine, and flat peach) and qualitative pomological traits also had significant effects on the quality. Nevertheless, each breeding program had specific characteristics that distinguished it from the others. Even so, within each breeding program there is high variability among cultivars. Therefore, growers should not base their strategy exclusively on the choice of breeding program. Principal component analysis for each fruit type (melting peach, nectarine, nonmelting peach, and flat peach) allowed a selection of a set of cultivars from different breeding programs with the highest quality performance. For example, cultivars such as 'Azurite', 'IFF 1230', 'Amiga', 'Fire Top', 'African Bonnigold', 'Ferlot', 'Mesembrine', and 'Platifirst' had higher sweetness and flavor compared to the others. Therefore, this study could help breeders to make decisions for the selection of new cultivars able to improve the quality features of fruit intake, technicians to know better quality performance of peach cultivars, and consumers to meet their expectations for fruit with high health benefits and a specific taste.

6.2. Introduction

Peach [*Prunus persica* (L.) Batsch] is the most important stone fruit crop in Spain, which ranks second in European production, after Italy and followed by Greece and France (Europêch, 2011). Peach is also the most dynamic fruit species in terms of new cultivars released per year (Byrne, 2002). New cultivars originate from more than 70 active breeding programs which are mainly found in USA, followed by Europe (Italy and France) (Byrne, 2002) and are the sources of many of the cultivars grown in Spain (Llácer et al., 2009). Sometimes, these cultivars show an uncertain agronomic, and so qualitative, performance when they are grown under climatic conditions that are different from those where they were originally developed (Berra et al., 2011; Iglesias et al., 2010; Reig et al., 2013). Breeders have traditionally selected primarily for external quality (fruit size and appearance) (Monet et al., 2007), with organoleptic and nutritional traits being a secondary goal (Byrne, 2002; Duthie et al., 2000; Fideghelli et al., 1998; Wargovich, 2000). Today, however, health concern is one of the major driving forces of the world food market, and it is the first or second most important concern of consumers, though this varies regionally. Consumers realize the connection between diet and health and therefore tend to associate their diets with the prevention of cardiovascular disease, vision problems, obesity, arthritis/joint pain, and high cholesterol (Dillarg and German, 2000; Sloan, 2008).

Fruits and vegetables are excellent functional foods as they are high in antioxidant and nutritional compounds (Tomás-Barberán and Robins, 1997). These naturally occurring substances not only play an important role in visual appearance (pigmentation and browning) and taste (astringency) but also have health-promoting properties, acting as antioxidants by scavenging harmful free radicals, which are implicated in most degenerative diseases (Rice-Evans et al., 1996). As a result, there is growing interest in fruit quality and nutritional composition in breeding programs worldwide (Wolfe et al., 2008). Many of them, to improve fruit quality, produce cultivars with excellent taste, high sugar levels, and balanced sugar/acid ratios (Esti et al., 1997). Others have directed their interest to the identification and quantification of phenolic compounds in fruit to evaluate their potential health-promoting properties (Cantín et al., 2009a) and to develop peaches with high levels of compounds potentially beneficial to human health (Vizzotto et al., 2007).

The huge peach cultivar supply and fruit health benefits contrast with the decrease of peach consumption in Spain (Iglesias et al., 2010), as is the case in other western countries (Europe and the United States) (Crisosto et al., 2001; Llácer et al., 2012). Poor internal fruit quality, perceived when the fruit is consumed, is the main reason claimed by consumers for declining to buy fresh fruit (Byrne et al., 2002; Iglesias et al., 2010). Internal fruit quality is related mainly to two factors: firmness and flavor. Firmness is essential for postharvest management, marketing, and consumer acceptance. Too soft or too firm flesh has a negative impact on quality attributes (Crisosto et al., 2006). High firmness is a consequence of harvesting immature fruits and implies less flavor, aroma, texture, and juiciness. As a result, the consumer is disappointed and does not buy peaches again during that season (Llácer et al., 2009). Many authors (Colaric et al., 2005; Hudina and Stampar, 2000) have suggested that sensory quality attributes and the nutritive value of peach (*Prunus persica* L.) fruits as well as of other fruits play an important role in consumer satisfaction and influence further consumption.

The high number of new cultivars on the market makes their technical management and their quality performance identification difficult for both growers and technicians. As far as we know, no analyses have been performed on fruit quality (flesh firmness, soluble solids content, titratable acidity), sensory evaluation (sweetness, sourness, and flavor) and nutrient contents and antioxidant capacity (individual and total sugar content, individual and total acid content, relative antioxidant capacity, and anthocyanin content) of peach commercial cultivars from different breeding programs grown under Mediterranean climate conditions. Therefore, the aims of this work were (1) characterization of 106 peach cultivars by measuring fruit quality, sensory, nutrient, and antioxidant capacity traits, (2) to study the influence of the breeding program and pomological traits on the quality, sugar, acid, anthocynin content and relative antioxidant capacity profile in *Prunus persica* fruits, (3) to examine relationships among all variables evaluated and (4) to select commercial peach cultivars with enhanced fruit quality, sensory, nutrient and antioxidant capacity traits by principal component analysis (PCA).

6.3. Material and Methods

6.3.1. Plant material

The study was carried out during the 2010 and 2011 seasons on fruits of 106 peach cultivars from an experimental collection plot located at the Estació Experimental de Lleida, IRTA (Catalonia, Spain). Their breeding program, fruit type, flesh color and fruit shape are described in Table 6.1. To simplify the analysis, both flat peach and flat nectarine cultivars were considered flat peach cultivars.

The experimental orchard contained three trees per cultivar planted in a single block, trained in the central axis system, grafted on INRA® GF–677 rootstock, and spaced 4.5 m × 2.5 m. The rows were oriented from northeast to southwest. Trees were trickle–irrigated using drip irrigation with two drips per tree delivering 4 L h^{-1}. Standard commercial management practices recommended for the area were followed, including fertilization, plant disease and pest control, in accordance with the guidelines of integrated fruit production. The weather conditions for the period 2010–2011 were usual for this warm Mediterranean area: high summer temperatures (>30 ºC) and low rainfall (379 mm per season). Hand thinning in early May was performed each season.

At harvest date, when firmness ranged from 39N to 49N, 24 fruits per cultivar (8 fruits per tree) and season were picked to make the following determinations. The fruits were picked from the periphery of the tree and at 1.5–2.0 m above ground level.

6.3.2. Fruit quality determinations

A total of 18 of 24 fruits per cultivar and season were assessed for flesh firmness (FF), soluble solids content (SSC), and titratable acidity (TA). Flesh firmness of two opposing cheeks (the most and least exposed to light) of each fruit was measured using an 8 mm tip penetrometer fixed in a drill stand (Penefel, Copa-Technology, CTIFL, Saint Etienne du Gres, France). SSC and TA were determined on flesh juice extracted by an automatic juicer (Moulinex, type BKA1). SSC was determined using a digital calibrated refractometer (Atago PR-32, Tokyo, Japan), and the results are expressed in ºBrix. TA was measured with an automatic titrator (Crison GLP 21, Barcelona, Spain) and determined by titrating 10 mL of juice with 0.1 M NaOH to a pH end point of 8.2. The results are given as grams of malic acid per liter. The ripening index (RI) was then calculated as the SSC/TA ratio. To characterize the cultivars, two groups were established according to the TA value (Iglesias and Echeverría, 2009): sweet (<6 g malic acid per litre); non-sweet (>6 g malic acid per litre).

Table 6.1. Characteristics of the cultivars evaluated: breeding program, fruit type, flesh color and fruit shape.

Cultivar	Unscrambler Code	Breeding program	Fruit Type	Flesh Color	Fruit Shape
African Bonnigold	1	ARC	NME	Y	R
Alice	2	Martorano di Cesena	NE	Y	R
Amiga	3	A.Minguzzi	NE	Y	R
ASF 05-25	4	ASF	NE	W	R
ASF 05-93	5	ASF	FP	W	F
ASF 06-88	6	ASF	FP	W	F
ASF 06-90	7	ASF	FP	W	F
August Red	8	Bradford	NE	YR	R
Azurite	9	Monteuax-Callet	ME	Y	R
Big Bel	10	Zaiger	NE	WR	R
Big Nectared	11	ASF	NE	Y	R
Big Sun	12	Europepinieres	ME	Y	R
Big Top	13	Zaiger	NE	YR	R
Catherina	14	L.Houg	NME	Y	R
Country Sweet	15	Zaiger	ME	YR	R
Diamond Bright	16	Bradford	NE	Y	R
Diamond Ray	17	Bradford	NE	YR	R
Donutnice	18	ASF	FP	W	F
Early Top	19	Zaiger	NE	Y	R
Endogust	20	ASF	NE	WR	R
Extreme July	21	Provedo	ME	YR	R
Extreme Red	22	Provedo	NE	Y	R
Extreme Sweet	23	Provedo	ME	Y	R
Fairlane	24	U.S.D.A	NE	Y	R
Feraude	25	INRA	NME	Y	R
Fercluse	26	INRA	NME	Y	R
Ferlot	27	INRA	NME	Y	R
Fire Top	28	Zaiger	NE	YR	R
Flataugust	29	ASF	FP	W	F
Flatpretty	30	ASF	FP	W	F
Flatprincess	31	ASF	FP	WR	F
Fullred	32	ASF	ME	Y	R
Garcica	33	PSB	NE	WR	R
Gardeta	34	PSB	NE	Y	R
Grenat	35	Monteuax-Callet	ME	Y	R
Hesse	36	U.California	NME	Y	R
Honey Blaze	37	Zaiger	NE	Y	R
Honey Fire	38	Zaiger	NE	Y	R
Honey Glo	39	Zaiger	NE	Y	R
Honey Kist	40	Zaiger	NE	Y	R
IFF 1182	41	CRA	NE	WR	R
IFF 1190	42	CRA	ME	Y	R
IFF 1230	43	CRA	ME	WR	R
IFF 1233	44	CRA	ME	YR	R
IFF 331	45	CRA	ME	W	R
IFF 813	46	CRA	NE	Y	R
IFF 962	47	CRA	ME	Y	R
Latefair	48	Zaiger	NE	Y	R
Luciana	49	PSB	NE	Y	R
Magique	50	Europepinieres	NE	WR	R
Mesembrine	51	INRA	FP	YR	F
Nectabang	52	ASF	NE	Y	R
Nectabelle	53	ASF	NE	Y	R

Table 6.1. Continued.

Cultivar	Unscrambler Code	Breeding program	Fruit Type	Flesh Color	Fruit Shape
Nectabeauty	54	ASF	NE	Y	R
Nectabigfer	55	ASF	NE	W	R
Nectadiva	56	ASF	NE	Y	R
Nectaearly	57	ASF	NE	W	R
Nectafine	58	ASF	NE	Y	R
Nectagala	59	ASF	NE	Y	R
Nectajewel	60	ASF	NE	W	R
Nectalady	61	ASF	NE	Y	R
Nectaperla	62	ASF	NE	WR	R
Nectapi	63	ASF	NE	Y	R
Nectapink	64	ASF	NE	Y	R
Nectaprima	65	ASF	NE	Y	R
Nectareine	66	ASF	NE	YR	R
Nectariane	67	ASF	NE	Y	R
Nectarjune	68	ASF	NE	WR	R
Nectarlight	69	ASF	NE	W	R
Nectaroyal	70	ASF	NE	Y	R
Nectarreve	71	ASF	NE	W	R
Nectatop	72	ASF	NE	Y	R
Nectavanpi	73	ASF	NE	Y	R
NG 4/720	74	A.Minguzzi	NE	YR	R
NG-187	75	A.Minguzzi	NE	Y	R
Noracila	76	PSB	NE	YR	R
O'Henry	77	G.Merril	ME	YR	R
Onyx	78	Monteuax-Callet	ME	WR	R
Oriola	79	INRA	FP	W	F
PG 3/1312	80	A.Minguzzi	ME	Y	R
PG 3/138	81	A.Minguzzi	ME	YR	R
PG 3/719	82	A.Minguzzi	ME	Y	R
PI 2/84	83	A.Minguzzi	NME	Y	R
Pink Ring	84	CRA	FP	W	F
Platibelle	85	INRA	FP	W	F
Platifirst	86	INRA	FP	WR	F
Platifun	87	INRA	FP	W	F
Rich lady	88	Zaiger	ME	YR	R
Romea	89	CRA	NME	Y	R
Rose Diamond	90	Bradford	NE	Y	R
Subirana	91	Agromillora	FP	W	F
Summersun	92	ARC	NME	Y	R
Summersweet	93	Zaiger	ME	WR	R
Surprise	94	INRA	ME	WR	R
Sweet Dream	95	Zaiger	ME	Y	R
Sweetbella	96	ASF	ME	WR	R
Sweetlove	97	ASF	ME	WR	R
Sweetmoon	98	ASF	ME	W	R
Sweetprim	99	ASF	ME	WR	R
Sweetstar	100	ASF	ME	WR	R
UFO 3	101	CRA	FP	W	F
UFO 4	102	CRA	FP	W	F
UFO 7	103	CRA	FP	Y	F
UFO 8	104	CRA	FP	Y	F
Very Good	105	ASF	ME	Y	R
Zee Lady	106	Zaiger	ME	Y	R

Abbreviations: PE, peach; NE, nectarine; NMP, nonmelting peach; FP, flat peach; Y, yellow; YR, yellow-red, W, white; WR, white-red; R, round; F, flat.

6.3.3. Sensory determinations

A total of 3 of the 24 fruits per cultivar and season were subjected to sensory evaluation by a panel of four experts. On the basis of the work of Oraguzie et al. (2009), the panel was set up using the following criteria: (1) membership in the IRTA–Fruit Growing area, (2) at least 3 years of experience in stone fruit sensory evaluation, and (3) participation in a sensory training exercise. Before the assessments and for each season, the experts undertook a 1 week long course of specific training on peach sensory attributes (Table 6.2) according to the procedures determined by the International Organization for Standardization (no. 8586-1, 1993) provided by the IRTA sensory group. An overall sensory score, from 1 to 10, was used to understand the influence of all sensorial attributes together, representing a fair and indicative value of threshold acceptability for consumers (Konopacka et al., 2010). Each sample for sensory evaluation consisted of three pieces of 1.5 cm^3 (without skin), one from each of three fruits per cultivar. Peeled fruit samples were identified by a random two–digit code and presented to the expert in white plastic cups in random order. The intensity of each sensory attribute was recorded on 150 mm unstructured line scales, anchored at 0 (absent) and 150 (extreme). The experts were instructed to use mineral water, and crackers were provided as a palate cleanser between each sample assessment.

Table 6.2. Sensory attributes corresponding to 106 peach cultivars.

Attribute	Definition[a]	Reference standard[b]	Intensity (150-mm scale)[c]
Sweetness	Characteristic of sugar	50% juice[b]	Taste 75
Sourness	Characteristic of acid	50% juice	Taste 80
Flavor	Characteristic of peach flavor	Puree of canned peach	75

[a] Definitions and references used for each attribute and their position on the intensity scale (López et al., 2011).
[b] Commercial peach juice diluted to 50% with filtered water.
[c] Conversion: 1mm = 0.0394 inch.

6.3.4. Extraction and quantification of sugars and organic acids

To extract and quantify the main soluble sugars and organic acids per cultivar and season, 10 mL of flesh juice were pooled. An aliquot of 5 mL was taken and diluted in ultrapure water (1:1). The mixture was vortexed (10 s) and filtered using triple sterile gauze. A 2 mL volume was extracted and immediately frozen in liquid nitrogen, and stored at –25ºC until analysis. At the moment of analysis, the extracts were defrosted at 4 ºC followed by centrifugation at 11000 rpm for 15 min at 4 ºC. A 500 µL volume of supernatant was extracted and clarified by a Whatman polyvinylidene difluoride (PVDF) syringe filter (13 mm, 0.22 µm, reference 6779-1302) and purified using a Sep Pak light 130 mg C18 column (Waters, WAT023501). Sep Pak was previously activated with 1 mL of methanol and conditioned with 1 mL of water. To ensure the total elution of the compounds of interest, 500 µL of Milli-Q water was finally added. A 100 µL volume of filtrate was diluted with ultrapure water (1:10) in a 1 mL HPLC vial. Sugars and organic acids were analyzed by a Waters HPLC system.

In the case of sugars, 10 µL from the HPLC vial was injected and isolated by a strong Hamilton HC-75 (Ca^{2+}) cation-exchange resin column (305 × 7.8, 9 µm Teknokroma, Barcelona, Spain, reference HC-79476) at 90 ºC. Flow rate was set at 0.6 ml min^{-1} using ultrapure water as the mobile phase. Compounds were detected by a 2414 refractive index detector (×16) at 30ºC. External calibration was performed at six calibration levels by dilution of a stock solution composed of 2.5 $g{\cdot}L^{-1}$ sucrose, 0.6 $g{\cdot}L^{-1}$ glucose and fructose and 0.25 $g{\cdot}L^{-1}$ sorbitol. In this case, the lowest calibration level for sorbitol was taken as the instrumental limit of quantification (LOQ) because of its low concentration present in the samples. Calibration curves showed good linearity, and their determination coefficients (R^2) were higher than 0.9. Results from individual sugars are expressed as a mean of the proportion (%) with respect to the total sugar content, and the total sugar content is expressed as grams per liter of flesh juice.

To determine the organic acids, 20 µL from the HPLC vial was injected and isolated by a reverse-phase strong Hamilton HC-75 (Ca^{2+}) cation-exchange resin column (305 × 7,8, 9 µm Teknokroma, Barcelona, Spain, reference HC-79476) at 90 ºC. The flow rate was set at 1 $mL{\cdot}min^{-1}$ using ultrapure water as the mobile phase buffered at pH 3. Compounds were detected by a 2414 refractive index detector (×16) at 30 ºC. External calibration was performed at six calibration levels by dilution of a stock solution composed of 1.0 $g{\cdot}L^{-1}$ malic acid, citric acid, and quinic acid and 0.05 $g{\cdot}L^{-1}$ shikimic acid. The lowest calibration level for shikimic was taken as the LOQ because of its low concentration present in the samples. Calibration curves showed good linearity, and their determination coefficients (R^2) were higher than 0.9. Results from individual organic acids are expressed as a mean of the proportion (%) with respect to total acid content, and the total acid content is expressed as grams per liter of flesh juice.

Sweetener potency was defined as the number of times the compound was sweeter than sucrose, on the basis of its equisweetness (Cardoso and Bolini, 2007). The equisweet concentrations used were 1, 1.75, and 0.75 for sucrose, fructose, and glucose, respectively (Pangborn, 1963) and 0.60 for sorbitol (Schiweck and Ziesenitz, 1996).

6.3.5. Relative antioxidant capacity (RAC) and anthocyanin content

A total of 3 of the 24 fruits were chosen from each cultivar and season to measure anthocyanin content and RAC as described by Cantín et al. (2009a). RAC was quantified by the 2,2-dipyridyl-1,1-diphenyl-2-picrylhydrazyl (DPPH) radical method adapted from Brand-Williams et al. (1995). The results are expressed in micrograms of Trolox per gram of fresh weight (FW). Total anthocyanin content analysis was determined by the method of Fuleki and Francis (1968) adapted to peach tissue. Anthocyanins were quantified as milligrams of cyanidin-3-glucoside per kilogram of FW using a molar extinction coefficient of 25 965 cm^{-1} M^{-1} and a molecular weight of 494 (Abdel-Aal and Hucl, 1999).

6.3.6. Statistical Analysis

Three replications for each parameter evaluated and season were used for each cultivar. To obtain basic statistics for the entire plant material studied, the number of observed cultivars, maximum, minimum, and mean values, mean standard error, and standard deviation for each trait were recorded. All data were treated by means of analysis of variance (GLM procedure) using the SAS program package (SAS, 1997). Differences between fruit type were tested with Tukey's honestly significant difference (HSD) test at a significance level of 0.05 ($P \leq 0.05$). Differences between flesh color, fruit shape and TA range were tested with Student's test at the 0.05 significance level ($P \leq 0.05$). For this, mean values of the proportion of sugars and organic acids were transformed to an arcsine distribution. Correlations between traits to reveal possible relationships were calculated from raw data of the 2 years using the Pearson correlation coefficient at $P \leq 0.05$. PCA was performed using Unscrambler 7.6 program package (CamoASA, 2001).

6.4. Results and discussion

6.4.1. Cultivar

The cultivars evaluated in this study exhibited considerable phenotypic variation in fruit quality, sensory, nutrient contents and antioxidant capacity traits (Table 6.3), as reported by several authors (Byrne et al., 1991; Cantín et al., 2009a,b). Mean values obtained per cultivar are not shown, but the names of the cultivars with the highest and lowest values are reported.

Table 6.3. Values of quality, antioxidant capacity, and anthocyanin and nutrients content traits of 106 commercial peach cultivars. For each trait, minimum, maximum, and mean values, mean standard error (MSE) and standard deviation (SD) are given.

Trait	Minimum	Maximum	Mean	MSE	SD
SSC (ºBrix)	9.5	19.8	12.9	0.2	2.0
TA (g acid malic L^{-1})	2.1	12.1	5.1	0.2	2.4
RI	1.1	6.2	3.1	0.1	1.4
Sweetness	4.3	9.6	7.1	0.1	1.1
Sourness	2.8	10.4	6.2	0.2	1.9
Flavor	3.3	7.7	5.8	0.0	1.0
Overall	2.7	7.5	5.0	0.1	0.9
Sucrose content (%)	55.7	72.9	67.3	0.3	3.2
Glucose content (%)	6.6	15.4	10.2	0.1	1.5
Fructose content (%)	6.7	16.8	10.7	0.1	1.7
Sorbitol content (%)	1.0	15.9	5.2	0.3	3.0
Sucrose/Glucose	3.7	10.7	6.8	0.1	1.3
Glucose/Fructose	0.8	1.3	0.9	0.0	0.1
Total sugar content (g L^{-1}) [a]	89.1	184.5	126.7	2.1	21.9
Sweetening power	91.0	102.46	97.0	0.1	1.8
Malic acid content (%)	42.9	84.3	59.3	0.7	7.5
Citric acid content (%)	3.7	31.6	14.23	0.7	7.1
Quinic acid content (%)	14.5	57.5	27.36	0.7	7.4
Shikimic acid content (%)	0.1	1.8	0.59	0.0	0.2
Total acid content (g L^{-1}) [b]	5.6	18.5	9.33	0.2	2.4
RAC (µg of Trolox g^{-1} of FW)	144.2	711.7	338.32	8.9	92.5
Anthocyanins (mg of C3G kg^{-1} of FW)	0.7	11.4	3.50	0.2	2.2

Abbreviations: SSC, soluble solids content; RI, ripening index; TA; titratable acidity; RAC, relative antioxidant capacity; C3G, cyanidin-3-glucoside.
[a] Sum of sucrose, glucose, fructose and sorbitol for each cultivar.
[b] Sum of malic, citric, quinic and shikimic acids for each cultivar.

The evaluated fruit quality traits showed a wide range of variability. SSC ranged from 9.5 to 19.8 ºBrix, with a mean of 12.9 ºBrix which is higher than the minimum (8.0 ºBrix) established by the EU to market peaches and nectarines (R-CE no. 1861/2004). 'Nectapink' (19.8 ºBrix), 'Nectafine' (19.0 ºBrix), and 'Nectalady' (18.1 ºBrix) showed the highest SSC and 'Nectabang' (9.5 ºBrix), 'Nectaprima' (9.7 ºBrix), and 'Sweetprim' (9.6 ºBrix) the lowest, mainly because the latter are early maturity season varieties, which are reported to have less SSC (Iglesias and Carbó, 2009; Legua et al., 2011). SSC is an important quality trait in peaches and nectarines due to its reported relationship with consumer acceptance and satisfaction. However, this relationship is cultivar dependent, as there is no single reliable SSC that ensures consumer satisfaction, which is also influenced by other quality traits, such as TA (Crisosto and Crisosto, 2005). With respect to TA, important differences among cultivars were observed, with the minimum levels found for 'PG 3/719' (2.1 g of malic acid L^{-1}), 'Nectadiva' (2.2 g of malic acid L^{-1}), and 'Platifirst' (2.3 g of malic acid L^{-1}) and the maximum levels for 'August Red' (12.1 g of malic acid L^{-1}), 'Fire Top' (10.9 g of malic acid L^{-1}), and 'Early Top' (10.7 g malic acid L^{-1}). RI is also a major instrumental quality trait of the mature peach fruit. It is commonly used as a quality index (Bassi and Selli, 1990) because it is related to taste perception (Byrne et al., 1991; Robertson et al., 1988), is a potential indicator of sweetness (Crisosto et al., 2006; Di Miceli et al., 2010), and plays an important role in consumer acceptance of some peach, nectarine, and plum cultivars in ripe fruits (Crisosto and Crisosto, 2005). RI ranged from 1.1 to 6.2. 'Sweetbella' (6.2), followed by 'PG 3/719' (6.1) and 'Nectadiva' (6.0), had the highest value, and 'Sweetprim' (1.0), 'Early Top' (1.0), and 'Fire Top' (1.1) had the lowest values, due to high TA (about 10 g of malic acid L^{-1}) and quite low SSC (11 ºBrix).

Sensorial traits varied among cultivars in the range of 4.3–9.6 for sweetness, 2.8–10.4 for sourness, 3.3–7.7 for flavor and 2.7–7.5 for the overall score (Table 6.3). 'Nectapink' (9.6), 'Nectatop' (9.3), and 'IFF 331' (8.8) had the highest sweetness values, while the lowest were for 'IFF 1230' (4.3), 'Amiga' (4.4), and 'Onyx (4.8). The highest sourness values were obtained for 'Onyx' (10.4), 'Endogust' (9.3), and 'Fire Top' (9.8) and the lowest for 'Platifirst' (2.7), 'UFO 4' (2.9), and 'Sweetstar' (3.1). 'Nectapink' (7.7), 'Gardeta' (7.6), and 'Garcica' (7.6) had the highest flavor values, and 'African Bonnigold' (3.3), followed by 'Onyx' (3.4), and 'IFF 1230' (3.7) had the lowest value. Finally, the highest overall scores were for 'Platifun' (7.5), 'Zee Lady' (6.6), and 'Garcica' (6.5), and the lowest for 'Onyx' (2.6), 'IFF 1230' (3.0), and 'Fire Top' (3.1).

Sucrose, glucose, fructose, and sorbitol contents were analyzed separately, as they play an important role in peach flavor quality (Robertson et al., 1988). Sucrose is important as an energy source and as a preservative of fruit flavors (Huberlant and Anderson, 2003). As with other studies in peaches (Byrne et al., 1991; Cantín et al., 2009b; Colaric et al., 2005; Esti et al., 1997; Robertson et al., 1988; Wu et al., 2005), we found sucrose was the major soluble sugar (Table 6.3), ranging from 55.7% to 72.9% of the total sugar content, followed by the reducing sugars (fructose and glucose) and sorbitol. 'Pink Ring' (72.9%), 'Nectabelle' (72.9%), and 'Nectabigfer' (72.1%) had the highest sucrose concentration and 'Fairlane' (55.7 %), 'August Red' (56.2%), and 'Endogust' (59.5%) the lowest. 'Amiga' (15.4%) and 'Fairlane' (15.3%), followed by 'IFF 331' (13.2%), had the highest glucose concentration and 'Nectavanpi' (6.6%), 'Nectapi' (6.7%), and 'Nectalady' (6.8%) the lowest. 'Amiga' (16.8%), together with 'Azurite' (15.1%) and 'IFF 331' (13.5%), had the highest fructose concentration and 'Nectalady' (6.8%), 'Nectavanpi' (7.1%), and 'UFO 3' (7.1%) the lowest. Glucose and fructose had comparable concentrations, which supports the findings of other studies (Champman and Hovart, 1990; Wu et al., 2005). Since fructose is rated higher (1.75) than sucrose (1) and glucose (0.75) in terms of sweetness (Pangborn, 1963), those cultivars which in general had a high fructose percentage presented the highest sweetening power (R^2 = 0.8). These cultivars were 'Amiga' (102.4), 'Mesembrine' (100.5), and 'Azurite' (100.4). 'Nectalady' (91.0), 'Nectavanpi' (91.9), and 'UFO 8' (92.3) showed the lowest sweetening power. Finally, the levels of sorbitol, a polyalcohol sugar, were very low and relatively variable in terms of total sugar content (from 1.0% to 15.9% of the total sugar content). Sorbitol plays an important role in the texture and flavor of peach nectarine fruits (Cantín et al., 2009b). Sorbitol is also an interesting polyalcohol in terms of nutrition for special dietary purposes, such as diet control or dental health (Forni et al., 1992; Rapaille et al., 2003). Therefore, those genotypes with the highest sorbitol percentage, namely, 'Nectalady', 'August Red', and 'Nectafine' (15.9%, 14.6%, and 14.2%, respectively), could be of interest for peach breeders (Ledbetter et al., 2006) to use as genitors to transmit this trait. The fact that the sorbitol content is always low in peach and nectarine fruit suggests that sorbitol is metabolized into reducing sugars (Moriguchi et al., 1990).

The main acids in stone fruits are malic acid, citric acid, quinic acid, and traces of shikimic acid (Wu et al., 2005). For all cultivars evaluated, malic acid was, in general, the most abundant acid at maturity (42.9–84.3% of total acids content), followed by quinic acid

(14.5–57.5%), citric acid (3.7–31.6%), and traces of shikimic acid (0.1–1.8%) (Table 6.3), as also reported by several authors (Wills et al., 1983; Wu et al., 2002, 2005). However, some studies have reported citric acid to be the second (Byrne et al., 1991; Wu et al., 2005) and quinic acid (Byrne et al., 1991; Wu et al., 2002) the third most abundant organic acid in most peach and nectarine cultivars. Among cultivars, 'Nectaroyal' (84.3%), 'Nectafine' (77.9%), and 'IFF 813' (75.6%) presented the highest malic acid content and 'Nectabigfer' (42.9%), 'ASF 06-90' (43.9%), and 'Platifirst' (45.8%) the lowest. The range found in quinic acid was 4-fold, while in citric and shikimic acids it was 10-fold. 'Nectareine' (57.5%), followed by 'IFF 331' (48.6%) and 'UFO 4' (43.2%), showed the highest quinic acid content and 'Fire Top' (14.56%), 'NG-187' (15.7%), and 'Big Bel' (15.8%) the lowest. Wu et al. (2003) reported that quinic acid imparts a slightly sour and bitter taste and has antibacterial properties beneficial to health. 'IFF 1182' (31.6%), 'Noracila' (31.0%), and 'Amiga' (30.8%) had the highest citric acid content and 'UFO 8' (3.7%), 'Ferlot' (3.7%), and 'Hesse' (3.7%) the lowest. Finally, 'UFO 3' (1.8%), 'UFO 4' (1.0%), and 'Platifirst' (1.0%) had the highest shikimic acid content and 'PI 2/84' (0.1%), 'Catherina' (0.2%), and 'Alice' (0.2%) the lowest.

RAC and anthocyanin content also showed a wide range of variability (Table 6.3). RAC varied from 144.2 to 711.7 μg of Trolox g^{-1} of FW among cultivars. 'Nectapink' (711.7 μg of Trolox g^{-1} of FW), followed by 'Fercluse' (568.6 μg of Trolox g^{-1} FW), and 'Grenat' (566.0 μg of Trolox g^{-1} of FW) had the highest RAC value and 'Azurite' (144.2 μg of Trolox g^{-1} FW), 'Nectadiva' (184.4 μg of Trolox g^{-1} FW), and 'Sweetbella' (191.4 μg of Trolox g^{-1} FW) had the lowest values. Values in a similar range were obtained in other studies with peach cultivars (Abidi et al., 2011; Cantín et al., 2009a), but lower than in other studies where peel was included in the test sample (700-6000 μg of Trolox g^{-1} of FW) (Gil et al., 2002; Tomás-Barberán et al., 2001) due to unequal distribution of phenolic compounds in the flesh (~ 30%) and skin (~70%) (Cevallos-Casals et al., 2006). On average, unpeeled fruit contains 1.5-fold higher levels of phenolics than peeled fruit (Asami et al., 2003). Cyanidin-3-glucoside has been identified as the main anthocyanin in *Prunus persica* along with a smaller amount of cyanidin-3-rutinoside (Asami et al., 2003; Hsia et al., 1965; Ishikura, 1975; Van Blaricom and Senn, 1967). The total anthocyanin content varied greatly among cultivars, ranging from 0.7 to 11.4 mg of C3GE kg^{-1} of FW (C3GE = cyanidin-3-glucoside equivalents), depending on the percentage of red pigmentation of the flesh. In this study, cultivars with red endocarp flesh such as ‘Nectareine’ (11.4 mg of C3GE kg^{-1} of FW), ‘Onyx’ (10.1 mg of C3GE kg^{-1} of FW), and ‘IFF 1233’ (9.9 mg of C3GE kg^{-1} of FW) had higher anthocyanin content than nonmelting peach cultivars of pure yellow flesh such as ‘PI 2/84’ (0.9 mg of C3GE kg^{-1} of FW), ‘Feraude’ (0.9 mg of C3GE kg^{-1} of FW), ‘Ferlot’ (0.8 mg of C3GE kg^{-1} of FW), and ‘African Bonnigold’ (0.7 mg of C3GE kg^{-1} of FW).

In this work it was also observed that the fruit type and flesh color had no direct effect on the cultivar for all quality traits evaluated, except for anthocyanin content in the case of flesh color. One example of this was observed in the case of RAC (Figure 6.1).

All cultivars were grown under the same environmental conditions and cultivation practices; thus the differences observed in all quality traits should be attributable to the cultivar effect. This indicated that adequate genetic variability is present for the potential development of new cultivars with enhanced fruit quality.

6.4.2. Breeding program

A comparison between cultivars depending on the breeding program selected and for a given fruit type (melting peach, nectarine, and flat peach) was carried out for fruit quality, sensorial, nutritional, and antioxidant capacity traits (Table 6.4). The nonmelting peach type was not included in this section due to the limited number of breeding programs; a minimum of three cultivars were required for statistical comparisons to be possible.

ASF melting peaches showed in general higher SSC compared to the others (Table 6.4). Moreover, together with Mounteaux-Callet and CRA, they had the highest TA, followed by Zaiger and A. Minguzzi melting peaches. In spite of these differences, great variability was observed in TA within each breeding program (data not shown), mainly due to the fact that each breeding program had sweet and nonsweet cultivars. A. Minguzzi, Zaiger, and ASF melting peaches had the highest sweetness scores, followed by INRA, CRA, and Monteaux-Callet melting peaches. The last one also showed the highest sourness and lowest flavor and were the least rated melting peaches and together with CRA melting peaches showed the highest percentage of fructose compared to the others. Owing to the important role of sorbitol in the texture and flavor of peach and nectarine fruits (Cantín et al., 2009b), this interesting trait was valued, among others, in the Zaiger breeding program. In general, high malic acid content coincided with low quinic acid content when melting

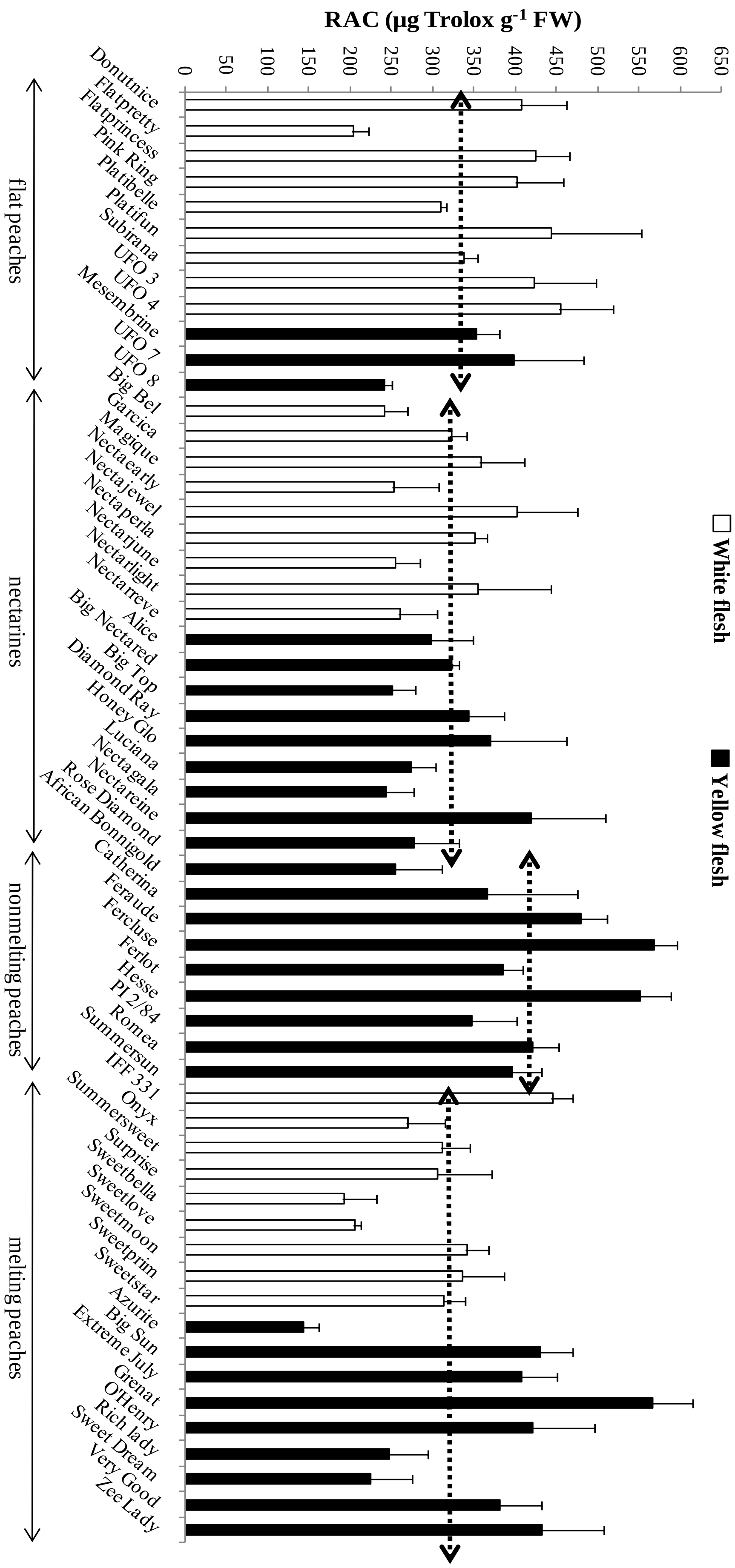

Figure 6.1. Fruit RAC (DPPH method) of flat peach, nectarine, nonmelting peach, and melting peach cultivars: white bars, white flesh; black bars, yellow flesh. Values are mean ± standard error (*n* = 6). Lines show averages for flat peaches, nectarines, nonmelting peaches, and melting peaches.

peach breeding programs were compared. Monteaux-Callet melting peaches showed the highest citric acid and anthocyanin contents.

Among nectarine breeding programs, SSC was higher in ASF compared to the other programs (Table 6.4). Significantly higher TA was observed for Bradford cultivars compared to the others. ASF and PSB nectarines had the highest sweetness. PSB nectarines showed the lowest sourness, highest flavor, highest overall scores, and the highest percentage of sucrose and sucrose/glucose ratio. The high glucose and fructose values from A. Minguzzi nectarines gave them the highest sweetener potency. In contrast, despite high sorbitol percentage and high total sugar content, ASF nectarines had the lowest sweetener potency. In general, high citric and malic acid contents coincided with low quinic acid content. ASF nectarines had the highest shikimic acid content and Bradford and Zaiger nectarines the highest total acid content, followed by A. Minguzzi, ASF, and PSB nectarines. The last one showed also the highest anthocyanin content.

ASF flat peaches had significantly higher SSC, TA, and sourness values than the CRA and INRA flat peaches (Table 6.4). This was due to the higher mean TA (11.0 g of malic acid L^{-1}) from 'Donutnice' compared to the mean TA (3.2 g of malic acid L^{-1}) from the remaining ASF cultivars. Moreover, ASF flat peaches had the highest total sugar content and sweetener potency as a result of their high glucose, fructose, and sorbitol percentages.

The breeding program had a significant influence on these quality traits; however, each breeding program had specific characteristics that distinguished it from the others. Even so, within each breeding program there is high variability among cultivars. Therefore, growers should not base their strategy exclusively on the choice of breeding program.

6.4.3. Qualitative trait effect

Significantly differences were observed among fruit types (Table 6.5). Yellow melting peaches showed the highest fructose content compared to the others. White melting peaches were the best rated by the expert panel. Yellow nectarines showed the highest sorbitol content and white nectarines the highest citric acid content. Nonmelting peaches showed the highest malic acid and RAC mean value.

Finally, white flat peaches showed the highest sucrose and shikimic acid contents compared to the others. The results from this study were partly in agreement with the study of 14 peach progenies carried out by Cantín et al. (2009b), who reported that

Table 6.4. Mean values of quality, antioxidant capacity, and anthocyanin and nutrients content traits by fruit type and origin (nonmelting peach is not included) over 2010 and 2011 seasons.

		Melting peach					Nectarine					Flat peach		
Quality Traits	Mean ± MSE[a]	A. Minguzzi (3)[b]	ASF (7)	CRA (5)	Monteaux-Callet (3)	Zaiger (5)	A. Minguzzi (3)	ASF (25)	Bradford (4)	PSB (4)	Zaiger (9)	ASF (7)	CRA (5)	INRA (5)
SSC (ºBrix)	13.01 ± 0.10	11.79 ab	12.57 a	11.72 ab	11.02 b	12.34 ab	11.73 b	14.01 a	12.55 ab	12.37 b	12.91 ab	14.28 a	12.44 b	13.03 b
TA (g acid malic L^{-1})	4.93 ± 0.11	2.94 b	5.01 a	5.39 a	6.37 a	4.71 ab	6.78 b	4.46 c	9.20 a	4.31 c	6.69 b	4.34 a	2.53 b	3.16 b
RI	3.33 ± 0.07	4.18 a	3.43 ab	2.79 ab	2.34 b	3.31 ab	2.00 bc	3.48 a	1.43 c	2.96 ab	2.36 b	4.33	5.98	4.24
Sweetness	7.22 ± 0.07	7.47 a	6.89 a	6.60 ab	5.82 b	7.32 a	6.38 b	7.55 a	6.21 b	7.84 a	6.71 b	7.76	7.69	7.63
Sourness	6.04 ± 0.10	4.85 b	6.43 ab	6.31 ab	7.42 a	6.08 ab	7.14 ab	5.96 bc	8.51 a	5.25 c	7.37 a	5.14 a	3.79 b	4.49 ab
Flavour	5.92 ± 0.07	5.77 ab	5.51 ab	5.24 bc	4.38 c	6.30 a	4.88 c	6.15 b	5.65 bc	7.24 a	5.49 bc	6.57 a	5.77 b	6.32 ab
Overall	5.07 ± 0.05	5.12 ab	4.71 b	4.63 b	3.43 c	5.55 a	4.18 c	5.18 b	4.75 bc	6.13 a	4.79 bc	5.45	5.15	5.67
Sucrose content (%)	6.48 ± 0.18	68.70	68.00	66.81	66.12	67.22	63.09 d	67.94 b	63.70 cd	70.65 a	66.29 bc	67.24 b	70.81 a	67.67 b
Glucose content (%)	10.10 ± 0.09	10.41	10.27	10.93	10.41	10.44	13.20 a	9.37 d	11.31 b	9.0 cd	10.33 bc	10.41 a	8.31 b	10.90 a
Fructose content (%)	10.61 ± 0.10	11.58 ab	10.69 ab	11.71 a	12.41 a	10.07 b	14.08 a	9.65 d	11.74 b	9.73 cd	11.00 cd	10.94 a	8.61 b	11.60 a
Sorbitol content (%)	5.35 ± 0.16	2.73 c	4.39 ab	3.83 bc	3.63 c	5.54 a	4.12 bc	6.66 ab	7.74 a	3.22 c	6.16 ab	5.65 a	4.45 ab	3.48 b
Sucrose /Glucose	7.00 ± 0.08	6.89	6.87	6.33	6.63	6.74	4.94 c	7.63 a	5.65 bc	7.89 a	6.60 b	6.55 b	8.79 a	6.37 b
Glucose/Fructose	0.97 ± 0.01	0.92 ab	0.90 ab	0.94 a	0.87 b	1.05 a	0.94	0.98	0.98	0.94	0.94	0.95	0.97	0.94
Total sugar content (g L^{-1})[c]	127.54 ± 1.27	120.15 ab	122.51 a	112.19 ab	101.03 b	110.75 a	108.55 b	142.02 a	122.67 b	122.32 b	124.49 b	135.60 a	127.96 ab	118.87 b
Sweetener potency	96.84 ± 0.11	98.42 a	97.06 ab	97.82 a	97.84 a	96.00 b	100.12 a	95.86 c	97.38 b	96.44 bc	97.00 b	97.59 a	94.80 b	98.25 a
Malic acid content (%)	56.85 ± 0.48	57.72 a	61.99 a	48.48 b	56.66 a	61.42 a	58.22	57.84	59.22	56.82	57.05	54.94	52.55	51.94
Citric acid content (%)	14.19 ± 0.36	14.49 ab	13.00 b	11.74 b	20.16 a	12.26 b	21.7 a	11.97 b	20.07 a	19.94 a	18.25 a	11.821 b	8.09 c	15.84 a
Quinic acid content (%)	0.60 ± 0.02	27.21 ab	24.40 b	31.70 a	22.68 b	25.66 b	19.63 b	28.00 a	18.74 b	22.66 b	22.74 b	32.48 b	38.33 a	31.42 b
Shikimic acid content (%)	27.20 ± 0.38	0.57	0.59	0.38	0.48	0.64	0.40 ab	0.60 a	0.35 b	0.56 ab	0.47 ab	0.74	1.01	0.78
Total acid content (g L^{-1})[d]	9.60 ± 0.16	7.10 b	8.95 b	11.73 a	9.98 ab	8.77 b	10.62 ab	9.51 b	13.39 a	8.51 b	11.70 a	9.11 a	7.19 ab	7.46 b
RAC (µg of Trolox g^{-1} of FW)	325.24 ± 6.76	347.12	289.61	321.55	326.43	319.1	275.34	328.12	343.57	307.77	316.88	334.73	383.72	329.23
Anthocyanin content (mg of C3G kg^{-1} of FW)	3.67 ± 0.16	2.91 b	3.50 b	3.72 ab	6.75 a	2.89 b	5.39 ab	3.29 b	4.02 ab	6.36 a	3.80 ab	3.37	2.19	3.23

Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; RAC, relative antioxidant capacity; C3G, cyanidin-3-glucoside. Mean separation within rows by Tukey's test ($P \leq 0.05$). In each row by fruit type values with the same letter are not significantly different.

[a]Mean value and mean standard error considering all breeding programs evaluated together.

[b]Number of cultivars tested.

[c]Sum of sucrose, glucose, fructose and sorbitol for each cutivar.

[d]Sum of malic, citric, quinic and shikimic acids for each cultivar.

Table 6.5. Mean values of quality, antioxidant capacity, and anthocyanin and nutrients content traits associated with qualitative pomological traits from 106 commercial peachcultivars over 2010 and 2011 seasons.

Quality Traits	Fruit type							Flesh Colour				Fruit shape		Group and TA range	
	YPE (18)[a]	WPE (10)	YNE (38)	WNE (13)	NMP (9)	YFP (3)	WFP (15)	Y (54)	YR (14)	W (21)	WR (17)	R (88)	F (18)	SW (70)	NSW (36)
SSC (ºBrix)	12.06 b	12.14 b	13.28 a	13.68 a	12.71 ab	13.16 ab	13.42 a	13.05 ab	12.25 c	13.59 a	12.58 bc	12.88 b	13.37 a	13.07	12.77
TA (g acid malic L^{-1})	4.95 a	5.11 a	5.73 a	5.32 a	5.51 a	2.94 b	3.58 b	5.22 a	5.94 a	3.83 b	5.43 a	5.46 a	3.47 b	3.70 b	7.88 a
RI	3.03 bc	3.41 b	2.86 bc	2.85 bc	2.51 c	4.96 a	4.69 a	3.01 b	2.66 b	4.05 a	3.17 b	4.47 a	2.90 b	3.88 a	1.78 b
Sweetness	6.94 bc	6.53 c	7.10 bc	7.17 abc	6.55 c	7.89 a	7.68 a	6.98 b	7.15 ab	7.67 a	6.64 b	6.95 b	7.71 a	7.50 a	6.26 b
Sourness	6.42 a	6.41 a	6.55 a	6.78 a	6.94 a	4.67 b	4.60 b	6.51 a	6.38 a	5.15 b	6.55 a	6.60 a	4.62 b	5.19 b	8.34 a
Flavour	5.93 ab	5.07 c	5.91 ab	5.98 ab	5.50 bc	6.26 a	6.27 a	5.88 b	5.85 b	6.34 a	5.27 c	5.75 b	6.27 a	6.05 a	5.43 b
Overall	5.33 ab	5.43 a	5.00 b	4.39 c	4.87 bc	5.02 ab	4.87 bc	5.00 b	4.99 b	5.44 a	4.49 c	4.92 b	5.41 a	5.24 a	4.55 b
Sucrose (%)	66.81 bc	68.77 abc	66.42 c	67.98 abc	68.40 ab	67.72 abc	68.61 a	67.10 bc	65.91 c	68.91 a	67.52 ab	67.12 b	68.46 a	68.41 a	64.67 b
Glucose (%)	10.40	10.50	10.21	10.15	10.57	9.84	9.96	10.15 b	10.87 a	9.92 b	10.46 ab	10.32	9.99	9.80	11.4
Fructose (%)	11.56 a	10.55 ab	10.67 ab	10.34 b	11.18 ab	10.52 ab	10.47 b	10.80 b	11.69 a	10.37 b	10.55 b	10.84	10.48	10.31 b	11.95 a
Sorbitol (%)	4.69 b	3.75 b	6.47 a	5.34 ab	3.58 b	5.32 ab	4.50 b	6.66 a	5.06 ab	4.38 b	4.80 ab	5.36	4.63	4.92 b	6.03 a
Sucrose /Glucose	6.60	6.86	6.90	7.04	6.59	7.40	7.10	6.94 a	6.22 b	7.24 a	6.73 ab	6.80 b	7.15 a	7.27 a	5.81 b
Glucose/Fructose	0.91	1.00	0.97	0.98	0.95	0.93	0.95	0.95 b	0.93 b	0.96 ab	1.00 a	0.96	0.95	0.96	0.97
Total sugar content (g L^{-1})[b]	117.91 bc	114.91 c	131.37 a	133.04 a	123.57 abc	129.89 ab	128.93 ab	129.90 a	113.40 b	131.89 a	119.86 b	126.22	129.09	129.78 a	118.99 b
Sweetener potency	97.66 a	96.77 ab	96.66 ab	96.88 ab	98.05 a	96.72 ab	97.11 ab	97.01	97.57	97.13	96.72	97.06	97.04	125.51 a	116.38 b
Malic acid content (%)	59.32 ab	58.8 ab	59.4 ab	56.57 bc	62.68 a	55.12 bc	53.15 c	60.72 a	55.13 b	55.25 b	56.35 b	58.74 a	53.48 b	57.24 b	59.38 a
Citric cid content (%)	13.37 bc	14.37 abc	15.25 ab	17.50 a	10.37 c	10.69 c	12.11 bc	12.70 b	18.53 a	12.51 b	16.82 a	14.37 a	11.87 b	12.17 b	18.41 a
Quinic acid content (%)	26.76 b	26.21 b	24.87 b	25.32 b	26.63 b	33.50 a	33.86 a	26.07 b	25.84 b	31.47 a	26.17 b	25.68 b	33.80 a	28.88 a	22.52 b
Shikimic acid content (%)	0.54 b	0.59 b	0.52 b	0.59 b	0.30 c	0.67 ab	0.87 a	0.50 b	0.48 b	0.76 a	0.64 ab	0.51 b	0.83 a	0.65 a	0.36 b
Total acid content (g L^{-1})[c]	8.99 bc	9.13 ab	9.95 a	9.92 a	9.93 a	7.53 c	8.29 c	9.59 a	9.52 ab	8.49 b	9.72 a	10.04 a	8.07 b	8.66 b	12.36 a
RAC (µg Trolox g^{-1} FW)	354.45 ab	289.25 c	326.42 b	332.10 b	418.65 a	330.75 b	350.25 ab	349.41 a	336.75 ab	355.03 a	294.97 b	349.75	349.18	337.38	340.12
Anthocyanin content (mg C3G kg^{-1} FW)	3.48 a	4.35 a	3.88 a	3.53 a	1.49 b	2.70 ab	3.13 ab	2.90 b	5.33 a	2.93 b	4.40 a	3.68	3.17	3.75 a	3.01 b

Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; RAC, relative antioxidant capacity; C3G, cyanidin-3-glucoside; YPE, yellow melting peach; WPE, white melting peach; YNE, yellow nectarine; WNE, white nectarine; NMP, nonmelting peach; YFP, yellow flat peach; WFP, white flat peach; Y, yellow; YR, yellow-red; w, white; WR, white-red; R, round; F, flat, SW, sweet; NSW, nonseweet. Mean separation within rows by Tukey's test ($P \leq 0.05$). In each row by fruit type values with the same letter are not significantly different.

[a]Number of cultivars tested.

[b]Sum of sucrose, glucose, fructose and sorbitol for each cutivar.

[c]Sum of malic, citric, quinic and shikimic acids for each cultivar.

nectarine fruits showed higher SSC, glucose content, total sugar content, and glucose/fructose ratio than melting peach fruits, probably because more subacid cultivars were selected. Kader (1999) considered mean values of SSC over 10 ºBrix as the minimum value for consumer acceptance for yellow-flesh nectarines. In this study, all fruit types provided values above 12 ºBrix, which is common in warm climates and considering the entire range of cultivars.

Yellow-fleshed cultivars showed the highest sorbitol and malic acid content (Table 6.5). Yellow-red-fleshed cultivars had the highest glucose and fructose mean values. White-fleshed cultivars had the highest flavor, sucrose, citric acid, and shikimic acid contents and were the best rated. White-red-fleshed cultivars had the highest glucose/fructose ratio, and together with yellow-red-fleshed cultivars, they showed the highest anthocyanin content. These results were in agreement with those obtained by Vizzotto et al. (2007) who reported that peach cultivars with red-colored flesh had higher anthocyanin content than light-colored fleshed cultivars. Cantín et al. (2009a) and Gil et al. (2002) reported that white-fleshed cultivars showed higher antioxidant capacity than yellow-fleshed ones. In addition, Vizzotto et al. (2007) reported that the antioxidant activity of red-fleshed cultivars was higher than that of light-colored flesh cultivars of peach. Nevertheless, this study was not in agreement with theirs. On the other hand, Cantín et al. (2009b) and Robertson et al. (1990) reported higher SSC and individual and total sugar contents in white-fleshed fruits than in yellow-fleshed cultivars. It is assumed that white- and yellow-fleshed cultivars differ in acidity and sugar composition, and this may contribute to the different preferences shown by groups of consumers (Cantín et al., 2009b). Nevertheless, this study showed similar results in glucose and fructose between white- and yellow-fleshed cultivars.

Flat peach cultivars have been reported to have excellent flavor with a sweet taste, low TA, and high sugar content, around 7.3% of greater SSC than round peach cultivars (Iglesias and Carbó, 2009; Wang et al., 2010). This agrees with the results obtained, although the flat peach SSC was 5% higher than the round peach SSC (Table 6.5).

By group and TA range (Table 6.5), sweet cultivars showed higher sweetness, flavor, overall score, RI, sucrose and total sugar content, sweetener potency, and quinic acid, shikimic acid, and anthocyanin content than nonsweet cultivars. Sourness, TA, and fructose, sorbitol, malic acid, citric acid and total acid contents were significantly higher in nonsweet cultivars than sweet cultivars. However, Picha et al. (1989) reported that low-acid (or sweet) cultivars contain less malic acid than normal cultivars at any stage during development. On the other hand, no differences were observed in SSC between sweet and nonsweet cultivars. One example of this result is shown in Table 6.6, where sweet cultivars ('Big Top', 'Gardeta', and 'Luciana') were compared to nonsweet cultivars ('Amiga', 'Diamond Ray', and 'Rose Diamond').

Table 6.6. Sweetness, sourness, SSC, TA, individual sugar and individual organic acid contents of three sweet cultivars and three nonsweet cultivars over the 2010 and 2011 seasons.

Traits	**Nonsweet**			**Sweet**		
	Amiga	Diamond Ray	Rose Diamond	Big Top	Gardeta	Luciana
Sweetness	4.43 c	6.50 b	5.73 b	8.46 a	8.31 a	6.92 ab
Sourness	7.80 b	9.55 a	7.01 bc	5.52 cd	5.14 d	5.85 cd
SSC (ºBrix)	10.82	13.22	10.65	11.45	13.20	11.77
TA (g acid malic L^{-1})	7.40 b	10.21 a	6.02 c	4.59 d	4.11 de	3.21 e
Sucrose content (%)	60.03 b	64.63 ab	65.36 ab	65.87 ab	71.53 a	70.30 a
Glucose content (%)	15.41 a	11.54 b	10.56 bc	10.09 bc	8.51 c	9.07 bc
Fructose content (%)	16.82 a	12.16 b	9.89 b	11.09 b	9.47 b	9.89 b
Malic acid content (%)	48.09 c	60.05 ab	65.31 ab	45.87 c	52.78 bc	65.29 a
Citric acid content (%)	30.84 a	22.75 b	16.69 bc	22.66 b	17.86 bc	11.94 c
Quinic acid content (%)	20.58 b	16.90 b	19.27 b	31.01 a	28.85 a	22.08 b

Abbreviations: SSC, soluble solids content; TA, titratable acidity. Mean separation within columns by Tukey's test ($P \leq 0.05$). In each column values with the same letter are not significantly different.

These cultivars differed mainly in TA value and the perception of sourness. Liverani et al. (2003) when comparing sweet to nonsweet cultivars, have reported that TA is from 3 to 5 times higher and RI at commercial harvest is 3–4 fold higher. In the present study we also found these differences in TA and RI between the two groups of cultivars, though the magnitude of difference was only a factor of 2–3, in agreement with those reported by Iglesias and Echeverría (2009).

The influence of qualitative pomological characteristics on these quality traits indicates that they also play an important role in determining fruit quality.

6.4.4. Correlations among fruit quality traits

Pearson's correlation coefficients between pairs of traits are shown in Table 6.7. Among individual sugars, the highest correlations were positively found between glucose and fructose ($r = 0.7$, $P \leq 0.01$), as reported by other authors (Abidi et al., 2011; Cantín et al., 2009b; Dirlewanger et al., 1999). Sweetener potency was highly correlated with glucose (r = 0.7, $P \leq 0.01$) and fructose (r = 0.8, $P \leq 0.01$).

Malic acid was significantly negatively correlated with quinic acid (r =-0.6, $P \leq 0.01$). However, several studies (Dirlewanger et al., 1999; Esti et al., 1997; Wu et al., 2003) have found a positive correlation between malic and quinic acids.

In this study, a poor correlation was found between RAC and anthocyanin content. This result suggests that the anthocyanin content has little effect on the antioxidant capacity in peaches and nectarines due to their lower anthocyanin content compared to strawberries, raspberries, or plums. Nevertheless, this study suggests that the anthocyanin trait should be taken into consideration and included in breeding programs for the selection of higher fruit quality cultivars, mainly because many breeding programs improve new cultivars with red or orange flesh, mainly to attract consumers due to health benefits from anthocyanins (Byrne et al., 2012; Conte et al., 2010).

Sweetness is mostly attributable to mono- and disaccharides rather than to other compounds (Byrne et al., 1991; Colaric et al., 2005). However, we found that sweetness had a high significant correlation with flavor (r = 0.7, $P \leq 0.01$), as reported by Crisosto et al. (2006) and López et al. (2011) and overall score (r = 0.6, $P \leq 0.01$) (Table 6.7).

Flavor had a high significant correlation with overall score (r = 0.7, $p \leq 0.01$). Kader (2008) and Byrne (2012) suggested that to provide better tasting fruits and vegetables to consumers, one of the main objectives to achieve this was to replace poor-flavor cultivars with good-flavor cultivars from among those that already exist and/or by selecting new cultivars with desirable flavor and textural quality.

Many authors have reported a not very high correlation between SSC and total sugar content for citrus (Echeverria and Ismail, 1990) and peach (Byrne et al., 1991; Cantín et al., 2009b) cultivars, probably owing to the contribution of optically active soluble compounds (pectins, salts, and organic acids) other than sugars and the high correlation between SSC and organic acids (Wu et al., 2003). However, high correlation between SSC and total sugar content (r = 0.7, $P \leq 0.01$) was found.

Table 6.7. Pearson's correlation coefficients between traits in 106 commercial peach cultivars over the 2010 and 2011 seasons.

Quality Trait	Sweetness	Sourness	Flavour	Overall	SSC	RI	TA	Sucrose content	Glucose content	Fructose content	Sorbitol content	Total sugar content[a]	Sweetener potency	Acid malic content	Acid citric content	Acid shikimic content	Acid quinic content	Total acid content[b]	RAC
Sourness	-0.37**																		
Flavour	0.72 **	-0.14 **																	
Overall	0.64 **	-0.22 **	0.76 **																
SSC	0.30 **	NS	0.21 **	0.22 **															
RI	0.38 **	-0.63 **	0.19 **	0.29 **	0.37 **														
TA	-0.38 **	0.72 **	-0.21 **	-0.31 **	NS	-0.82 **													
Sucrose content	0.25 **	-0.29 **	0.16 **	0.26 **	-0.14 **	0.30 **	-0.44 **												
Glucose content	-0.29 **	0.35 **	-0.18 **	-0.23 **	-0.15 **	-0.35 **	0.37 **	-0.56 **											
Fructose content	-0.29 **	0.28 **	-0.17 **	-0.25 **	-0.17 **	-0.38 **	0.35 **	-0.68 **	0.72 **										
Sorbitol content	NS	0.08 *	NS	NS	0.57 **	NS	0.18 *	-0.62 **	-0.10 **	NS									
Total sugar content[a]	0.37 **	NS	0.28 **	0.34 **	0.72 **	0.38 **	-0.18 **	0.14 **	-0.28 **	-0.37 **	0.46 **								
Sweetener potency	-0.15 **	0.24 **	NS	-0.08 *	-0.12 **	-0.24 **	0.18 **	-0.26 **	0.70 **	0.82 **	-0.36 **	-0.11 **							
Acid malic content	NS	0.24 **	0.10 **	NS	0.31 **	NS	0.13 **	-0.07 *	NS	-0.15 **	0.31 **	0.31 **	0.29 **						
Acid citric content	-0.26 **	0.25 **	-0.15 **	-0.17 **	-0.39 **	-0.50 **	0.42 **	-0.24 **	0.36 **	0.46 **	-0.22 **	-0.46 **	-0.42 **	-0.29 **					
Acid shikimic content	0.21 **	-0.13 **	0.10 **	0.19 **	NS	0.29 **	-0.34 **	0.37 **	-0.14 **	-0.33 **	-0.11 **	0.32 **	0.32 **	0.13 **	-0.24 **				
Acid quinic content	0.19 **	-0.44 **	NS	NS	0.10 *	0.49 **	-0.48 **	0.19 **	-0.26 **	-0.15 **	NS	NS	-0.12 *	-0.61 **	-0.40 **	NS			
Total acid content[b]	-0.18 **	0.48 **	-0.11 **	-0.13 *	NS	-0.49 **	0.59 **	-0.10 **	0.16 **	0.08 *	NS	NS	NS	-0.20 **	0.10 **	-0.09 *	0.12 **		
RAC	NS	-0.12 **	NS	NS	0.23 **	NS	NS	-0.21 **	-010 *	0.11 **	0.21 **	NS	NS	NS	NS	-0.36 **	NS	-0.17 **	
Anthocyanins	-0.11 **	-0.08 *	-0.09 *	NS	NS	NS	NS	NS	NS	NS	NS	-0.10 *	-0.10 *	-0.21 **	0.22 **	-0.10 **	NS	NS	0.08 *

Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; RAC, relative antioxidant capacity. One and two asterisks represent statistical significance at $P \leq 0.05$ and $P \leq 0.01$ respectively. NS = not significant.

[a]Sum of sucrose, glucose, fructose and sorbitol for each cutivar.

[b]Sum of malic, citric, quinic and shikimic acids for each cultivar.

6.4.5. Principal component analysis and grouping of cultivars

PCA was applied to describe all the information contained in the data set to detect the most important variables for data structure determination. This can help to select a set of cultivars with better quality performance (Ruiz and Egea, 2008) and to determine the best cultivars for each fruit type.

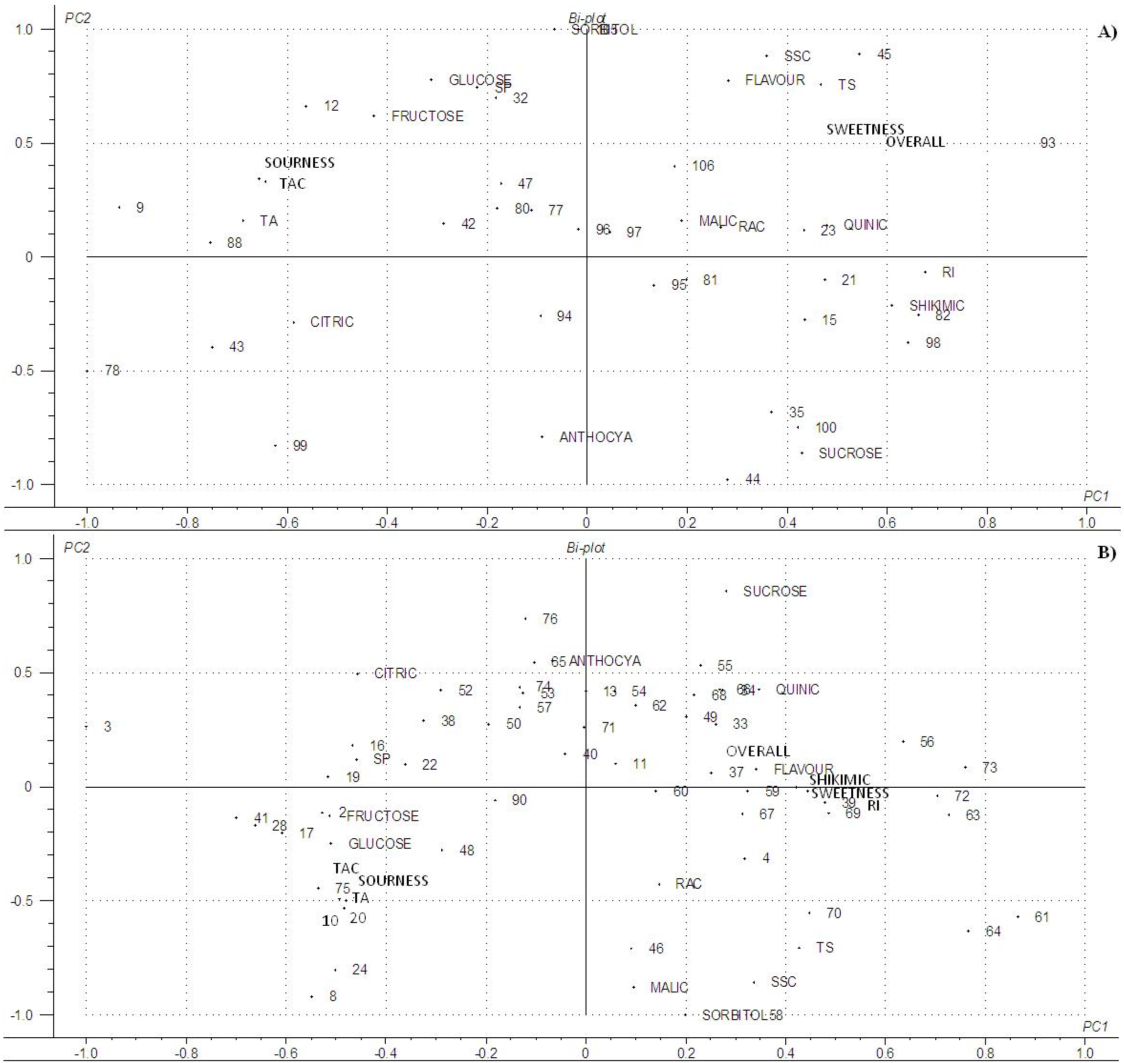

Figure 6.2. Segregation of the 106 peach cultivars, divided by fruit type: (A) melting peach, (B) nectarine, according to antioxidant capacity, quality, anthocyanin and nutrient contents determined by PCA from the data of the 2010 and 2011 seasons. *Abbreviations*: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; TS, total sugar content; SP, sweetener potency; TAC, total acid content; RAC, relative antioxidant capacity; Anthocya, anthocyanin content.

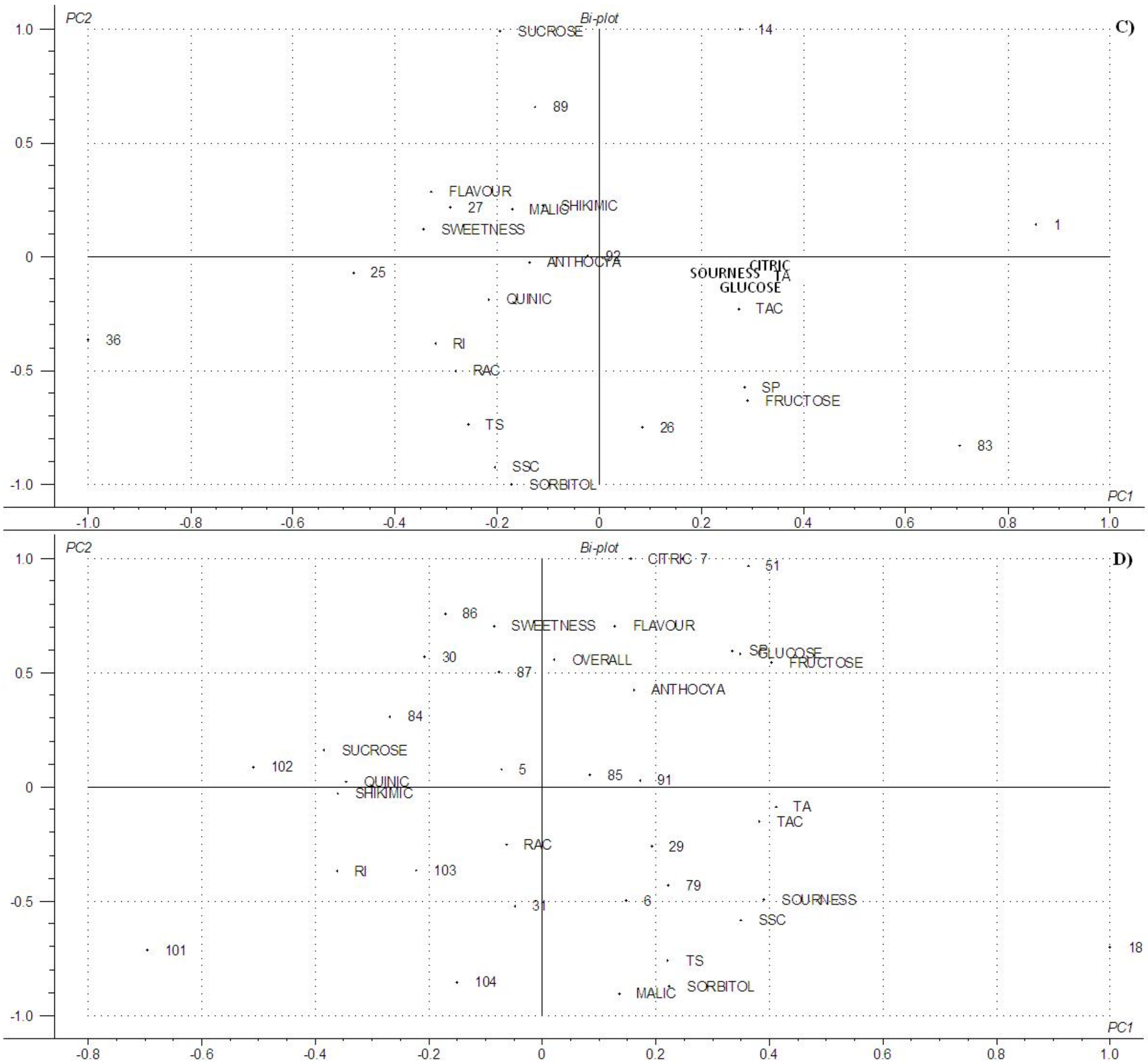

Figure 6.3. Segregation of the 106 peach cultivars, divided by fruit type: (C) nonmelting peach, and (D) flat peach, according to antioxidant capacity, quality, anthocyanin and nutrient contents determined by PCA from the data of the 2010 and 2011 seasons. *Abbreviations*: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; TS, total sugar content; SP, sweetener potency; TAC, total acid content; RAC, relative antioxidant capacity; Anthocya, anthocyanin content.

The results for melting peach cultivars are presented in Figure 6.2A. The variances explained by the first two PCs were 34% and 22%, respectively. This biplot showed a clear separation among melting peach cultivars. Strong relationships were found among sourness, TA, and total acid content (TAC) and between overall score and sweetness. Positive values for PC1 suggested cultivars that have higher values of sweetness, overall score, RI, and quinic acid and shikimic acid contents and lower values of sourness, TA, citric acid content, and TAC. Cultivars such as ‘Azurite’, ‘IFF 1230’, ‘Onyx’, ‘PG 3/719’, ‘Summersweet’, and ‘Sweetmoon’ belong to this group. Flavor, SSC, glucose, fructose, sorbitol, total sugar (TS) contents ,and sweetener potency (SP) exhibited positive values for PC2, whereas sucrose and anthocyanin contents showed negative values. Cultivars such as 'Big Sun', 'Fullred', 'Grenat', 'IFF 1233', 'IFF 331', 'Sweetprim', 'Sweetstar', and 'Very Good' belong to this group.

As for nectarine cultivars, the first two PCs accounted for 61% of the total variance (Figure 6.2B). Sweetness, flavor, overall score, RI, and shikimic acid content exhibited positive values for PC1, while glucose and fructose contents and SP exhibited negative values. Strong relationships between overall score and flavor, and among sweetness, RI, and shikimic acid content were found for PC1. 'Amiga', 'Fire Top', 'IFF 1182', 'Nectadiva', 'Nectalady', 'Nectapi', 'Nectapink', 'Nectatop', and 'Nectavanpi' were part of this group. Sucrose, citric acid, quinic acid and anthocyanin contents showed positive values for PC2, while sourness, SSC, TA, sorbitol, TS, and malic acid contents, TAC, and RAC showed negative values. Strong relationships among SSC and sorbitol, TS, and malic acid content were found for PC2. 'August Red', 'Fairlane', 'IFF 813' and 'Noracila' were characterized by these relationships.

The variances explained by the first two PCs for nonmelting peaches were 52% and 15% respectively (Figure 6.3C). Positive values for PC1 suggested cultivars with high sourness, TA, glucose and citric acid contents, and TAC and low sweetness, flavor, overall score, RI, and malic acid and quinic acid contents. 'African Bonnigold', 'Hesse' and 'PI 2/84' belong to this group. A strong relationship for SSC and sorbitol and TS contents was observed in PC2. Positive values for PC2 suggested cultivars with more sucrose and low SSC, RI, fructose, sorbitol, and TS contents, SP, and RAC, such as 'Catherina' and 'Romea'.

As expected, flat peach cultivars presented a different behavior compared to the other fruit types (Figure 6.3D). An examination of PC1 shows that the cultivar 'Donutnice' had high TA and TAC and low sucrose, quinic acid and shikimic acid contents, and examination of PC2 showed that 'ASF 06-90', 'Mesembrine', and 'Platifirst' had more sweetness, flavor, overall score, glucose and fructose contents, SP, and citric acid and anthocyanin contents and less sourness, SSC, sorbitol, TS, and malic acid contents, and RAC.

The most appropriate combination of these fruit quality, sensorial, nutritional, and antioxidant capacity traits should be considered by the breeder when planning future crosses to achieve higher quality value (good flavor, taste, health benefits, etc.) and by technicians and researchers to obtain more information about which peach cultivars will satisfy market and consumer demands. With these improved cultivars consumer expectations of fruits with high health benefits can be met.

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<u>Capítulo 7</u>

The effect of nectarine cultivar [*Prunus persica* (L.) Batsch] on fruit and postharvest softening

7.1. Abstract

The study was conducted to determine the ripening and postharvest softening behaviors of 11 nectarine cultivars grown under Mediterranean conditions. Harvesting was done weekly on five harvest dates (H1-H5) over three consecutive seasons (2009, 2010, and 2011). For each cultivar at each harvest date and season, diameter (DA), red skin color (SC), flesh firmness (FF), I_{AD} index, soluble solids content (SSC), titratable acidity (TA), and ethylene production were measured after harvest. Postharvest softening was also evaluated by storing the fruits under regular atmosphere at 10ºC during four weeks. The study of FF during ripening showed different behaviors among cultivars. It was also observed that early maturing cultivars tended to loss flesh firmness faster than mid and late maturing cultivars. Ripening process also evaluated by chlorophyll degradation by DA meter showed different cultivar behaviors and maturity season effect on that. Nevertheless, no good relationship was found between these two traits. On the other hand, ethylene production evaluated during ripening was not able to explain the different cultivars behaviors on flesh firmness decrease. Softening behavior was mainly dependent on maturity season. Early maturing cultivars at the day were maximum differences were found between cultivars tended to soft faster than mid and late ones over the five harvest dates evaluated. On the other hand, the day when flesh firmness differences among cultivars were maximums did not differ among seasons but differ among harvest dates. As expected, the longest useful storage time decreases (from 15 days to 10 days) as the harvest date increases (from H1 to H5) in all cultivars evaluated.

7.2. Introduction

In climacteric fruits, such as peach [*Prunus persica* (L) Batsch.], fruit ripening involves a series of biochemical and structural changes (Pech et al., 1994). These may be related to adequate amounts of ethylene while the onset of the syndrome might be due to enhanced hormone sensitivity (Tieman and Klee, 1999; Tonutti et al., 1999). During the maturation/ripening on the tree, peach fruit suffers a very slow decline of firmness at the beginning (softening), followed by a rapid and dramatic firmness decrease, as a result of numerous modifications of the cell wall polysaccharide architecture by cell wall-modifying enzymes, implying changes in texture, a degradation of chlorophyll, a biosynthesis of pigments and volatile compounds, as well as an accumulation of sugars and organic acids (Borsani et al., 2009; Hayama et al., 2006; Giovannoni, 2001, 2004; Trainotti et al., 2003),

To describe the ripening changes, fruit firmness is a useful tool (Valero et al., 2007), besides fruit size and peel background color (Eccher Zerbini et al., 1994; Kader, 1999). Nevertheless, it exists other physiological, biochemical or biomolecular parameters to identify ripening stage, such as ethylene and aroma volatile compounds emission, respiration, soluble pectins, chlorophyll, carotenoid and/or flavonoid content, and mRNA levels of ripening-related genes, which are strictly related to the progression of ripening (Golding et al., 2005; Carrari et al., 2006). Some of these assays cannot be routinely performed since they are complex, costly and do not provide the real-time information needed in the agronomic practice (Ziosi et al., 2008). Interestingly, a hand-held instrument (DA meter, Sinteleia, Bolonga, Italy) has been developed using absorbance within the chlorophyll absorption range, that allows an indirect determination of the chlorophyll content in the fruit flesh and skin (Lurie et al., 2013; Nyasordzi et al., 2013; Ziosi et al., 2008). DA-meter is a portable instrument, with moderate cost (Noferini et al., 2008), that provides the real-time information without fruit destruction.

Fruit pace of softening is a quality trait that is directly related to susceptibility to mechanical damage during postharvest (Crisosto et al., 2001). Fruit softening has relevant economic implications, and it poses severe limits to late harvesting, because soft fruit are easily bruised during handling and transport, and are more susceptible to decay (Eccher Zerbini et al., 2006). Traditionally to evaluate softening a destructive method, such flesh firmness determination, has been used, but currently many authors use non destructive methods such as time-resolved reflectance spectroscopy (TRS) and I_{AD} (Lurie et al., 2013; Tijskens et al., 2007). They provide the real-time information without fruit destruction, but by now they are too complex to evaluate softening behavior of a great number of peach cultivars. The determination of the storage time influence on the evolution of firmness is a desirable objective for producers, distributors and market agents (Diezma-Iglesias, et al., 2006), since they attempt to store fruits for some time to improve marketing prices (Peirs et al., 2000).

There is a perception that some peach cultivars ripen and soften slower than others in both field and postharvest. Nevertheless, no information exist on cultivar effect on ripening and softening behavior although peach fruit ripening and softening has been studied by many authors (Tijskens et al., 2007; Ziosi et al., 2008; Noferini et al., 2009; Lurie et al., 2013). So, the aims of this study are to prove that there are different cultivars behaviors in both ripening and postharvest softening, and try to establish a feasible way of classify them.

7.3. Materials and Methods

7.3.1. Plant material

The study was carried out during the seasons of 2009, 2010 and 2011 on fruits of 11 nectarine cultivars (traditional and new ones) grown on commercial orchards placed in the area of Lleida (Northem of Spain). They were two early maturing cultivars: ‘Big Bang’ and ‘Ambra’, five mid maturing cultivars: ‘Big Top’, ‘Nectareine’, ‘Nectaross’, ‘Honey Royale’, and ‘Venus’, and four late maturing cultivars: ‘Big Nectared’, ‘Red Jim’, ‘Nectalady’, and ‘August Red’ (Table 7.1). ‘Big Top’ was studied as a ‘reference cultivar because it is know that it has a clear low ripening. Trees were grafted onto INRA®GF-677 rootstock, spaced 5m × 3m, and trained in the catalan open vase (Montserrat and Iglesias, 2011). All cultivars achieved the full crop obtaining annual yields from 38 t ha^{-1} (early harvest season cultivars) to 57 t ha^{-1} (mid and late harvest season cultivars).

The trial was conducted selecting 19 trees per cultivar and season, based on the uniformity of tree size and crop load. The first 4 trees were chosen to determine relative growth rate. Forty fruits (ten fruits per tree) were diameter measured at weekly intervals beginning two weeks before commercial harvest (henceforth: H1 and H2), at commercial harvest (henceforth: H3), and continuing for two weeks after the commercial harvest (henceforth: H4 and H5). Firmness at commercial harvest was around 55 $\pm$ 5 N. The remaining 15 trees were used to avoid the possible effect of yield reduction by the repeated harvests. Five plots of three trees were selected per cultivar and one plot was used to each harvest date (from H1 to H5). Weekly, a total of 276 fruits of each plot (92 fruits from each tree) were picked and then analyzed to determine non destructive and destructive measurements, ethylene production and firmness loss during cold storage. The fruits collected at each harvest were considered to represent a maturity category (similar fruit size and fruit color).

Table 7.1. Cultivar, origin, country and maturity season.

Cultivar		Origin	Country	Maturity season
Big Bang	New	ASF	France	E
Ambra	Traditional	D.C.A	Italy	E
Big Top	New	F. Zaiger	USA	M
Nectareine	New	ASF	France	M
Nectaross	Traditional	CRA	Italy	M
Honey Royale	New	F. Zaiger	USA	M
Venus	Traditional	CRA	Italy	M
Big Nectared	New	ASF	France	L
Red Jim	Traditional	J.C. Sorenson & J.K.Ito	USA	L
Nectalady	New	ASF	France	L
August Red	Traditional	N. L. Bradford	USA	L

7.3.2. Ripening on the tree

For each harvest, cultivar and season, 40 fruits per tree were diameter (DA) measured on the tree to an accuracy of 0.01 mm using a digital calliper (Mitutoyo's digimatic calliper, Japan). Means DA over the season were used to calculate the relative growth rate (RGR) according to the method of Hunt (1990).

Thirty similar fruits from the 276 fruits collected each harvest, cultivar and season were selected to measure red coloration of the skin (SC) and index of absorbance difference (I_{AD} index) on each individual fruit. Red skin color was visually scored as the percentage of the skin surface with red color. I_{AD} index was determined by a DA meter (Sinteleia, Bolonga, Italy) and the measure was expressed as the absorbance at 670 nm (near the chl-a absorption peak, Cubeddu et al., 2001) minus the absorbance at 720 nm (background of the spectrum). It has a high correlation with the amount of chl-*a*, destructively measured in the outer mesocarp. Therefore I_{AD} can be an indicator of fruit clorophyll content (Ziosi et al., 2008). The measurement was taken at two equatorial points of the fruit and given as an average of the two measurements.

After non destructive measurements the following destructive ones were done: flesh firmness (FF), soluble solids content (SSC) and titratable acidity (TA). Flesh firmness from two opposite peeled cheeks of each fruit (the most and least exposed to light) was measured with a penetrometer with an 8 mm tip fixed in a drill stand (Penefel; Copa-Technology; CTIFL, Saint Etienne du Gres, France). SSC and TA were determined on flesh juice extracted by an automatic juicer (Moulinex, Type BKA1). SSC was determined using a digitally calibrated refractometer (Atago PR-32, Tokyo, Japan) and the results were expressed in ºBrix. TA was measured with an automatic tritator (Crison GLP 21, Barcelona, Spain) and determined by titrating 10 mL of juice with 0.1 M NaOH to a pH endpoint of 8.2. Results were given as grams of malic acid per litre.

7.3.3. Ethylene production

Six similar fruits from 276 fruits collected per harvest, cultivar and season were assessed for ethylene production. This was measured in an acclimatized chamber at 20ºC. Three replicates of two fruits each were placed in 1.5 L flasks continuously ventilated with humidified air at a flow rate of 1.5 L h^{-1}. Then, gas samples (1 ml) were taken daily from the headspace and injected into a gas chromatograph fitted with a FID detector (Agilent Technologies 6890, Wilmington, Germany) and an alumina column 80/100 (2 m x 3 mm) (Teknokroma, Barcelona, Spain). Gas analyses were conducted isothermally at 100ºC. N_2 carrier, air and H_2 flows were 45, 400 and 45 mL min^{-1}, respectively. The injector and detector were kept at 120 and 180ºC, respectively.

7.3.4. Postharvest softening

In order to monitor postharvest softening, 240 fruits per harvest, cultivar and year were kept in a cold storage at 10ºC up to 28 days. During this period of time every 2-3 days a sample of 20 fruits was moved to a room at 20ºC and held there for 5 hours. After that, flesh firmness from two opposite peeled cheeks of each fruit (the most and least exposed to light) was measured with a penetrometer with an 8 mm tip fixed in a drill stand (Penefel; Copa-Technology; CTIFL, Saint Etienne du Gres, France).

7.3.5. Statistical analysis

Data from the analytical determinations were subjected to analysis of variance (GLM procedure). Ripening potential was assessed by determining the rate of change (b_1) in flesh firmness (FF) and I_{AD} index. A linear regression equation of the form $y = b_0 + b_1x$ was then fitted to the data to determine the slope/gradient (b_1) using JMP®8 program package (SAS, 2010). Degree day accumulations were integrated into the equations instead of daily time intervals, because fruit growth and development are dependent on temperature (Haun and Coston, 1993). Degree-day accumulations were calculated by the formula used by Rodríguez and Flórez (2006). To assess differences between cultivars a Tukey's honestly significant difference (HSD) test at $P \leq 0.05$ significance level was applied for slope. LSMeans were compared with Tukey's honestly significant difference (HSD) test at $P \leq 0.05$ significance level. To have a global overview of the cultivars and trends in firmness evolution after storage at 10ºC, a principal component analysis (PCA) was performed for each harvest date from the characterization of the samples by the firmness values measured for four weeks every 2-3 days at 10ºC.

7.4. Results

7.4.1. Ripening on the tree and ethylene production

Red coloration of the skin (SC), I_{AD} index, and quality parameters such as flesh firmness (FF), soluble solids content (SSC) and titratable acidity (TA) were analyzed every seven day intervals for each harvest date and cultivar (Table 7.2).

FF, I_{AD} and TA decreased while SC and SSC showed an increasing trend during ripening (from H1 to H5). At commercial harvest (H3), the FF mean values of the different cultivars were lower than 63.7 N/0.5 cm^2 (around 55 N), and the SSC mean values were greater than 8 ºBrix, which are the maximum and minimum values of FF and SSC respectively for marketing fresh peaches and nectarines established by the EU (Commission Regulation (EC) No. 1861/2004). On the other hand, comparing traditional to new cultivars it was observed that although both showed similar SSC mean values at H3, traditional cultivars had 2 times higher TA, and were lesser red-colored than the new ones.

Table 7.2. SC, I_{AD}, FF, SSC and TA mean values of 11 nectarine cultivars studied over 3 seasons. Values are the means ± standard deviation for 90 fruits in each harvest. Comparison is within each column for each parameter and cultivar.

Cultivar	Harvest	SC (%)	I_{AD}	FF (N)	SSC (ºBrix)	TA (g malic acid L^{-1})
Big Bang	H1	17.4 ± 14.1 c	1.3 ± 0.2 a	78.0 ± 11.1 a	8.7 ± 0.5 d	5.6 ± 0.5 a
	H2	31.5 ± 17.4 c	1.0 ± 0.2 b	61.7 ± 7.7 b	8.7 ± 0.5 d	5.3 ± 0.5 b
	H3	66.3 ± 23.4 b	0.6 ± 0.2 c	49.8 ± 9.3 c	9.3 ± 0.7 c	4.8 ± 0.5 c
	H4	93.6 ± 5.1 a	0.3 ± 0.1 d	35.1 ± 11.6 d	10.6 ± 0.9 b	4.0 ± 0.7 d
	H5	95.2± 5.5 a	0.2 ± 0.1 e	26.8 ± 10.0 e	10.9 ± 0.6 a	3.2 ± 0.8 e
Ambra	H1	8.8 ± 8.0 d	1.7 ± 0.4 a	81.0 ± 10.3 a	8.9 ± 0.4 c	10.2 ± 1.2 a
	H2	14.0 ± 12.3 d	1.6 ± 0.2 b	64.4 ± 6.1 b	8.6 ± 0.5 d	10.1 ± 0.8 a
	H3	40.6 ± 22.5 c	0.8 ± 0.3 c	54.3 ± 7.4 c	9.0 ± 0.2 c	9.0 ± 0.6 b
	H4	61.0 ± 25.0 b	0.3 ± 0.2 d	38.0 ± 9.0 d	9.8 ± 0.8 b	8.4 ± 1.2 c
	H5	90.2 ± 5.2 a	0.1 ± 0.1 e	20.7 ± 9.0 e	10.6 ± 0.6 a	7.6 ± 0.7 d
Big Top	H1	19.1 ± 16.6 c	1.8 ± 0.1 a	75.0 ± 6.9 a	8.8 ± 0.6 e	7.2 ± 0.4 a
	H2	50.4 ± 45.8 b	1.3 ± 0.3 b	60.4 ± 9.4 b	9.2 ± 0.6 d	5.6 ± 0.8 b
	H3	71.1 ± 19.9 a	0.8 ± 0.2 c	49.1 ± 5.3 c	10.3 ± 0.9 c	5.1 ± 0.5 c
	H4	85.2 ± 10.7 a	0.5 ± 0.2 d	45.7 ± 5.2 d	11.1 ± 1.0 b	4.1 ± 0.4 d
	H5	86.1 ± 11.3 a	0.3 ± 0.1 e	37.2 ± 5.9 e	11.6 ± 1.4 a	3.7 ± 0.4 a
Nectareine	H1	34.0 ± 18.6 c	1.4 ± 0.3 a	72.8 ± 10.6 a	10.0 ± 0.3 d	4.6 ± 0.2 a
	H2	41.4 ± 17.4 c	1.1 ± 0.3 b	57.9 ± 10.8 b	10.7 ± 0.8 c	4.3 ± 0.7 b
	H3	70.4 ± 20.6 b	0.6 ± 0.3 c	52.5 ± 10.0 c	11.5 ± 0.7 b	4.8 ± 2.3 a
	H4	77.9 ± 12.4 ab	0.3 ± 0.2 d	47.2 ± 7.3 d	11.9 ± 1.0 a	3.6 ± 0.4 c
	H5	88.3 ± 13.3 a	0.2 ± 0.1 e	41.6 ± 9.9 e	11.5 ± 0.7 b	3.4 ± 0.2 c
Nectaross	H1	28.6 ± 16.0 c	1.8 ± 0.2 a	85.7 ± 8.1 a	10.1 ± 0.5 e	7.7 ± 1.5 c
	H2	35.7 ± 19.2 bc	1.4 ± 0.4 b	71.0 ± 6.6 b	10.4 ± 0.7 d	8.7 ± 1.2 a
	H3	49.7 ± 21.4 ab	1.0 ± 0.4 c	63.1 ± 9.6 c	10.9 ± 0.6 b	8.3 ± 0.6 b
	H4	61.0 ± 20.7 a	0.5 ± 0.4 d	46.5 ± 18.6 d	10.6 ± 0.7 c	7.6 ± 1.1 c
	H5	66.5 ± 13.9 a	0.3 ± 0.3 e	35.5 ± 16.6 e	11.6 ± 0.6 a	7.1 ± 1.9 d
Honey Royale	H1	51.7 ± 19.0 c	1.9 ± 0.3 a	73.6 ± 12.1 a	11.4 ± 1.4 d	5.5 ± 1.2 a
	H2	74.5 ± 15.6 b	1.7 ± 0.3 b	62.8 ± 9.6 b	12.0 ± 1.0 c	5.4 ± 0.2 a
	H3	83.6 ± 13.9 ab	1.2 ± 0.4 c	58.2 ± 7.3 c	11.9 ± 1.5 c	5.0 ± 0.3 b
	H4	86.0 ± 15.9 ab	1.0 ± 0.3 d	55.4 ± 8.4 d	12.7 ± 1.0 b	5.0 ± 0.6 b
	H5	94.1 ± 4.6 a	0.8 ± 0.3 e	48.9 ± 8.6 e	14.1 ± 1.7 a	4.6 ± 0.6 c
Venus	H1	24.5 ± 17.0 c	1.8 ± 0.2 a	82.3 ± 7.9 a	9.7 ± 0.6 c	7.3 ± 1.0 c
	H2	32.1 ± 17.3 bc	1.4 ± 0.5 a	70.3 ± 9.0 b	9.8 ± 0.3 c	8.7 ± 0.6 a
	H3	43.2 ± 25.4 abc	1.2 ± 0.3 b	62.8 ± 6.4 c	9.9 ± 0.5 c	8.0 ± 0.6 b
	H4	51.2 ± 17.4 ab	0.7 ± 0.4 c	46.6 ± 12.5 d	10.5 ± 0.5 b	7.2 ± 1.2 c
	H5	55.6 ± 43.2 a	0.4 ± 0.2 c	36.6 ± 12.7 e	10.8 ± 1.0 a	6.5 ± 1.4 d
Big Nectared	H1	42.7 ± 14.7 c	1.5 ± 0.2 a	62.3 ± 5.7 a	11.2 ± 0.7 b	5.4 ± 0.1 a
	H2	52.6 ± 19.4 bc	1.0 ± 0.3 b	55.9 ± 5.2 b	10.8 ± 0.7 c	4.9 ± 0.6 c
	H3	55.4 ± 16.4 b	0.5 ± 0.3 c	48.2 ± 5.7 c	11.0 ± 0.6 bc	4.4 ± 0.9 d
	H4	60.6 ± 18.3 b	0.6 ± 0.3 d	44.9 ± 4.8 d	11.7 ± 1.9 a	4.5 ± 0.4 d
	H5	79.3 ± 7.8 a	0.2 ± 0.1 e	37.4 ± 7.2 e	11.7 ± 1.2 a	5.1 ± 0.5 b
Red Jim	H1	41.8 ± 17.1 c	1.7 ± 0.3 a	80.2 ± 7.0 a	11.5 ± 0.6 d	7.4 ± 0.5 c
	H2	49.1 ± 17.9 bc	1.5 ± 0.3 b	70.2 ± 8.7 b	12.1 ± 0.4 c	8.1 ± 0.4 ab
	H3	55.8 ± 13.4 abc	1.1 ± 0.5 c	61.7 ± 8.0 c	12.0 ± 0.9 c	8.5 ± 0.7 a
	H4	62.7 ± 21.3 ab	0.7 ± 0.4 d	53.6 ± 6.9 d	12.7 ± 0.9 b	8.4 ± 0.9 a
	H5	70.9 ± 19.4 a	0.7 ± 0.4 d	48.5 ± 11.6 e	13.5 ± 1.6 a	8.0 ± 2.4 b
Nectalady	H1	43.4 ± 17.1 c	1.6 ± 0.3 a	65.8 ± 9.4 a	12.1 ± 1.0 c	4.1 ± 0.6 a
	H2	47.2 ± 23.6 cb	1.3 ± 0.4 b	60.9 ± 8.2 b	13.6 ± 0.9 b	4.3 ± 0.6 a
	H3	64.9 ± 19.4 abc	0.9 ± 0.4 c	58.5 ± 7.0 c	13.6 ± 1.2 b	3.7 ± 0.2 b
	H4	68.8 ± 20.8 ab	0.9 ± 0.5 c	58.3 ± 8.4 c	14.8 ± 2.2 a	3.3 ± 0.5 c
	H5	77.7 ± 21.5 a	0.5 ± 0.5 d	54.9 ± 8.1 d	14.8 ± 0.9 a	4.2 ± 1.47 a
August Red	H1	23.5 ± 17.3 c	1.3 ± 0.3 a	67.5 ± 10.2 a	11.3 ± 0.9 d	9.4 ± 0.8 c
	H2	32.1 ± 16.3 bc	0.9 ± 0.5 b	63.2 ± 8.5 b	12.0 ± 0.5 b	10.2 ± 1.2 b
	H3	44.0 ± 21.8 abc	0.6 ± 0.4 c	57.4 ± 9.7 c	11.5 ± 0.5 c	9.9 ± 0.8 b
	H4	52.4 ± 21.7 ab	0.5 ± 0.3 c	56.6 ± 9.0 c	12.4 ± 0.6 a	9.9 ± 1.3 b
	H5	60.7 ± 20.4 a	0.3 ± 0.2 d	54.1 ± 8.1 c	12.5 ± 0.7 a	10.8 ± 2.8 a

Abbreviations: SC, red coloration of the skin; FF, flesh firmness; SSC, soluble solids content; TA, titratable acidity. Mean separation within columns by Tukey's test ($P \leq 0.05$). In each column by cultivar values with the same letter are not significantly different.

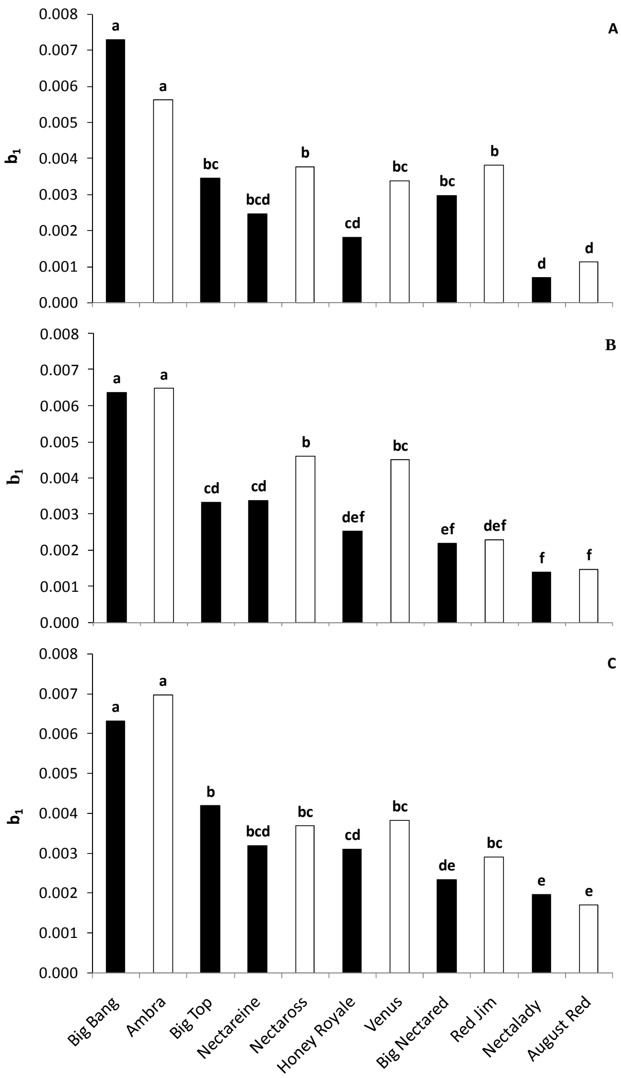

Figure 7.1. Rates of change × degree day^{-1} (b_1) of flesh firmness (FF) in 2009 (A), 2010 (B) and 2011 (C). Cultivars are ordered based on their commercial harvest date. Black columns represent the new cultivars and white columns the traditional ones. Columns with different letters are significantly different at $P \leq 0.05$.

The mean values of the rates of change (b_1) of flesh firmness (FF) varied according to the cultivar and season (Figure 7.1). A significant *cultivar × season* interaction was observed ($P \leq 0.001$). Nevertheless, over the three seasons 'Big Bang' and 'Ambra' showed a faster loss of firmness compared to the rest of the cultivars. Comparing traditional to new cultivars no significantly differences in b_1 mean values were observed for each season. On the other hand, a maturity season effect on loss of firmness was observed in all three seasons ($P \leq 0.05$). Moreover, early maturing cultivars, both new and traditional cultivars, showed higher rates of flesh firmness decrease than mid or later maturing cultivars.

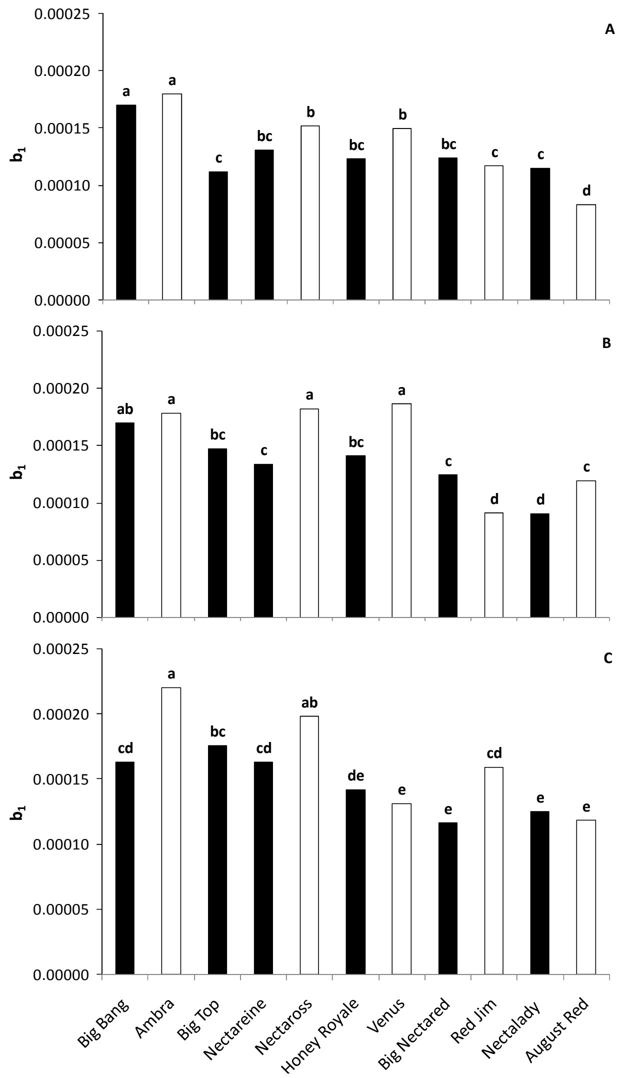

Figure 7.2. Rates of change × degree day^{-1} (b_1) of I_{AD} index in 2009 (A), 2010 (B) and 2011 (C). Cultivars are ordered based on their commercial harvest date. Black columns represent the new cultivars and white columns the traditional ones. Columns with different letters are significantly different at $P \leq 0.05$.

Concerning the rates of change (b_1) of I_{AD} (Figure 7.2), they also varied according to the cultivar and the season of the study. A significant *cultivar × season* interaction was observed ($P \leq 0.001$). As mentioned above, no significantly differences in b_1 mean values were observed for each season when traditional to new cultivars were compared. On the other hand, a maturity season effect on I_{AD} was also observed along the three years of the study ($P \leq 0.05$). Nevertheless, early maturing cultivars, both new and traditional cultivars, showed higher rates of firmness flesh decrease than mid or later maturing cultivars only in 2009.

Relative growth rates (RGR) were plotted against harvest dates to compare better the different cultivars behaviors (Figure 7.3). For all cultivars, the RGR decreased, indicating a negative relationship between RGR and harvest date (weeks). The maximum decrease in RGR was observed from the first to the third harvest date, after which RGR decreased at a lower rate. In this period of time (from H1 to H3) 'Big Bang' and 'Ambra' showed the highest RGRs in comparison to the other cultivars. Comparing traditional to new cultivars no differences were observed in RGR over the harvest dates.

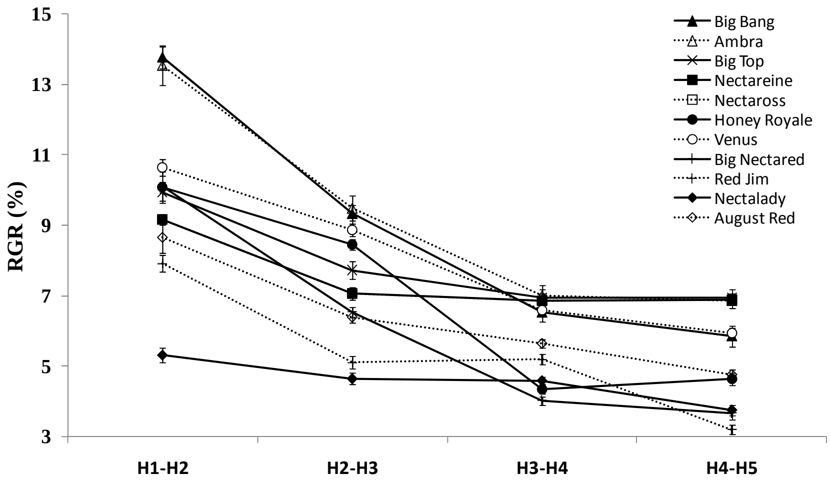

Figure 7.3. Relative growth rate patterns of the 11 nectarine cultivars. Vertical bars indicated ± S.E. of the mean of three seasons. Smooth lines represent the new cultivars and broken lines the traditional ones.

Ethylene emission measured 48 h after each harvest at 20ºC differed quantitatively among cultivars and seasons (Figure 7.4). Very low levels of ethylene were found in all cultivars and seasons at H1 and H2 with the exceptions of 'Nectaross' at 2009, and 'Big Bang' at 2011. Moreover, not all cultivars showed an increasing trend of ethylene production throughout the experimental period (from H1 to H5). This trend was clearly observed only in 'Big Bang' and 'Venus'.

7.4.2. Postharvest softening

An overview of the changes of fruit firmness of the eleven cultivars during four weeks at each harvest date over three seasons is showed in Figure 7.5, which depict the scores and loadings diagrams of a PCA analysis of all the cultivars characterized by the firmness values along storage as explained in the Material and Methods Section. Nectarines

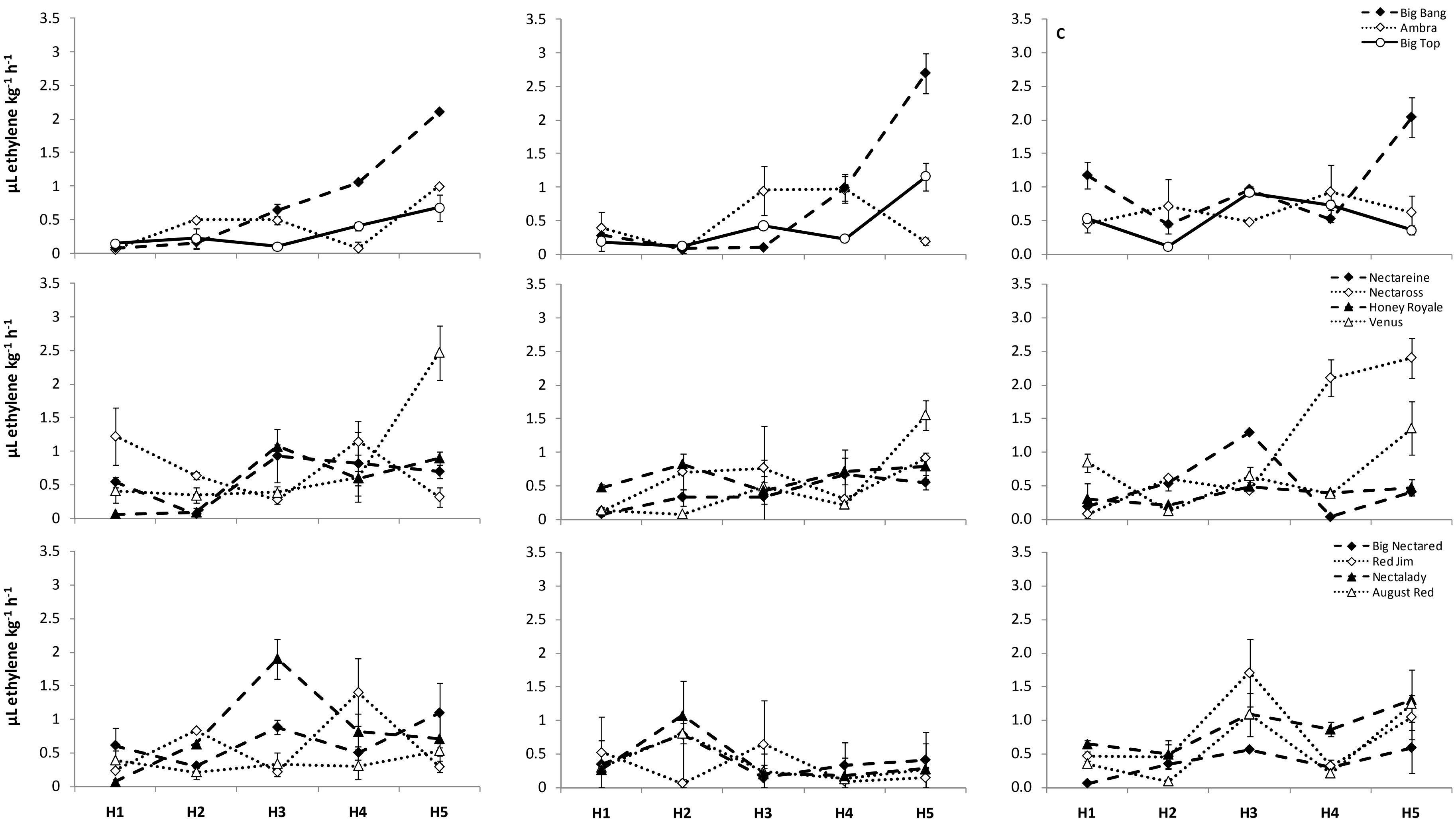

Figure 7.4. Time course of ethylene production of 11 nectarine cultivars held 48 h at 20ºC during ripening in 2009 (A), 2010 (B) and 2011 (C). The values are the means + SE of measurements of three replicates of two fruits each.

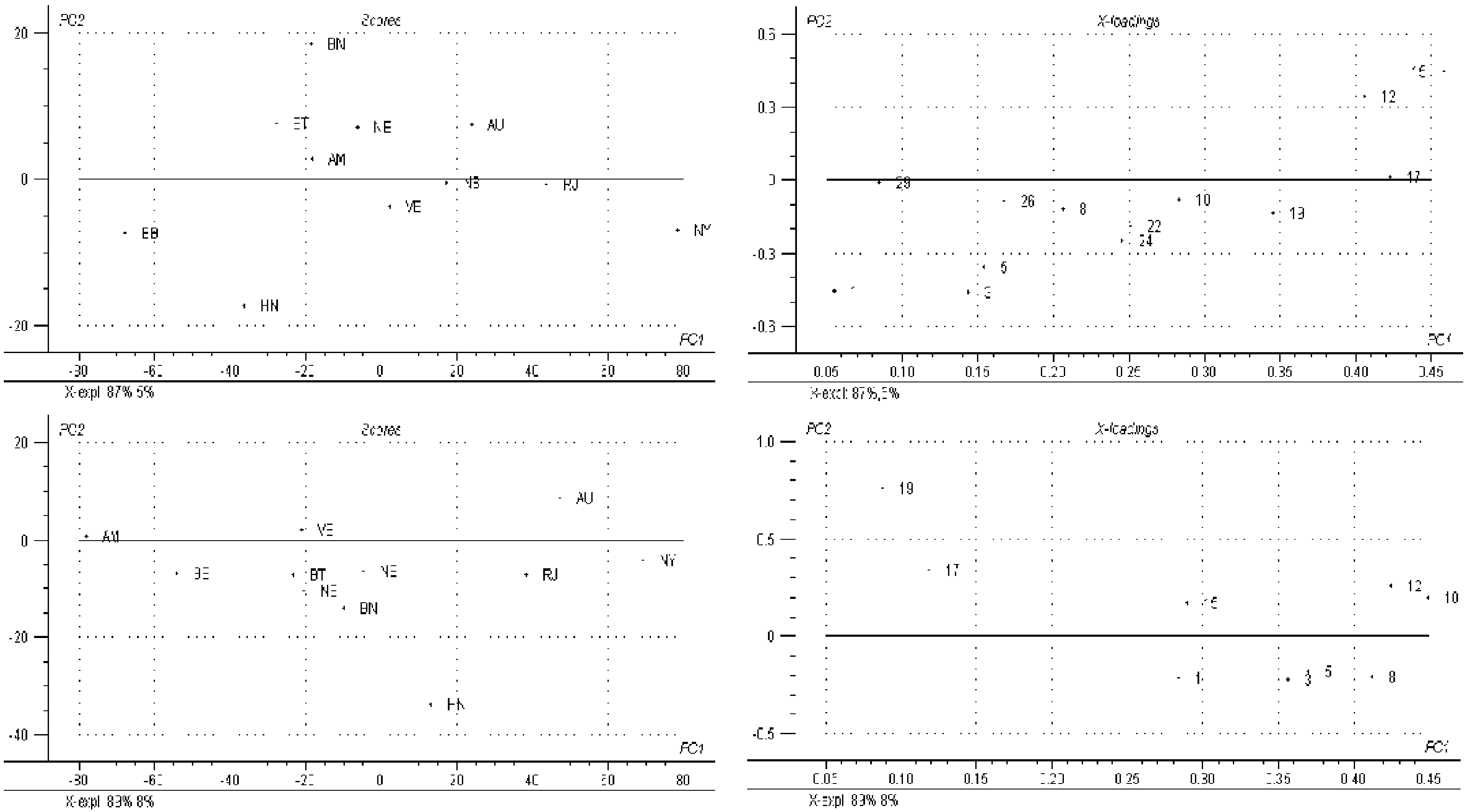

Figure 7.5. PCA model using the data of eleven nectarines at H3·: (A) scores, (B) loadings, and at H5: (C) scores, (D) loadings in 2010. *Abbreviations*: AM, Ambra; AU, August Red; BB, Big Bang; BN, Big Nectared; BT, Big Top; HN, Honey Royale; NE, Nectareine; NS, Nectaross; NY, Nectalady; RJ, Red Jim; VE, Venus.

kept at 10ºC displayed a typical softening behavior, with an initial stage of slow firmness decrease followed by a melting stage. Nevertheless, the number of days along which firmness maintains approximately the harvest value varied strongly depending on harvest date and cultivar.

The PC1 loadings were higher for the firmness values at 15 days after harvest indicating that at this day, the firmness differences between cultivars were maximum (Figure 7.5). This is a general trend in corresponding to harvest dates H1, H2 and H3 over the three seasons. Notice also that the storage days corresponding to the highest loading tended to decrease as the harvest date increased. From 15 days of storage at H1, H2 and H3 to 12 days in H4 and to 8-10 days in H5. This decrease indicated that the longest useful storage time decreases as the harvest date increases, as expected. On the other hand, not all the cultivars showed the same softening pattern across the harvest dates (from H1 to H5) and over the three seasons. However, the general trend was that at the day were the differences between cultivars were maximum, later maturing cultivars such as 'Nectalady' and 'August Red' showed higher mean FF values than early maturing cultivars such as 'Big Bang' and 'Ambra'(Figure 7.5).

7.5. Discussion

Ripening process in peach, as in other crops, implies a loss of FF due to an increase of the activity of cell wall degrading enzymes (Bonghi et al., 1998). Nevertheless this loss of FF has different paces during ripening depending on the cultivar evaluated as the results from this work reported. In addition, the decrease in FF varies according fruit texture (melting flesh, nonmelting and stony hard) (Bassi and Monet, 2008). Among the cultivars evaluated in this study, which they supposed to be melting cultivars, 'Big Top' is the indisputable melting cultivar reference and the most highly valued and widespread cultivar in the Europe (Berra et al., 2011; Iglesias, 2010). 'Big Top' is considered as a separate melting sub-group [melting very firm (Bassi and Monet, 2008)] due to its peculiar softening characteristics, resembling stony hard fruits in firmness and crispness at harvest but melting at a slow pace and developing ethylene (Bassi and Monet, 2008) at full ripening a few days after harvest.

Through the study of the loss of firmness as shown in Figure 7.1, the current work reported that different cultivars showed different ripening behavior compared to 'Big Top' in terms of FF evolution. In particular, late maturing cultivars such as 'Nectalady' and 'August Red' showed lower decrease of FF than 'Big Top' and the rest of cultivars. This behavior was observed for the three seasons. Keeping better fruit firmness either on pre and postharvest is a key point for growers and retailers in a global market, on which cultivars are exported more and more too far countries. At final destination, those cultivars should maintain the quality attributes in order to satisfy consumer demand. On the other hand, the fact that both new and traditional early maturing cultivars showed higher rates of change (b_1) of FF than mid or late maturing cultivars suggested that early cultivars tend to loss firmness over the time faster than mid or late ones. Indeed, both early cultivars, 'Big Bang' and 'Ambra' showed the highest RGR accumulated over the five harvest dates, which could help to explain the highest rates of firmness flesh decrease.

During ripening, peach fruits also suffer a degradation of the chlorophyll content. This degradation is reflected in the I_{AD} decrease (Chalmers and Van den Ende, 1975). Ziosi et al. (2008) reported that I_{AD} is cultivar-specific, probably as a consequence of the natural variability in chlorophyll content among cultivars. Each cultivar has specific I_{AD} values according to the different phases of maturation. Thus, the study of the rates of change (b_1) of I_{AD} obtained over the three seasons has demonstrated that different cultivar behaviors exist during ripening. Indeed, the cultivar effect on FF and I_{AD} can be correlated. A linear regression model to predict FF behavior during ripening based on I_{AD} behavior led to the r^2 values: 0.62, 0.64 and 0.60 for 2009, 2010 and 2011 respectively, suggesting that some cultivars fitted better than others. That is the case of 'Ambra' and 'Big Top' with r^2 of 0.56 and 0.52 respectively.

The ethylene biosynthesis pathway has been studied in detail in peach (reviewed in Ramina et al., 2007). In normal melting peach cultivars an increase in ethylene production is observed during ripening. However, the relationship between ethylene and fruit softening is unclear, because peach fruit softening begins significantly earlier than the increase in ethylene production (Tonutti et al., 1996). In this study, the cultivars 'Big Bang' and 'Ambra', which showed faster loss of FF compared to the other cultivars, showed also a different ethylene emission pattern across harvest dates (Figure 7.4), indicating a poor relationship between ethylene production and fruit softening in this case.

Lurie et al. (2013) reported that there seems to be an inverse relationship between the earliness of the cultivar and softening rate after harvest in peaches and nectarines examined by time-resolved reflectance spectroscopy (TRS) and I_{AD} on logistic models. Nevertheless, in this study the day when flesh firmness differences among cultivars were maximum, which did not differ among seasons but differ among harvest dates, later maturing cultivars such as ‘Nectalady’ and ‘August Red’ showed higher mean FF values than early maturing cultivars such as ‘Big Bang’ and ‘Ambra’ (Figure 7.5). On the other hand, it was no possible to observe different softening behaviors between traditional and new cultivars, due to not all cultivars showed the same softening pattern across the harvest dates and over the three seasons.

7.6. Conclusion

After measuring fruits of 11 cultivars during 3 years it has been demonstrated that different ripening cultivar behavior can be detected by FF and I_{AD} measurements. In addition, this study led us to evidence that early maturing cultivars tend to loss FF faster than mid and late maturing cultivars.

Neither, ethylene production nor I_{AD} could explain the differences in the kinetics of FF. In fact, the relationship between FF and I_{AD} measurements was poorly correlated, suggesting that the destructive method to obtain FF decrease cannot be replaced with the non destructive method used to obtain the I_{AD} index decrease during ripening. Therefore, this work suggested that texture could also play a role in these relationships.

Softening behavior was mainly dependent on maturity season. Early maturing nectarines soften faster than mid and late ones over the five harvest dates evaluated at the day when flesh firmness differences were maximum. Interestingly, softening behavior agreed with ripening behavior in regard with maturity season.

Finally, comparing ‘Big Top’ with the rest of the cultivars evaluated it was observed that other cultivars could loss FF slower in both ripening and postharvest softening.

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Capítulo 8

Discusión General

8.1. Discusión general

Los objetivos de esta tesis han sido la caracterización agronómica (Capítulo 3), el estudio de la sensibilidad a heladas primaverales (Capítulo 4), la evaluación morfológica del fruto (Capítulo 5), la caracterización tanto físico-química, sensorial y nutricional como la capacidad antioxidante y el contenido de antocianinas (Capítulo 6), y la evaluación de la maduración en campo y la pérdida de firmeza en poscosecha (Capítulo 7) de variedades comerciales de melocotón y nectarina. Dichas variedades proceden de la colección de variedades del IRTA-Estación Experimental de Lleida y de fincas comerciales de la zona frutícola de Lleida. Se han utilizado distintas metodologías con el objetivo de aportar distintas herramientas de trabajo, que sean de utilidad tanto para la selección de variedades en un programa de mejora genética y en programas de evaluación de variedades de melocotón, como también a los productores, a los técnicos de campo y a los distribuidores.

8.1.1. Comportamiento agronómico de variedades de melocotón [*Prunus persica* (L.) Batsch], procedentes de distintos programas de mejora genética, en condiciones de clima Mediterráneo.

La evaluación agronómica llevada a cabo en este estudio mostró una amplia variabilidad fenotípica entre el centenar de variedades comerciales de melocotón evaluadas en el IRTA–Estación Experimental de Lleida, en condiciones de cultivo del Valle del Ebro, aunque estudios recientes demostraron un bajo nivel de variabilidad genética existente entre variedades procedentes de programas de mejora de Europa y Estados Unidos (Aranzana y col., 2010; Sansavini y col., 2006). Esto reveló el alto potencial existente para la selección de aquellas variedades con un mejor comportamiento agronómico.

Se observó una relación entre la tipología de fruto y los distintos parámetros agronómicos evaluados, sugiriendo la importancia del estudio de dicha relación en los programas de mejora. Los melocotones mostraron un porcentaje de cuajado, un tamaño y un peso del fruto, una producción y una eficiencia productiva mayores que el resto de las tipologías de fruto, en definitiva una mayor rusticidad. Las nectarinas, en cambio presentaron, junto con los melocotones planos, un período de floración más amplio que el resto de tipologías, y un peso de fruto sin diferir del de las variedades de melocotón. Por otro lado, las pavías (melocotón de carne dura y hueso adherente) presentaron en general un inicio de floración más tardío que el resto de tipologías y los melocotones planos mostraron un mayor número de frutos en el árbol, dando lugar a una mayor carga frutal y a un menor peso del fruto, debido a la existencia de una correlación indirecta entre la carga frutal y el peso del fruto (Acevedo, 1991; Forshey y Elfving, 1977; Reginato y col., 1995). Además, se observó que parámetros agronómicos como el número de frutos por árbol y el peso del fruto podrían ser dependientes del tipo de fruto. Sin embargo, el inicio de floración, el período de floración y la fecha de recolección, resultaron más dependientes de la variedad que de la tipología del fruto.

Aunque no existan referencias anteriores, el estudio de los caracteres agronómicos en función del continente de origen (Estados Unidos y Europa) mostró una visión general sobre la procedencia más conveniente de las variedades cuando estas son cultivadas en la zona del Valle del Ebro. Los melocotones y las nectarinas procedentes de programas de mejora europeos mostraron mejor comportamiento agronómico que los melocotones y nectarinas obtenidos en los Estados Unidos. Los principales objetivos de los programas de mejora de los Estados Unidos difieren de aquellos procedentes de Europa (principalmente de Francia, Italia y España), debido a sus condiciones climáticas y sus necesidades de mercado específicas (Cantín y col., 2006; Llácer y col., 2009; Martínez-Calvo y col., 2006; Okie y col., 2008). Sin embargo, tienen en común no estudiar la adaptabilidad de una variedad en condiciones climáticamente diferentes de dónde ha sido obtenida. Este hecho da a lugar a que el comportamiento agronómico de algunas variedades sea incierto, cuando éstas son cultivadas en condiciones climatológicas diferentes a las de su origen (Berra y col., 2011).

La variabilidad agronómica observada entre los diferentes programas de mejora evaluados por cada tipología de fruto (melocotón, nectarina y melocotón plano), a excepción del pavía, ofrece la posibilidad de la selección de aquel programa de mejora que mejor se adapta a las condiciones climáticas del Valle del Ebro. Sin embargo, dentro de cada programa de mejora y según el carácter agronómico evaluado se observó una gran variabilidad entre variedades. Para ello, el análisis de componentes principales (PCA) nos permitió la simplificación de las variables estudiadas, agrupando las distintas variedades de cada tipología de fruto (melocotón, nectarina y melocotón plano) a excepción del pavía, de acuerdo a los caracteres agronómicos más importantes (eficiencia productiva, carga frutal, peso del fruto, densidad de floración y fecha de recolección comercial). Variedades de melocotón como: 'Sweetbella', 'PG 3/1312', 'Sweetstar', 'IFF 331', 'IFF 962', 'Fullred' y 'Sweet Dream'; de nectarina como: 'Nectatop', 'Nectarlight' y 'Nectafine', todas ellas procedentes de ASF; y variedades de melocotón plano como: 'UFO 4', 'ASF 05-93', 'Pink Ring' y 'Platifun' fueron las más productivas bajo condiciones climáticas del Valle del Ebro.

8.1.2. ¿Cómo afecta la simulación de una helada a las flores de melocotón [*Prunus persica* (L.) Batsch] de variedades procedentes de diferentes programas de mejora genética?

La zona del Valle del Ebro se ve frecuentemente expuesta a heladas durante la época de floración y de cuajado de los frutos. En este trabajo, el estudio del efecto de éstas en distintas variedades de melocotón reveló una relación entre la época de floración y el porcentaje de flores dañadas. Sin embargo, la proporción de flores afectadas por cada síntoma de daño en el pistilo fue similar para las tres épocas de recolección. Las variedades de floración temprana fueron las que presentaron menores porcentajes de flores dañadas, en contradicción con los estudios realizados en campo para la especie *Prunus persica* (Aygün y San, 2005; Okie y col., 1998), y las que menor porcentaje de flores presentaron con todas las partes del pistilo totalmente necrosadas (S4). Los resultados obtenidos para la tipología de flor (*rosacea* o *campanulacea*) concordaron con los referidos por Hilaire y Giauque (2003), quienes demostraron que las flores rosáceas son más resistentes a las bajas temperaturas que las campanuláceas.

Por otro lado, las tipologías de fruto (melocotón, nectarina y melocotón plano) no presentaron diferencias significativas en el porcentaje de flores dañadas, debido a la alta variabilidad encontrada entre variedades de un mismo tipo de fruto. Sin embargo, a excepción del melocotón plano, a medida que el grado de susceptibilidad del pistilo aumentaba mayor era la proporción de flores afectadas.

En algunos de los países de origen de las variedades evaluadas no se producen heladas primaverales y por lo tanto la tolerancia a éstas no ha sido un criterio de selección de la variedad. De ahí, la importancia de su evaluación en función del programa de mejora y de la tipología del fruto. Nuestros resultados no mostraron diferencias significativas para el porcentaje de flores dañadas entre los programas de mejora de melocotón, pero a medida que el grado de susceptibilidad del pistilo aumentaba mayor era la proporción de flores dañadas, siendo ASF el que mayor susceptibilidad presentó, seguido por CRA y Zaiger. En cambio, en nectarinas sí que se observaron diferencias significativas entre los programas de mejora, siendo PSB el que menor susceptibilidad presentó. Al igual que en el melocotón, todos los programas de mejora presentaron una mayor proporción de flores dañadas a medida que el grado de susceptibilidad del pistilo aumentaba.

La temperatura utilizada (-5,5ºC aproximadamente) para el estudio de sensibilidad a heladas de flores de 64 variedades de melocotón, bajo condiciones de laboratorio homogéneas y controladas y a un mismo estadio fenológico (F), mostró una gran variabilidad entre las variedades tanto en el porcentaje de flores dañadas como en el grado de susceptibilidad del pistilo. 'African Bonnigold' de procedencia sudafricana fue la variedad más sensible con un 90,1% de flores dañadas, y 'Rose Diamond' procedente de Estados Unidos fue la más tolerante con un 25,8%. Sin embargo, no todas las variedades mostraron la correlación de mayor susceptibilidad del pistilo mayor proporción de flores dañadas, ni todas las variedades con valores similares de porcentaje de flores dañadas mostraron porcentajes similares en los distintos grados de susceptibilidad del pistilo. Este hecho se puede atribuir, bajo condiciones de laboratorio y de estadio fenológico similar, a que flores de una misma variedad e inclusive de una misma rama mixta frecuentemente pueden presentar distintas respuestas a temperaturas bajas (Miranda y col., 2005). El desarrollo de la flor es un proceso continuo asociado a una progresiva vulnerabilidad del pistilo a bajas temperaturas (Proebsting y Mills, 1961), y el hecho que el desarrollo del pistilo no está estrictamente ligado a los cambios externos de la flor (Mirando y col., 2005). Esto parece apuntar a un atributo interno que hace que algunas flores sean más resistentes que otras (Wisniewski y col., 1997).

El estudio de tres temperaturas letales (LT_{10}, LT_{50} y LT_{90}) en 15 variedades de melocotón mostró que cada variedad puede tener una temperatura letal característica, y que las más sensibles a LT_{10} son las más sensibles a LT_{50} y LT_{90}, pero no siempre las más resistentes a LT_{10} lo son a LT_{50} y LT_{90}, a excepción de 'UFO 8'. Por otro lado y en un análisis de regresión lineal, una mayor resistencia a heladas se traduce en pendientes más bruscas (Miranda y col., 2005). Sin embargo, con el análisis probit, utilizado en este estudio, la pendiente no nos sirvió como un indicador de la tolerancia a heladas. Otros autores (Durner y Gianfagna, 1991; Lasheen y Chaplin, 1971) sugirieron que las diferencias entre variedades podrían ser debidas al contenido en azúcares, proteínas y aminoácidos en la flor. No obstante, y como ensayo preliminar, nuestro análisis de materia seca del pistilo, nos permitió observar diferencias entre variedades, pero no una buena correlación con las LTs, corroborando la importancia del análisis del contenido de azúcares, de proteínas y aminoácidos para cada variedad de melocotón.

8.1.3. Estudio de la diversidad morfológica del fruto y la obtención de un criterio para seleccionar variedades de melocotón [*Prunus persica* (L.) Batsch] de diferentes programas de mejora genética.

Los mercados, y principalmente los consumidores, demandan que los frutos de la especie *Prunus persica* tengan un buen tamaño, que sean homogéneos, sin mugrón y sin suturas protuberantes para evitar pérdidas en el manejo y transporte, y que presenten una piel sin alteraciones (o con poca presencia de lenticelas en el caso de las nectarinas) y con un elevado e intenso porcentaje de color rojo, preferiblemente superior al 80% de la superficie. De hecho, los consumidores asocian la elevada coloración del fruto con una mejor aparencia y calidad (Badenes y col. 2006; Bellini y col. 2004; Byrne y col. 2012; Espada y col., 2009; Iglesias y Echeverría; 2009; Kader 2002; Liverani, 2008; Topp y col. 2008; Wert y col. 2007). Estas necesidades se han convertido en los últimos años en uno de los principales objetivos por parte de los mejoradores genéticos (Bellini y col., 2004; Carbó y Iglesias, 2002; Liverani, 2008; Scorza y Sherman, 1996). Sin embargo, al igual que en el comportamiento agronómico, las condiciones climáticas diferentes a las del lugar de obtención de una variedad de melocotón, influyen en la apariencia del fruto, de ahí la importancia de este estudio.

El estudio de caracteres morfológicos tales como: diámetro del fruto, porcentaje de color rojo en la piel, esfericidad, simetría, altura, prominencia de la sutura y del mugrón, presencia de lenticelas, y adherencia del hueso, y del índice de apariencia (AQI) permitió observar un efecto significativo de la tipología del fruto (melocotón, nectarina, pavía, y melocotón plano) y del origen de la variedad (programa de mejora), dando un idea general de las similitudes y diferencias entre tipologías de fruto y programas de mejora, y cuáles de ellos son los que mejor se adaptan a los requerimientos del mercado, dictados por el Reglamento Europeo (CE) No. 1861/2004, que establece la norma para la comercialización de melocotones y nectarinas.

El análisis de componentes principales (PCA) por cada tipología de fruto permitió agrupar las variedades en función de los caracteres morfológicos evaluados y el índice AQI. Esto dio lugar a la observación de una gran variabilidad morfológica entre las variedades de la especie *Prunus persica*, a pesar de ser genéticamente muy similares (Aranzana y col., 2010). También permitió conocer cuáles de ellas podrían satisfacer o no los requerimientos de los mercados, saber cuáles presentan un mejor o peor índice de apariencia, y agrupar variedades en función de características similares. A título de ejemplo, variedades de nectarina como 'IFF 1882', 'Fire Top' y 'Amiga', y 'Gardeta', 'Nectapi', 'Nectarjune' y 'Nectatop' presentaron mugrón y placas de lenticelas en la piel respectivamente en los dos años de estudio, características no deseables en el mercado y a tener en cuenta en la elección de una variedad por parte de los agricultores.

8.1.4. Capacidad antioxidante, calidad, y contenido de antocianos y nutrientes de diversas variedades de melocotón [*Prunus persica* (L.) Batsch] cultivadas en España

Los resultados obtenidos tras la evaluación de 106 variedades de melocotón han mostrado una gran variabilidad fenotípica para los diferentes parámetros evaluados: calidad (contenido de sólidos solubles y acidez, y relación entre el contenido sólidos solubles y acidez); sensoriales (dulzor, acidez, aroma y valoración global del fruto), nutricionales (contenido de sacarosa, glucosa, fructosa, sorbitol, azúcares totales, ácido málico, ácido cítrico, ácido químico, ácido shikímico, ácidos totales, y poder edulcorante); la capacidad antioxidante (RAC) y el contenido de antocianinas. Todas las variedades presentaron un contenido de azúcares (SSC) mayor a los 8º Brix establecidos por el Reglamento Europeo (CE) No. 1861/2004, que reúne las normas para la comercialización de melocotones y nectarinas. Sin embargo, aunque el SSC esté relacionado con la aceptación y consumo del melocotón por parte del consumidor, no existe un valor específico de SSC que asegure esta satisfacción, ya que ésta también está influenciada por la acidez (TA) (Crisosto y Crisosto, 2005). De ahí, que el RI (relación SSC/TA) sea el parámetro instrumental de calidad que mayor importancia tiene en la aceptación por parte del consumidor de variedades de melocotón, nectarina y ciruelo en frutos maduros (Crisosto y Crisosto, 2005).

La caracterización sensorial permitió describir un gran número de variedades de melocotón en términos de dulzor, acidez y aroma, ya que a día de hoy no se ha encontrado ningún estudio previo con un volumen tan grande de variedades evaluadas. Sin embargo, en lo que a contenido de azúcares individuales, azúcares totales, ácidos orgánicos individuales y ácidos totales se refiere sí que se realizaron estudios previos (Byrne y col., 1991; Cantín y col., 2009b; Colaric y col., 2005; Esti y col., 1997; Robertson y col., 1988; Wills y col., 1983; Wu y col., 2002; Wu y col., 2005). Al igual que nuestros resultados confirmaron que la sacarosa es el azúcar más abundante, seguido por la fructosa, glucosa y sorbitol, el ácido málico es el ácido más abundante, seguido por el ácido quínico, cítrico y trazas de ácido shikímico. Por otra parte, los resultados obtenidos de la capacidad antioxidante estuvieron dentro del rango obtenido por otro estudios realizados en melocotón (Abidi y col., 2011; Cantín y col., 2009a), las variedades que presentaron mayor poder edulcorante fueron las que mayor contenido de fructosa presentaron, ya que la fructosa tiene 1.75 de capacidad edulcorante (Panborn, 1963), y el contenido de antocianos, concretamente contenido de cyanidin-3-glucoside, dependió del porcentaje de pigmentación roja en la pulpa de las variedades evaluadas (Vizotto y col., 2007).

Los programas de mejora pertenecientes a cada tipología de fruto (melocotón, nectarina y melocotón plano) mostraron una gran variabilidad entre ellos en la mayoría de los parámetros evaluados. Dependiendo del parámetro a estudiar, el programa de mejora con mejor comportamiento variaba.

Análogamente ocurrió cuando los diferentes parámetros de calidad (SSC, TA, RI); sensoriales (dulzor, acidez, aroma y valoración global del fruto), nutricionales (contenido de sacarosa, glucosa, fructosa, sorbitol, azúcares totales, ácido málico, ácido cítrico, ácido quínico, ácido shikímico, ácidos totales, y poder edulcorante); la capacidad antioxidante y el contenido de antocianinas, fueron evaluados en función de caracteres pomológicos, como la tipología de fruto (melocotón de pulpa amarilla o blanca, nectarina de pulpa amarilla o blanca, pavía, melocotón plano de pulpa amarilla o blanca); el color de la pulpa (amarilla, amarilla rojiza, blanca, blanca rojiza); la forma del fruto (redondo o plano) y el contenido de acidez (dulce o no dulce). El carácter pomológico con un mejor comportamiento mostraba una variación dependiendo del parámetro evaluado. Sin embargo, cabe destacar que nuestros resultados no confirmaron los resultados obtenidos por otros autores (Cantín y col., 2009b; Robertson y col., 1990; Vizzotto y col., 2007) en cuanto a que las variedades de pulpa blanca presentan una mayor capacidad antioxidante, SSC y un mayor contenido en azúcares individuales y totales que las variedades de pulpa amarilla, o que las variedades dulces presentan mayor contenido de ácido málico que las no dulces (Picha y col., 1989).

Por el contrario, si confirmaron que las variedades de forma plana tienen un mayor contenido de SSC que las redondas (Byrne y col., 2012; Iglesias y Carbó, 2009) y que las variedades dulces difieren de las más ácidas no por el contenido en SSC si no por el contenido de TA, presentando las más ácidas valores de TA 2-3 veces mayor que las dulces (Iglesias y Echeverría, 2009).

En cuanto a las relaciones entre los parámetros evaluados, cabe destacar las relaciones ya descritas por otros autores entre la glucosa y la fructosa (Cantín y col., 2009b; Dirlewanger y col., 1999; Wu y col., 2003), y entre el dulzor y el aroma (Crisosto y col., 2006; López y col., 2011). Sin embargo, este estudio encontró otras relaciones no descritas por estudios anteriores, como la relación del poder edulcorante y la glucosa y el poder edulcorante y la fructosa, así como relaciones inversas a estudios ya realizados como es el caso de la relación negativa entre el acido málico y el ácido quínico, la cual para varios autores fue positiva (Dirlewanger y col., 1999; Esti y col., 1997; Wu y col., 2003), y la alta relación entre SSC y el contenido total de azúcares, contrariamente a la encontrada en estudios anteriores de cítricos y melocotón (Byrne, 1991; Cantín y col., 2009b; Echeverría y Ismail, 1990), debido probablemente a la contribución de otras sustancias ópticamente activas, como pectinas, sales y ácidos orgánicos (Wu y col., 2003). Por otra parte, cabe destacar que aunque se encontró una baja relación entre el RAC y el contenido de antocianos, éste último debe ser tenido en cuenta en futuras selecciones de variedades para así atraer a consumidores debido a sus beneficios para la salud (Byrne y col., 2012; Conte y col, 2010).

El análisis de componentes principales (PCA) permitió la detección de las variables más importantes de entre las estudiadas en el presente trabajo, agrupando las distintas variedades en función de la tipología de fruto (melocotón, nectarina, pavía y melocotón plano) de acuerdo a sus características similares, y seleccionar aquellas variedades que tuvieron un mejor comportamiento cualitativo.

8.1.5. El efecto de la variedad de nectarina [*Prunus persica* (L.) Batsch] en la maduración en campo y en poscosecha.

Este trabajo se basó en el estudio de la maduración del fruto en campo, mediante el estudio del crecimiento relativo del fruto, del porcentaje de color rojo en la piel (SC), del contenido de sólidos solubles (SSC) y del contenido de acidez (TA), la pérdida de firmeza

(FF), la degradación del contenido de clorofila (I_{AD}) y la producción de etileno durante cinco fechas de recolección, y su comportamiento en poscosecha después de 28 días a 10 ºC, de 11 variedades de nectarina cultivadas (6 variedades nuevas y 5 variedades tradicionales) en parcelas comerciales.

La pérdida de firmeza durante el proceso de maduración del fruto implica la degradación de la pared celular por parte de enzimas específicas (Bonghi y col. 1998). Sin embargo, el ritmo de pérdida de ésta varía en función de la variedad y de la textura del fruto (*melting*, *nonmelting* y *stony hard*) (Bassi y Monet, 2008). Entre las variedades estudiadas, que supuestamente tienen una textura *melting,* 'Big Top' es considerada como la variedad de referencia. Se trata de la variedad más valorada por los consumidores y la más producida en Europa (Berra y col., 2011; Iglesias, 2010). Su textura es descrita por varios autores como *melting vey firm*: firme a cosecha, con una ablandamiento lento y una producción de etileno a los pocos días de ser cosechada (Bassi y Monet, 2008). Sin embargo, este estudio encontró variedades que presentaron ratios de pérdida de firmeza inferiores a 'Big Top', como 'Nectalady' y 'August Red'. Por otro lado, cabe destacar que las variedades tempranas, 'Big Bang' y 'Ambra', perdieron más firmeza a lo largo de las cinco fechas de recolección. De hecho, estas dos variedades presentaron un mayor crecimiento relativo acumulado a lo largo de las cinco fechas de recolección comparado con las otras variedades.

Un comportamiento similar a la pérdida de firmeza se encontró en el estudio de la degradación de la clorofila, mediante el estudio del índice I_{AD} a lo largo del proceso de maduración del fruto. El I_{AD} es específico de cada variedad (Ziosi y col., 2008), y cada variedad tiene valores específicos durante las diferentes fases de maduración. No obstante, este estudio demostró diferentes patrones de comportamiento entre las variedades en cuanto a la degradación de clorofila durante la maduración. Esto sugirió que la pérdida de firmeza y de clorofila a lo largo del tiempo podrían estar correlacionados. Sin embargo, un modelo de regresión lineal dio unos coeficientes de correlación inferiores a 0,85, sugiriendo que en todas las variedades no se correlacionaban bien dichos parámetros.

El estudio de la producción de etileno a 48 h a 20 ºC después de cada fecha de recolección y para variedad y año, no ayudó a explicar los diferentes patrones de comportamiento en campo de las distintas variedades. 'Big Bang' y 'Ambra' que mostraron una pérdida más rápida de firmeza a lo largo de las cinco fechas de recolección pero mostraron producciones de etileno muy diferentes.

El comportamiento poscosecha de las variedades se estudió mediante la pérdida de firmeza para las 4 últimas fechas de recolección. Lurie y col. (2013) sugirió que hay una relación inversa entre la época de recolección y su comportamiento poscosecha. No obstante, en este estudio se observó que el día en que el valor de la firmeza de las distintas variedades fue máximo, fueron las variedades tardías como 'Nectalady' y 'August Red' las que valores de firmeza más altos presentaron, y las variedades tempranas ('Big Bang' y 'Ambra') las que presentaron un valor más bajo. Por otro lado, no se observaron diferentes patrones de comportamiento entre las variedades tradicionales y las nuevas, debido a que no todas las variedades mostraron el mismo patrón a lo largo de las cinco fechas de recolección y de los tres años de estudio.

El estudio agronómico, morfológico, de calidad y de conservación del fruto del melocotonero llevado a cabo en la presente Tesis Doctoral mostró la gran variabilidad genética existente en las variedades comerciales de melocotonero procedentes de programas de mejora de todo el mundo. Esto ha permitido conocer cuáles de ellas presentan un buen comportamiento agronómico, morfológico, cualitativo y de conservación, cuando son cultivadas en condiciones climáticas diferentes a las que han sido obtenidas. Por lo tanto, esta información es de gran interés tanto para el sector de la mejora genética, como para el de la producción y el de la comercialización.

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Capítulo 9

Conclusiones

A la vista de los resultados obtenidos en la presente Tesis doctoral, se extraen las siguientes conlcuisones:

1. Se observó una amplia variabilidad fenotípica entre las variedades estudiadas para todos los parámetros evaluados respecto al comportamiento agronómico, a la sensibilidad frente a heladas primaverales, a la morfología del fruto, a la capacidad antioxidante, a la calidad (tanto sensorial como instrumental), al contenido de antocianos y nutrientes, al proceso de maduración en campo y al comportamiento en poscosecha, lo que permitió identificar las variedades que mejor comportamiento tuvieron para cada uno de los parámetros evaluados.

2. Se encontraron diferencias significativas entre los distintos parámetros agronómicos en función de la tipología de fruto (melocotón, nectarina, pavía, y melocotón plano), del país de origen (Europa y Estados Unidos), del programa de mejora y de la variedad. De entre todas las variedades evaluadas, fueron las de melocotonero: ‘PG 2/1312’, ‘IFF 962’, ‘IFF 331’; las de nectarina: ‘Nectatop’, ‘Nectarlight’y ‘Nectafine’; y las de melocotón plano: ‘ASF 05-93’, ‘Platifun’ y ‘Pink Ring’, las que mejor comportamiento agronómico presentaron.

3. El estudio de la sensibilidad frente a heladas bajo condiciones controladas de laboratorio proporcionó una información preliminar de cómo la época de floración (temprana, media, tardía), la tipología del fruto (melocotón, nectarina, melocotón plano) y el programa de mejora contribuyeron a la elevada variabilidad observada entre las variedades, lo cuál podría constituir la base para la búsqueda de marcadores moleculares (QTL y genes asociados) relacionados con la tolerancia de las nuevas variedades frente a las heladas primaverales.

4. El estudio de la morfología del fruto permitó encontrar una influencia de la tipología del fruto, del programa de mejora y de la variedad en cada uno de los caracteres evaluados. El establecimiento de un índice de apariencia permitió puntuar las distintas variedades de una forma rápida, dando mayor o menor ponderación a los distintos caracteres morfológicos en función de los criterios comerciales establecidos por la normativa vigente.

5. Se encontraron diferencias significativas en distintos parámetros de calidad instrumental, sensorial y nutricional del fruto, así como en la capacidad antioxidante y el contenido de antocianos del fruto, en función del programa de mejora y de los caracteres cualitativos, como la tipología de fruto, el color de la pulpa, la forma del fruto y el contenido de ácido málico. La variabilidad encontrada en cada parámetro permitirá la selección de aquellas variedades con perfiles sensoriales, de azúcares, de ácidos orgánicos, de capacidad antioxidante y de contenido de antocianos específicos para fines de mejora genética, y permitirá la obtención de información sobre cuál de estas variedades podrá satisfacer las necesidades del mercado y del consumidor.

6. La evaluación de la maduración en campo y del comportamiento en poscosecha de 11 variedades de nectarina demostró la fuerte influencia de la variedad y de la época de maduración. No se observó una relación clara entre los diferentes comportamientos observados entre las variedades durante la pérdida de firmeza en campo y los diferentes comportamientos observados entre las variedades durante la degradación de clorofila del fruto en campo y la producción de etileno. Por otro lado, las variedades tempranas pedieron la firmeza más rapidamente, tanto en campo como en poscosecha, que las variedades de recolección media o tardía. Tampoco se observó diferentes comportamientos entre las variedades nuevas y tradicionales.

Capítulo 10

Anejo

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Agronomical performance under Mediterranean climatic conditions among peach [*Prunus persica* L. (Batsch)] cultivars originated from different breeding programmes

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ABSTRACT

Nowadays more than 70 active peach breeding programmes are developed around the world, all of them, regardless of country, with their specific objectives. Nevertheless, there is no currently available information comparing different peach cultivars based in their origin in terms of agronomic performance and fruit quality under Mediterranean climatic conditions. For this reason, we evaluated the influence of fruit type, origin (continent and breeding programme) and cultivar on adaptability, production and susceptibility to powdery mildew. A study was carried out on 112 cultivars at the IRTA-Experimental Station of Lleida (Spain) during the 2009 and 2011 seasons in which melting peach cultivars presented better agronomical performance than nectarine, nonmelting peach and flat peach cultivars. Comparing continents, USA versus Europe, in terms of fruit type, melting peach and nectarine cultivars from Europe were best adapted to Mediterranean conditions. According to origin by fruit type, melting peach cultivars from Monteaux-Caillet, ASF, Zaiger and A. Minguzzi showed the best agronomical performance. In the case of nectarine, the ASF, PSB and Bradford breeding programmes provided the most interesting cultivars. The fact that there are only a few breeding programmes for flat peaches makes them all the more interesting to producers. In most of the traits studied important variability among cultivars was recorded, either within the same breeding programme. In spite of these results, the cultivars in each breeding programme were clearly different; this explains why producers tend to adopt the strategy of choosing cultivars from different breeding programmes.

1. Introduction

The peach [*Prunus persica* (L.) Batch.] is the third most important deciduous fruit crop in the world (Llácer et al., 2009c) and the second most important in the European Union (EU), after the apple. Spain is the second larger producer in the EU, after Italy, with 29% of the total production (Europêch, 2011). In Spain, peach production is mainly located in the Mediterranean area, with the Ebro Valley (Catalonia and Aragon) being the most important production area, followed by Murcia, Extremadura and Andalusia (Iglesias and Casals, 2007; Llácer et al., 2009a). Most of these regions are characterized by warm summers and cold winters. In contrast, Andalusia has warm summers and mild winters, and produces only low-chilling cultivars. Spain's climatic diversity allows it to produce a large range of cultivars, ranging from very early harvest (mid-April) to very late harvest (late October) (Llácer et al., 2009b).

The peach is the most dynamic of deciduous fruit species grown in the world. About 100 new peach and nectarine cultivars have been introduced per year over the last 10 years (Badenes et al., 2006; Byrne, 2002, 2005; Fideghelli et al., 1998; Sansavini et al., 2006). For this reason, there are more than 70 active breeding programmes around the world, led by the United States and followed by Europe, and particularly France and Italy, with a smaller percentage in South Africa, Australia, China, Japan, Mexico and Brazil (Byrne, 2002). The new cultivars currently planted in Spain are mainly in the Ebro Valley and have their origins in private programmes such as those of: Zaiger Genetics Inc. and N. & L. Bradford (California, USA) and universities (Davis and Michigan) in the United States; the DCA-Università di Bologna, University of Pisa and University of Florence in Italy; public institutes (such as INRA in France, CRA-Roma and Forlí in Italy); and public or private breeding programmes like CIV, CAV, A. Minguzzi, Martorano in Italy and AgroSelection Fruits (ASF), Europépinières and R. Monteux Caillet-Star Fruits in France (Iglesias et al., 2012). Due to its traditional dependence on foreign peach cultivars, Spain only started its own programmes about 12 years ago. This has involved several breeding

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How does simulated frost treatment affect peach [*Prunus persica* (L.)] flowers of different cultivars from worldwide breeding programmes?

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ABSTRACT

The proportion of frost damaged flowers (FD) and frost symptoms (S1, S2, S3 and S4) was evaluated on 56 peach cultivars from several breeding programmes during 2010 and 2011 seasons in order to understand the tolerance of peach cultivars to low temperature and the susceptibility of their pistils to frost damage. The cultivars were tested at full bloom ('F') under simulated frost treatment. Fifteen of these cultivars were also selected in 2012 to calculate frost temperatures (FT_{10}, FT_{50} and FT_{90}) and their relationship to pistil dry matter. Mid blooming cultivars showed lower tolerances to low temperature than late and early blooming cultivars. Their pistils were also more susceptible to low temperature, showing a higher proportion of more severe symptoms. Blooming time did not affect the degree of pistil susceptibility. Fruit type or peach subspecies (peach, nectarine and flat peach) showed similar susceptibilities to low temperatures; this was not, however, the case for pistils. Significant differences in FD were found for nectarine breeding programmes, but not for peach breeding programmes. The PSB nectarine breeding programme included most of the hardiest cultivars. The susceptibility of pistils to frost damage varied according to breeding programme. Great variability and significant differences were observed between cultivars with regard to FD and frost symptoms. The three frost temperatures considered in this study (FT_{10}, FT_{50} and FT_{90}) corroborated this variability, mainly because significant differences between cultivars were found within each frost temperature. Nevertheless, no significant relationship was found between them and pistil dry matter. These results provide growers with important information to help them when selecting cultivars for new orchards.

1. Introduction

Spain is the second largest peach producer in the European Union (EU), accounting for 29% of total production; it is also the fourth largest producer in the world (FAOSTAT, 2012; Iglesias, 2010). In Spain, peach production is mainly located in the Mediterranean areas, with Catalonia and Aragon being the most important producing areas (Iglesias, 2010). This specie is the main deciduous fruit crop, providing 33% of total fruit production. The climate conditions of the Ebro Valley are characterized by warm and hot summers and cold winters, with the latter being sufficient to cover chilling requirements. The average annual rainfall is 375 mm with peaks in spring and autumn. Nevertheless, the main peach producing areas in Spain, and particularly in the Ebro Valley, are frequently exposed to severe spring frosts during the blooming and fruit set periods (March and April). This climatic event frequently leads to important frost damage injury and can be a limiting factor in terms of obtaining optimal agronomical and economic performance (Kalberer et al., 2006).

Many authors (Osaer et al., 1998; Ballard et al., 1999; Miranda et al., 2005; Proebsting and Mills, 1978) have contributed to the literature on several frost temperatures (FT_{10}, FT_{50} and FT_{90}) for different species of *Prunus*. These FT indexes show the temperatures at which 10%, 50% and 90% of peach flowers are damaged. FTs are commonly used to determine the temperatures at which injury occurs and how many flower buds can survive (Faust, 1989). The temperatures at which fruit buds are injured primarily depend on their stage of development. When buds begin to swell and expand into blossoms, they become less resistant to freeze injury (Miranda et al., 2005). The sequence of the appearance of frost symptoms at full bloom, and therefore the degree of pistil susceptibility (and the severity of damage) is as follows (Royo et al., 1998): the first frost symptoms appear at the base of the style; this is followed by browning on the inside of the ovary, which later progresses from the inside towards the apex and basal zones and then to the other side of the ovary; the next tissue to be affected is the seminal primordium

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Antioxidant Capacity, Quality, and Anthocyanin and Nutrient Contents of Several Peach Cultivars [*Prunus persica* (L.) Batsch] Grown in Spain

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ABSTRACT: Antioxidant capacity, quality, and anthocyanin and nutrient contents of 106 peach cultivars from different breeding programs were evaluated at the Estació Experimental de Lleida, IRTA (Catalonia, Spain), during two growing seasons (2010 and 2011). High variability was found among cultivars within each quality trait, where different cultivars were scored as the best and the worst. For example, a 5-fold range (2.17−12.07 g of malic acid L^{-1}), 6-fold range (144.20−711.73 μg of Trolox g^{-1} of FW), and 11-fold range (0.70−11.43 mg of cyanidin-3-glucoside kg^{-1} of FW) were observed in titratable acidity, relative antioxidant capacity, and anthocyanin content, respectively. The breeding program within each fruit type (melting peach, nectarine, and flat peach) and qualitative pomological traits also had significant effects on the quality. Nevertheless, each breeding program had specific characteristics that distinguished it from the others. Even so, within each breeding program, there is high variability among cultivars. Therefore, growers should not base their strategy exclusively on the choice of breeding program. Principal component analysis for each fruit type (melting peach, nectarine, nonmelting peach, and flat peach) allowed a selection of a set of cultivars from different breeding programs with the highest quality performance. For example, cultivars such as 'Azurite', 'IFF 1230', 'Amiga', 'Fire Top', 'African Bonnigold', 'Ferlot', 'Mesembrine', and 'Platifirst' had higher sweetness and flavor compared to the others. Therefore, this study could help breeders to make decisions for the selection of new cultivars able to improve the quality features of fruit intake, technicians to know better quality performance of peach cultivars, and consumers to meet their expectations for fruit with high health benefits and a specific taste.

KEYWORDS: *Prunus persica, fruit quality, sweetness, sourness, sucrose, malic acid, relative antioxidant capacity, anthocyanin content*

■ INTRODUCTION

Peach [*Prunus persica* (L.) Batsch] is the most important stone fruit crop in Spain, which ranks second in European production, after Italy and followed by Greece and France.[1] Peach is also the most dynamic fruit species in terms of new cultivars released per year.[2] New cultivars originate from more than 70 active breeding programs, which are mainly found in the United States, followed by Europe (Italy and France),[2] and are the sources of many of the cultivars grown in Spain.[3] Sometimes, these cultivars show an uncertain agronomic, and so qualitative, performance when they are grown under climatic conditions that are different from those where they were originally developed.[4−6] Breeders have traditionally selected primarily for external quality (fruit size and appearance),[7] with organoleptic and nutritional traits being a secondary goal.[8−10,2] Today, however, health concern is one of the major driving forces of the world food market, and it is the first or second most important concern of consumers, though this varies regionally. Consumers realize the connection between diet and health and therefore tend to associate their diets with the prevention of cardiovascular disease, vision problems, obesity, arthritis/joint pain, and high cholesterol.[11,12]

Fruits and vegetables are excellent functional foods as they are high in antioxidant and nutritional compounds.[13] These naturally occurring substances not only play an important role in visual appearance (pigmentation and browning) and taste (astringency) but also have health-promoting properties, acting as antioxidants by scavenging harmful free radicals, which are implicated in most degenerative diseases.[14] As a result, there is growing interest in fruit quality and nutritional composition in breeding programs worldwide.[15] Many of them, to improve fruit quality, produce cultivars with excellent taste, high sugar levels, and balanced sugar/acid ratios.[16] Others have directed their interest to the identification and quantification of phenolic compounds in fruit to evaluate their potential health-promoting properties[17] and to develop peaches with high levels of compounds potentially beneficial to human health.[18]

The huge peach cultivar supply and fruit health benefits contrast with the decrease of peach consumption in Spain,[5] as is the case in other western countries (Europe and the United States).[19,20] Poor internal fruit quality, perceived when the fruit is consumed, is the main reason claimed by consumers for declining to buy fresh fruit.[2,5] Internal fruit quality is related mainly to two factors: firmness and flavor. Firmness is essential for postharvest management, marketing, and consumer acceptance. Too soft or too firm flesh has a negative impact on quality attributes.[21] High firmness is a consequence of harvesting

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