Cyprus University of Technology

Faculty of Geotechnical Sciences and Environmental Management

DOCTORAL THESIS

"The effect of canning process on textural properties, sensorial attributes and bioactive content of non-melting peach cultivars"

Author:

Marina Christofi

A thesis submitted in fulfilment of the requirements

for the degree of Doctor of Philosophy

in the

Department of Agricultural Sciences,

Biotechnology and Food Science

September, 2021

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF GEOTECHNICAL SCIENCES AND ENVIRONMENTAL MANAGEMENT

DEPARTMENT OF AGRICULTURAL SCIENCES, BIOTECHNOLOGY AND FOOD SCIENCE

"The effect of canning process on textural properties, sensorial attributes and bioactive content of non-melting peach cultivars"

Author:

Marina Christofi

Supervisor:

Dr. George Manganaris

A thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy
in the
Department of Agricultural Sciences,
Biotechnology and Food Science

September, 2021

Approval Form

Doctoral Thesis

"The effect of canning process on textural properties, sensorial attributes and bioactive content of non-melting peach cultivars"

Presented by

Marina Christofi

Dr. George Manganaris, Associate Professor (Supervisor)
Department of Agricultural Sciences, Biotechnology & Food Science
Cyprus University of Technology
Signature _____

Dr. Francisco A. Tomás Barberán, Research Professor,
Spanish National Research Council (CSIC),
Signature _____

Dr. Magda Krokida, Full Professor
Department of Chemical Engineering, National Technical University of Athens
Signature _____

Cyprus University of Technology
September, 2021

Doctoral Thesis

"The effect of canning process on textural properties, sensorial attributes and bioactive content of non-melting peach cultivars"

Presented by

Marina Christofi

Thesis Advising Committee

Supervisor: Dr. George Manganaris, Associate Professor
Department of Agricultural Sciences, Biotechnology & Food Science
Cyprus University of Technology

Member of the Committee: Dr. Constantinos Biliaderis, Full Professor
School of Agriculture
Aristotle University of Thessaloniki

Member of the Committee: Dr. Vlasios Goulas, Special Teaching Staff
Department of Agricultural Sciences, Biotechnology & Food Science
Cyprus University of Technology

Cyprus University of Technology
September, 2021

Copyrights

DECLARATION

This is to certify that the data presented in this doctoral thesis are the results of an original research work conducted by the author at the Cyprus University of Technology (CUT), unless otherwise indicated. The work contained herein has not been submitted, in whole or in part, to obtain any other degree or professional qualification in this or any other academic institution. Data of this study have been published or submitted in three peer-reviewed journals. In addition, part of the data of the current dissertation have been defended as an oral presentation in a conference, held under the auspices of the European Cooperation in Science and Technology – COST action (CA15136).

Signature: Marina Christofi

PUBLICATIONS

During the course of this PhD degree, data have been published or submitted in peer-reviewed journals which are based on the work presented in this thesis. They are listed here for reference:

1. Christofi, M., Mourtzinos, I., Lazaridou, A., Drogoudi, P., Tsitlakidou, P., Biliaderis, C.G. and Manganaris, G.A., 2021. Elaboration of novel and comprehensive protocols toward determination of textural properties and other sensorial attributes of canning peach fruit. *Journal of Texture Studies*, 52, 228-239.

2. Christofi, M., Mauromoustakos, A., Mourtzinos, I., Lazaridou, A., Drogoudi, P., Theodoulidis, S., Biliaderis, C.G. and Manganaris, G.A., 2021. The effect of genotype and storage on compositional, sensorial and textural attributes of canned fruit from commercially important non-melting peach cultivars. *Journal of Food Composition & Analysis*, 103, 104080.

3. Christofi, M., Pavlou, A., Lantzouraki, D.Z., Tsiaka, T., Myrtsi, E., Zoumpoulakis, P., Haroutounian, S.A., Mauromoustakos, A., Biliaderis, C.G. and Manganaris, G.A., 2021. Profiling phytochemicals in fresh and canned fruit of non-melting peach cultivars: impact of genotype and canning process on their content. *Manuscript under evaluation*

Oral Presentation

1. The impact of genotype and canning process on phenolic and carotenoid composition of eight non-melting peach cultivars reveals varietal differences among fresh and processed products. International Conference on Carotenoid research and applications in agro-food and health, 26-28 November 2019, Lemesos, Cyprus

ACKNOWLEDGEMENTS

The completion of this PhD dissertation could not have been accomplished without the continued support and nurturing of my husband Stavros Panayiotou. Nobody has been more important to me in the pursuit of this PhD than him. His endless patience, generous guidance and encouragement kept me going even in most difficult moments faced throughout all these years.

I would like to thank my esteemed supervisor, Dr. George Manganaris for his invaluable supervision, support and tutelage during the course of my PhD degree. I offer to him my sincere appreciation for the learning opportunities provided me and his continuous motivation on all aspects of this research. Besides my academic advisor, I would like to express my deepest gratitude to Prof. Costas Biliaderis, as a member of my advisory committee, for his treasured support and extensive guidance which was really influential in shaping my experimental procedures and critiquing my results throughout this PhD. My gratitude extends to his research group in Aristotle University of Thessaloniki, particularly to Dr. Athina Lazaridou for her vast and insightful knowledge she conveyed to me especially regarding the elaboration of mechanical and textural protocols, as well as to Dr. Ioannis Mourtzinos for his knowledge and guidance provided me during the development of a comprehensive protocol in sensory analysis of canned peach products.

I am grateful to all of those with whom I have had the opportunity to interact during my mobility grant to Aristotle University of Thessaloniki under the scheme of a 3-

month scientific mission, funded by the COST action (CA15136). I am deeply indebted to Dr. Pavlina Drogoudi for her precious assistance and scientific contribution kindly providing especially in the beginning and during this PhD. I additionally thank Mr. Evangelos Karaindros, an agronomist, for provision of the raw fruit material of the examined cultivars and Mr. Stelios Theodoulidis, CEO of Venus Growers, for providing his technical assistance and support during fruit processing.

I would also like to express my sincere thanks to Dr. Andrea Pavlou for her precious contribution, constructive suggestions and decisive role in the analysis of phytochemicals. My sincere thanks also goes to Dr. Andy Mauromoustakos who kindly assisted me to become acquainted with sophisticated statistical analysis in this dissertation. I very much appreciate the support and the practical advices of Mr. Panagiotis Mousikos.

I must also thank Dr. Panagiotis Zoumpoulakis and his research group members, Dr. Dimitra Lantzouraki and Dr. Thalia Tsiaka as well as Dr. Serkos Haroutounian and his research group members, particularly Mrs. Elena Mirtsi, for providing their knowledge in analytical chemistry and performing the phytochemical analyses using state-of-the-art infrastructure.

Most importantly, I would like to thank and express my forever grateful to my family, for always being there for me when I needed. This dissertation stands as a testament to their unconditional love and patience.

My heartfelt thanks to all!

ABSTRACT

Peach (*Prunus persica* (L.) Batsch) belongs to the Rosaceae family and Amygdyloideae subfamily, grouped under the *Prunus* genus with origin from the Asian continent. It is one of the most important temperate fruit crops worldwide in terms of production volumes. A significant portion of peach fruits are being processed and are being offered as canning product throughout the year. Canned peach fruit is an added-value product, attractive to a different target market than the fresh fruit and facilitate year-round availability. Peach canning industry largely expands its finished products in the global market, having important economic implications for the main peach producing countries. Despite the great economic importance, a limited number of studies have dealt with the assessment of textural properties, compositional and sensorial perception as well as the nutritional profile of peaches destined for canning process.

Fruit of eight clingstone non-melting peach cultivars (cvs. 'Romea', 'Catherina', 'Mirel®', 'Fercluse®', 'Andross', 'Everts', 'Ferlate®', 'VLG') with scalar on-tree ripening, spanning from beginning of July to mid of September, was used as study material for the needs of the current dissertation. Fruits were harvested at commercially maturity stage based on destructive and non-destructive indicators and qualitative attributes, including flesh colour, flesh firmness, soluble solids content and titratable acidity of fresh produce, were determined. Subsequently, lots of fruit with similar maturity indices per cultivar were processed at two filling mediums; the standard (LS, light syrup) and a low-calorie filling medium (GJ, grape juice syrup) to fit with current consumer-market trends. Canned peaches were assessed for their qualitative and textural attributes.

The latter were assessed with the employment of a multipurpose texture analyzer through application of three large deformation assays (Puncture, Texture Profile Analysis, Kramer shearing). Individual organic acids and sugars in the fresh and canned fruit were quantified using liquid chromatography. Sensory quality attributes of canned products were evaluated through the establishment of a customized quantitative descriptive analysis. Total phenolics, total carotenoids and individual bioactive compounds (both in fresh and canned forms) were determined with the employment of UV-vis spectrophotometer and LC-MS/MS, respectively.

The abovementioned protocols were employed in three interrelated, yet complementary, research works. Initially, the aim of the first technical study was dual and included the setting up of a list of sensorial descriptors and the elaboration of an analytical toolkit to evaluate the textural properties of canned peaches using large deformation mechanical analysis. Thereafter, the effect of canning process on compositional, sensorial and textural attributes of fruit of an array of non-melting peach cultivars, packed in LS and GJ syrup was assessed. Such analyses were conducted after 6 and 24 months post-canning. Subsequently, the phytochemical content (carotenoids and phenolic compounds) of the examined cultivars was determined in order to assess the effect of both the genotype and the canning process on the bioactive content of peach fruit.

The objective of the initial study dealt with the setting up of a list of sensorial descriptors and the elaboration of a toolkit to evaluate the textural properties of canned peaches using large deformation mechanical testing. To this aim, a standardized vocabulary ("consensus language") was initially developed towards the determination and

quantification of 15 sensorial attributes through a quantitative descriptive analysis (QDA) approach. Textural properties were additionally evaluated with a TA-XT Plus texture analyzer by applying three discrete large deformation tests [(a) puncture test with a flat cylindrical probe; (b) texture profile analysis (TPA) with a flat compression plunger; and (c) Kramer shear test (KST) cell with a bladed fixture]; that is a total of nine textural properties, namely, "puncture firmness" (individual halves), "Kramer" hardness (applied in a complex mixture of peach slices), "TPA" hardness (central section of halves), fracturability, consistency, cohesiveness, springiness, chewiness, and total hardness. The established protocols, providing complementary information, are readily applicable to the canning industry in setting up qualitative tests to determine product shelf life as well as to assist on going breeding programs for the evaluation of new candidate clingstone cultivars.

Subsequently, the above-mentioned protocols were employed in an array of non-melting peach cultivars. Descriptive quantitative analysis indicated discrete varietal differences, providing useful insights for the industry regarding the quality and marketing potential for canned products of each cultivar. Fruit packed in diluted clarified grape juice concentrate, aiming towards a less caloric content product, demonstrated an inferior consumer perception regarding bitterness, astringency and off-taste. Storage of the canned fruit (6 versus 24 months) led to texture depletion modifications on a cultivar-dependent manner. 'Ferlate®' registered desirable textural properties, while 'Mirel®', besides the appealing orange-coloured fruit pieces, aligned with satisfactory sensorial properties, provide further marketing options for the peach canning industry. Both early ('Romea')

and late season ripening ('VLG') cultivars were proven amenable to canning with acceptable quality attributes, offering a sustainable solution towards extension of the non-melting peach harvesting season. However, their qualitative attributes were inferior of the rest examined cultivars and new genotypes with early or late ripening can be exploited towards the extension of the peach canning campaign.

Lastly, the effect of genotype and canning process on bioactive content was determined. Data showed that the individually quantified phytochemicals as identified in fresh fruit, differ significantly among the examined cultivars. Notably, the widely grown 'Andross' cultivar demonstrated the highest contents. In terms of phytochemical profile upon canning, the use of grape juice as filling medium, a liquid matrix higher in bioactive content compared to sugar syrup, resulted in reduction of the degradation of bioactive compounds, possibly by balancing out diffusion processes between fruit tissue and packing medium. In addition, grape juice also supplies a good source of polyphenols while this is not the case for the sugar-based standard syrup. Overall, the canning process differentially affected individual carotenoids and phenolic compounds. Peach carotenoids and α-tocopherol with the exemption of β-carotene were more stable than phenolic compounds upon thermal treatment and subsequent storage. The sum of zeaxanthin and lutein remained unaffected by the caning process compared to β-carotene. All soluble phenolic compounds, including neochlorogenic acid, chlorogenic acid, procyanidin B1 and catechin, showed a dramatic decrease after the canning process. Oligomeric and polymeric proanthocyanidins, which are relevant phenolics in peach, were not studied in the present project as they were not extracted with the solvents used. Overall, the unique

cellular matrix of each cultivar seems to modulate the degree of loss of bioactive compounds as well as the cellular degradation of the fruit tissues and thereby affecting the diffusion of biochemical components into the liquid media, thus rendering certain cultivars and packing liquids more appropriate for canning.

Results reported herein shed light on largely unexplored areas of research dealing with the canning industry. The established protocols that can be used for determination of sensorial and textural properties of canned peach products can be exploited both by the industry to evaluate a given product and additionally provides to breeders an excellent tool to select new advanced clingstone peach cultivars, amenable to canning with superior properties. Moreover, the proposed analytical toolkit would be valuable to establish appropriate thermal processing protocols aiming at desirable end-product quality characteristics as well as to monitor the shelf life of these processed fruit products. From the nutritional standpoint, the unique cellular matrix of individual peach fruit cultivars seems to modulate the degree of loss of bioactive compounds during the canning process. The present study was focused on those phenolic that could be absorbed in the small intestine and therefore can have direct systemic effects. The analysis of oligomeric and polymeric proanthocyanidins, which are relevant phenolics in peach, should be considered as a future perspective, as they interact with gut microbiota and are relevant (poly)phenols regarding health-promoting effects.

Keywords: *Prunus persica*, clingstone, texture, aroma, firmness, fruit processing, quantitative descriptive analysis, sensory evaluation, texture profile analysis, phenolics, carotenoids, nutrition, canning

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

§	Section
®	Registered
ACN	Acetonitrile
ANOVA	Analysis of Variance
APSI	Atmospheric Pressure Chemical Ionization
ARC	Agricultural Research Council
ATOC	DL-a-tocopherol
BCAR	β-carotene
BHT	Butylated hydroxytoluene
°Brix	Degrees Brix
°C	Celsius
C	Chroma
CA	Controlled atmosphere
ca.	Approximately
CAT	Catechin
CHLA	Chlorogenic acid
CIE	Commission Internationale de l'Éclairage

CO_2	Carbon dioxide
CPT	Critical pitter threshold
CRD	Completely Randomized Design
CU	Chilling units
CV	Coefficient of variation
cv.	Cultivar
DDFT	Department of Deciduous Fruit Trees
ESI	Electrospray Ionization
EU	Europe
FF	Flesh firmness
FRAP	Ferric reducing antioxidant power
FW	Fresh weight
FW	Fresh weight
g	Gram
GAE	Gallic acid equivalents
GDH^{o}C	Growing degree hours Celsius
GJ	Grape juice
ha	Hectare

HPLC	High Performance Liquid Chromatography
HSD	Honest Significant Difference
h^o	Hue angle
i.e.	In other words
INRA	National Institute for Agronomic Research
IPB&GR	Institute of Plant Breeding and Genetic Resources
IPRs	Intellectual property rights
Kg	Kilogram
KST	Kramer shear test
L	Litre
LC/MS	Liquid Chromatography/Mass Spectrometry
LS	Light syrup
m/z	Mass-to-charge ratio
MAFF	Ministry of Agriculture, Forestry and Fisheries of Japan
MeOH	Methanol
MF	Melting flesh
mg	Milligrams
mL	Millilitre

mM	Millimole
mm	Millimetre
MT	Million tonnes
N	Newton
NCHLA	Neochlorogenic acid
NIFTS	NARO Institute of Fruit Tree Science
NIHHS	National Institute of Horticultural and Herbal Science
NMF	Non-melting flesh
O_2	Oxygen
P/6	6 mm diameter probe
P/75	75 mm diameter plunger
PB1	Procyanidin B1
PBRs	Plant breeders rights
PH	pit hardening
QDA	Quantitative descriptive analysis
RI	Ripening Index
SD	Standard deviation
SE	Standard error

SSC	Soluble solids content
T	Thousand
TA	Titratable acidity
TAC	Total antioxidant capacity
TC	Total carotenoid
TE	Trolox equivalents
TPA	Texture profile analysis
TPC	Total phenolic content
TPTZ	2,4,6-tripyridyl-s-triazine
Trolox	6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid
UPOV	International Union for the Protection of New Varieties of Plants
v/v	Volume to volume
VE	Vitamin E
VEAC	Vitamin E acetate
ZELUT	zeaxanthin+lutein

1. Introduction

1.1. Origin and geographical distribution of peach

Peach (*Prunus persica* (L.) Batsch) belongs to the Rosaceae family and Amygdyloideae subfamily, grouped under the *Prunus* genus with origin from the Asian continent. The term *Prunus* has been reported to have derived from the Greek word '*Prounos* or *Proumnos*' (Das et al., 2011). *Prunus persica* is a species of Chinese or Persian origin, having a wide geographic range. Historically, peach was first domesticated and documented in Northwest China, in the region between the Tarim Basin and the north slopes of the Kunlun Shan mountains for more than 3000 years, later introduced into Persia (actual Iran) via the Silk Road and was spread by the Romans throughout Europe more than 2000 years ago.

It was brought to Greece during 400 to 300 BC, where is believed that the 'peach' nomenclature was given by the early Greek and Roman writers (Sturtevant, 1919). Thereafter, the peach was disseminated to other parts of Europe and North Africa where its improvement was initiated. From Europe, the peach was initially reached in North America by the early Spanish and Portuguese explorers from the 16th century (Magness, 1951). The peach was then dispersed to inland and throughout the United States by the Indians, from the tropical highlands of South and Central America, to humid subtropics of Florida and southern Brazil and to the coldest regions in northern USA and southern Canada (Byrne et al., 2012). The next phase of peach introduction in the USA was a direct import from China and England in the mid-1850s, from which emerged the well-known

‘Chinese Cling’ at the Delaware Experimental Station. This cultivar and its seedlings, such as ‘Elberta’, ‘J. H. Hale’, ‘Belle of Georgia’ and their derivatives became one of the main ancestors of the modern cultivars grown in the U.S. and elsewhere in the most important peach-growing countries (Bassi and Monet, 2008, Scorza et al., 1985). Currently, the peach is cultivated and distributed in different regions of the world especially in Northern China (half of world’s total peach production), North America (USA – largest producing states are California, South Carolina and Georgia) and Southern Europe (Italy, Spain, Greece) (Lachkar et al., 2020). As a whole, peach is one of the most important fruit crops in the world that have been expanded and adapted to such diverse climatic and geographic regions.

1.2. Agronomic characteristics

The peach tree is a deciduous, medium sized fruit tree that can reach up to 8 m in height, but under commercial cultivation is usually kept between 3-4 m, with adaptability from cold temperate to tropical zone areas. The lifespan of tree is 25-30 years but in commercial plantings is typically 12-15 years depending on the region, disease resistance, pests and winter damage. This species is well adapted to hot and warm climates with low rainfall and humidity (low frequency of diseases). Fruit production begins in the second year after planting. Peach trees are insect-pollinated and self-fertile; having an impressive blossoming. Flower fertilization from self-pollination is generally high (ranging from 10 to 90 % of fruit set), resulting in a high number of fruitlets (Bassi and Monet, 2008).

Because of that high fertility rate, fruit thinning is required in order for fruit to gain commercial size (Zheng et al., 2014).

Peach is adaptable to temperate and mild climates and it requires high temperatures during the summer to fully develop the fruit and low temperatures during the winter to break the dormancy period. They are intolerant to severe cold and cannot be grown successfully where temperatures normally fall to −23 to −26 °C, but the species do not grow adequately if the winter is too mild. Therefore, a commonly used method is to measure the amount of chilling and/or heat unit requirements. Each cultivar require a specific number of chilling units, spanning from 50 up to 1050 h below 7.5 °C followed by the growing degree hours Celsius (GDHºC) required after endodormancy (chilling accumulates) to start blooming (Fadón et al., 2020). Subsequently, the time of full bloom is highly dependent on these two factors (Eskin, 1991, Citadin et al., 2001).

Peach tree and basic fruit morphological characteristics are illustrated in Figure 1.1A. The trunk is smooth with a reddish-brown bark in the first year, which gains a rougher texture with age. The root system is characterized by dark orange color, extending within 50-60 cm in depth. The plant forms a rounded crown with upwardly-reaching branches dressed with lance shaped, alternate, dark green leaves that are around 8-15 cm long, 1.5-3.5 cm in width, 1.0-1.5 cm petioles, with pinnately veined glands and small stipules (Haleema et al., 2020).

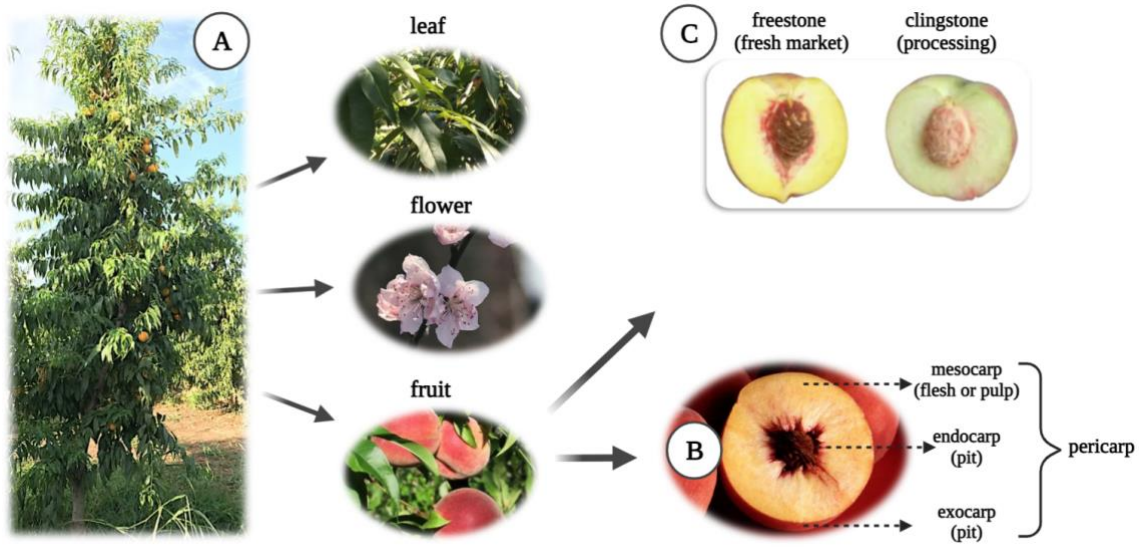


Figure 1.1: Basic illustration of peach tree and fruit characteristics.

The flowering period occurs during mid-spring for about 2 weeks before the vernal leaves develop. Flowers are borne in the leaf axils along the shoots of the previous season's growth. They are 2.5-3 cm in diameter, single or combined, with five petals ranging from pure white to dark red color (Bassi and Monet, 2008). The base of the flower is characterized showy (rose shaped) with large petals or non-showy (bell-shaped) with small petals consisting of five petals, five sepals and three whorls of stamens fused on the hypanthium (Obi et al., 2018).The flowers are vulnerable to damage by late spring frosts.

Peach fruit is referred to as 'stone fruit', characterized by round (globose) or elongated (either oval or more or less oblong) fruit, with the fleshy portion comprising of a single seed surrounded by a pericarp (Figure 1.1B). The pericarp is segregated into three layers: the lignified endocarp (pit or stone) that encloses the seed, the juicy mesocarp consisting of the soft edible region of the fruit, and the thin membranous exocarp (skin)

(Dardick and Callahan, 2014). This species fruit crop is defined as a ‘drupe’, since during its development the endocarp undergoes a hardening process by secondary cell wall formation and lignin deposition (Rodriguez et al., 2019). The weight of fruit varies from small (<110 g) to large (>230 g) and very large (>300 g) size depending on the time of ripening and final use; under commercial standards is commonly from 180 to 230 g (Bassi and Monet, 2008). The seed is red-brown, around 1.3–2.0 cm long, oval in form and is enclosed by a wood-like husk.

Peach is classified as a climacteric fruit due to a dramatic increase of respiration and ethylene production during ripening. The following four distinct stages (S1-S4) describe the on-tree peach fruit development from flowering to ripening: The first stage (S1) which is the fruit set and is characterized by cell division and elongation (first exponential growth phase); pit hardening (S2), when the endocarp hardens to form the stone and scarcely increases the fruit size; pre-climacteric phase (S3), which coincides with the second exponential growth phase, with a resumption of rapid cell division and fruit size enlargement; and the final stage (S4) which is the climacteric stage or fruit ripening, with final cell division, cell expansion, and maturation (Obi et al., 2018, Lombardo et al., 2011). In addition to fruit detachment from the tree, the fruit continues to ripen in an ethylene-dependent manner prior to human consumption.

Peaches that are grown for commercial purposes are distinguished as ‘clingstones’ – pit clings to the flesh and have a non-melting firm flesh, and ‘freestones’ – pit is easily removed from flesh and have a melting flesh texture (Figure 1.1C). Fruit flesh colour may be white, yellow or red and the skin either pubescent or glabrous. There are three major

commercial fruit types: peach (pubescent skin); nectarine (glabrous skin); and canning peach (non-melting flesh) (Bassi and Monet, 2008). The peach cultivars without fuzz are called nectarines (*Prunus persica* var. nectarina). This feature is controlled by a gene with two alleles. The dominant allele G is responsible for the fuzz and recessive allele g is responsible for smooth skin, so nectarines have a gg genotype (Ramming, 1991).

The ripening season in the major production zones of the Northern Hemisphere can range from mid-April to mid-October for freestone peaches destined for fresh market, and late-June to mid-September for clingstone peaches delivered for processing, accordingly to the region, climatic conditions and market opportunities (Byrne et al., 2012).

1.3. Worldwide economic significance

Peach is one of the reference species for *Prunus* due to its high economic value, being one of the most important fruit tree crops in global commerce. The major production sharing zones are Asia (62.3 %), Europe (21.3 %), Americas (11.6 %), followed by Africa (4.3 %) and Oceania (0.5 %). Currently, the total production is estimated at over 25.7 million tons (MT) worldwide. In 2019, the latest data obtained from Food and Agriculture Organization (FAO) showed that the top five individual producing countries of peaches and nectarines in Asia, Europe, America and Africa are as follows:

- **Asia**: vast majority in China (15.8 MT), followed by Turkey (0.6 MT), Iran (0.5 MT), Republic of Korea (0.2 MT) and Uzbekistan (0.18 MT).
- **Europe**: Italy (1.5 MT), Spain (1.2 MT), Greece (0.8 MT), France (0.2 MT) and Serbia (0.07 MT).

- **America**: USA (0.8 MT), Chile (0.3 MT), Argentina (0.2 MT), Brazil (0.18 MT) and Mexico (0.15 MT).
- **Africa**: Egypt (0.35 MT), Algeria (0.2 MT), Morocco (0.15 MT), South Africa (0.14 MT) and Tunisia (0.13 MT).
- **Oceania**: Australia (0.08 MT) and New Zealand (362 T).

According to Food and Agriculture Organization, the world production of peaches and nectarines has been steadily increased in recent years, ranging from 2000 to 2019 periods (Figure 1.2). This increase has been exclusively attributed to the exponential peach fruit production in China. The production was doubled from 13.2 to 25.7 (MT) in 2019 compared to 2000. Similarly, the global cultivation area has shown a steady increase between 2000 (1200 k hectares) and 2019 (1500 k hectares); an evident increase of production per hectare was monitored due to advanced cultivation practices. The top five producing countries for peaches and nectarines are: China, the leading producer country (15.8 MT), followed by Italy (1.5 MT), Spain (1.2 MT), USA (0.8 MT) and Greece (0.8 MT). Other countries that have been added to the top of ten producing countries between 2000 and 2019 are Turkey (0.6 MT), Iran (0.5 MT), Chile (0.3 MT), Egypt (0.3 MT) and France (0.2 MT) (FAOSTAT).

Based on 2019 year, the most cultivated areas of peach fruit in the world is China with 839,000 ha, followed by the European countries (~223,000 ha), Spain with 85,000 ha, Italy with 64,000 ha and Greece with 48,000 ha, and the United States with 36,000 ha (USDA, 2019). In Europe, the production and cultivation are mainly concentrated in Spain, Italy, Greece and France (Mediterranean region), partially due to the lower risk of

frost damage comparing to the countries of the northern Europe (Charrier et al., 2015). However, over the recent years, a substantial decrease of cultivation of peaches destined for the fresh market was monitored in the European continent due to low market value of the commodity.

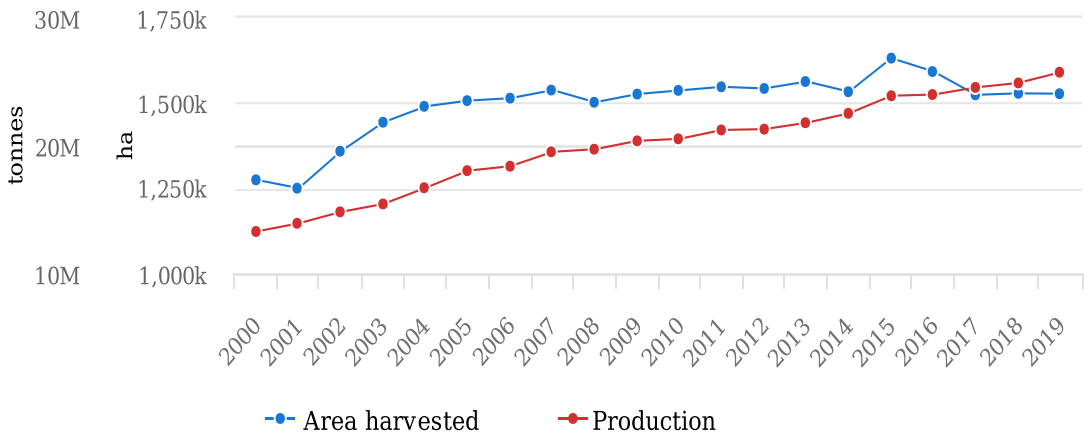


Figure 1.2: World production and area harvested of fresh peaches and nectarines from 2000-2019 (FAOSTAT).

According to FAO statistics, the top five exporting countries in peaches and nectarines in 2019 were: Spain (0.83 MT), Greece (0.16 MT), Italy (0.15 MT), China (0.14 MT) and Turkey (0.10 MT). During 2000-2019 period, the total exports quantities of fresh peaches and nectarines in Europe largely exceeding exports of the other four major production zones, namely Asia, Americas, Africa and Oceania (Figure 1.3). In particular, the total export quantity in 2019 was as follows: World (2.1 MT), Europe (1.3

MT), Asia (0.44 MT), Americas (0.17 MT), Africa (0.07 MT) and Oceania (0.016 MT). In addition to the total exports in Europe in 2000 was 0.9 MT (total export value: 616,596 $) while in 2019 was raised to 1.3 MT (total export value: 1,311,009 $). Potential reason for considerably lower export quantities of the other major production zones might be the internal consumption (domestic fresh market) of this precious product during this period. The world total exports were 2.1 MT (export value: 2,230,058 $) in 2019, doubly increased as compared to 2000 year that was 1.1 MT (export value: 827,314 $). Similarly, the total import quantities of peaches and nectarines follows the same trend as the export quantities, with Europe being dominant compared to the other four zones (FAOSTAT).

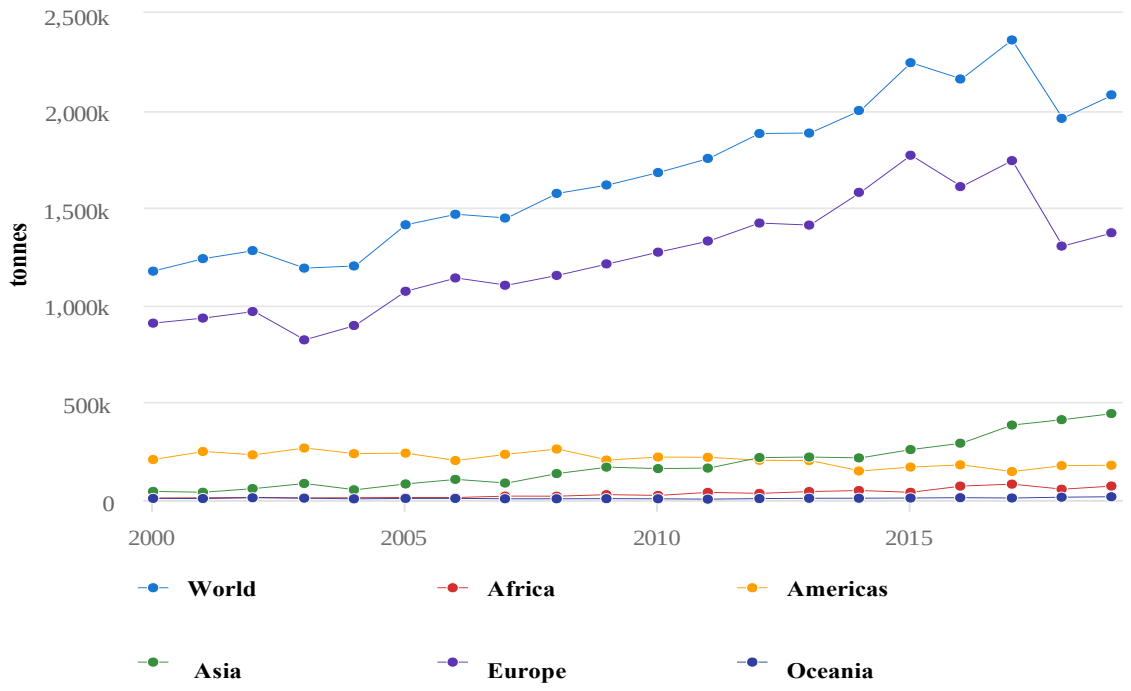


Figure 1.3: World total exports of fresh peaches and nectarines over the period 2000-2019 (FAOSTAT).

1.4. Uses

Peaches are economically essential and they are one of the most popular fruits consumed worldwide. The fruit may have melting or non-melting flesh and varies in flesh colour from white to yellow and orange. The yellow-fleshed peaches are most commonly used in the United States, yellow- and white-fleshed are popular in Europe, while the white-fleshed peaches are very common in Asian countries (Font i Forcada et al., 2014). Apart from eaten as fresh, peach is largely consumed after processing, mainly as canned product. Other products being used as frozen, dried juice and nectars, baby food purees, jams, jellies, pulp for yogurts, soft drinks, liquors on smaller scale. Moreover, the seeds are utilized as rootstocks and the hard endocarp is used as a source of energy (charcoal production). The peach kernel oil is utilized in manufacturing of a large number of cosmetics and pharmaceutical products (Gangwar et al., 2008). The peach flowers are largely used as ornamentals, especially in China and Japan, where it is a symbol of longevity (Byrne et al., 2012).

Due to the short shelf-life period of peach fruit after harvesting, its preservation is an important aspect of the food production and marketing chain. Hence, the processing of peach into canned is extremely developed and consumed in large quantities in many areas. This aspect is the core activity of this thesis and it will be treated in more detail in a later section.

1.5. Worldwide peach cultivation: Brief history of breeding

Peach species exist as diverse genetic lines, and germplasm collections have been established and distributed in different countries particularly in China, Japan, America, Italy, Spain, Greece, France, Turkey, India, and South Africa. A great number of peach cultivars being grown around the world, with particular emphasis on current trends in the industry (market demands). The main objective being pursued in breeding programs of the world is to develop new cultivars better suited to growers' and consumers' demands on the current and future trends. As the programs being evolved, the breeding is working towards the advancement in peach genetics and genomics of certain agronomic traits, the training systems, increased demand for fruit quality and novel fruit types, adaptability and disease resistance, enhanced postharvest performance, as well as the increased awareness of the health benefits of fruit consumption and season extension (Byrne, 2005, Sansavini et al., 2006). The latter, in particular aims to expand production zones into the milder winter zones to allow year-around availability. Notably, ~90 % of available cultivars require more than 800 h of chilling units (CU) in the last 50 years, while nowadays ~80 % of the new ones range from 300-800 h of CU (Sansavini et al., 2006).

Due to the wide variations of peach species exhibited in the market and the increasing industrialisation of peach-related activities globally, granting varietal ownership was begun in order to provide a secure business environment that legally protects and certifies the precise characteristics of a seed under a specific name – 'plant patent'. The patent defined the technological territory of an invention and, therefore, formed the basis of determining infringement, so enabling the inventor to demand

compensation for the use of their invention (Thiele-Wittig and Claus, 2003). Under patent law, an applicant was and still is expected to supply a detailed description of the invention which is being claimed as novel. The inventor is required to disclose the description of the invention so that others skilled in the art may replicate the invention, thus ensuring that knowledge is socially diffused (Tsvakirai, 2017). In 1953, countries agreed to the International Code of Nomenclature of Cultivated Plants which detailed the definition of plant varieties and norms for granting varietal names. Based on this agreement, the International Union for the Protection of New Varieties of Plants (UPOV) Convention developed the *sui generis* system in 1963 which enabled protection of new plant varieties (Tsvakirai, 2017). This form of varietal protection was referred to as 'plant breeders rights' (PBRs) or intellectual property rights (IPRs). The greatest contribution of the PBRs was that they enabled the breeders to have the right to earn royalties by allowing other parties to use their reproduced seed (Tsvakirai, 2017).

In the 20th century, numerous cultivars were developed and released by the peach breeding programmes, mainly by the private sector, of which ~60 % for peaches and ~40 % for nectarines, while the new clings for canning were bred by the public sector (Strada and Fideghelli, 2003). The peach breeding programs were dramatically changed by the substitution of the public breeding to the private sector breeding programs; which now release the majority of the peaches and nectarines in the USA, France and Spain. Currently, almost all regions of the world have their own breeding programs to produce peach cultivars that adapt to a particular region. Therefore, there is no single cultivar,

which is dominant worldwide, or in individual peach-growing countries (Reiger, 2004, Siddiq et al., 2012).

Starting from its origin, China has the longest history of peach cultivation and the greatest richness of genetically diverse germplasm; preserving the largest collections of peach germplasm that were spread and used internationally by various peach breeding research programs to develop commercial cultivars (Byrne et al., 2012). The main peach germplasms groups were established in the late 80s and maintained in three national repositories namely 'Nanjing', 'Zhengzhou', and 'Beijing'. The Nanjing collection represents the southern group, the Zhengzhou collection is focused on the northwest group and the other one in Beijing houses the northern peach germplasm (Ma et al., 2007). The northern and north-western group is characterized by genotypes adapted to cold winters and hot dry summers including the 'Miantao' and 'Mintao' white peach groups (tolerate dry and cold), yellow fleshed peaches and a few nectarines. The southern group is adapted to a humid subtropical to temperate climate and relatively mild winters which are generally white, subacid and include many 'pantao' (flat peaches) cultivars (Byrne et al., 2012).

In general, the national collections hold 2,000 accessions from China and foreign countries, of which ~600 cultivars are local (Li et al., 2013). Besides Chinese national collection species, there are significant national collections in Japan (600 accessions), Korea (300 accessions), the USA (280 accessions), Brazil (732 accessions), Ukraine (~1,500 accessions) and in Europe (over 2,000 accessions) particularly in Spain, Italy and France (Byrne et al., 2012). All these collections are largely composed of commercial

cultivars with some accessions to represent traditional cultivars, rootstocks and wild seedlings.

China possesses considerable number of peach cultivars (>1000 cultivars) with various fruit characteristics, adaptability and marketability, concentrated in different geographic regions. More than 495 registered cultivars and 648 good peach genotypes with detailed information on origin and fruit characteristics were evaluated and developed by the existing germplasm collections of the national repositories to aid peach growers and the local agricultural economy (Huang et al., 2008). In general, the peach production is allocated into regional groups with differences on climate and ecological conditions; mostly in northern, central to eastern and north-western growing regions of China. The five top peach-producing provinces are Shandong, Hebei, Henan, Hubei and Jiangsu; the former three taking up more than 40 % of the share (Huang et al., 2008). Most Chinese cultivars grown for fresh market are white-fleshed and melting type, owning approximately 80 % of the total cultivars in Chinese peach production while non-melting and yellow-fleshed types are mainly used for canning (Zhu et al., 2003, Kant et al., 2018).

The Chinese canning industry breeding flourished in the 1960s with yellow, non-melting clingstone peaches and the development of the predominant cultivars ‘Fenghuang’ and ‘Lianghuang’ for canning peach production in the early 80s (Zuhua et al., 1989). The fresh market breeding programmes began in the 70s with low acid, white-fleshed freestone peaches. The peach production is mainly oriented to the Chinese domestic fresh market with substantial amounts of fresh peach and processed products exported to other countries. The main traditional commercial cultivars widely used in

Chinese peach production includes the northern cultivar ‘Feicheng Tao’ (big fruit size, good transportability, storage quality), ‘Shenzhoushuimi’ (Sheng zhou melting honey), ‘Hanlumi’ (Cold dew honey), ‘Huayumi’ (Flower pure honey) and ‘Baihua’ (White flower) (Huang et al., 2008). The ‘Chinese Cling’ (‘Shanghai Suimitsuto’) has played a key role in the development of new cultivars both domestically (‘Okubo’, ‘Hakuho’, ‘Yuhualu’ and ‘Zhaohui’) and in other peach-producing areas, such as Japan, USA and Europe (Byrne et al., 2012).

Japan is one of the very first countries where peach was commercially cultivated, with formal peach breeding programs starting in 1935 by NARO Institute of Fruit Tree Science (NIFTS) in Tsukuba that resulted in the development of many canning and table-use cultivars such as ‘Chiyohime’ and ‘Akatsuki’; the latter is currently the most widely cultivated table-use peach cultivar in Japan (Sawamura et al., 2017). Most of the peaches that are grown are white-fleshed clings, but there are also yellow-fleshed peaches, such as ‘Ogonto’ and ‘Golden Peach’ that are destined for the fresh market. Most of the Japanese peach cultivars are thought to be originated from offsprings of traditional cultivars like ‘Hakuho’ and ‘Hakuto’. The latter is thought to be synonymous with ‘Chinese Cling’. The ten most important Japanese cultivars in terms of production (% of total production) as reported in an early study in 2003 are as follows: ‘Hakuho’ (20.2 %), ‘Akatsuki’ (12.6 %), ‘Kawanakajima Hakuto’ (9.8 %), ‘Hikawa Hakuho’ (8.0 %), ‘Asama Hakuto’ (5.0 %), ‘Yamane Hakuto’ (3.6 %), ‘Shimizu Hakuto’ (3.6 %), ‘Nagasawa Hakuho’ (3.2 %), ‘Yahata Hakuho’ (3.0 %) and ‘Takei Hakuho’ (2.8 %) (Yamamoto et al., 2003). The Japanese peach production is limited to the temperate zones (31 °N and 41

°N) of the islands Honshu, Shikoku and Kyushu (Sawamura et al., 2017). According to the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) in 2013, there are six regions with the greater cultivated areas (total 9250 ha) including Yamanashi Prefecture (ca. 2930 ha), Fukushima Prefecture (ca. 1740 ha), Nagano Prefecture (ca. 1040 ha), Wakayama Prefecture (ca. 760 ha), Okayama Prefecture (ca. 620 ha), and Yamagata Prefecture (ca. 600 ha) (Sawamura et al., 2017).

America is considered as an important peach producing country and a reference region in terms of the origins of commercial cultivars. The 'Chinese Cling' ('Shanghai Shui Mi') was one of the main introductions from China into the USA (North America) in the middle of eighteenth century which led to the development of modern American cultivars that share a few common ancestors. This seed was initially used to produce the cultivars 'Georgia Belle' and 'Elberta' in the early industries across the USA. Subsequently, a number of peach breeding programs were started in different states in order to develop well adapted peach cultivars based on the climate conditions of each region.

The breeding regions are located in north, south, deep south and west of USA (Okie et al., 2008). The first formal institutional breeding program was established in Geneva, New York in North America in 1895 followed by a number of other states including Illinois (1907), California (1907), Ontario (1911), New Jersey (1914), Virginia (1914), Massachusetts (1918), Maryland and Michigan (in the 1920s), Georgia and Texas (in the 1930s), Louisiana, Florida, and North Carolina (in the 1950s) and Arkansas (in the mid-1960s) (Okie et al., 2008, Byrne et al., 2012). Initially, most cultivars had white-

fleshed with melting texture bred specifically for the fresh market. Subsequently, the yellow-fleshed peaches due to the less bruising characteristic were introduced. Moreover, breeding programmes of melting and non-melting flesh cultivars were initiated in Latin America, including southern Brazil (Pelotas and Sao Paulo areas, in the 1950s) and Mexico (in the 1980s) aiming to supply the fresh and processing outlets (Byrne, 2005). Additional efforts at a lesser extent were taken place from countries such as Chile, Uruguay and Argentina to develop peach cultivars that will be well-adapted under their edaphoclimatic conditions. Since 20th century, the peach breeding programs in US were considerably progressed with new, improved cultivars distributed globally and replaced existing local cultivars.

The major fresh market peach cultivars bred in the north-eastern and south-eastern USA are listed by ripening date and presented in Table 1.1, including the place of origin and release date.

Table 1.1: Major fresh market peach cultivars in the north-eastern and south-eastern USA (Okie et al., 2008).

Cultivar	**Origin**	**Year of release**
North-eastern USA		
'Harrow Diamond'	Ontario	1984
'Harrow Dawn'	Ontario	1996
'Sentry'	USDA-ARS, West Virginia	1980
'Garnet Beauty' (='Redhaven' mutation)	Ontario	1958
'Redhaven'	Michigan AES	1940

‘JohnBoy’ (=‘Loring’ mutation)	New Jersey AES	1988
‘Harrow Beauty’	Ontario	1983
‘Flamin Fury PF17’	Michigan – Friday	1993
‘Bounty’	USDA-ARS, West Virginia	1988
‘Loring’	Missouri AES	1946
‘Flamin Fury PF23’	Michigan – Friday	1993
‘Blake’	New Jersey AES	1953
‘Harcrest’	Ontario	1983
‘Cresthaven’	Michigan AES	1963
‘Jerseyqueen’	New Jersey AES	1964
‘Encore’	New Jersey AES	1980
‘Laurol’ (=‘Jerseyqueen’ mutation)	New Jersey	1992
‘Flamin Fury PF24-007’	Michigan – Friday	1996
‘Redskin’	Maryland AES	1944
South-eastern USA		
‘Springprince’	USDA-ARS, Georgia	1998
‘Sunbrite’	USDA-ARS, Georgia	1976
‘Goldprince’	USDA-ARS, Georgia	1989
‘Rubyprince’	USDA-ARS, Georgia	1997
‘Summerprince’	USDA-ARS, Georgia	1992
‘Juneprince’	USDA-ARS, Georgia	1985
‘GaLa’	USDA, Louisiana	1992
‘Harvester’	Louisiana AES	1973
‘Cary Mac’ (=‘Loring’ mutation)	South Carolina	1976
‘Redglobe’	USDA-ARS, Maryland	1954
‘Majestic’	Louisiana AES	1979
‘Summergold’	USDA-ARS, Georgia	1970
‘Fireprince’	USDA-ARS, Georgia	1985
‘Contender’	North Carolina AES	1987

‘Cresthaven’	Michigan AES	1963
‘Sunprince’	USDA-ARS, Georgia	1981
‘O’Henry’	California – Merrill	1970
‘Flameprince’	USDA-ARS, Georgia	1993
‘Big Red’	USDA-ARS, California	1980
‘Autumnprince’	USDA-ARS, Georgia	1998

USDA-ARS, US Department of Agriculture–Agricultural Research Service; AES, Agricultural Experiment Station.

The United States commercial peach production is distributed across 23 states, with California being the leading peach-producing state, accounting for 73 % of total US production in 2015 (Shuoli et al., 2017). The following states namely South Carolina, Georgia (Southern Atlantic states) and New Jersey are the second, third and fourth top production states, respectively. Approximately 48 % of fresh peaches and 96 % of processed peaches were produced in the above-mentioned states (Shuoli et al., 2017). In the United States, most of the processing peach industry is concentrated in the Central Valley of California where the relatively long and largely rain-free growing season favours high quality and productivity (Gradziel and McCaa, 2008). A large number of non-melting cultivars have been developed to provide the processing plants with a continuous supply of raw fruit (Figure 1.4). The vast majority of California peach production is clingstone type (non-melting flesh trait) peaches delivered for processing, predominately for canning (~75 %) followed by freezing (~17 %), drying (1.5 %) and other uses (Boriss and Brunke, 2006). In the major processing peach production regions, cultivars are developed within or alongside breeding programmes for fresh market fruit

since the genetics and breeding methodologies are identical (Zhang et al., 1990, Layne, 1997). For instance, the University of California at Davis has maintained a processing peach breeding program since the 1980s with the support of the California peach growers and processors. The current objective of the breeding program is to develop improved cultivars for the extra-early and early harvest seasons.

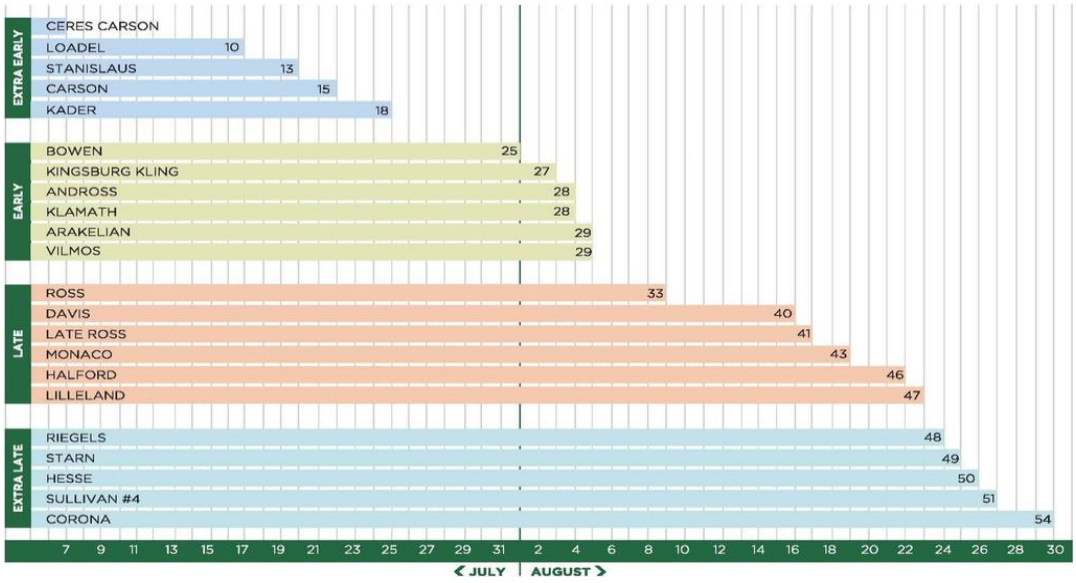


Figure 1.4: Major California processing peach cultivars sorted by relative ripening times. Numbers indicate days to harvest after the initial cultivar 'Ceres Carson' (Source: Gradziel and McCaa, 2008).

Worth noting that the cultivar development in California is mainly driven by private breeding programmes that has led to global work ability improvements and enforce intellectual property rights (IPRs). This is occurred due to reduced funding of government breeding programmes. As a result, the four dominant private breeding programmes in California, namely Zaiger Genetics, Inc., Bradford Genetics, Inc., Burchell Nursery, Inc. and Sun World International, Inc. developed their own revenue

source from strong international programmes linked closely to licensed nursery companies by testing and promoting new cultivars with exclusive rights of tree sales such as ‘cultivar clubs’ and ‘branded’ stone fruit series (Okie et al., 2008).

In Europe, Italy and France are the leading countries in the selection of new cultivars; starting from Italy in the 1920s where the first peach breeding program was initiated followed by France in the 1960s and further programmes in other European countries such as Spain, Greece, Serbia, Ukraine and Poland (Byrne et al., 2012). Most of the European cultivars are closely related to North American cultivars, since much of the initial work was introduced and adapted to the Europe by private and public funded programs. As reported by Badenes et al. (2015), the European breeding programs are hampered by the low intraspecific genetic diversity, which is due to the self-compatibility of this homozygous species along with the low number of genotypes introduced and thus used for breeding.

For most of the 20th century, peach breeding in countries outside the USA was limited (Okie et al., 2008). In many places, cultivars from US breeding programmes were imported to replace local cultivars that were no longer profitable to grow. Through the latter half of the 20th century there was limited breeding in Italy (mainly by A. Morettini in Florence) and France (primarily by R. Monet at Bordeaux), and other countries. Many national breeding programmes have been initiated or expanded since the mid-1980s (Okie et al., 2008). For the beginning of the 21st century, a new peach germplasm collection worldwide was initiated by four research institutions which carried out peach breeding programs in Aragon, Catalonia, Valencia and Murcia, with the aim to extend the peach

genetic diversity available (Badenes et al., 2015). As a result of this initiative, a new database containing 95 accessions and 38 variables is available; being preserved in Zaragoza and Murcia with high and low chilling requirements.

In Italy, the peach cultivation is historically long; being one of the first peach industries began in the world. There are ~2400 accessions in the Italian peach collections of which 20 % are of Italian origin (Okie et al., 2008). Nonetheless, the release of about 200 Italian cultivars pedigrees showed to be inferior than US cultivars, particularly from California (Okie et al., 2008). Based on the exploitation of the local white-fleshed peach germplasm, of which results are 'Aliblanca' and 'Alirosada' (from Forlì), 'Maria Bianca' (from Florence) and 'Rubia' and 'Rubisco' (from Bologna). As the mid-1960s in northern Italy about 50 % of the commercial production was of white-fleshed, local cultivars. Some notable active private breeding programmes are Bubani, CIV nurseries, Minguzzi, Morsiani, Montanari and Ossani, which are located in northern Italy (Emilia-Romagna region) and contributed more than 50 % of the Italian peach introductions in the last 25 years (Okie et al., 2008).

Italy is the largest peach producer and the major exporter in the European zone. The leading destination country is Germany, representing 40 % of its total exports while Spain is the main supplier accounting for ~80 % of total imports (USDA, 2019). Italy can be a good example of cultivar distribution, since its peach production is divided into northern and southern districts with specific climate and soil conditions. Emilia-Romagna and Piedmont in the north and Campania in the south regions account for the 80 % of the total Italian peach production. Other important regions are Sicilia, Puglia, Calabria,

Basilicata, and Veneto. For commercial purposes, there are >150 cultivars, where only 60-80 would really be needed to cover a 4-month season for each peach type (Sansavini et al., 2006). Some of the favoured peach cultivars grown in Italian orchards are 'Fayette', 'Springcrest', 'Royal Glory', 'Redhaven', 'Rich Lady', 'May Crest', 'Summer Rich' and 'Sinphonie'. Among these, cultivars from Italian programmes are 'Springbelle', 'Maria Marta', 'Rosa del West' and 'Rome Star'. Most of the Italian peach crop is destined for the local and national markets.

Since the beginning of the 1960, modern peach breeding was initiated in France with key partners as National Institute for Agronomic Research (INRA), several nurseries and private breeders. Numerous peach cultivars, most of these are white-fleshed, were created and proposed to fruit growers by the end of the 1980s, since French peach orchards were mainly planted with U.S. cultivars (California) (Pascal and Monteux-Caillet, 1998). For instance, partnerships with nurserymen such as J. L. Escande, Euro-pepinieres and A. Maillard, Meynaud Freres, G. Valla, a private peach breeder namely Rene Monteux-Caillet and INRA were implicated to emerge the French obtentions of new cultivars (Okie et al., 2008, Pascal and Monteux-Caillet, 1998). These collaborations led to the development of white peach cultivars such as 'Une de Mai', 'Cristaline', 'Caprice', 'Surprise', 'Elise', 'Opale', and 'Melina' and yellow 'Conquise'. The majority of the peach production is concentrated in Rhône-Alpes, Roussillon, Gard and Crau. Today French cultivars represent about 30 % of the peach industry in France. New INRA releases are nationally distributed by the association of nurseries 'CEP Innovations' (Okie et al., 2008).

Spain has become the biggest producer and exporter characterised by intense innovation and improvement of technology in the last two decades in terms of new cultivars and rootstocks, extending seasonality (early season harvest), training systems and technical advances in irrigations, fertilization, crop protection and postharvest technology (Iglesias, 2013). The Spanish commercial production is mainly concentrated in the Ebro Valley (Catalonia and Aragon), followed by Valencia, Murcia, Andalucía and Extremadura (Iglesias and Echeverría, 2021). Among these areas, there is a great climatic diversity which allows to produce a large range of cultivars, extending the harvesting period from middle of April (very early harvest, Andalucía) to end of October (very late harvest, Catalonia and Aragon). For instance, Andalucía can produce only low chilling cultivars because the region is characterized by warm summers and mild winters (chilling hours range 200-400 h). While a high chilling hours range between 600 and 1100 h at <7 °C is found in Ebro Valley (Llácer et al., 2009).

The Spanish peach industry has traditionally been dependent on foreign peach cultivars coming mainly from USA, France and Italy. The origin of the cultivars produced in Spain is mainly from private programmes such as Zaiger Genetics Inc. and N. & L. Bradford (California, USA) and different universities (Davis and Michigan) in the United States; the DCA-Università di Bologna, University of Pisa and University of Florence in Italy; public institutes (INRA in France, CRA-Roma and Forlí in Italy); and public or private breeding programmes such as CIV, CAV, A. Minguzzi, Martorano in Italy and AgroSelection Fruits (ASF), Europépinières and R. Monteux Caillet-Star Fruits in France (Reig et al., 2013a, Iglesias, 2013). Only recently, Spain initiated its own breeding

programs in the last two decades, allowing well adapted cultivars (in terms of agronomical performance and fruit quality) to the local growing conditions where their selection is carried out. 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.) (Reig et al., 2013a).

Spain is the largest planted area of European countries estimated crop area around 86,000 ha. Most Spanish peaches are delivered for fresh consumption and there is also significant amount destined for fruit processing. Some of the reference peach (yellow flesh) cultivars grown in Spain are those of 'Rich' series from Zaiger's Genetics (USA) as 'Ruby Rich®', 'Summer Rich®', or 'Rich Lady®' and other reference cultivars such as 'Crimson Lady®', 'Elegant Lady®', 'Rome Star®', 'O' Henry®', and 'Tardibelle®' (Iglesias, 2013). Among new cultivars that are widely planted in the last years are 'Sugar Time®', 'Crispbella^{cov}', 'Royal Summer®', 'Extreme Sweet®', 'Sweet Dream^{cov}' and 'Sweet Henry®'. Additionally, few white fleshed peach cultivars are newly available like 'Patty®', 'Fresh White®', 'Maura®', 'Summer Sweet®' and 'Sweetmoon^{cov}'. About clingstone peach, there are few traditional cultivars accompanied by foreign cultivars such as 'Romea^{cov}', 'Catherina®', 'Carson', 'Mountain Gold' and the popular "Baby Gold" series. The undisputed reference of the Spanish industry is 'Big Top®' as yellow flesh nectarine cultivar and the flat peaches (including flat nectarines) which have been developed and added to the market recently. Furthermore, most common peach rootstocks available are INRA®GF-677, which offers broad adaptability followed by Garnem (GxN15) and Cadaman (Iglesias and Echeverría, 2021).

Turkey is another important peach producing country; ranks sixth across the world. The top provinces of peach production are Bursa, Canakkale, Izmir, Aydin, Adana, Mersin, and Marmara region; totalled plantation area is ~46,000 ha (USDA, 2020). The latter was the first region of peach growing since 1960. The first peach breeding study was carried out in the 1990s on a local cultivar namely 'Ustun' (very late ripening cultivar, mid-October), followed by breeding of early and late ripening peach cultivars in Adana during 1995-1999 (Tanriver and Küden, 2003, Kuden et al., 2018). Peach cultivars including 'Early Amber', 'Spring Crest', 'May Crest', 'Red Haven' and 'Early Red' are the most common cultivars planted in Turkey, with the biggest share of 'Redhaven', 'Cresthaven', 'Triogem', and 'Dixired' peach tree cultivars (Engindeniz et al., 2003). Peach is much appreciated fruit by Turkish consumers as fresh or processed as fruit juice and pulp (nectar form) and in canned or drying forms. For instance, cultivars such as 'Lovell' and 'Muit' are used in drying whereas 'Redhaven', 'Fairhaven', 'Kalhaven' are used in deep-freezing (fruit is sold as frozen) (Engindeniz et al., 2003). Germany, Russia, Iraq, Saudi Arabia and Austria are its leading exporting markets.

In India almost all the plantations are located in the north-western areas such as Punjab, Haryana, Uttar Pradesh, Uttarakhand and Himachal Pradesh. The main volume is concentrated between the months April and July and the fruit is generally consumed as fresh or processed (delicious squash and other products); being prepared from the following local cultivars viz. 'Sharbati', 'Shan-e-Punjab', 'Saharanpuri', 'Prabhat' and 'Florda Red', cultivated in the north Indian plains (Gangwar et al., 2008). The Gene bank of NBPGR (Regional Station, Shimla) is actively involved in management and

conservation of *Prunus* genetic resources; possessing 22 indigenous and 27 exotic accessions namely ‘Summer Glo’, ‘NemaGuard’, ‘Candor’, ‘Stark Early Glo’, ‘Flordaball’, ‘Flordasun’, ‘Sunred’, ‘Dixi Red’, ‘C. O. Smith’, ‘Snow Queen’, ‘Peach S-37’, ‘July Elberta’, ‘Fire Prince’, ‘Duke’, ‘Alton Peach’, ‘Ambri’, ‘Okubo’, ‘Kanto 5’, ‘Nishiki’, ‘Luna’ etc (Sharma et al., 2001). The most common cultivars grown in India are ‘Shan-e-Punjab’, ‘July Elberta’, ‘J. H. Hale’, ‘Crawford’s Early’ (locally selected as Paradelux), ‘Red June’ (Elberta selection), ‘Shaharanpur’, ‘Prabhat’ and ‘Flordasun’ (Das et al., 2011, Kant et al., 2018).

The main peach production areas in Pakistan are found in Khyber Pakhtunkhwa, Swat, Baluchistan, including the northern regions of Peshawar, Parachinar, Chitral, Hazara, Quetta, Pashin, Ziarat, Mastung, Skurdu, Hunza and Murree hills. Fruit has traditionally being cultivated in Peshawar and Swat regions, of which ‘Early Grand’, ‘Florida King 6-A and 8-A’, ‘Maria desiza’ and ‘Indian blood’ are the most popular cultivars followed by ‘Golden Early’, ‘Shah Pasand’ and ‘Shireen’ grown in Baluchistan (Habib, 2015). The peach produced is mainly destined to the national market as well as abroad as fresh and processed products. The leading exporting countries are Afghanistan and Gulf countries. The peach production area of District Swat has dropped due to considerable problems faced by peach growers including non-availability of extension field services, lack of irrigation water, lack of cold storage facilities, extra commissions, distant markets, scab disease and fruit fly (Khalil et al., 2014).

Peach breeding in South Africa has historically been emphasized on canning clingstones (non-melting) and low-chill peaches. Subsequently, the efforts were extended

to the fresh market peaches in both melting and non-melting flesh. Since 1937, the breeding programme of Agricultural Research Council (ARC) Infruitec–Nietvoorbij has played a significant role in South Africa's peach industry growth by providing new, well-suited to local conditions cultivars. As a result, almost 100 new cultivars were developed to cater the South African canning industry, dried fruit industry and fresh market, both locally and abroad (Tsvakirai, 2015). The commercial peach production is divided into clingstone and dessert freestone peaches that is largely absorbed from the processing sector (canning and drying), and to a lesser extent sold fresh, respectively (Pieterse, 2011). Most of South Africa's peach production is located in the Western Cape region. Among the dessert (freestone) peach production areas, Ceres is the leading followed by Piketberg, Wolseley, Tulbagh, Northern Province, Klein Karoo, and Free State. The major production area of cling peaches is the Klein Karoo, which accounts almost the half of the production in the country with relatively large volumes coming from Ceres, Wolseley, Tulbagh, the southern Cape and Worcester (National Agriculture, 2012). The main dessert peach cultivars 'Transvalia' (major), 'Witzenberg', 'San Pedro', 'Novadonna', 'Summersun', 'Experimental', 'Fairtime' and 'Excellence'. While the clingstone non-melting peach cultivars included 'Keisie' (major), 'Kakamas' (major), 'Sandvliet', 'Oom Sarel', 'Prof Neethling', 'Cascade', 'Supreme', and 'Prof Malherbe'.

Victoria state account for the 70 % of the total peach production of Australia, largely concentrated in the Goulburn Valley and Sunraysia areas of the state. There is none production in the Northern Territory and the Australian Capital Territory of the Australian states. Most of Australia's peach production is oriented to the processing sector

and domestically to the fresh market (~70 %), with small volumes of fresh produce to be exported in Taiwan, Hong Kong, Singapore, and the United Arab Emirates while more than 50 % of processed fruit is exported to Canada, Japan and Europe (Keogh et al., 2008). The most common cultivars (white and yellow fleshed) are 'Daisy' (white), 'Tasty Zee' (white), 'Pixzee' (yellow), 'Tropic Beauty' (yellow), 'Anzac' (white) and 'Zaiwel' (white).

Brazil and Mexico share similarities in annual preach production as well as in climatological conditions, with main advantage of sharing germplasm information and use. The majority of peach production is concentrated in the semiarid central north regions of Mexico and in the southern states of Rio Grande do Sul and Sao Paulo in Brazil (Pérez-González, 2000). In Brazil, when the peach breeding programmes were initiated in 1950, all cultivars released were public domain opposed to the protection character of new cultivars released by 1997 (Raseira et al., 2013). The first four Brazilian peach cultivars protected were released in 2009 and 2012 by Embrapa Clima Temperado, namely 'BRS Kampai'(white freestone) and 'BRS Libra'(yellow clingstone), and 'BRS Regalo' (white freestone) and 'BRS Fascínio' (white freestone), respectively. Cultivars 'Diamante', 'Magno', 'Br-3' and 'Chiripa' were first introduced to grow in central Mexico from Brazil as major clingstone canning cultivars (Pérez-González, 2000).

The first public breeding program was commenced in 1961 by National Institute of Horticultural and Herbal Science (NIHHS) in Republic of Korea. The white-fleshed cultivar 'Yumyeong' was initially bred and released by the NIHHS in 1977 followed by

10 peach and 4 nectarine cultivars up to date (Jun et al., 2016). Most of peach production is used to be consumed as fresh and the total cultivated area was 16,704 ha in 2015.

Limited information is available concerning peach breeding programmes and cultivation in remaining peach producing countries of the top ten list including Iran, Chile, and Egypt.

1.6. The case of Greece

1.6.1. Importance of peach cultivation

According to the Greek peach industry, the international cultivars played a significant role in the evolution of the peach tree cultivation up to date; mainly those cultivars coming from US are closely related to the local cultivars of the major peach producing countries in Europe. In Greece, the first peach propagation was achieved at the beginning of the 20th century. The Department of Deciduous Fruit Trees (formerly named as the 'Pomology Institute', Naoussa, Greece) belongs to the Institute of Plant Breeding and Genetic Resources (IPB&GR), and contains a large selection of local and mostly of foreign origin cultivars. An earlier programme involved trying to obtain both scion cultivars and rootstocks well adapted to the Greek environmental conditions (spring frost, calcareous soils), with the aim to disease resistance of non-melting peaches (yellow and white fleshed), using local ('Flagar',white), US ('Andross', 'Fortuna') or Japanese ('Akatsuki', white) parents (Okie et al., 2008). A more recent programme was started aiming to enrich and organize the field gene bank collections, create parent plants for the production of

certified propagating material and evaluate, utilize and improve local cultivars including peach tree (Drogoudi, personal communication).

The production of peaches and nectarines is one of the most dynamic sectors of the Greek agricultural zone, since the cultivation area was estimated to 48 % between the deciduous fruit trees (total planted area 99,000 ha) in 2017, respectively; where significant volumes are exported (Figure 1.5).

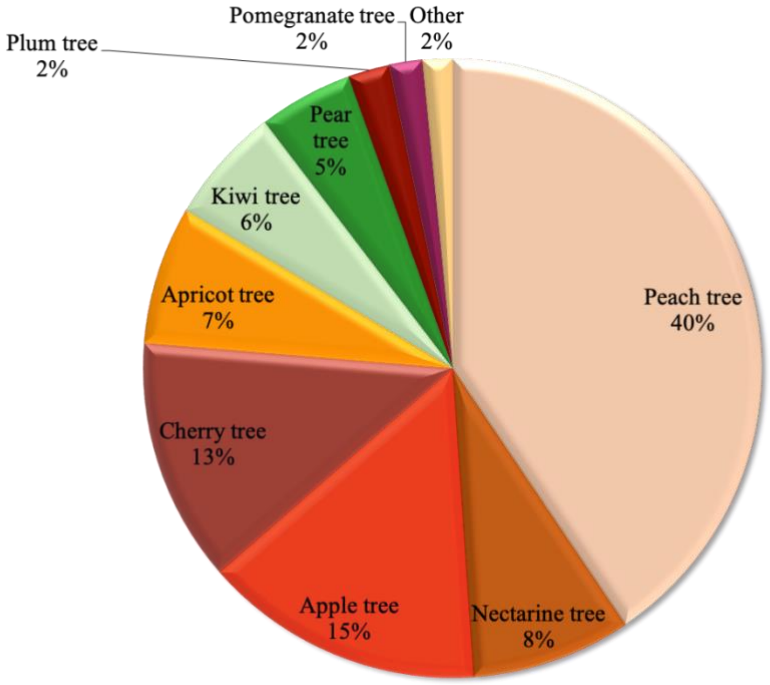


Figure 1.5: Percentage of cultivated area of various deciduous fruit trees grown in Greece in the year 2017 (Source: Hellenic Statistical Authority).

Thirty-three peach cultivars that are currently grown and distributed by local cooperatives were assessed in a recent study and are presented in Table 1.2, including the origin, harvesting time and phenotype of the cultivars. The origin of these cultivars was

from the following countries and breeding programs: USA (51 %), Italy (40 %), Greece (7 %) and France (2 %). During the experimental year 2013 of that study, the climatic conditions were calculated including the chilling hours (0–7.2 °C) was 1442 h, annual precipitation was 591 mm and the average temperature was 16.7 °C (max. 32.4 °C and min. 18.8 °C and precipitation 75.5 mm during summer months) (Drogoudi et al., 2017). In general, the region of Imathia (2nd dominant peach area) is characterized by dry summers and sufficient chilling.

Table 1.2: Origin, year of release, flesh type, flesh colour and harvest date of the peach cultivars grown in Greece (Drogoudi et al., 2017).

Cultivar	**Cultivar abbreviation**	**Origin**	**Year of release**	**Flesh type**	**Flesh colour+**	**Harvest date**
'Alirosada'	AL	Italy	2004	MF	WR	20 July
'Aurelia'	AU	Italy	1983	MF	YR	17 August
'Crest Haven'	CH	USA	-	MF	Y	10 August
'Fayette'	FY	USA	1966	MF	Y	22 August
'Flaminia'	FL	Italy	1983	MF	Y	18 September
'Gladys'	GL	USA	1986	MF	WR	3 September
'June Gold'	JG	USA	1958	MF	YR	26 June
'Maria Bianca'	MB	Italy	1980	MF	W	9 July
'Maria Luisa'	ML	Italy	1980	MF	Y	29 June
'Maria Marta'	MM	Italy	1991	MF	Y	20 July
'Maura'	MA	USA	1997	MF	WR	20 July
'O' Henry'	OH	USA	1968	MF	YR	3 September
'Octavia'	OC	USA	2006	MF	W	17 August
'Patty'	PA	USA	2000	MF	WR	25 June

‘Profiti Ilia’	PI	Greece	-	MF	Y	3 September
‘Rich Lady’	RL	USA	1990	MF	YR	30 June
‘Rome Star’	RS	Italy	1993	MF	Y	26 July
‘Royal Gem’	RGE	USA	1985	MF	Y	18 June
‘Royal Glory’	RGL	USA	1987	MF	Y	4 July
‘Spring Belle’	SB	Italy	1985	MF	Y	12 June
‘Summer Rich’	SR	USA	1989	MF	YR	20 July
‘Sun Crest’	SC	USA	1959	MF	Y	20 July
‘Symphonie’	SY	France	1984	MF	YR	23 July
‘Tardibelle’	TB	Italy	-	MF	Y	18 September
‘Tardired’	TR	Italy	2000	MF	Y	13 September
‘Andross’	AD	USA	1953	NMF	Y	10 August
‘Catherina’	CAT	USA	1970	NMF	Y	19 July
‘Everts’	EV	USA	1962	NMF	Y	31 August
‘Fortuna’	FO	USA	1941	NMF	Y	20 July
‘Loadel’	LO	USA	-	NMF	Y	26 July
‘PI-A37’	A37	Greece	1985	NMF	Y	25 July
‘Andromeda’	IB42	Greece	1985	NMF	Y	15 August
‘Romea’	RO	Italy	1987	NMF	Y	4 July

[+] Y, yellow; YR, yellow red; W, white; WR, white-red.

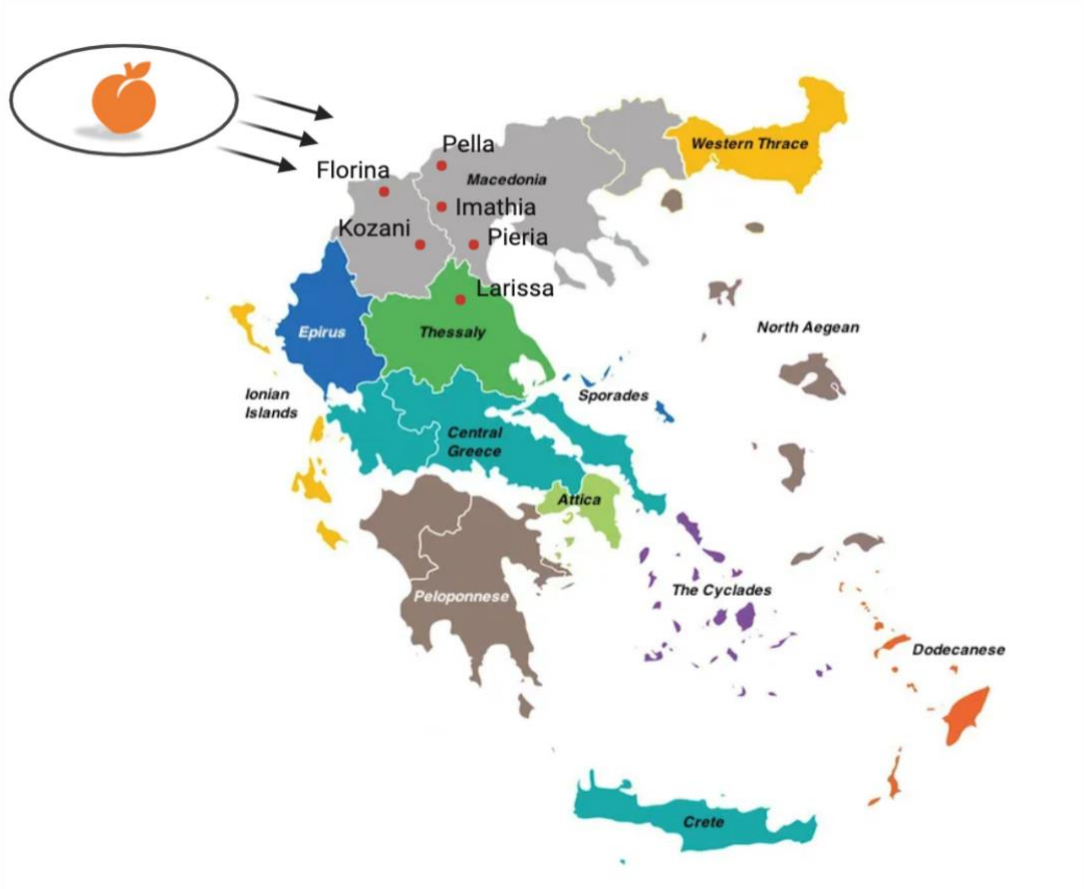


Figure 1.6: The regional map of Greece including the main peach producing areas in the northern Greece (Macedonia and Thessaly).

The total peach production is mainly concentrated in the northern Greece, counties of Pella, Imathia, Pieria, Florina and Kozani of central and west Macedonia, and to a lesser extent in the area of Larissa, in Thessaly (Figure 1.6). The total cultivation area was estimated to 21,000 ha in 2020, with regions of Pella and Imathia producing the greatest volumes (80 %). Despite the fact that peach fruit is consumed as fresh, a significant amount of total peach production is absorbed by the processing sector, mainly as canned product. Peach canning accounts for over 85 % of all processed peach production with

other products being used as frozen and puree (Figure 1.7). Particularly, the value of domestic canned peach production at wholesale prices is estimated at approximately € 240 million in 2018/19 (Source: Greek Canners Association). More than 2/3 of the domestic production of clingstone peach is destined for canning; the canned peach product possesses high exporting orientation. Data of can peach production and exports between the period 2010 to 2020 performed by the Venus Growers (Veria, Greece), a highly reputable peach canning industry, are presented in a tabulated form (Table 1.3).

Greece is the leading EU peach processor, which shares similar cultivars as well as production needs and strategies as California. Peach canning is one of the most popular of all processed fruit, with Greece being the leading country in exports of canned peaches worldwide. The following sections further elaborate on the non-melting clingstone peach cultivars grown in Greece, the peach canning industry and quality determinants of the canning products.

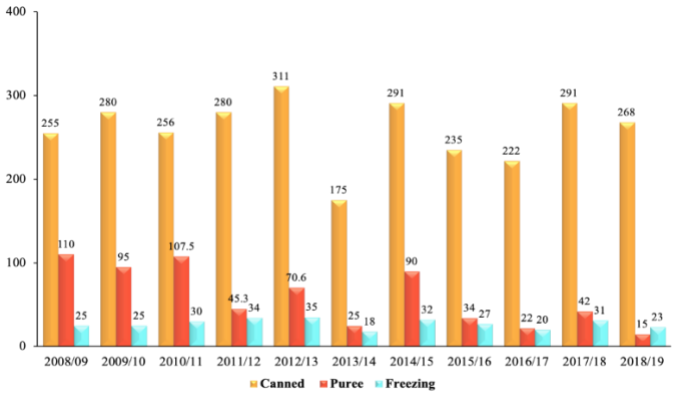


Figure 1.7: Domestic production of clingstone peach during the season period 2008/09 to 2018/19. Processing of clingstone peaches per product category in thousand tonnes (Source: Greek Canners Association).

Table 1.3: anned peach produce, export quantity and export value of the cannery "Venus Growers" (Source: Venus Growers).

Year	Clingstone peach production (tonnes)	Peach canned export (tonnes)	Export value (€)
2010	400.000	274.282	223.866.896
2011	366.000	275.223	224.939.396
2012	440.000	280.490	259.755.014
2013	245.000	259.117	250.463.253
2014	425.000	225.226	231.164.977
2015	302.000	253.211	237.863.623
2016	277.000	228.839	218.686.486
2017	380.000	212.820	198.220.716
2018	316.000	248.782	222.839.191
2019	430.000	260.712	233.373.083
2020	400.000	303.845	274.254.352

1.6.2. Processing peach cultivars

The first cultivars used for canning in Greece were initially ‘Elberta’ and later the ‘Red Haven’, but the final product was of inferior quality due to low flesh firmness. During the period 1980 to 2000 the market was dominated by three cultivars (‘Andross’, ‘Catherina’ and ‘Everts’) that their ripening period was overlapping. Nowadays, towards the expansion of peach campaign destined for processing both early- and late-ripening cultivars were introduced. A breeding program at the Department of Deciduous Fruit Trees resulted in the breeding selections PI-A37, PI-E45 and PI-IB42, which are selected seedlings of the cultivar ‘Andross’. PI-A37 shares after ‘Andross’ the greatest percent of cultivated areas. The main non-melting peach cultivars grown nowadays in Greece are ‘Romea’, ‘Catherina’, ‘Fortuna’, ‘Loadel’, ‘PI-A37’, ‘Andross’, ‘PI-IB42’, ‘Everts’ and

‘PI-E45’ and were documented to exhibit good agronomical characteristics (Drogoudi and Tsipouridis, 2007). More recently, newly released of clingstone peach cultivars, some of which are patent cultivars, including ‘Mirel®’, ‘Fercluse®’, ‘Fergold®’, ‘Ferlate®’ and ‘VLG’ were introduced to overlap the harvesting period and their agronomical characteristics are under evaluation. In general, the total production of non-melting peach cultivars is geographically allocated to the counties of Pella (57 %), Imathia (38 %), Florina (3 %) and Larissa (2 %).

In 2020, the cultivated area of clingstone peaches was estimated to 19,257 ha. According to the data of the ‘Association of Imathias Agricultural Cooperatives’, the non-melting peach cultivars currently grown in Greece and the cultivated area (ha) per cultivar are presented in Table 1.4.

Table 1.4: Processing peach cultivars cultivated in Greece in 2020 (Source: Association of Imathias Agricultural Cooperatives, president Mr. Giannakakis)

Cultivar	**Area harvested (ha)**
‘A37’	193.59
‘Andross’	7500.94
‘Baby Gold No.5’	0.3
‘Bowen’	15.07
‘California’	70.49
‘Carolina’	1.36
‘Carson’	6.63
‘Catherina’	4740.86
‘Club’	1.12
‘Dixon’	0.86
‘Everts’	2458.32
‘Fercluse’	480.13
‘Fergold’	101.08
‘Ferlate’	18.03
‘Fortuna’	426.97
‘Golden Queen’	0.57
‘Halford’	2.52
Loadel’	336.76
‘Marlen’	0.37
‘Merriam’	22.44
‘Mirel’	2.45
‘Okubo’	2.32
‘PI-A37’	2314.77
‘PI-IB42’	133.65
‘PRO 443’ (Jalon)	13.08
‘PRO 570’	6.37
‘PRO C 105’ (Yuste)	13.3

‘PRO C 182’ (Leyre)	34.85
‘PRO C 220’ (Poblet)	48.09
‘PRO C 236’ (Veruela)	31.19
‘PRO C 84’ (Guadalupe)	25.54
‘Punto IT’	3.66
‘Romea’	192.18
‘Starn’	55.27
‘Vivian’	0.98
Total	19256.47

Nowadays, cultivation of cultivars with different maturation time is required in order to extend the harvesting period and supply the industry with fruit for longer. For instance, some important non-melting clingstone cultivars commercially used in Greece and exhibited on-tree ripening in succession over a period spanning from July until mid-September are presented in Figure 1.8 (indicative harvesting period per cultivar is provided). ‘Romea’ is the earliest producing processing peach cultivar grown in Greece and its yield is relatively lower compared with the late-ripening cultivars. ‘Catherina’ is a high yield cultivar with good fruit quality. It is the most favoured cultivar by growers due to its stable production under unfavourable climatic conditions (i.e. spring frost or rain during flowering). ‘Mirel’ is a patented mid-ripening cultivar, recently released from France which is characterised by high production volumes, good fruit quality and good fruit holding ability. ‘Fercluse’ is a mid-season patented cultivar with a more orange coloured fruit flesh. ‘Andross’ is considered as a reference processing peach cultivar cultivated in Greece for decades in appreciably high production volumes. It is a mid-

ripening cultivar, with the highest production volumes compared to others non-melting cultivars. ‘Everts’ is a late-ripening cultivar with yellow coloured fruit flesh. ‘Ferlate’ is a late-ripening patented French cultivar also characterised by orange-coloured flesh. ‘VLG’ is late-ripening (mid-September) cultivar with unknown origin, characterized by satisfactorily production that can potentially offer the option to extend the canning season. The quality characteristics of these cultivars at harvest and after canning process are being further examined in this dissertation.

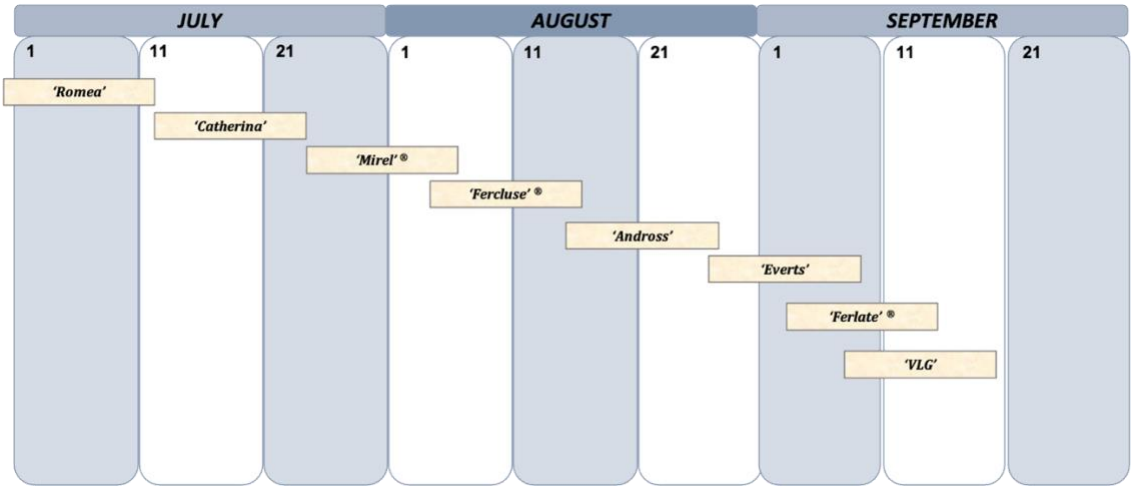


Figure 1.8: The chart maturity of some selected cultivars with scalar ripening (spanning from beginning of July to mid of September) corresponding to the current growing season in Greece.

1.6.3. Overall peach quality characteristics at harvest

As the peach matures, marked changes in terms of its quality attributes and nutritional value including soluble solids content (SSC), acidity, colour, and firmness. All these quality indexes can be determined by chemical analyses, since the major compounds are sucrose, malic and citric acids, carotenoids, polyphenols, and pectic substances. The

physiological maturity of peach at harvest greatly influences its postharvest quality (shelf-life, sensory quality, handling, transportation, processing, marketing). The proper harvest date is difficult to define, which is may vary according to the cultivar and region, yet is interrelated to easily applied aforementioned organoleptic characteristics. The different quality traits of peach fruit have been extensively studied (single and combined) and some indicative levels of its chemical components are presented in the following paragraph.

Sugar content is estimated by the soluble solids content (SSC) in degrees Brix and the acid content from titratable acidity (TA); where the levels in peach found to be 9.2-19.83 ºBrix and 0.13-1.16 %, respectively (Font i Forcada et al., 2014, Reig et al., 2013b, Byrne et al., 1991, Belisle et al., 2018). The use of the sugar/acid ratio is a good indicator of maturity (ripening index, RI) and is assessed by the SSC and TA (Selli and Bassi, 1990). Higher ratios are usually preferred; exhibiting in families with the highest SSC (Cantín et al., 2010). Furthermore, total sugars/organic acids ratio, as calculated between analysed total sugars (the relative content of each individual sugar) and total organic acids (content of specific acid), has been positively correlated to sensory perception of sweetness (Colaric et al., 2005).

A commercial standard in terms of fruit firmness was set by EU at 63.7 N (maximum levels) using the typical 8mm diameter probe (Commission Regulation (EC) No. 1861/2004). According to Crisosto et al. (2001), firmness thresholds indicating critical changes during postharvest ripening and susceptibility to bruising damage were set as fruit “ready to buy” (18-35 N) and “mature and immature” (35 N threshold).

Another important quality index is colour which is mainly indicated by the loss of chlorophyll, the synthesis of new pigments such as carotenoids and/or anthocyanins, and among other pigments during the development of the fruit (Ferrer et al., 2005). A recent study of 94 peaches and nectarines showed that the flesh colour parameters (L*, a*, b*, Chroma, hue angle) varied greatly, between 10.6 and 76.8 (L*), −1.18 to 60.8 (a*), −8.9 to 69.1 (b*), 25.3 to 80.6 (Chroma) and 16.9 to 91.4 (hue angle) (Font i Forcada et al., 2014). For instance, when the values of Chroma are high and the values of a* are increasing, then the fruit is high in anthocyanins content while the levels of chlorophyll/carotenoids are low (Ferrer et al., 2005).

In addition to the size of the fruit destined for fresh market should be large (AA or A size, where size codes range from D at 56–60 mm to AAA at 80–89 mm) (Okie et al., 2008). In general, there are destructive (SSC, TA and flesh firmness) and/or non-destructive (skin colour and fruit size) measurements of peach quality (maturity) indexes for commercial purposes.

1.7. The peach canning industry

1.7.1. Harvest operation and storage

Most peaches utilized for canning are clingstone types that in almost all cases are characterized by a non-melting character. While the clingstone trait represents a hazard for processed fruit because of the greater likelihood of pit fragments being retained in the processed product, it is associated with firm, non-melting flesh that is required for surviving the rigors of bulk transport and processing. The firmer, non-melting flesh also

allows clingstone peaches to be field harvested and canned when there are near their optimal ripeness with full size and optimal colour and flavour. As a general rule, the optimum maturity of peaches for canning purposes is when the fruit is yellow-coloured and not too soft (Siddiq et al., 2012). Peaches are mainly hand-picked or alternatively they can be mechanically harvested, using a shaker and a catching frame system. Following the initial field sorting of green, undersized or damaged fruit, bins are loaded on to trucks and transported to the processor. Prior to processing, the fruit are first washed and sorted by size.

To be successful, a cultivar must be compatible with the nuances of every component of the processing pathway. The pitting operation typically involves cutting the fruit along the suture and then application of a torque load to twist the peach halves from the pit, requiring good mesocarp firmness. A critical requirement for processing peach is the ability to maintain a tree-ripe flesh firmness of 30 N or greater through harvest, transport, and processing. If fruit become too soft, they are easily bruised when bulk-handled with additional losses occurring during the pitting and peeling operations. In addition, overly soft flesh may disintegrate during thermal processing. Consequently, high levels of fruit loss can occur during harvesting and processing. While harvesting the fruit at the fully-ripe stage increases the damage from soft fruit, it maximizes crop yield as well as fruit color, sugar content and flavour (Gradziel and McCaa, 2008).

Often, peaches are stored prior to canning process in order to provide more uniform availability of raw product to the processing plants. Storage conditions that maximize postharvest life and protect from fruit browning and decay development are

similar to the ones used for fresh peaches. In certain cases, an even longer pre-canning storage time may be required. Some benefits have been reported on the use of controlled atmosphere (CA) technology (2 % O_2 and 5 % CO_2) at 1.1 °C (Couvillon and Krewer, 2018). This treatment can maintain higher flesh firmness retention and retard decay more effectively than air storage. However, CA storage of fruits picked at the optimum maturity stage produced little benefit over air storage, except for conditions of high disease pressure.

1.7.2. The canning process

The most common method of preserving peach which is highly perishable fruit, is canning. Canned peaches include canned yellow clingstone peaches, canned spiced yellow clingstone peaches, canned solid-pack yellow clingstone peaches, and canned artificially sweetened yellow clingstone peaches (Siddiq et al., 2012). Accordingly, the canned peaches can be sold in many styles, such as halves, quarters, slices, diced or mixed pieces of irregular sizes. The two major forms of canned peach products are in halves and slices. While the final product and even method of preparation may vary, most processing involves a common sequence of basic events. The canning process is schematically depicted in Figure 1.9, as recently described (Christofi et al., 2021a, Christofi et al., 2021b).

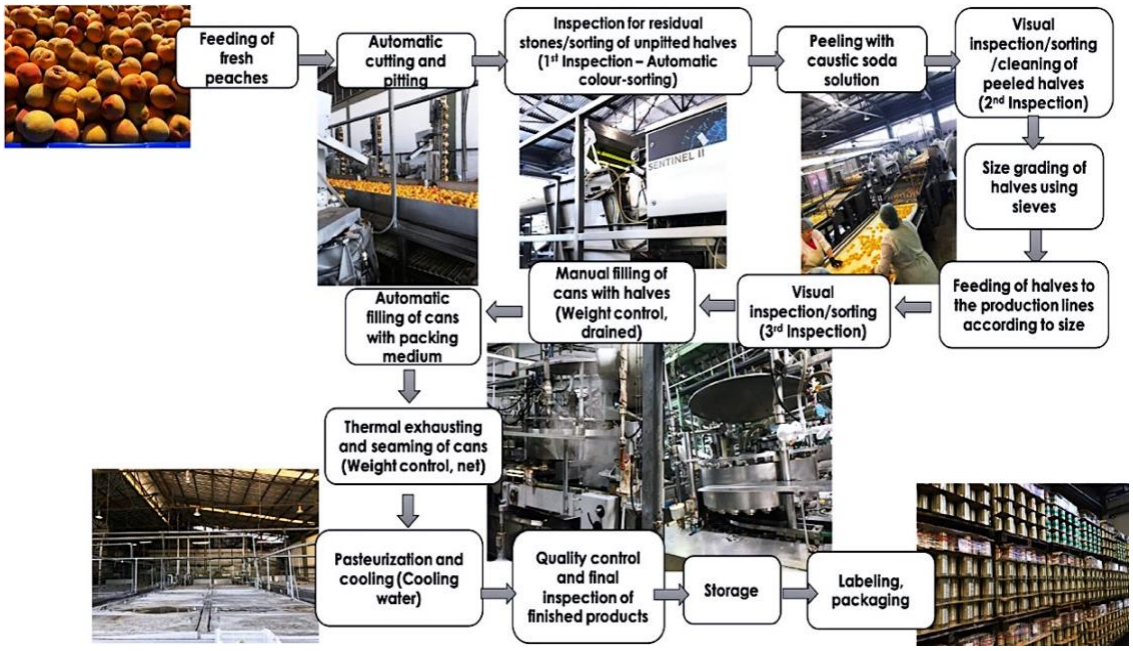


Figure 1.9: Schematic illustration of processing steps for canning of peaches at Venus Growers premises (Veria, Central Macedonia, Greece).

The peach production line is fully automated and consists of in-line equipment. The following steps for canning peaches are in a shape-specific manner of a regular manufacturing process at the premises of the Venus Growers Cooperative Unit:

- *Grading*: Fresh peaches are mechanically graded according to their size since their arrival at the cannery (wide range of sizes from field).

- *Halving and pitting*: Fresh peaches are fed in the production line where they are halving and pitting using automatic machines.

- *Peeling and washing*: The peach halves are lye-peeled with a caustic soda solution by spray method. Conditions such as contact time, strength and temperature of the lye (soda) solution depend on the maturity of the fruit. The whole procedure of peeling and

washing of clingstone peaches is standardized and follows all the recommended quality control measures determined by the fruit processing firm (Venus Growers).

- *Quality grading and sorting*: Quality grading involves the following protocol:
    - 1st Inspection for residual stones and sorting of unpitted halves using an automatic color sorting system – Colour grading
    - 2nd Visual inspection and sorting for defects of the peeled halves followed by size grading of halves using sieves – Size grading
    - 3rd Visual inspection/sorting of halves cup down/cup up prior to filling of cans with the peach halves manually and addition of the filling medium – Final quality grading. The fruit which is not canned as halves goes directly to the slicing machine.

- *Filling and syruping*: The graded halves are hand-packed to the tins (metal cans) and the weight is controlled followed by the addition of enough packing medium to fill the interstitial spaces, with the aid of an automatic vacuum filler (rotary syruper). Canned fruit is generally packed based on specified cut-out Brix concentrations including heavy syrup (18-22 °Brix), or light syrup (14-16 °Brix), or diluted clarified concentrated fruit juice such as grape juice (low calorie pack: 11-13 °Brix and presence of phenolics).

- *Exhausting and closing*: The filled cans are then thermally exhausted and introduced in an automatic closing machine for seaming. The final weight is controlled.

- *Processing and cooling*: The hermetically sealed cans are pasteurized in boiling water (97-98 °C, 22 min), using a rotary or horizontal line pasteurizer that allows rolling

of the can. The key parameter of pasteurization is the achievement of core temperature > 85 °C for 5 min (the temperature inside the cans must reach 91-92 °C during the pasteurization). Thereafter, the canned products are cooled down by cold water spraying for 10 min (~ 40-42 °C), to bring the cans to room temperature (25-30 °C).

- Quality control and final inspection of finished products are carried out, followed by storage and labelling/packaging. A minimum of six-month storage is typically employed to achieve osmotic and so quality equilibrium among all components present within the cans.

1.8. Quality attributes of canning products

1.8.1. Overall canning peach quality parameters

Appearance (colour and freedom from defects), texture, and flavour are the important quality attributes of canned peaches. Bright yellow colour with no red coloration in the pit cavity, firm texture, and a good flavour are desired. Peaches with fruit sizes larger than 60 mm (55-75 mm, size A and 2A) and yellow gold fruit flesh our most desirable, but the fruit pit cavity should not develop a pink to red colour from the formation of red anthocyanins (Gradzie and Thorpe, 2010). Anthocyanins are very labile and subject to browning in canning operations; this has led to the selection for flesh of canning peaches that is anthocyanin-fresh free (Bassi and Monet, 2008). Since localization of anthocyanins in skin is independent from that in flesh, commercial canning peaches may or may not develop a red over-colour, given the fruit is peeled before canning. Fruit should be

practically free from defects or blemishes such as from decay, worms, worm holes, and split pits, and free from damage caused by scab, bacterial spot, other disease, insects, bruises, or other means, fairly uniform in size and symmetry for the applicable style.

Endocarp splitting (at the carpel suture) or shattering (radial fractures) may affect either early or late-ripening cultivars pending to orchard conditions. It is reported that cultural practices to improve fruit size (supplemental irrigation, girdling, etc.) may also increase the incidence of endocarp splitting or shattering (Burrell and Reighard, 2017). The percentage of fruit with split pits increased by 58.2% in heavily-thinned trees compared with moderately- or lightly-thinned trees, and by 22.9% for the earliest time of thinning (15 d before pit hardening (PH)) compared with thinning during, or after PH (Drogoudi et al., 2009). These two undesired endocarp modifications are commercially a problem because the potential consumer safety, especially children, in eating the stone fragments. In the canning industry these fruits are not processed because its fragments are difficult to eliminate from processed fruits. The soluble solids content of fruit is not a strict requirement because syrup can be adjusted at the end of the canning process resulting in processed products ranging from 10 % (light) to 22 % (extra heavy). The packing medium may differ, ranging from light syrup (LS, of 15.4 °Brix – pH = 3.56) to pear or grape juice. An alternative filling medium targeting less caloric content, is diluted clarified concentrated grape juice (12.3 °Brix – pH = 3.66) .

Throughout the canning process, large amounts of fruit are damaged during mechanical pitting operations. Fruit disintegration is thus referred to as pitting damage because it is produced during the pitting operation in the canning process. A strong

correlation between fruit firmness measured in the weakest position on the fruit and pitting damage has been established. The percentage of 'Andross', 'Carson', and 'Ross' fruit with pitting damage increased as fruit firmness fell below 18 N (4 lbf). This value is called the critical pitter threshold (CPT). Thus, peach canning quality is horticulturally determined by reaching a minimum flesh colour, an adequate fruit size and a firmness greater than 18 N to maximize consumer quality and avoid losses (Valero et al., 2003).

1.8.2. Quality and sensorial attributes

The components of quality can be sensory and nutritional. Most important sensory attributes are taste, aroma, texture and appearance. The quality of peach fruit is determined by six main parameters as follows: 1) malic and citric are the major acids that contribute to the acidity (taste); 2) sucrose is the major sugar followed by the glucose and fructose that gives the sweetness (taste); 3) volatile compounds such as a series of lactones are largely controlled the aroma (odour); 4) carotenoids are responsible for the yellow-orange colour (appearance); 5) polyphenols contribute to the astringency and bitter flavour (taste); and 6) texture which is a function of cultivar and maturity and controlled by alterations in the pectic substances (Couvillon and Krewer, 2018). Considering all the above-mentioned actualities and the fact that the peach canning industry largely expands its finished (canned peach) products in the global market, then the quality of peach canning products must be a priority. All these external and internal quality aspects embody a set of features critical to consumer's quality acceptance and the product's market success. Thus, the determination and quantification of canned peach quality parameters can be obtained with the employment of objective (analytical methods) and

subjective (human sensorial perception) measurements (Figure 1.10). These approaches of quality evaluation when employed together can provide complementary information for a complete description of all attributes describing the product.

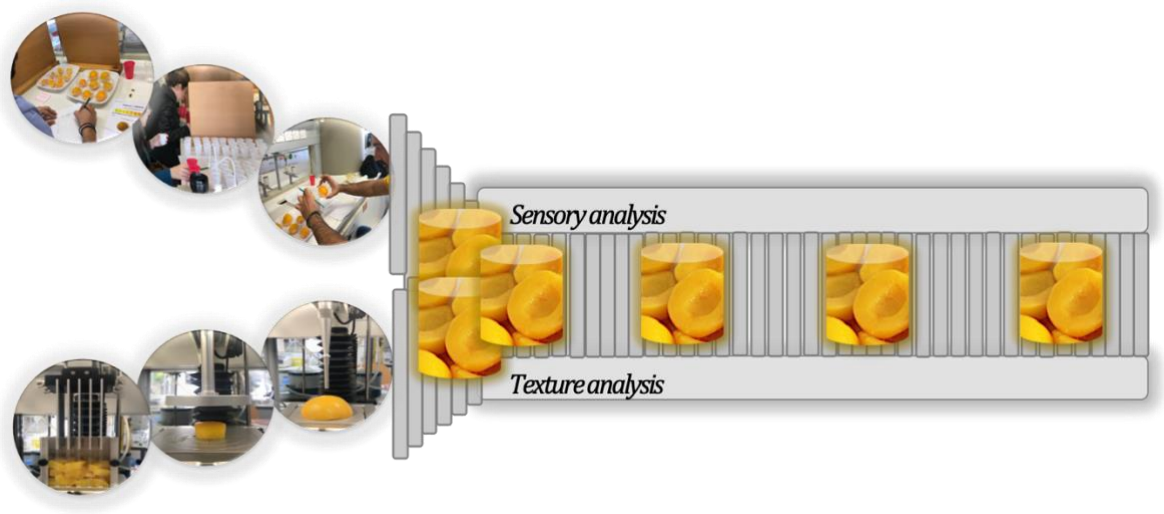


Figure 1.10: Analysis of textural properties and sensorial attributes of final canned peach product towards development of comprehensive protocols for the canning industry.

Subjective measurements of the peach quality attributes (appearance, texture, taste and odour), often referred to as 'sensory perception' or 'sensory evaluation', encompass all methods to measure, analyze and interpret human responses to its properties as perceived by the five senses: taste, smell, touch, sight, and hearing (Civille and Oftedal, 2012, Chen and Opara, 2013). There are two sensory tests: affective tests provide information on the preference or acceptability of products, and analytical tests seek to determine the level of specific attributes (Florkowski et al., 2014). Among the analytical tests, a descriptive test was chosen over the discriminative test (determine differences in samples and products) in order to measure and quantify specific attributes of canned peach

products. For instance, quantitative descriptive analysis (QDA) is a scaling technique where the panellist is asked to rate the intensity of a particular attribute on a scale. Normally, descriptive panels consist of 8-12 trained panellists, who are pre-screened for their sensory acuity under specific training sessions to be readily distinguish different (individual) taste characteristics. In sum, the basic steps required to implement a QDA are as follows: 1) Development of a standardized vocabulary (consensus language); 2) Quantification of selected sensory characteristics; and 3) statistical analysis of the results and sensory profile of products.

There are several studies regarding sensory analysis of foodstuff to evaluate product's quality attributes related to consumer preference and acceptability. In particular, descriptive sensory analysis is extensively used to characterize attributes of an array of fresh horticultural commodities (Aprea et al., 2012, Causse et al., 2001, Jaeger et al., 2003, Oliver et al., 2018, Péneau et al., 2007). Apart from the fresh product, several studies have focused on sensory evaluation of processed fruits (Bonneau et al., 2018, Bett-Garber et al., 2010, Haug et al., 2013, Lieb et al., 2018). A range of sensory descriptors for canned peach fruit has been assessed by an early preliminary study that challenged accepted interpretations in the field of quality evaluation (Manganaris et al., 2005).

Colour, texture and taste of processed products are critical attributes to consumer's quality acceptance and the product's market success. Therefore, the peach canning industry has adopted a minimum maturity index based on visual flesh colour at inch depth using three coloured plastic disks as prototypes to match the flesh colour (Crisosto et al., 2007, Delwiche, 1988). Texture of peach fruit is another important quality attribute, which

is substantially modified during canning process and represents the most strongly correlated attribute with descriptive sensory attributes (Contador et al., 2016). Taste which in mainly driven by sugar and organic acid content; however in canning peach is controlled and equilibrated due to the standard cut-out brix levels of packing medium used. The cut-out syrup (final syrup) is largely dependent on the added syrup. For instance, a syrup added before processing with a 40 ºBrix will usually "cut-out" at 22 to 25 ºBrix because the juice of the fruit will dilute the syrup during processing (Barrett et al., 2004). Further use of acids (citric, ascorbic acid) and sugar as a common means of preventing browning in peeled and sliced peach fruit as well as to prevent the loss of texture, colour, and flavour (Barrett et al., 2004).

1.8.3. Textural properties

There are many definitions for the texture of food, as have been proposed in the literature. One can define texture as the way in which the various constituents and structural elements of a food are arranged and combined in a micro- and macro- structure and the external manifestations of this structure in terms of flow and deformation (deMan et al., 1976). Another definition considers texture as an important sensory characteristic. Thus, texture is the attribute of a food resulting from a combination of physical properties and perceived by the senses of touch (kinesthesis & mouthfeel), sight and hearing (Jowitt, 1974). The study of texture is crucial for understating the functional properties and the stability of food products because texture affects the mechanical behaviour upon processing, transport or storage of the product, and in this way it determines the shelf life of the product. Moreover, texture is directly related to the sensorial perception of food in

the mouth during chewing. Finally, the texture and food structure in general have a direct impact on the physiological activity of nutrients and other bioactives in a food matrix by affecting their bio- availability during digestion (Bourne, 2002).

The texture of peach fruit is affected by the changes in cell wall components during the heat processing treatment. The constituents of the primary cell wall are polysaccharides such as pectins, cellulose and hemicelluloses (Van Buren, 1979). During thermal processing, the cell wall matrix of fruit undergo modifications such as tissue softening and disintegration which is primarily attributed to degradation of pectic substances due to their typical non-enzymatic depolymerisation and solubilisation (Zhang et al., 2012, Nguyen et al., 2010, De Roeck et al., 2010). Pectins are mainly polygalacturonic acids with differing degrees of G-galactosyl, L-arabinosyl or L-rhanmosyl residue and the most abundant macromolecules within the cell wall matrix (mainly in the middle lamella) (Hui, 2006).

Further to the subjective methods of sensory evaluation, for the study of texture of solids foods, such as fruit, objective methods such as large deformation mechanical tests are often used. These rheological methods measure the deformation of the matter under stress. The magnitude of the applied stress is high enough to result in failure of the food macro-structure. Overall, such destructive tests describe the interrelations between force, deformation and time. The ultimate goals of the objective rheological methods are to establish the relationship between the mechanical parameters and the sensorial attributes of the tested products and to monitor the textural changes that take place during preservation or storage of the food product. In this dissertation, the relationship between

objective (instrumental) measurements and subjective measurement of texture (sensorial evaluation) of canned peach fruit is studied and monitored in the following chapters.

For texture determination of fruit, the manual penetrometers are used frequently by the postharvest industry because they are inexpensive, easy to use without requiring special skills and some of those are transportable and thus, they can be used in the field to test whether the fruit has reached a certain level of ripeness. They have probes with an ending that can penetrate into the fruit up to a certain distance. A force-meter that is adapted to the probe measures the force that is required for the targeted deformation. Another type of manual penetrometer is that it measures the extent of deformation when a certain level of force is applied. A cone or needle is released from this penetrometer and allowed to freely move and then the depth of penetration of the cone or needle entering the sample is measured. Although these types of empirical instruments are easy to use, stresses and deformations that are being applied and the conditions under which the testing is carried out are not controlled. As a result, there is low repeatability and precision in this type of measurements. Such disadvantage can be overcome by using the multiple measuring instruments, like Instron or the Texture Analyser of the Stable Micro Systems company, that can provide many different mechanical parameters of the solids and semi-fluid food matrices under controlled conditions of stresses and strains applied. In these instruments, the probe comes into contact with the sample through an ending having the appropriate shape depending on the test. To make this possible, there is a motor-driven mechanical device for the vertical, horizontal or rotational movement of the probe, under controlled speed, an electronic system for the calculation of strain or stress applied to the

tested product and a computerized system for data reading and recording of the strain and stress changes with time (Chen and Opara, 2013, Bourne, 2002).

The most common large deformation mechanical test for firmness determination is the puncture or penetration test; applicable to a broad array of horticultural commodities (Ciacciulli et al., 2018, Fuentes-Pérez et al., 2014, Ruiz-Altisent et al., 2006), including canned peach (Manganaris et al., 2005). A probe with different ending (e.g. cylinder, cone, sphere and needle) is penetrated into the product and the required force for its rupture is measured. The puncture test is primarily used to measure the required force to penetrate the fruit flesh at a fixed distance with a steady speed rate of the moving probe. It is a straightforward assay, used for both fresh and processed fruit and is often adopted compared to a compression test due to the simplicity of conditions to replicate the test (sample size and shape is predictable). Another type of mechanical test is the compression test, where the firmness is calculated as the force required to deform, up to a certain level of deformation, the tested product without rupture it. Texture Profile Analysis (TPA) test is a double compression test that mimics the mouth's biting action; being used extensively to quantify multiple textural parameters (hardness, springiness, cohesiveness, fracturability, chewiness etc) of processed products (Jaworska et al., 2010, Trejo Araya et al., 2009). In the case of peach, few preliminary studies employed TPA technique on thermally or minimally processed peach products (Denoya et al., 2016, Zhang et al., 2014, Zhang et al., 2012). Furthermore, a shearing test such as a "bulk" firmness test is designated to evaluate simultaneously the mechanical responses of a number of pieces of specific weight with the employment of a multi-bladed device (Kramer shear test cell,

KST). This device is commonly used to analyse the bulk textural features of multi-particle products, such as cereals (Chaunier et al., 2005, Kerr et al., 2001) and to evaluate the texture of both raw ingredients and finished food products (Ayour et al., 2017, Walter et al., 2002), yet with limited exploitation to horticultural commodities (Canet et al., 2004, Sousa et al., 2007). KST has been employed on some thermally processed commodities, such as pasteurized apricots (Ribas-Agustí et al., 2017) and diced tomatoes (Rao and Barringer, 2006). To the best of our knowledge, this large deformation mechanical testing has never been applied for canned peach halves. Overall, all these types of mechanical tests can be made using the Texture Analyzer, depending on the product and the processes that the researcher wanted to evaluate by carrying out the respective measurement.

1.8.4. Phytochemical profile

The outstanding popularity of peach fruit and its related products is additionally due to their health-promoting properties There are two groups of nutrients: a) macronutrients including water, carbohydrates, fats, proteins, organic acids and fibers that provide the energy to the body, and b) micronutrients including minerals and vitamins essential to human health. Peach fruit is considered as a beneficial fruit for human in terms of its macro- and micro-nutrients. Its major components are carbohydrates, sugars, dietary fibers, minerals and organic acids as well as a wide range of physiologically active micronutrients, including various bioactive compounds or extra-nutritional substances (not essential for life) that occur in small amounts and induce subtle effects in physiological and cellular activities (Kris-Etherton et al., 2004). In a recent study, bioactive compounds are defined as the essential and non-essential compounds (e.g.

vitamins or polyphenols) that are naturally occurring and being part of the food chain, capable of affecting an organism's health state (Biesalski et al., 2009). Thus, all these important substances can be used by the body for nourishing, growth, maintenance and repair as well as to determine the overall fruit quality of final produce (fresh and processed).

Peach fruit is one of the richest fruit in water content (89 %) and low in caloric value: a medium sized raw fruit (~150 g) has 50 calories, 0.5 g of fat, 0.0 g of cholesterol and sodium, 15.0 g of carbohydrate, 13.0 g of sugar, 2.0 g of fiber and 1.0 g of protein. This fleshy fruit encompasses a complex of essential compounds including vitamins, mainly C and E, dietary fibers and minerals such as calcium, potassium, magnesium, iron, manganese, phosphorous, zinc, and copper. Beyond the basic nutrition, the peach fruit is relatively rich in non-essential compounds known as phytochemicals (natural metabolites), mostly of small molecular weight, with enhanced antioxidant properties, including phenolics, such as chlorogenic and neochlorogenic acids, catechin, epicatechin, and carotenoids compounds, such as β-carotene, lutein and zeaxanthin (Gil et al., 2002, Tomás-Barberán et al., 2001a, Stojanovic et al., 2016). Phenolic compounds such as flavonoids possess strong antioxidant activity that are considerably beneficial in human health, protecting human body against cellular oxidation reactions (Gazzani et al., 1998, Cevallos-Casals et al., 2006). Carotenoids such as β-carotene, lutein and zeaxanthin, found to play a role in skin, vision and age-related macular degeneration; considering to have a relevant role in antioxidant ability of human body (Campbell and Padilla-Zakour, 2013, Fraser and Bramley, 2004, Paiva and Russell, 1999). Another important

micronutrients are vitamins which are essential nutrients for normal metabolism process, growth and vitality of human organism and deficient amounts of these can lead to obesity, diabetes and heart diseases (Hassan, 2012). Furthermore, based on these bioactives, the health-promoting benefits of peach fruit have been reported in relation with chronic disease prevention such as Parkinson's and Alzheimer's, metabolic and cardiovascular pathologies, diabetes and cancers (Cevallos-Casals et al., 2006, Gil et al., 2002, Ames et al., 1993, Noratto et al., 2015).

In general, carotenoids are naturally occurring group of pigments that are present in all photosynthetic organisms and are the sources of the yellow, orange and red colours of plants (Dragovic-Uzelac et al., 2007). They are segregated into two groups: a) xanthophylls which are oxygenated molecules such as lutein and β-cryptoxanthin, and b) carotenes which are unoxygenated molecules like hydrocarbon carotenoids, including β-carotene. Phenolic compounds are the most abundant secondary metabolites derived from plant metabolism; sharing a common chemical structure comprising an aromatic ring with one or more hydroxyl substituents. They are divided into two categories based on their structure: a) simple phenols containing one aromatic ring and b) polyphenols having more than one aromatic ring (Bento et al., 2018, Umar Lule and Xia, 2005). There are several classes of phenolic compounds including flavonoids, phenolic acids, tannins, stilbenes, and lignans. They exist in free, esterified and insoluble-bound forms, depending on whether they occur in the free form or are covalently bound to other molecules such as fatty acids (soluble esters) or insoluble macromolecules (insoluble-bound phenolics are usually bound to cellular wall in plants) (Shahidi and Yeo, 2016, Nayak et al., 2015).

Additionally, vitamins are classified into water soluble vitamins (vitamin C, folic acid, vitamin B12) and fat soluble vitamins (vitamins A, D and E) (Hassan, 2012).

The main carotenoid and phenolic compounds found in peaches are enlisted in Table 1.5, including their chemical structures. In sum, β-carotene is the major carotenoid compound found in peach (peel and pulp) followed by β-cryptoxanthin, while the chlorogenic acid and its isomer, neochlorogenic acid (hydroxycinnamic acid derivatives) are the predominant phenolic acids. The content of β-carotene ranging from 110-3790 μg/Kg (peel) and 40-1680 μg/Kg (flesh), while values of β-cryptoxanthin ranging from 60-360 μg/Kg (peel) and 60-160 μg/Kg (flesh) (Gil et al., 2002). The concentration of chlorogenic acid in white and yellow fleshed peaches ranged between 7.5-20.6 mg/100 g fresh weight (FW) in exocarp and 1.0-5.2 mg/100 g FW in mesocarp, and from 8.0-14.0 mg/100 g FW in exocarp and 0.9-11.0 mg/100 g FW in yellow fleshed peaches (Ceccarelli et al., 2016). As for neochlorogenic acid, the white flesh peach values ranged from 0.6-3.8 mg/100 g FW (exocarp) and 1.0-5.5 mg/100 g FW (mesocarp), and from 0.5-2.8 mg/100 g FW (exocarp) and 0.9-3.3 mg/100 g FW in yellow fleshed peaches (Ceccarelli et al., 2016). As reported in many studies, the phytochemicals are not uniformly distributed in the fruit tissue, particularly most of them are concentrated in the peel and in a lesser amount in flesh tissue (Liu et al., 2015, Gil et al., 2002, Campbell and Padilla-Zakour, 2013).

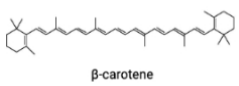
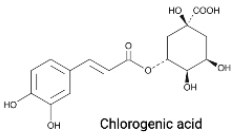
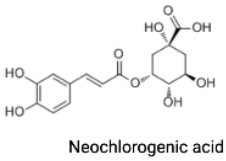
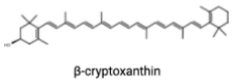
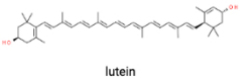
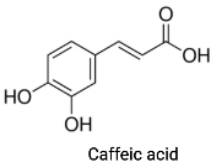
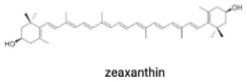
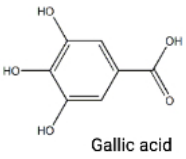
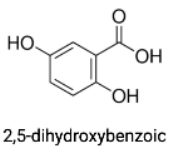
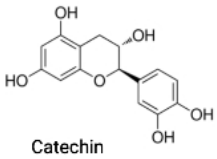
In addition to the fresh consumption, peaches are subjected to canning process as a means of preservation. In this context, thermal processing can have a different impact on the composition of the phytochemical profile of the final products. Even though

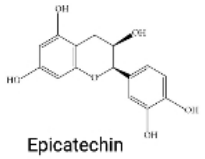
variations in phenolic composition due to cultivar or processing treatments have been shown to influence peach antioxidant capacity, there have been relatively few studies on the effect of processing on phenolic constituents (Asami et al., 2003). Oliveira et al. (2012) reported that pasteurization of fresh peaches resulted in a significant reduction of carotenoid content, exception made for zeaxanthin (increased during storage). Other studies showed that thermal processing and storage have negative impacts on peach procyanidins (Techakanon et al., 2017, Hong et al., 2004). On the other hand, phenolic compounds appear to be less affected by thermal treatment (pasteurization process). In contrast, Campbell and Padilla-Zakour (2013) reported that processed clingstone peaches contained higher quantities of bioactive compounds than fresh fruit, while Durst and Weaver (2013) showed that canned peaches are nutritionally equivalent to fresh produce and presented increased contents of vitamins A and C after the canning process.

Overall, these bioactive compounds found in small quantities inside various foods, beverages and plant matrices can be determined by laboratory tests using different analytical methods, whereas the main factors involved in the isolation of these compounds from different foodstuff should be considered. Among these, the nature of plant matrix and the objectives of extraction such as the targeted active compounds, extracting preparation, nature of solvent, temperature and time should be evaluated (Chuo et al., 2020). Chemical analysis of these compounds necessitates fractionation with different solvents, since they possess different hydrophobicity; i.e. phenolics are mostly hydrophilic, while carotenoids are generally considered as highly lipophilic. The complex nature of bioactive compounds in fruit makes difficult to characterized in one-step

method. A series of basic steps is commonly used for the analysis of phytochemicals inside different food matrices: a) pre-treatment technique, b) selection of extracting procedure and solvent, and c) instrumental analysis using simple and complicated techniques. Before the extraction of phytochemical compounds, the sample is prepared accordingly such as drying, crushing and grinding. Subsequently, the sample is extracted using an effective solvent with the employment of conventional (maceration, Soxhlet system) and non-conventional extractive methods (ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction) (Sridhar et al., 2021). Opposed to the simple use of conventional methods, non-conventional approaches pose positive effects such as low extraction time, less energy consumption and low solvent consumption (Zwingelstein et al., 2020, Wang and Weller, 2006). Moreover, a wide range of extraction solvents including methanol, ethanol, acetone, hexane, ethyl acetate, petroleum ether and aqueous mixtures of them have been extensively used as a means of extracting peach phytochemicals in several studies (Cantín et al., 2009, Gil et al., 2002, Loizzo et al., 2015, Vizzotto et al., 2007, Tomás-Barberán and Ferreres, 2012, Asami et al., 2003, Giuffrida et al., 2013, Oliveira et al., 2017). After extraction, the active compounds are obtained by isolation and purification, followed by the identification and quantification. Different methodologies such as simple spectrophotometry UV-vis methods and sophisticated techniques (UPLC-MS, HPLC-DAD-ESI/MS, LC-MS) have been previously used to determine total and individual phenolic and carotenoid content in peach fruit (Mokrani et al., 2016, Cantín et al., 2009, Tomás-Barberán et al., 2001a, Aubert et al., 2014).

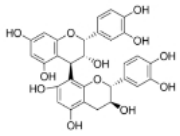
Table 1.5: Main carotenoids and phenolic compounds in peach fruit.

Chemical structure	Carotenoid compounds	Chemical structure	Phenolic compounds
	Carotenes		*Hydroxycinnamic acids*
 β-carotene	β-carotene	 Chlorogenic acid	Chlorogenic acid
	Xanthophylls	 Neochlorogenic acid	Neochlorogenic acid
 β-cryptoxanthin	β-cryptoxanthin		
 lutein	Lutein	 Caffeic acid	Caffeic acid
 zeaxanthin	Zeaxanthin		*Hydroxybenzoic acids*
		 Gallic acid	Gallic acid
		 2,5-dihydroxybenzoic acid	2,5-Dihydroxybenzoic acid
		 Catechin	*Flavanols* Catechin



Epicatechin

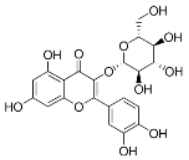
Epicatechin



Procyanidin B1

Procyanidin dimers B1-B7

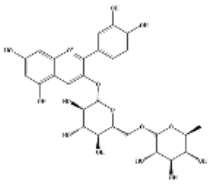
Flavonols



Quercetin 3-glucoside

Quercetin 3-glucoside

Anthocyanins



Cyanidin 3-O-rutinoside

Cyanidin 3-O-rutinoside

1.9. Research Aim

Canned peach is an added-value product, attractive to a different target market than the fresh fruit and facilitate year-round availability. Peach canning industry largely expands its finished products in the global market, having important economic implications for the main peach producing countries. Despite the great economic importance, a limited number of studies have dealt with the assessment of textural properties, compositional and sensorial perception as well as the nutritional profile of peaches destined for canning process. Thus, it is of great importance to establish protocols, providing complementary information which are readily applicable to the canning industry in setting up qualitative tests to determine product shelf-life as well as to assist on going breeding programs for the evaluation of new candidate clingstone cultivars destined for canning purposes; having positive impact on human health.

The current study was composed of 3 independent, yet interrelated experiments. Initially, the aim was the setting up of a list of sensorial descriptors and the elaboration of a toolkit to evaluate the textural properties of canned peaches using large deformation mechanical analysis. The relationship between sensorial (subjective) and instrumental (objective) measurements was further investigated.

Another objective of the current study was to evaluate the effect of canning process on compositional, sensorial and textural attributes of fruit from seven commercially important non-melting peach cultivars, packed in standard and a low-calorie filling medium to fit with current consumer-market trends. To further elucidate

the storage potential of canned products, such analyses were conducted after 6 and 24 months after the canning process.

Lastly, taking into consideration that relatively few data exist on bioactive profile and the changes occurring after the canning process for widely grown non-melting peach cultivars, the current dissertation tried to shed some additional light on the compositional variability and impact of processing on carotenoid and phenolic acid composition in peach, for both fresh and canned fruit tissues, from eight important non-melting peach cultivars.

2. Research Methodology

2.1.Fruit material

The present study was conducted in 8 clingstone non-melting peach cultivars (‘Romea’, ‘Catherina’, ‘Mirel®’, ‘Fercluse®’, ‘Andross’, ‘Everts’, ‘Ferlate®’ and ‘VLG’). grown in a commercial orchard located in Northern Greece (Agia Marina, Imathia, Central Macedonia) (Figure 2.1).

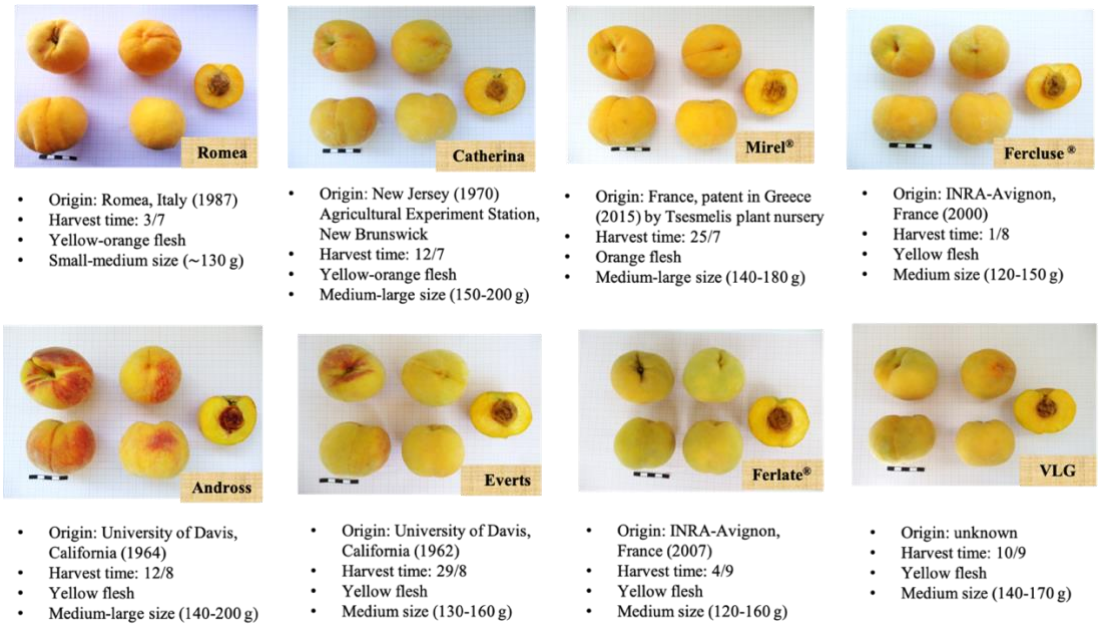


Figure 2.1: Non-melting peach cultivars with scalar on tree ripening that are commercially used in Greece.

For each cultivar, fruit were harvested at commercial maturity stage based on fruit size and exocarp background colour and were segregated into two lots; one lot (30 fruit) for fresh produce and the other lot (*ca.* 40 kg of fresh fruit) was subjected to canning process at the premises of the cannery. For comparative purposes regarding the sensorial

properties, canned peaches were prepared in light syrup (LS, initial of ~20.0 °Brix) and a low-calorie medium (grape juice (GJ) syrup, initial of ~16.0 °Brix) and stored until analysis at room temperature (23 ± 2 °C), respectively. A total production of 192 metal cans (~ 820 g net weight) was prepared for the 8 cultivars and the 2 syrups used as packing media.

Fresh fruit were assessed for physicochemical (flesh colour, flesh firmness (FF), soluble solids content (SSC) and titratable acidity (TA)) and phytochemical contents, and the canned peach halves packed in LS and GJ were evaluated for sensorial attributes after 6 months of storage and for textural properties after 6 and 24 months of storage as well as for their bioactive content. The fruit material and experimental design per study are analytically described in the 'Materials and methods' sections of §3-**Error! Reference source not found.**.

2.2. Canning process

The canning process took place at the premises of the Venus Growers Cooperative Unit (Veria, Greece), a large fruit processing firm, and the whole procedure is analytically described and schematically depicted in §1.7.2, Figure 1.9.

2.3. Determination of quality attributes of fresh fruit

For each cultivar, thirty fruit of uniform maturity stage at harvest were assessed for flesh colour, flesh firmness (FF), soluble solids content (SSC) and titratable acidity (TA). Fruit colour was measured in the mesocarp using a Minolta chromatometer (CR-410; Konica Minolta, Tokyo, Japan), providing the colour parameters of L*, a*, b*, chroma and hue angle (h°) (Figure 2.2). L* corresponds to a dark-bright scale from 0 (black colour) to 100 (white colour), a* positive value indicates redness (–a* is greenness) and b* positive value yellowness (–b* is blueness) on the hue circle. Subsequently, chroma (square root of $[(a^*)^2 + (b^*)^2]$) and hue angle [arctangent (b*/a*) (degrees)] were determined. Chroma (saturation or vividness) registers high values as colour becomes more intense and it decreases as colour becomes duller. The hue angle is expressed in °degrees and range from 0 to 360°; 0° depicts red colour, 45° orange-red, 90° yellow, 180° green and 270° corresponds to blue colour.

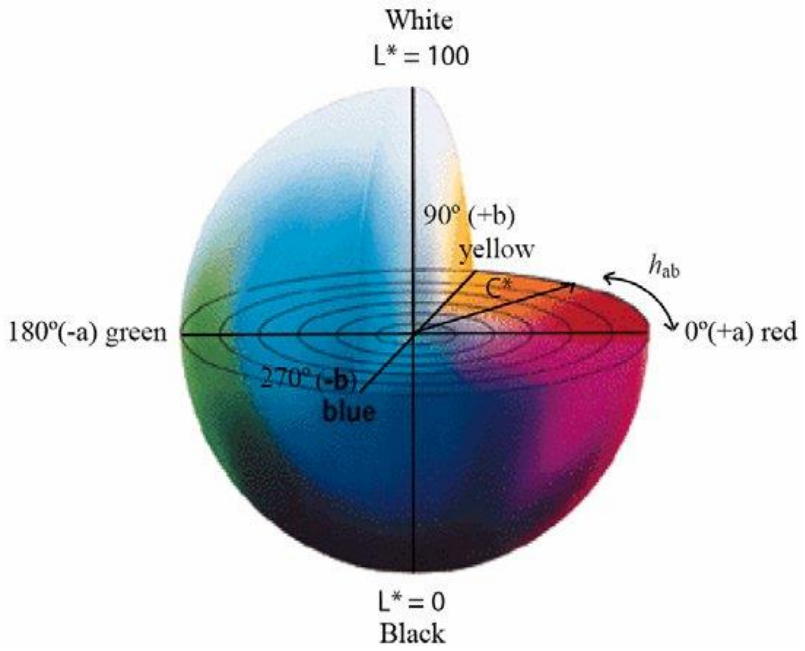


Figure 2.2: The three-dimensional CIELab colour space as defined by the CIE (Commission Internationale de l'Éclairage) in 1976, adopted by Jordheim (2007).

Fruit firmness was measured on two equatorial sides of each fruit, after the removal of a 1 mm thick disk of skin from each side of the fruit, using a penetrometer (Model FT-327, Effegi) fitted with an 8 mm plunger tip and the results were expressed in Newtons (N). Soluble solids content (SSC) and titratable acidity (TA) were determined in juice made with a fruit juicer of each sub-lot followed by filtration (three sub-lots of 10 fruit each). SSC was measured using a digital refractometer (model PR-32α, Atago, Tokyo, Japan) and the results were expressed as "degrees Brix" (°Brix). TA was determined by manually titrating 5 mL of juice with a 0.1 M of NaOH solution, using a phenolphthalein solution to mark the pH end point of 8.2, and the results were expressed as g malic acid L^{-1}. The ratio SSC to TA (SSC/TA), as an indicator of fruit taste or sweetness, was also calculated.

2.4. Determination of quality attributes in canned fruit

Canned fruit (three replications of one metal can each) for each of the two packing media (LS and GJ) were instrumentally tested for quality attributes after six and twenty-four months of storage. Canned halved fruit were first washed with distilled water for 2 min and were subsequently drained prior to analysis. Colour of twenty-four halves per packing medium was measured to determine the coordinates L*, chroma and h^o, as previously described.

Texture measurements of canned samples were conducted using a multipurpose texture analyzer TA-XT.plus (Stable Microsystems, Godalming, Surrey, UK), equipped with a 30 kg load cell and employing a 6 mm flat steel cylindrical probe, a 75 mm flat steel compression plate, and a 5-bladed fixture, respectively, for the corresponding three large deformation mechanical testing assays performed; i.e. puncture test, texture profile analysis (TPA) and Kramer shear test (KST) (Figure 2.3). For the latter measurement, the testing material was in the form of ca. 200 g of peach cuboid pieces with similar dimensions (22mm x 12mm x 11mm) derived from the halves using a stainless steel multiple mold cutter. Prior to the initiation of each assay, calibration was carried out using a 5-kg weight and all measurements were conducted under controlled temperature (23±2 ◦C). The comprehensive protocols developed regarding textural properties of canned peach fruit are described in detail in the first experiment (§3). A total of eight textural attributes (puncture firmness, TPA hardness, springiness, cohesiveness, consistency, chewiness, Kramer hardness and total hardness) were thus determined, as elsewhere described in detail in the second experiment (§4).

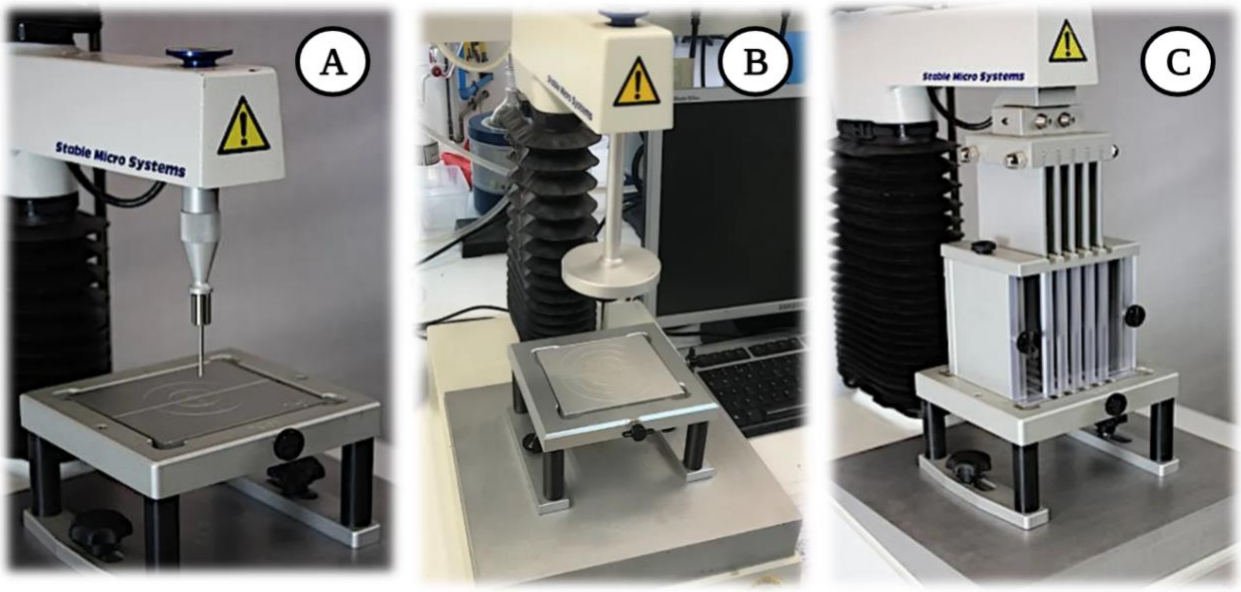


Figure 2.3: TA-XT Plus texture analyser for application of three discrete large deformation tests [(A) Puncture test with a flat cylindrical probe; (B) Texture profile analysis (TPA) with a flat compression plunger; and (C) Kramer shear test (KST) cell with a bladed fixture].

The SSC and TA contents were determined by homogenization of the canned halves using a laboratory homogenizer (model: ES3, EZ600 black, Blendtec, USA) at high speed for 2 min and centrifugation (model: 3-18K, Sigma, Germany) of the resulting fine puree at 3000 x g, for 10 min at 4°C. The supernatant was then used to quantify the soluble solids content as previously described. TA was measured with an automatic compact titrosampler (862 compact titrosampler, Metrohm AG, Switzerland) and the data were expressed as g malic acid L^{-1} of liquid product. All measurements were conducted in triplicate for each of the packing media.

2.5. Determination of organic acids and sugars

The experimental procedures followed for the extraction and determination of individual organic acids and sugars are schematically presented in Figure 2.4. Organic acids and sugars were determined both in the fresh and canned fruit, after freeze-drying and storage at -20◦C until needed. The extraction protocol was carried out following the methodology described by Orazem et al. (2011), with slight modifications. Briefly, 0.5 g of freeze-dried sample, pulverized into powder with a mortar and pestle, was homogenized with 10 mL water (HPLC grade) using vortex mixer (Stuart scientific, SA8, UK) at room temperature for 2 min. Subsequently, the homogenate was centrifuged at 3000 x g for 15 min at 5◦C (model: 3-18K, Sigma, Germany) and the supernatant was used for chromatographic analysis after filtration through a 0.45-μm cellulose filter (Macherey-Nagel, Duren, Germany) into vials.

Samples were analysed for individual organic acid and sugar contents using an HPLC system (Waters 1525, Milford, USA) consisting of a vacuum degasser, a binary pump, an autosampler, a thermostated column compartment, and a detector: i.e. a dual λ absorbance detector (for organic acids) or a refractive index detector (for sugars) were employed for detection of analytes. The data collection and analysis were performed by the Empower software (Waters Corporation, Milford, USA). Analysis of organic acids was performed using an Aminex (HPX-87H) ion exclusion column (300 mm x 7.8 mm; BioRad, USA). The column thermostat was maintained at 60 ◦C, and the flow rate at 0.6 mL min^{-1}. The mobile phase (isocratic system) consisted of a 4 mM H_2SO_4 aqueous solution. The elution profiles were monitored by absorbance measurements at 210 nm and

malic, citric, shikimic, fumaric and tartaric acid contents were quantified and expressed as mg g^{-1} of fresh weight (FW). For the chromatographic separation of sugars, an Aminex (HPX-87C) carbohydrate column (300 mm x 7.8 mm; BioRad, USA) was used, with the temperature maintained at 60 ˚C. The mobile phase (isocratic system) was water (HPLC grade) at a flow rate of 0.6 mL min^{-1}. Sucrose, glucose and fructose contents were determined and expressed in mg g^{-1} of FW. Identifications were performed by comparing retention times (t_R) with those of standards. Quantifications were carried out using calibration curves based on different injected amounts of the standard compounds.

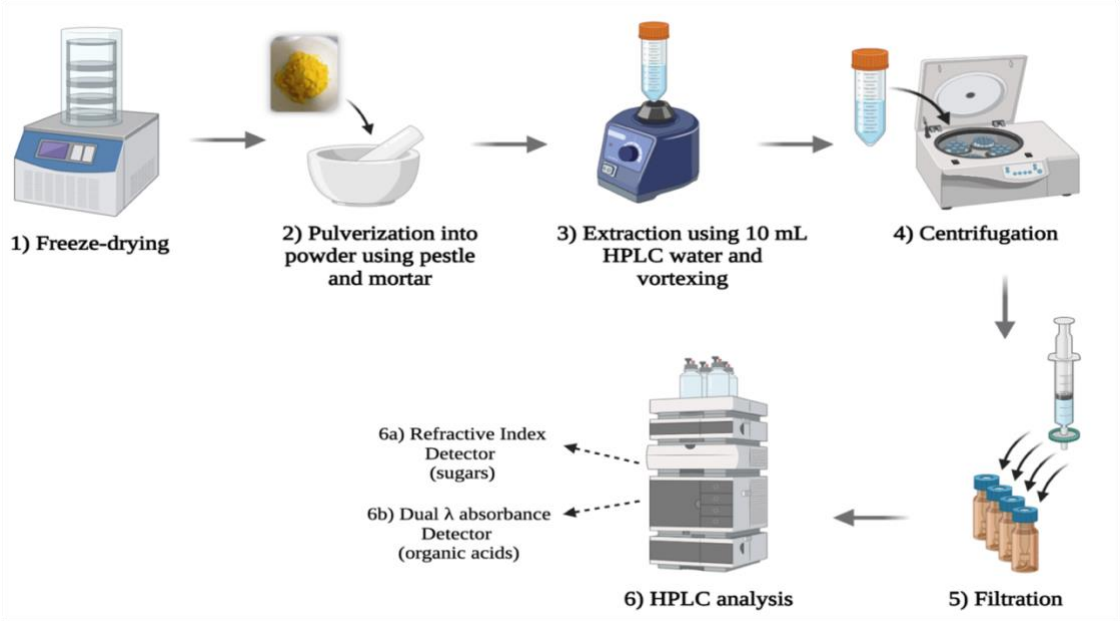


Figure 2.4: Schematic illustration of the experimental procedure used for the analysis of individual organic acids and sugars.

2.6. Sensory analysis of canned fruit

Quantitative descriptive analysis (QDA) was developed and used to characterize the sensorial attributes (odour, appearance, texture and taste) of canned peach halves at the

two packing media, i.e., light syrup (LS) and grape juice (GJ). The elaboration of comprehensive sensory analysis (QDA) protocol was initially employed in canned 'Andross' peach halves and are described in detail in the first experiment (§3) and the rest canned cultivars were assessed in the second experiment (§4).

The sensory evaluation took place in a properly designated room with individual booths for each panellist under controlled temperature and humidity, with white light illumination at the premises of Cyprus University of Technology (Figure 2.5). The sensory analysis included the pre-screening and training of panellists and the development of a consensus vocabulary, appropriate for canned peach. Subsequently, two successive assessment sessions took place according to the ISO standards (ISO, 4120:2004; 6658:2005; 8589:2007; 5492:1991; 4121:2003). Samples were coded and served in a randomised order to the 12-member trained sensory panel that was asked to evaluate the following 15 sensorial attributes using a 10-point (intensity) evaluation scale: peach aroma, peach color, color uniformity, brightness, residual peel, blemished fruit pieces, hardness, difficulty in chewiness, sweetness, acidity, bitterness, astringency, peach flavour, fruitiness and off-flavour.

Figure 2.5: Pictures captured during the sessions of the sensory analysis of canned peach organised at Cyprus University of Technology.

2.7. Extraction and determination of total carotenoids, phenolics and antioxidant activity

The experimental methodology used for the extraction and determination of total and individual phenolics and carotenoids in fresh and canned peach tissue are schematically presented in Figure 2.6.

2.7.1. Extraction of carotenoids

Carotenoids were extracted from peach samples using classical methanol-solvent extraction under subdued light to eliminate degradation of phytochemical compounds. The lyophilised peach samples (0.5 g) were homogenized with 25 mL methanol

(containing 0.1% butylated hydroxytoluene – BHT to prevent degradation of carotenoids compounds during the extraction process) for 2 min using a vortex (Falc Instruments, Italy). The extraction took place for 24 h at 4 ∘C. After each extraction step, the solid material was separated from the supernatant under vacuum filtering and the methanolic extract was evaporated for solvent removal using a speed-vacuum evaporator (Labconco Corporation, Kansas City, USA) at 30 °C. The dry residues were subsequently stored at -20 °C until analysis.

2.7.2. Total carotenoids content

The total carotenoids content of peach extracts was determined using a spectrophotometric analysis at a specific maximum absorption wavelength and the extinction coefficient of the carotenoids of interest (Hart and Scott, 1995). The dried residues were resuspended in extraction solvent (methanol). The spectrophotometric determination of peach carotenoid content was measured at 450 nm against the blank (methanol) using a UV-VIS spectrophotometer Shimadzu UV-1900 (Shimadzu, Japan). The results were expressed as μg of β-carotene equivalents per g of dry weight (μg g^{-1} DW). All analyses were conducted in triplicate.

2.7.3. Extraction of phenolics

The extraction of phenolic compounds followed the method described by Tomás-Barberán et al. (2001a), with modifications. Briefly, lyophilized peach samples (2 g) were homogenized with 50 mL of extraction solution methanol/water (7/3, v/v) and vortexed thoroughly. The extraction took place for 24 h at 4 °C. The extracts were passed through

a Buchner filter and a 10 mL aliquot of the extract was evaporated to dryness in a speed-vacuum evaporator (Labconco Corporation, Kansas City, USA) at 30 °C. The dry residues were kept at -20 °C until analysis.

2.7.4. Total phenolic content

The total phenolic content of peach extracts was determined by applying the micro-method of Folin–Ciocalteu's colorimetric assay as elsewhere described (Mokrani et al., 2016). The dried extracts were resuspended in methanol before dilution. The reaction mixtures consisted of 20 µL of peach extract or methanol (blank), where 100 µL of Folin–Ciocalteu reagent (diluted previously 10 times with water) were added. The tube was vortexed and then allowed to stand at room temperature for 3 min when 80 µL of saturated sodium carbonate (75 g L^{-1}) solution was added. The mixture was then kept in the dark at room temperature for 1 h. The absorbance was measured at 765 nm using a plate reader (TECAN, Infinite 200® PRO). The total phenolic content was expressed as µg gallic acid equivalents (GAE) per g of dry weight (µg g^{-1} of DW).

2.7.5. Total antioxidant capacity

The total antioxidant capacity (TAC) was evaluated using the ferric reducing antioxidant power (FRAP) assay. The ferric reducing antioxidant power assay, based on the reduction of a ferric-2,4,6-tripyridyl-s-triazine complex to the ferrous form, was employed as previously described by (Drogoudi et al., 2017). A sample containing 3 mL of freshly prepared FRAP solution (0.3 mol L^{-1} acetate buffer, pH 3.6, containing 10 mmol L^{-1} 2,4,6-tripyridyl-s-triazine (TPTZ) and 40 mmol L^{-1} $FeCl_3$ $10H_2O$) and 50 µL of fresh or canned

peach extract was incubated at 37 °C for 4 min and the absorbance was measured at 593nm (TECAN, Infinite 200® PRO). A standard curve of 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was plotted and the results were expressed as μg of Trolox equivalent per g of dry weight (μg g^{-1} DW). All samples were analysed in triplicate.

2.8. Determination of individual phenolics and carotenoids compounds

2.8.1. LC-ESI-MS analysis of peach phenolics

Qualitative and quantitative profiles of phenolic compounds were performed using an Accela Ultra High-Performance Liquid Chromatography system coupled with a TSQ Quantum Access triple quadrupole mass spectrometer equipped with an autosampler (Thermo Fischer Scientific, Waltham, MA, USA). The chromatographic analysis was conducted with a C18 column (Fortis Technologies Ltd, C18, 150 x 2.1 mm, 3 μm) as the stationary phase. The injection volume was 10 μL and the column temperature was set at 35 °C. The mobile phase was water (A) and acetonitrile (ACN) (B) with the addition of formic acid (0.1 %) in both solvents. The mobile phase's gradient program was: 0.0–2.0 min: 10 % B, 2.0–16.7 min from 10 % B to 100 %, 16.7-18.7 min 100 % B, and 18.8–22.0 min 10 % B to re-equilibrate the column. The flow rate was 0.2 mL/min.

Mass spectrometry was conducted using electrospray ionization (ESI) in negative polarity and it operated in selected reaction monitoring (SRM) mode. Before the analyses, all the target analytes' molecular ion transitions and their collision energies were obtained by direct infusion in full scan. The ion source and vacuum parameters were optimized to

be applicable to all of analytes. A nitrogen generator (Peak Scientific) was used to generate nitrogen as sheath and auxiliary gas. The gases' pressures were set at 25 and 10 Arb, respectively. The spray voltage was set at 3500 V, capillary temperature at 320 °C and collision pressure at 1.5 mTorr.

Prepared analytes' stock solutions consisted of methanolic solutions at different concentrations in a range of 20 to 100 μg mL^{-1}. All stock solutions were maintained at -4 °C. Before the analyses, stock solutions were diluted with water: acetonitrile (90:10) to achieve concentrations ranging from 0.05 to 2.50 μg mL^{-1}. These were utilised for the construction of calibration curves immediately prior the analyses. All standards solutions and samples were measured in triplicate.

2.8.2. LC-APCI-MS analysis of peach carotenoids

Beta-carotene, the sum of zeaxanthin and lutein, and DL-a-tocopherol were determined using an HPLC (High Pressure Liquid Chromatography) tandem mass spectrometric method in conjunction with an Acclaim C30 reversed phase column (Particle size 3 um, 2.1×150 mm i.d, Pore size 200 Å) (Thermo Fisher Scientific, Waltham, MA, USA) and a guard column. Trans-b-apo-8-carotenal and vitamin E acetate were used as internal standards for the carotenoids and vitamin E, respectively. Mass spectrometric analyses were performed using a 3200 Q TRAP linear ion trap triple-quadrupole mass spectrometer (AB Sciex Instruments, Framingham, MA, USA) equipped with an atmospheric pressure chemical ionization (APCI) source operating in the positive ion mode. Targeted Multiple Reaction Monitoring (MRM) transitions were recorded for the spectrometric analysis

including the precursor [M+H]+ ion, a quantifier and a qualifier product ion for each compound.

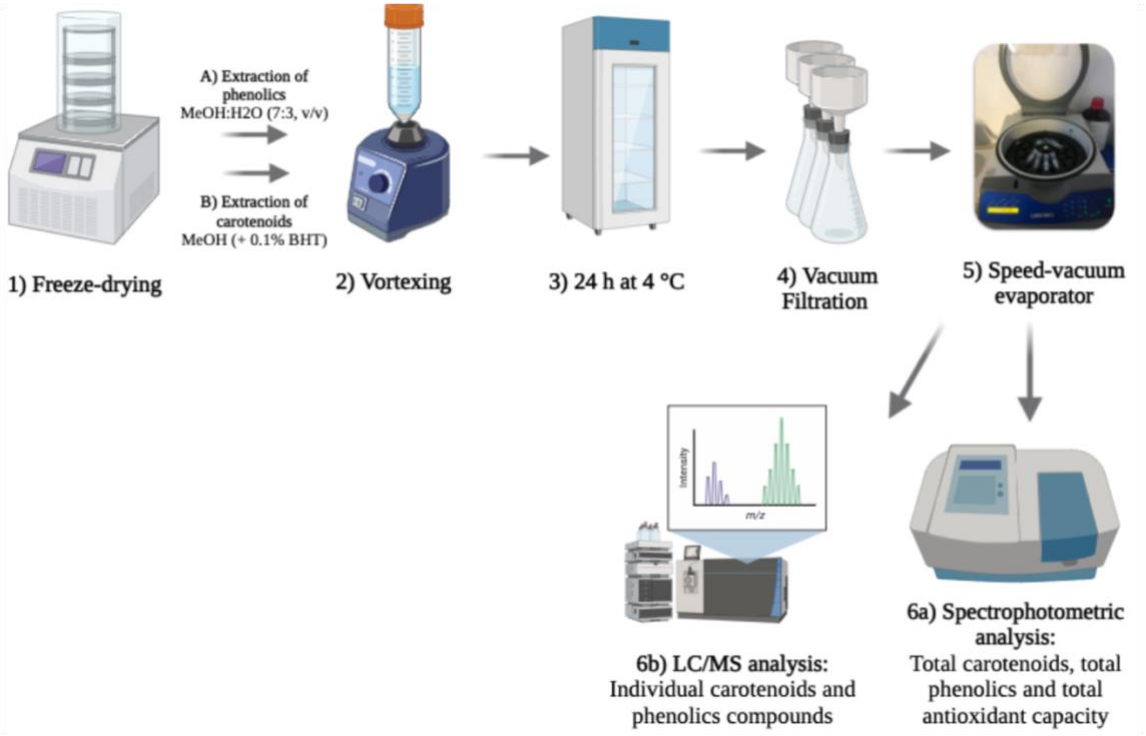


Figure 2.6: Schematic illustration of the experimental procedure followed for the analysis of total and individual carotenoids and phenolics compounds.

2.9. Statistical Analysis

The statistical analyses per experiment are analytically described in the 'Statistical analysis' section of each experiment (chapters §3, 4, **Error! Reference source not found.**).

3. Elaboration of novel and comprehensive protocols towards determination of textural properties and other sensorial attributes of canning peach fruit

Abstract

Peach (*Prunus persica*) products are destined for fresh consumption or are being consumed after processing in various forms. Despite its huge economic importance, no standardized protocols to define sensorial attributes and mechanical properties of canned peaches exist. Thus, the aim of the current study was dual and included the setting up of a list of sensorial descriptors and the elaboration of a toolkit to evaluate the textural properties of canned peaches using large deformation mechanical testing. A standardized vocabulary ('consensus language') was initially developed towards the determination and quantification of fifteen sensorial attributes through a descriptive quantitative analysis (QDA) approach. Textural properties were additionally evaluated with a TA-XT Plus texture analyser by applying three discrete large deformation tests [(a) puncture test with a flat cylindrical probe; (b) texture profile analysis (TPA) with a flat compression plunger; and (3) Kramer shear test (KST) cell with a bladed fixture]; i.e. a total of nine textural properties, namely, 'puncture firmness' (individual halves), 'Kramer' hardness (applied in a complex mixture of peach slices), 'TPA' hardness (central section of halves), fracturability, consistency, cohesiveness, springiness, chewiness and total hardness were assessed. We hereby present novel protocols that encompass the comprehensive determination of sensorial and textural properties. The established protocols, providing complementary information, are readily applicable to the canning industry in setting up

qualitative tests to determine product shelf life as well as to assist on going breeding programs for the evaluation of new candidate clingstone cultivars destined for canning purposes.

Keywords: *Prunus persica*; clingstone; texture; aroma; firmness; fruit processing; quantitative descriptive analysis; sensory evaluation; texture profile analysis

3.1. Introduction

Peach (*Prunus persica*) is a widely-consumed commodity both as fresh or after processing in various types of products (juice, canned, frozen or dehydrated fruit). Peach quality that is destined for fresh consumption is mainly based on a set of features that encompass both external characteristics (size, shape, colour) and internal properties (taste, colour, texture, aroma) that are perceived by the consumer. The determination of flesh firmness, titratable acidity (TA) and soluble solids content (SSC) are typical and easy-to-quantify quality parameters that have been correlated with sensorial attributes and linked with consumer acceptance (Legua et al., 2011). Previous studies on sensory evaluation of fresh peach fruit showed that appearance, aroma, flavour, sweetness, sourness, and texture were the most commonly used quality indicators by the consumers (Delgado et al., 2013). A linear relationship between SSC and consumer acceptance for peach fruit has been established with values below 11% being considered as non-acceptable (Crisosto and Crisosto, 2005). A combination of quality parameters rather than a single parameter is generally recommended to be used as determinants of the consumers' acceptance and preference ratings.

Several sensorial attributes are directly connected with chemical compounds present in peach. Sweet taste is mainly attributed to sucrose that accounts for 40–85 % of the total soluble sugars content, followed by glucose and fructose (10-25%) and sorbitol (< 10%) (Cirilli et al., 2016). Malic acid is the predominant organic acid of peach fruit, contributing to the intensity of sourness (Crisosto and Crisosto, 2005, Esti et al., 1997). Moreover, volatile esters that give the characteristic aroma of peach, such as (E)-2-hexenyl acetate, (Z)-3-hexenyl acetate and hexyl acetate, are compounds which have been positively correlated with consumer preference responses (Eduardo et al., 2010). In addition, phytochemical compounds, such as polyphenols and carotenoids further contribute both to the flavour (astringency, bitter taste), nutritional quality and to the overall appearance of the peach fruit, respectively (Drogoudi et al., 2016, Legua et al., 2011, Reig et al., 2013a).

A key quality attribute of peach, either as fresh fruit or processed product, is texture that is a sensory property directly linked to the perception in the mouth during chewing (Harker et al., 2010, Szczesniak, 2002), being overall the most significantly correlated attribute with the descriptive sensory attributes (Contador et al., 2016, Felts et al., 2019). In addition, several approaches have been elaborated as a suitable means for the assessment of changes in textural parameters and cell wall modifications during fruit processing (Ortiz et al., 2017). Further to sensory evaluation of fruit texture, instrumental texture measurements, such as large deformation mechanical tests (compression and puncture tests) have been often employed in other horticultural commodities (Rolle et al., 2012). With these methodological approaches the deformation of a matter under stress is

assessed with the aim to establish relationships between mechanical properties and related sensorial attributes of the tested product.

Although an extensive number of studies dealing with peach quality preference destined for fresh fruit consumption is available, this is not the case when we are referring to peach products after processing. Quality of canned fruits is seriously compromised by the loss of their flesh firmness during pasteurization (Ribas-Agustí et al., 2017), while vacuum pasteurization in an array of apple cultivars unravelled varietal differences in textural properties following thermal processing (Bourles et al., 2009). The peach canning industry largely expands its finished products in the global market, having important economic implications for the main peach producing countries. To our knowledge and despite its economic importance, protocols that encompass the assessment of sensorial properties of processed peach products through comprehensive subjective and objective determinations do not exist. The present study aimed to set up a list of descriptors for sensorial analysis of canned peaches and to elaborate a toolkit to evaluate the textural properties of such products. The relationship between sensorial and instrumental measurements is additionally discussed.

3.2. Materials and Methods

3.2.1. Fruit material

Peach fruit (*Prunus persica*) of the cultivar 'Andross' was used for the needs of the current study. 'Andross' is considered as a reference clingstone peach cultivar for canning, being highly appreciated for its agronomic attributes (high yield) and the superior qualitative

physico-chemical properties of the fruit, such as intense yellow flesh colour, high flesh firmness and a high aromatic profile after processing.

Fruit were harvested at commercial maturity stage based on background colour. Fruit without defects and of uniform size (Grade A) were selected with a hand-held size calibrator. Besides size, to ensure homogeneity of the entire batch of raw material, the maturity stage of all fruits was determined non-destructively with the employment of a portable device (DA-meter,Turoni srl, Forli, Italy) which provides an index that expresses the absorbance difference (index of absorbance difference, IAD) between two wavelengths (670 and 720 nm) near the absorption peak of chlorophyll a (A670nm-A720nm). Such IAD measurements correspond to chlorophyll concentration (ground color) below the skin and provide an accurate estimate of fruit physiological maturity and consumer acceptance (Minas et al., 2021).

Fruit with similar maturity degree index values (IAD), were further selected and subsequently segregated into two lots. One lot (30 fruit) was used for direct analysis, as fresh product, and the other lot (*ca.* 40 kg of fresh fruit) was subjected to canning process, prior to analysis.

3.2.2. Methodology

The whole procedure of canning process was analytically described and schematically depicted in §1.7.2, Figure 1.9. The quality attributes of fresh and canned fruit were also determined as described in §2.3 and §2.4, respectively. The sensorial attributes of canned peach fruit were further assessed as previously described in §2.6.

3.2.3. Statistical analysis

Differences between textural and qualitative properties of two syrups were tested by means of a Student's *t*-test using Graph pad Prism 8. Sensory data were subjected to statistical analysis with the employment of SenPAQ software (Qi statistics). Analysis of variance (ANOVA) was performed on all panel data sets considering the samples, assessors, and their interactions as fixed variables. Significant differences were established using the Tukey honestly significant difference (HSD). All measurements were reported as means ± standard deviation (SD), and considered significant when $p<0.05$.

3.3. Results and Discussion

3.3.1. Qualitative attributes of fresh fruit

The quality attributes (color parameters, firmness, SSC, TA) of the freshly harvested 'Andross' fruit are presented in Table 3.1. 'Andross' fruit yellowish flesh colour was characterized by high L* (80.65), b* (78.51) and h* (79.52) values, and respectively low a* values (14.55). Drogoudi and Tsipouridis (2007) ranked 'Andross' as the cultivar with the most intense yellow flesh colour (high b* and low a* values) and the brightest intensity, as evidenced by the high L* values. Flesh firmness was ~ 30 N, SSC was 11.3% and TA was 0.46 %. Such qualitative attributes are considered appropriate for harvesting of fruit intended for canning and are similar to those reported by previous studies (Drogoudi and Tsipouridis, 2007, González-Buesa et al., 2011).

Table 3.1: Quality characteristics of harvested 'Andross' peach fruit.

Quality attributes	
L*	80.65 ± 2.52
a*	14.55 ± 3.42
b*	78.51 ± 3.91
Chroma	79.90 ± 4.10
H*	79.52 ± 2.26
Flesh Firmness (N)	29.64 ± 5.36
Soluble solids content (Brix)	11.30 ± 0.38
Titratable acidity (%)	0.46 ± 0.02

Values are means ± standard deviation (SD); N= 30 for color parameters and fresh firmness and n=3 for SSC, TA and Ripening index (SSC/TA).

3.3.2. Elaboration of protocols for determination of textural properties

Three independent assays were developed to evaluate the texture of canned peach halves, including: (A) puncture test for the determination of firmness in the middle of individual peach halves; (B) texture profile analysis (TPA) for the determination of hardness, fracturability, consistency, cohesiveness, springiness, chewiness; and (C) bulk mechanical behaviour using the Kramer shear cell method to determine the hardness and the total work of shearing. All three assays are schematically presented in Figure 3.1 and the developed protocols are provided below.

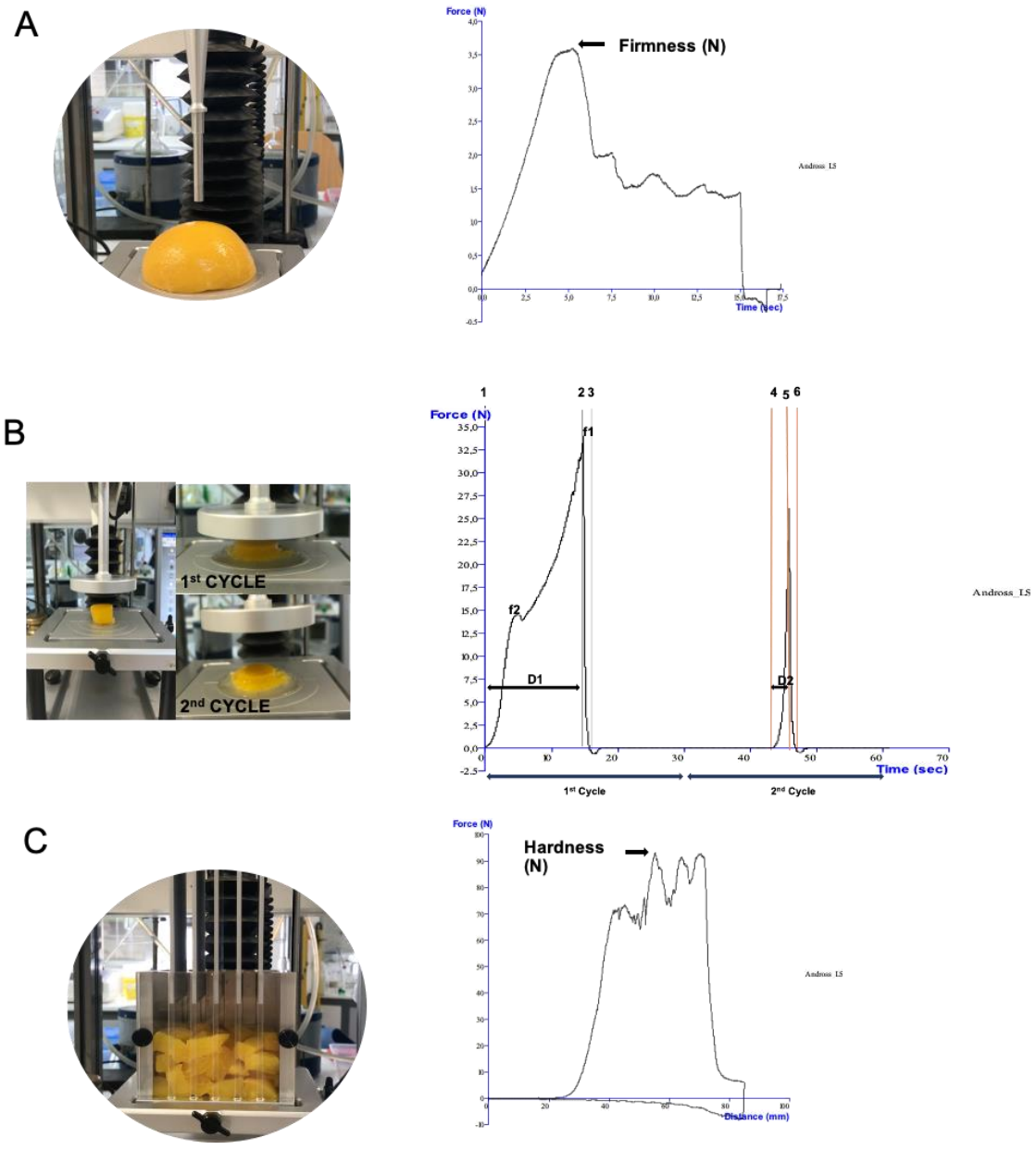


Figure 3.1: Principal assays and probes used in texture analysis of canned peach fruit: (A) Puncture test using a flat cylinder steel probe (∅6 mm); (B) TPA using a flat compression steel platen (∅75 mm); and (C) Kramer shear test cell with fixed 5-steel blades.

3.3.2.1. Puncture test protocol

An adjusted puncture test analysis for canned peach halves was developed **(**Figure 3.1A**)**. The sample (halved peach) was placed on a flat steel plate [heavy duty platform (HDP/90)] and the tests were performed with a 6 mm diameter probe (P/6). The probe penetrated into the sample at a speed rate of 1 mm/s up to a depth of 15 mm and the required penetration force for its rupture, defined as puncture firmness, was calculated as the maximum force applied.

The puncture test is the most commonly used large deformation mechanical test for firmness determination, applicable to a broad array of horticultural commodities (Ciacciulli et al., 2018, Fuentes-Pérez et al., 2014, Ruiz-Altisent et al., 2006), including canned peach (Manganaris et al., 2005). The puncture test is primarily used to measure the required force to penetrate the fruit flesh at a fixed distance with a steady speed rate of the moving probe. It is a straightforward assay, used for both fresh and processed fruit or vegetables and is often adopted compared to a compression test due to the simplicity of conditions to replicate the test (sample size and shape is predictable). The puncture test has been described as a sensitive probe to evaluate the internal structure of the tested product since the responses are related to tissue structural integrity (Ribas-Agustí et al., 2017). However, this assay alone does not encompass the entire profile of textural properties of canned peach products and needs to be coupled with other protocols to probe all textural attributes in a more holistic and comprehensive manner.

3.3.2.2. Texture profile analysis protocol

The TPA or the "Two Bite Test", is a double compression test that mimics the mouth's biting action. This technique is being used extensively to quantify multiple textural parameters of processed food products (Jaworska et al., 2010, Trejo Araya et al., 2009). In the case of peach, there have been a few preliminary studies where TPA analysis was employed for thermally or minimally processed peach products (Denoya et al., 2016, Zhang et al., 2012, Zhang et al., 2014).

Our approach encompassed an extensive set of preliminary experiments towards optimization and standardization of a protocol for TPA test applicable to canning peach fruit. Conditions such as sample size and shape, the speed rate of the probe and the degree of deformation were examined. Initially, the sample was made repeatable in size and shape for each measurement using customized cutting devices to obtain uniform tissue segments from each peach halve. The different test conditions explored were test speed (0.5, 0.8, 1.0 mm/s), and degree of deformation (75, 80, 85%). The selection of the TPA test parameters was based on: a) very good repeatability between measurements (using a set of measurements to achieve coefficients of variation (CV) below 20 % for all measured parameters); and b) avoiding a complete rupture of the tested samples during the two compression cycles.

For the TPA tests, uniform cylindrical pieces (15mm height x 30mm diameter) were obtained from the halved peaches by cutting perpendicularly to the outer surface of the fruit with a cork cutter-like device. Subsequently, the sample (outer face up) was placed on the flat steel HDP/90 Heavy Duty Platform and the tests were performed with

a 75 (P/75) mm diameter flat plunger that entirely covered the surface area of the sample. The compression force at a deformation speed rate of 0.8 mm/s, up to a maximum deformation of 80 % of the original height, was then applied. Two cycles of compression took place at 5 s interval to simulate the human chewing action and the TPA parameters, hardness, fracturability, consistency, cohesiveness, springiness and chewiness, were evaluated (Figure 3.1B); the expression of each TPA parameter and the mathematical equations used for their determination from the deformation profile are provided in Table 3.2 and Figure 3.1B.

Table 3.2: Textural parameters and calculations used in TPA analysis of canned peaches.:

Parameter	**Expression**	**Calculation***	**Units**
Hardness	The maximum peak force during the first compression cycle	Force 1(f_1)	N
Fracturability	The force at the first significant break in the TPA curve	Force 2 (f_2)	N
Consistency	The total positive force area of the double compression	Area (1:3) + Area (4:6)	N·mm
Cohesiveness	The ratio of the positive force area during the second compression to that during the first compression	Area (4:6) / Area (1:3)	-
Springiness	The ratio of the distance beginning from the start of the second peak and ending to its maximum force to the distance beginning from the start of the first peak and ending to its maximum force	Distance (4:5) (D2) / Distance (1:2) (D1)	-
Chewiness	The product of hardness x cohesiveness x springiness	Hardness x Cohesiveness x Springiness	N

*Each calculation (symbol) of texture parameter expression is illustrated in Figure 3.1B.

3.3.2.3. Kramer shear test protocol

Canned peach samples were additionally tested with a "bulk" firmness test which is designated to evaluate simultaneously the mechanical responses of a number of pieces of specific weight with the employment of a multi-bladed device (Kramer shear test cell, KST) (Figure 3.1C). This device is commonly used to analyse the bulk textural features of multi-particle products, such as cereals (Chaunier et al., 2005, Kerr et al., 2001) and to evaluate the texture of both raw ingredients and finished food products (Ayour et al., 2017; Walter et al., 2002), yet with limited exploitation to horticultural commodities (Canet et al., 2004, Sousa et al., 2007). KST has been employed on some thermally processed commodities, such as pasteurized apricots (Ribas-Agustí et al., 2017) and diced tomatoes (Rao and Barringer, 2006). To the best of our knowledge, this large deformation mechanical testing has never been applied for canned peach halves.

In the present study, sample preparation involved chopping of canned peach halves into pieces (22mm length x 12mm width x 11mm height) and placing them into the Kramer cell to cover its entire space uniformly (i.e. restricting any gaps in the cell) to improve reproducibility of the measurements. The steps of the established protocol are as follow. Canned peach halves were removed from the can, washed, drained and weighed out into equal portions. Three to four canned peach halves (*ca.* 200 g) were sliced into smaller pieces using a hand-held potato cutter and placed across the bottom of a five-bladed Kramer shear cell which was secured and screwed in the heavy-duty platform before filling. Prior to testing, a calibration procedure was performed to assure that the blades start always at the same distance from the bottom of the cell. Thereafter, the

weighed sample was evenly distributed to fill the shear cell by 50 % of its capacity; this volume level was kept constant in order to minimize variation between analyses. The cell blades were then driven into the sample at a crosshead speed of 3 mm/s and a total distance of 85 mm. The maximum force ("Kramer hardness") and total area under the shearing curve ("work of shearing" or "total hardness") were obtained and used as indicators of textural properties.

3.3.3. Textural properties and other qualitative attributes of canned fruit

Table 3.3 presents cumulative results of all textural properties [puncture firmness, 'Kramer' hardness, 'TPA' hardness, consistency, cohesiveness, springiness, chewiness and total hardness] determined for 'Andross' canned fruit in the two packing media (LS and GJ) by employing the above-mentioned tests. The puncture firmness of 'Andross' fruit in LS was 3.18 N, significantly lower (P<0.01) to GJ (4.04 N). TPA analysis allowed the simultaneous determination of hardness, springiness, cohesiveness, consistency and chewiness. In general, the experimental values were similar for both packing media; only a slight increment (P<0.05) of cohesiveness for the GJ samples was noted. The GJ samples exhibited higher Kramer hardness values (133 N), yet not statistically significant compared to the LS values (110 N). The total work of shearing or 'total hardness' (N.mm) represents the energy required for cutting the canned peach samples; no significant differences among LS and GS samples were noted, pointing that fruit tissue structure, following osmotic equilibrium in the two media tested, is the main determinant of the textural responses recorded than the packing medium employed.

Overall, a comprehensive toolkit of textural analysis has been developed and applied for first time to canned peach fruit products. This toolkit allows the determination of textural parameters as assessed with the employment of three large deformation assays (Puncture, TPA, KST). In the current study, although differences among the examined samples were evident using the common puncture test (in this assay, both compression and shear forces are involved), this was not the case when more delicate and comprehensive texture analyses were employed (TPA, KST).

The basic colour parameters were identical for samples packed in both media, showing high L* and b*, and low a* values (Table 3.3). Hue angle (H*) was 90° in both cases, typical for yellow fleshed products. 'Andross' halves that were filled with LS registered significantly higher SSC values ($P<0.001$) compared to 'halves' filled with GJ, while TA appeared unaffected by the packing medium used. The three significantly different properties (Cohesiveness *,$p < 0.05$; Puncture Firmness **, $p < 0.01$; SSC *** $p < 0.001$) found between the two packing media of "Andross" canned fruit are illustrated in Figure 3.2.

Table 3.3: Colour parameters (L, a*, b*, Chroma and H*), soluble solids content, titratable acidity and textural properties of 'Andross' canned fruit in LS and GJ samples, obtained by three different large deformation tests: Puncture, TPA and KST.*

	Packing medium	
Quality attribute	**Light syrup (LS)**	**Grape juice syrup (GJ)**
L*	54.90 ± 2.63	54.74 ± 2.37
a*	-0.17 ± 1.40	-0.60 ± 1.68
b*	45.62 ± 3.02	45.15 ± 4.25
Chroma	45.64 ± 3.02	45.19 ± 4.22
H*	90.29 ± 1.77	90.95 ± 2.25
SSC (Brix)	15.40 ± 0.17***	12.27 ± 0.34***
TA (%)	0.36 ± 0.01	0.34 ± 0.02
Puncture Firmness (N)	3.18 ± 0.58**	4.04 ± 0.54**
TPA Hardness (N)	28.73 ± 9.94	24.71 ± 10.38
Springiness	0.20 ± 0.03	0.20 ± 0.03
Cohesiveness	0.09 ± 0.01*	0.10± 0.01*
Consistency (N.mm)	170.5 ± 42.9	146.8 ± 66.5
Chewiness (N)	0.49 ± 0.18	0.44 ± 0.16
Kramer Hardness (N)	110.3 ± 27.4	133.4 ± 20.4
Total Hardness (N.mm)	2980 ± 382	3120 ± 456

Results are presented as mean ± standard deviation (SD); N= 24 for colour parameters, n=3 for SSC and TA, and n=6 for KST and n=9 for Puncture and TPA tests. Means followed by asterisk(s) within a row are significantly different: * at $p < 0.05$; ** at $p<0.01$; and *** at $p<0.001$.

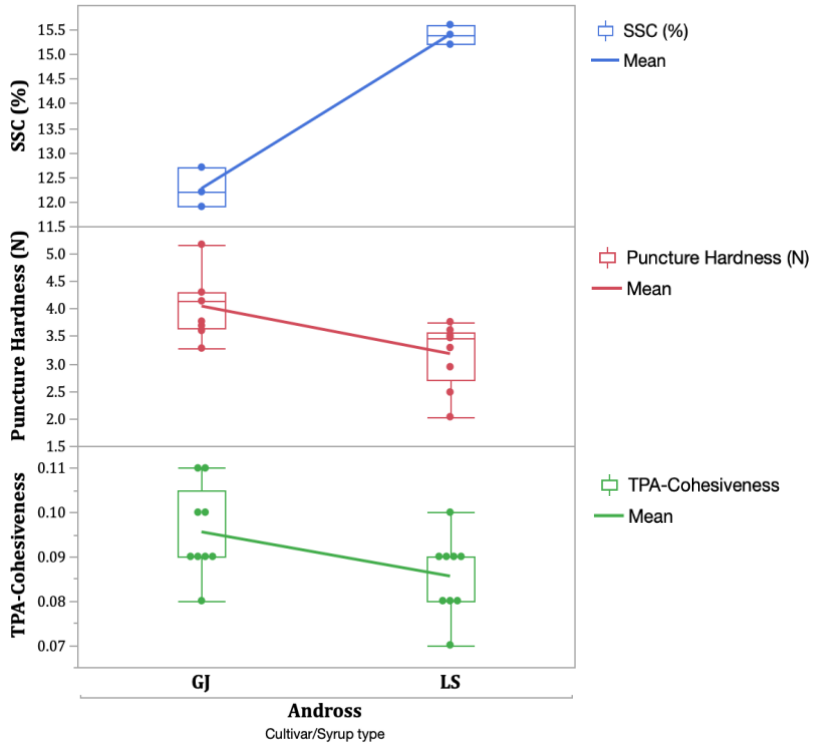


Figure 3.2: Box-and-whisker plots represent the intrinsic variability of the three instrumental properties (cohesiveness, puncture firmness, SSC) that showed significant differences between the two packing media of 'Andross' canned fruit in GJ and LS. Individual data points of each attribute are shown in dots. The mean values of the boxplots of each characteristic are connected with a straight line.

3.3.4. Sensory analysis

There has been an accumulating interest in several studies regarding sensory evaluation of foodstuff to assess product's quality attributes related to consumer preference and acceptability. In particular, descriptive sensory analysis is extensively used to characterize attributes of an array of fresh horticultural commodities (Aprea et al., 2012, Causse et al., 2001, Jaeger et al., 2003, Oliver et al., 2018, Péneau et al., 2007). Apart from the fresh

product, several studies have focused on sensory evaluation of processed fruit as well (Bonneau et al., 2018, Bett-Garber et al., 2010, Haug et al., 2013, Lieb et al., 2018). A range of sensory descriptors for canned peach fruit has been identified by an early preliminary study that challenged accepted interpretations in the field of quality evaluation (Manganaris et al., 2005).

However, as for textural studies, no standardized protocols on descriptive sensory profile of canned peach fruit exist that is a long-due request by the canning industry. The key steps of a sensory analysis plan generally include the following principles: setting specific analysis goals; define the product type; design the tests; select an appropriate group of panelists; assess and analyse the results (Lawless and Heymann, 2010). We hereby present a customised sensory analysis protocol that was developed to assess a range of attributes for canned peaches. Based on the aforementioned principles, the pillars of our approach encompassed the screening and training of the panelists, the development of a standardized vocabulary, the sample evaluation for the processed peach products packed with two different liquid media and data interpretation.

3.3.4.1. Pre-screening and training of panelists

A panel of twenty judges were pre-screened for sensory acuity and trained based on their ability to discriminate differences between canned peach products, describe basic flavours/tastes and distinguish different levels of intensity of a given attribute by following the ISO standards 6658(2005) and 4120(2004). Initially, the panelists were introduced to the principles of sensory evaluation followed by training on basic flavours/tastes with the aim to create memory and become familiar with each taste

individually, as well as to recognize and describe the examined taste. According to the methodology of triangle test, nine basic attributes of flavours, along with corresponding aqueous reference solutions, were used to train the panel. The samples were prepared and served in plastic glasses (20 mL) as follows: bitterness (caffeine; 0.2 g/L), acidity (citric acid; 0.2 g/L), sweetness (sucrose; 6 g/L), salty (cooking salt; 1.3 g/L), umami (monosodium glutamate; 0.3 g/L), astringency (tannic acid; 0.5 g/L), metallic (iron III sulphate heptahydrate; 0.01 g/L), fruity (isoamyl acetate; 20 mg/L) and 'green' flavor (z-Hex-3-en-1-ol; 0.4 mL/L). Each specific flavour was presented to the panelist to select the sample perceived as different every time; one out of three samples was the taste of interest. The panelists were considered as reliably performing when they had succeeded to identify the odd sample in the triangle test by providing 100 % correct answers upon repetition of the test.

Based on the ranking test, the panelists were subsequently trained and assessed in their ability to describe and distinguish graded levels of intensity of the aforementioned flavours. A series of samples (4 samples of graded intensity of the same attribute) in specific random order were presented to each panelist in plastic water glasses (20 mL per sample) so as to ensure that evaluations are not affected by the order the samples are presented. The concentrations of all reference standards (compounds) used to assess the sensory attributes are presented in Table 3.4. The success of the test was determined based on the ability of the panelist not to invert more than one adjacent pair; if this was not the case, the panelist was eliminated from the specific type of analysis.

Table 3.4: Concentrations of reference standards (compounds) employed in evaluation of sensory attributes.

Material	**Description of flavour/taste**	**Concentrations**			
Caffeine (g/L)	Bitterness	0.15	0.22	0.34	0.51
Citric acid (g/L)	Acidity	0.10	0.20	0.30	0.50
Sucrose (g/L)	Sweetness	4.50	9.00	14.0	25.0
Cooking salt (g/L)	Salty	0.84	1.20	2.00	2.50
Monosodium glutamate (g/L)	Umami	0.21	0.30	0.39	0.50
Isoamyl acetate (mg/L)	Fruity	5.00	10.0	20.0	40.0
Hexyl acetate (mg/L)	Green	0.50	5.00	20.0	50.0

3.3.4.2. Development of standardized vocabulary

The final sensory panel constituted of twelve trained panelists who were asked to evaluate commercial canned peaches over two training sessions within one day (morning and afternoon session), lasting 2 h each. In the first session, the panelists were asked to describe the sensory perception in respect to smell, visual features, taste and hardness of commercial canned peaches and write down any perceived characteristic as well as all the descriptive terms that were relevant to product physical and sensorial properties. A sensory vocabulary of fifteen sensorial attributes was thus developed and used to describe the canned samples for odour (1 attribute), appearance (5 attributes), texture (2 attributes)

and taste/flavour (7 attributes). A complete list of all sensorial attributes, definitions and reference standards used in the training sessions are summarized in Table 3.5.

A short period of resting and cleansing of the oral cavity of each panelist with mineral water and a toasted bread sample was taking place between successive assessments of the basic tastes and rankings. During the second session, each sensory attribute was scaled on a 10-points intensity evaluation scale; a structured rating scale, anchored at the ends by the terms “low” or “none” on the left and “very” on the right, was presented and the two extreme ends of the scale were discussed and adopted among the panelists. For evaluation, the cans of peach halves were opened on that day and the reference standards were freshly prepared each time of performing the sensory session.

Table 3.5: List of sensory attributes, definitions and reference standards used in the training sessions of the sensory panel.

	Attributes	**Definitions***	**Reference standards (intensity)***
ODOR	Peach aroma	Intensity of characteristic aroma of commercial canned peach (none to very)	None: Mineral water Very: Freshly prepared commercial canned peach was blended to puree
APPEARANCE	Peach color	Based on colour scale given, define the colour of peach halve (greenish yellow to dark orange)	A colour scale was constructed and given
	Colour uniformity	Based on scale given, define the degree of colour uniformity (non-uniform to uniform)	Images were taken and given as an example of the two ends
	Brightness	Based on scale given, define the glossy surface showing bright reflection (less shiny to very shiny)	Images were taken and given as an example of the two ends
	Residual peel	The skin remaining after peeling with caustic soda (none to very)	-
	Blemished fruit	Something spoils the appearance of peach halve which is otherwise aesthetically perfect (none to very)	Images were taken and given as an example of the two ends
TEXTURE	Hardness	Force required to compress and deform 75 % of the halve centre, using your thumb (low to very hard)	Low: Cream cheese Moderate: Soft pitted canned olive Very hard: Raw peanut
	Difficulty in chewiness	The degree of difficulty observed during chewing of peach halve (low to very)	Try the appropriate piece of area (as shown in additional part) and evaluate the samples based on the

			chewing time (<3 s: low and > 12 s: very)
TASTE	Sweetness	Taste characteristic of sucrose (low to very)	Low: Freshly prepared canned peach puree with sucrose (4.5 g/L) Very: Freshly prepared canned peach puree with sucrose (30 g/L)
	Acidity	Taste characteristic of citric fruits (low to very)	Low: Freshly prepared canned peach puree with 50 % more water Very: Freshly prepared canned peach puree with citric acid (0.5 g/L)
	Bitterness	Taste characteristic of caffeic acid (none to very)	None: Mineral water Very: Freshly prepared aqueous solution with caffeine (0.5 g/L)
	Astringency	Sensation of dryness on the palate or muscle contraction (squeeze lips) caused by some substances like tannins (none to very)	None: Mineral water Very: Freshly prepared canned peach puree with tannic acid (0.5 g/L)
	Peach flavour	Typical flavour of commercial canned peach (low to very)	Low: Freshly prepared canned peach puree with 50 % more water Very: Freshly prepared canned peach was blended with peach nectar
	Fruitiness	The characteristic fruity note associated with fruits besides peach (low to very)	Low: Freshly prepared aqueous solution with isoamyl acetate (5.0 mg/L) Very: Freshly prepared aqueous solution with

			isoamyl acetate (40 mg/L)
	Off-flavour	Intensity of atypical flavour perceived in your mouth after chewing and is often associated with deterioration of the product such as overcooked (none to very) *If yes please specify	None: Commercial canned peach Very: Commercial canned peach halve was baked in oven for 20 min (180°C)

*Definitions and reference standards of sensory attributes as adapted from literature information: Bonneau et al. (2018), Cardoso and Bolini (2008), Gunness et al. (2009), Apostolopoulos and Brennan (1994), ISO 5492:1992 (E/F) - Glossary of terms relating to sensory analysis.

3.3.4.3. Evaluation of the samples

Two successive evaluation sessions were carried out to assess the intensity of all 15 sensory attributes of canned peach in each filling medium as previously indicated. All sensory evaluations were performed in a designated area with twelve individual booths under controlled illumination and temperature (ISO 8589:2007); samples (halves of canned fruit) were served to the panelists in an encoded (3-digit code) transparent plastic bowl, whereas the reference standards were presented by name. The panelists were asked to evaluate and score the intensity of attributes for each sample with reference to standards on a graded scale in the following order: odour was examined first by sniffing the sample, then appearance was assessed, followed by texture (testing by hand and oral) as instructed in the training session. Lastly, the taste/flavour attributes were evaluated.

The organoleptic profile of all sensorial attributes of ‘Andross’ canned peach samples in LS and GJ packing media are summarized in Figure 3.3. The sensory panelists showed fairly good repeatability and consistency in their scores. For both samples, four

attributes related with brightness, bitterness, astringency and off-flavour were significantly different between the two canned samples tested. Conversely, there were no significant differences between the two products regarding all other remaining attributes, including peach aroma, colour, colour uniformity, residual peel, blemished, hardness, chewiness, sweetness, acidity, fruitiness and peach flavour. Overall, both samples were characterized by a similar pattern of scoring with slight differences.

Among the examined attributes, the sensory descriptors of colour uniformity and texture were the highest rated for LS peaches, followed by their GJ counterparts. Zero scores were noticed in both samples in terms of residual peel, astringency and off-flavour for LS and residual peel and blemished fruit for GJ. Regarding the taste profile, LS and GJ samples were high in the descriptors of sweetness (5.8-5.6), fruitiness (6.1-5.9) and peach flavour (6.4-5.8), whereas rather low intensities in acidity (1.1-1.6), bitterness (0.1-0.9), off-flavour (0.0-1.0) and astringency (0.0-0.7), were registered. A similar trend was observed for the appearance profile, with higher scores being recorded for colour (5.4-5.3), colour uniformity (7.0-6.6) and brightness (5.7-6.6), as well as for the lower scores in residual peel (0.0) and blemished fruit (0.1-0.0). The texture (6.9-7.0) and peach aroma, odour (6.5-6.2) attributes were also scored with relatively high intensities by the panellists.

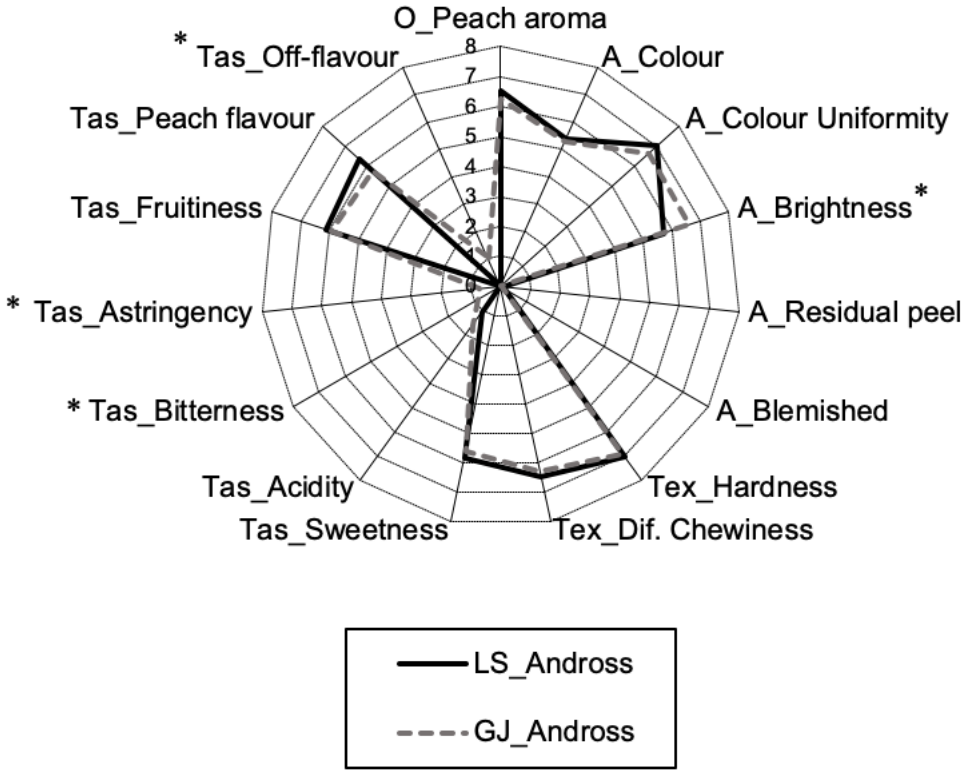


Figure 3.3: Sensory profile of 'Andross' canned peach fruit in light syrup (LS_Andross) and grape juice (GJ_Andross). The data are obtained from 15 examined attributes as scored by the sensory panel. For each sensory attribute the perceived mean intensity increases outward from the centre point. Attributes with asterisk (*) indicate statistically different (P<0.05) between two syrups. Abbreviations such as (O) is for odour, (A) for appearance, (Tex) for texture and (Tas) for taste.

3.4. Conclusions

In the current study, mechanical tests were coupled with sensorial analysis towards the provision of a comprehensive toolkit to assess qualitative attributes and textural properties of canned peach fruit. In particular, through an array of large deformation tests, nine textural attributes can be evaluated, i.e. 'puncture firmness' (on individual halves),

‘Kramer’ hardness (applied in a complex mixture of peach slices), ‘TPA’ hardness (using the central section of halves), fracturability, consistency, cohesiveness, springiness, chewiness and total hardness. Furthermore, with a descriptive sensorial qualitative analysis, as elaborated in the present work, 15 different attributes, related to odor, appearance, texture and taste can be determined. Using the former objective tests, canned peach products can be differentiated on the basis of textural parameters, whereas for the latter, evaluation is based on several sensorial attributes related to consumer preferences and therefore permits discrimination among samples of varying quality. Overall, both approaches provide complementary information on important quality parameters of canned peach products and can be adopted by both breeders and the canning industry to select new clingstone peach cultivars suitable for canning. Moreover, the proposed analytical toolkit would be valuable to establish appropriate thermal processing protocols aiming at desirable end-product quality characteristics as well as to monitor the shelf life of these processed fruit products.

4. The effect of genotype and storage on compositional, sensorial and textural attributes of canned fruit from commercially important non-melting peach cultivars

Abstract

Peach (*Prunus persica*) fruit is widely consumed, both as fresh or as processed (mostly by canning) product. Despite its economic importance, a limited number of studies have dealt with quality assessment of clingstone peach cultivars after thermal processing. Thus, the aim of the current study was to evaluate the effect of canning process on compositional, sensorial and textural attributes of fruit from seven non-melting peach cultivars which exhibit on-tree ripening in succession, spanning from July till mid-September in the northern hemisphere. Descriptive quantitative analysis indicated discrete varietal differences, providing useful insights for the industry regarding the quality and marketing potential for canned products of each cultivar. Fruit packed in diluted-clarified grape juice concentrate, aiming towards a less caloric content product, demonstrated an inferior consumer perception regarding bitterness, astringency and off-taste. Storage of the canned fruit (6 versus 24 months) led to texture depletion modifications on a cultivar-dependent manner. 'Ferlate®' registered desirable textural properties, while 'Mirel®', besides the appealing orange-coloured fruit pieces, aligned with satisfactory sensorial properties, provide further marketing options for the peach canning industry. Both early ('Romea') and late-season ripening ('VLG') cultivars were proven amenable to canning with acceptable quality attributes, offering a sustainable solution towards extension of the non-melting peach harvesting season.

Keywords: *Prunus persica*, clingstone, texture, sensory, firmness, fruit processing

4.1. Introduction

Peach (*Prunus persica*) is one of the most important fruit crops cultivated worldwide, being widely consumed, both as fresh or as processed (mostly by canning) product. Peach cultivars are classified as either melting flesh (MF) or non-melting flesh (NMF) on the basis of fruit texture following maturity (Morgutti et al., 2006). The latter are firmer and are destined mainly for canning due to their superior retention of flavour and texture during the canning process (Slaughter et al., 2006).

Peaches are subjected to canning as a means to add value (product differentiation, attractive to a different target market than the fresh fruit) and facilitate year-round availability. Intriguingly, a limited number of studies have dealt with assessment of the quality attributes and storage potential of clingstone peach cultivars after thermal processing. Therefore, it is of great importance to demonstrate the ability of the processing industry to deliver high quality products in terms of their organoleptic properties such as colour, flavour/taste and texture. However, the quality characteristics of the end product may vary considerably, as being highly affected by the cultivar, the maturity stage at harvest and the processing protocol applied (Techakanon et al., 2017).

Flavour, texture and colour of processed products are critical attributes to consumer's quality acceptance and the product's market success. Such quality characteristics can be determined by sensory analysis for flavour and texture, and by instrumental methods for compositional, physicochemical and textural properties (Ross, 2009, Farina et al., 2019). These quality assessment approaches when employed together

can provide complementary information for a complete description of all attributes describing the product.

Any well-documented relationship between the instrumental and sensory measurements is very beneficial to identify whether an instrumental method can predict the corresponding sensory characteristics (Ross, 2009). An early study elucidated the interrelationships between sensory and mechanical characteristics of canned peaches and demonstrated that the mechanical parameters are good predictors of fruit textural properties (Apostolopoulos and Brennan, 1994). Only recently, a comprehensive toolkit to determine an array of textural and sensorial properties of canned peaches has been elaborated.

The peach canning industry has adopted a minimum maturity index based on visual flesh colour at inch depth using colour disks as prototypes to match the flesh colour (Crisosto et al., 2007). Texture of peach fruit is another important quality attribute, which is substantially modified during the canning process, while the mechanical properties are also strongly influenced by the cultivar and maturity stage of the peach fruit (Belisle et al., 2018). As a general rule, the optimum maturity of peaches for canning purposes is when the fruit is yellow-coloured and not too soft (Siddiq et al., 2012). Only recently, orange-fleshed cultivars are being promoted, offering a new canning product. Another important agronomic feature of newly introduced non-melting cultivars is that their on-tree ripening period is expanded from late June until mid-September in the northern hemisphere (Drogoudi and Tsipouridis, 2007). Considering all the above-mentioned actualities, there is a constant request by the peach canning industry to introduce new

cultivars (both early and late-harvested) that can expand the harvesting season and subsequently the seasonal production period for the canning industries.

Through breeding programs, a significant number of new cultivars have been released. However, few or no information exist about such cultivars regarding their properties on both fresh fruit and their processed products after canning. Therefore, the current study aims to implement such analysis on seven commercially important non-melting peach cultivars, packed in standard and a low-calorie filling medium to fit with current consumer-market trends. To further elucidate the storage potential of canned products, such analyses were conducted after 6 and 24 months.

4.2. Materials and Methods

4.2.1. Chemicals

For HPLC analysis, sulphuric acid and water of HPLC purity grade were purchased from Merck (Darmstadt, Germany), whereas analytical grade sucrose, fructose and glucose (all with contents > 99%) were obtained from European Directorate for the Quality of Medicines and Healthcare (EDQM, Strasbourg, France). The organic acid standards including malic, citric, shikimic, fumaric and tartaric acids were acquired from Sigma-Aldrich (St. Louis, MO, USA). Aqueous solutions used in different experiments were prepared using water of HPLC-purity grade. For sensory analysis, the reference compounds of each taste note, such as caffeine, citric acid, tannic acid, monosodium glutamate, iron (II) sulphate heptahydrate, isoamyl acetate and hexyl acetate, used to train the panel, were all of food grade and supplied by Sigma-Aldrich.

4.2.2. Fruit material

Peach fruit (cultivars ‘Romea’, ‘Catherina’, ‘Mirel®’, ‘Fercluse®’, ‘Everts’, ‘Ferlate®’, ‘VLG’) were harvested at the ‘commercially maturity stage’ based on fruit size and exocarp background colour from a commercial orchard located in Northern Greece (Agia Marina, Imathia, Central Macedonia). Three of the aforementioned cultivars are considered as new releases from breeding programs (‘Mirel®’, ‘Fercluse®’, ‘Ferlate®’) and one of unknown origin (‘VLG’), with few or no details known regarding the sensorial and textural properties of its canned product.

For each cultivar, *ca.* 40 kg of harvested fruit without any visual defects were selected and sorted into distinct groups using a hand-held fruit size calibrator (Grade A). To assure maturity homogeneity of the samples per cultivar, we have further applied a non-destructive assessment of maturity index with the employment of a hand-held DA-meter (Turoni srl, Forli, Italy), as elsewhere described (Drogoudi et al., 2016). Thirty fruits were used for direct quality analysis of the fresh produce and the remaining fruits were canned at the premises of Venus, as previously described in §1.7.2, Figure 1.9.

4.2.3. Methodology

Quality attributes of fresh and canned peach fruit such as flesh colour, flesh firmness, SSC and TA were determined as previously described in §2.3 and §2.4. The firmness of canned peach halves was measured using the comprehensive protocol developed in the previous experiment (chapter §3) and as described in §2.4. Briefly, texture measurements of canned samples were conducted using a multipurpose texture analyzer TA-XT.plus (Stable Microsystems, Godalming, Surrey, UK), equipped with a 30 kg load cell and employing

a 6 mm flat steel cylindrical probe, a 75 mm flat steel compression plate, and a 5-bladed fixture, respectively, for the corresponding three large deformation mechanical testing assays performed; i.e. puncture test, texture profile analysis (TPA) and Kramer shear test (KST). Puncture tests were performed on canned peach halves by penetration of the probe at a speed of 1 mm s^{-1} up to a depth of 15 mm and firmness was calculated as the mean of the maximum force registered in Newtons ("puncture firmness"). Subsequently, each sample was compressed to 80% deformation of the original height of a uniform cylindrical piece of peach flesh tissue (15 mm height x 30 mm diameter) twice at a speed of 0.8 mm s^{-1}. With the TPA test, determination of hardness, springiness, cohesiveness and chewiness was feasible based on the force–distance–time data of two consecutive cycles of compression-decompression. In the bulk analysis of Kramer-shear test, canned peach halves (200 g) were sliced and packed uniformly in the cell, followed by shearing with the blades at a speed of 3 mm s^{-1} and distance of 85 mm. The maximum force (N) or "Kramer hardness" and the total work of shearing ("total hardness") were recorded. All experiments were conducted in triplicate for each packing medium, at room temperature ($23 \pm 2\ ^{\circ}C$).

Subsequently, individual organic acids and sugars were identified and quantified following the protocol described in §2.5. The sensory analysis of canned peach samples (LS and GJ) were assessed using the comprehensive protocol elaborated in the first experiment (chapter §3) and as described in §2.6. Briefly, a 12-personel trained panel, being selected from an initial 20-member panel, based on their acuity during pre-screening sessions, was initially subjected to a comprehensive training session. The framework of

the training session was structured as follows: (a) initial practice with commercial canned peaches in halves and familiarity with the theory of pre-defined attributes relevant to odour, appearance, texture and taste of canned peach; (b) final vocabulary development of sensorial attributes; (c) discussion of sensory attributes definitions and reference standards; (d) presentation and discussion of a 10-point evaluation scale in terms of how to score each characteristic in reference to a respective standard for the evaluated attribute; and (e) final practice of the same procedure set up before the final assessment day. Two assessment sessions were performed to appraise a sum of fifteen sensory attributes of canned peach samples in total, namely: odour, peach colour, colour uniformity, brightness, residual peel, blemished fruit, hardness, difficulty in chewiness, sweetness, acidity, bitterness, astringency, peach flavour, fruitiness and off-flavour. In addition, a colour index scale was constructed and used as reference by the panel (Figure 4.1).

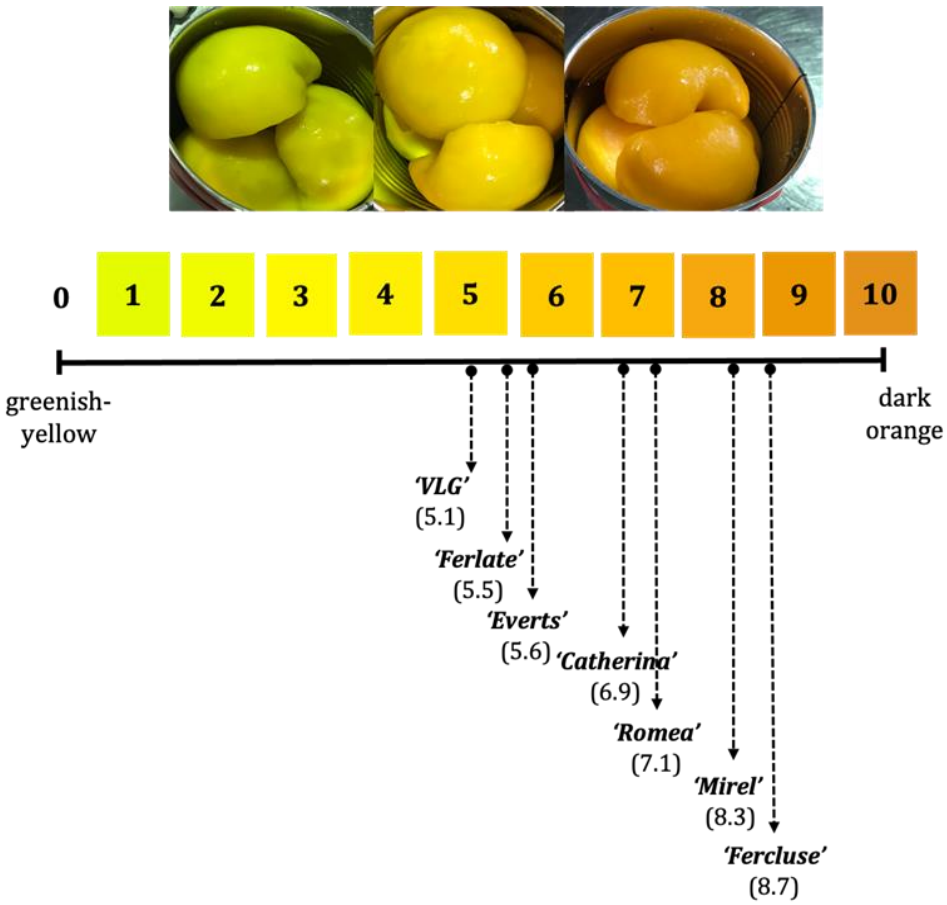


Figure 4.1: Colour intensity index for canned peaches assessment. The evaluation scale was structured with the following scores: 1-2 for light green; 3-4 for slightly yellow; 5-6 for yellow; 7-8 for light orange; 9-10 for dark orange (MacDougall, 2002). Peach cultivars can be categorized in three distinct colour groups according to the mean scores of cultivars in both syrups as follows: (1) yellow for 'VLG', 'Ferlate®' and 'Everts', (2) yellow-orange for 'Catherina' and 'Romea', and (3) orange for 'Mirel®' and 'Fercluse®'.

Nine basic attributes of flavours, along with corresponding aqueous reference solutions, were used to train the panel. The reference compound of each flavour was caffeine (bitterness), citric acid (acidity), sucrose (sweetness), cooking salt (salty),

monosodium glutamate (umami), tannic acid (astringency), iron (II) sulphate heptahydrate (metallic), isoamyl acetate (fruity) and hexyl acetate (green). The samples (canned halves) were placed into transparent plastic bowls and were presented monadically according to a balanced design, labelled with arbitrary three-digit codes. The assessors were requested to evaluate the intensity of each attribute perceived on a 10-point structured rating scale, anchored at the ends by the terms “none” or “low” on the left and “very” on the right.

4.2.4. Statistical analysis

Statistical analysis was conducted using the JMP Pro (Version 15.2, SAS Institute, Cary, NC). Fresh fruit properties were evaluated using one-way ANOVA to compare cultivars. Canned fruit properties analysis followed a Completely Randomized Design (CRD) with a three way 7x2x2 full factorial treatment model and analysis to address the significance of cultivar, storage time, packing medium and all their interactions (two-way and three-way) using the Fit Model Least Squares platform. Significant differences ($p < 0.05$) among samples (effects/treatments) were evaluated using the Tukey’s Honest Significant Difference (HSD) multiple comparison test.

Sensory panel data were analysed using the SENPAQ software (Qi Statistics, Ruscombe, UK). The main effects (sample and assessor) were tested against the sample by assessor interaction, with sample as a fixed effect and assessor as a random effect. For those attributes exhibiting significant difference in the two-way ANOVA, Tukey’s Honest Significant Difference (HSD) multiple comparison test was applied to determine which sample means differed significantly ($p < 0.05$).

In order to investigate the linear relationships between the instrumental and sensory data of four grouped properties (hardness, chewiness, sweetness and acidity) of canned peach fruit, we calculated and reported the Pearson pairwise correlations and their significance with the employment of the JMP Pro software (Version 15.2, SAS Institute, Cary, NC).

4.3. Results and Discussion

4.3.1. The effect of cultivar on quality attributes of fresh peach fruits

Flesh firmness (FF), colour parameters (L*, chroma, h°), SSC, TA, and contents of individual acids differed significantly ($p < 0.05$) among the examined cultivars (Table 4.1). Flesh firmness values were within the standard range preferred by the canning industry, spanning from 34.2 N (early-ripening 'Romea') up to 47.5 N (late-ripening 'Ferlate®').

SSC ranged from 10.1 to 12.4 °Brix; the early-ripening cultivars ('Catherina', 'Romea', 'Mirel®') showed the lowest content, yet above the threshold set by the canning industry. Higher SSC values were registered for mid- ('Fercluse') and late-ripening ('Everts', 'Ferlate', 'VLG') cultivars. Previous studies have also demonstrated a higher SSC accumulation in mid- to late-ripening peach cultivars compared to early-ripening cultivars due to the non-interruption of the growing process (Drogoudi et al., 2016, Drogoudi et al., 2017). Being a general quality criterion for both freestone and clingstone cultivars, the SSC as a quality indicator should be higher than 10% and 11% for early- and mid-/late-ripening cultivars, respectively (Farina et al., 2019, Hilaire, 2003). Sucrose

was the predominant sugar, followed by glucose, while fructose was found at lower concentrations. In previous studies, glucose and fructose have been reported to be present in equimolar quantities (Génard and Souty, 1996, Orazem et al., 2011), whereas in the present work, the level of glucose for most of the cultivars was 2- to 3- fold higher than fructose (Supplementary Table S 1).

The TA values ranged between 4.4 ('Everts') and 6.7 ('Mirel®') g malic acid L^{-1}; as a general trend higher values were exhibited for the early-ripening cultivars and lower values for their late-harvested counterparts (Table 4.1). Peach acidity is mainly controlled by the genotype as a cultivar dependent parameter, as well as by environmental conditions and fruit maturity (Crisosto, 1999). Peach fruit with TA values of less than 5.0 g malic acid L^{-1} are considered of relatively low acidity and are those mainly appreciated by the consumers for fresh fruit consumption. However, no upper TA concentration threshold of acceptance for peach fruits that are destined for canning has been established since the final taste is being also affected by the addition of the packing medium (syrup).

Significant differences among the examined cultivars in all organic acids analysed were found. Malic acid appeared as the prevalent organic acid detected, with citric and shikimic acids being present to a lesser extent, while fumaric acid was at trace or non-detectable levels (Supplementary Table S 1). The highest level of malic acid was determined in 'Mirel®' (7.0 mg g^{-1} FW) and 'Romea' (6.9 mg g^{-1} FW), while 'VLG' fruits registered the lowest amounts (4.5 mg g^{-1} FW). 'Mirel®' fruits also contained the highest amount of citric acid (2.2 mg g^{-1} FW) among the examined cultivars. Shikimic acid was found at the highest levels in 'Everts' (2.9 mg g^{-1} FW) and at a lower concentration in

‘Catherina’ and ‘Romea’ (1.1 mg g^{-1} FW). As a whole, the total acids content was higher in ‘Mirel®’ (11.7 mg g^{-1} FW) and lower in ‘VLG’ (6.8 mg g^{-1} FW). Malic acid, followed by citric, shikimic and fumaric acids are the main organic acids present in peach fruit (Orazem et al., 2011), all contributing to the sour taste (Esti et al., 1997, Wanpeng et al., 2017). The TA values followed a similar pattern with the sum of organic acids per cultivar, although this was not always the case when comparing SSC values with the individual sugars per cultivar.

Early to mid-season ripening cultivars exhibited SSC/TA in the range of 15.2 and 18.7; greatest values (>25.0) were noted in the late-season cultivars, namely ‘Everts’ and ‘VLG’ (

Table 4.1). The SSC/TA ratio is commonly used as a quality indicator and higher ratios are in most cases linked with enhanced overall peach fruit quality and consumer's acceptability (Crisosto and Crisosto, 2005).

In this study, all peach cultivars also showed slight yet significant differences among the examined flesh colour parameters. 'Everts' exhibited the highest L, chroma and hue angle values, being characterised as the cultivar with the brightest and most intense yellow colour (*

Table 4.1**)**. Late-season ripening cultivars generally tended to demonstrate higher hue angle values (>80.0°) than the early and mid-season cultivars. Notably, new releases of the breeding programs, such as 'Mirel®' and 'Fercluse®' demonstrated an orange-coloured canned product, thus providing further marketing possibilities for the canning industry (Figure 4.1). Colour, both for fresh and processed peach products, has a strong influence on consumer's opinion to either accept or reject this commodity; actually, the flesh colour, jointly with flesh firmness, are the main criteria of the maturity stage for clingstone peaches prior to handling the fruit in the cannery (Crisosto et al., 2007).

Table 4.1: Fruit quality attributes of the examined non-melting peach cultivars at harvest.

Cultivar	Quality attributes						
	FF (N)	**SSC (°Brix)**	**TA (g malic acid L^{-1})**	**SSC/TA**	**L***	**Chroma**	**h°**
Romea	34.2 ± 0.9 c	10.9 ± 0.1 c	6.4 ± 0.01 a	17.0 ± 1.1 e	78.6 ± 0.3 a	78.0 ± 0.5 cd	75.2 ± 0.1 c
Catherina	35.0 ± 0.6 c	10.1 ± 0.1 d	5.4 ± 0.01 b	18.7 ± 0.4 d	80.0 ± 0.1 cd	73.8 ± 0.2 d	73.9 ± 0.1 d
Mirel®	42.3 ± 0.5 b	10.2 ± 0.1 d	6.7 ± 0.02 a	15.2 ± 0.4 f	78.0 ± 0.1 d	78.2 ± 0.2 bc	73.5 ± 0.1 d
Fercluse®	36.0 ± 0.9 c	12.4 ± 0.1 a	4.8 ± 0.01 bc	25.8 ± 1.4 b	80.7 ± 0.2 bc	82.3 ± 0.2 ab	71.4 ± 0.1 e
Everts	41.2 ± 0.9 b	11.6 ± 0.1 b	4.4 ± 0.02 c	26.4 ± 1.4 ab	82.5 ± 0.2 ab	85.6 ± 0.2 a	83.8 ± 0.1 a
Ferlate®	47.5 ± 0.7 a	11.9 ± 0.1 ab	5.1 ± 0.01 b	23.3 ± 0.4 c	80.4 ± 0.1 bc	79.6 ± 0.1 bc	82.7 ± 0.1 a
VLG	39.0 ± 0.4 bc	12.1 ± 0.1 ab	4.5 ± 0.03 c	26.9 ± 1.0 a	82.0 ± 0.2 bc	81.2 ± 0.4 bc	81.0 ± 0.1 b

One-way ANOVA was performed by the linear model on raw data followed by Tukey's honest significant difference (HSD) multiple comparison test. Values are means ± standard error (SE); N=30 for flesh firmness and colour parameters and n=3 for SSC and TA. Values in the same column followed by different letters are significantly different at $p < 0.05$.

4.3.2. The effect of canning process on organic acid content

The levels of total and individual organic acids were affected by canning, cultivar and canning x cultivar interaction ($p < 0.05$). For all acids, the main effects for cultivar and canned fruit type interactions are highly significant (Table 4.2). The content of organic acids significantly decreased after canning in both syrups, registering overall mean loss values by 65% and 74% in GJ and LS media, respectively. Malic acid was the predominant acid on fresh tissue, followed by citric and shikimic acids, while a substantial reduction due to thermal processing and storage in its content was monitored (Table 4.2). Citric acid appeared to be the least affected acid among several cultivars, exhibiting greater retention compared to the other two acids, as also has been reported for grapefruit juice (Igual et al., 2010); it is possible that complexation of this organic acid with cell wall components may be responsible for its confinement within the peach tissues.

Tartaric acid was detected only in processed peach samples of 'Romea', 'Mirel®', 'Fercluse®' and 'VLG' cultivars packed in GJ, registering values in the range 0.1-0.3 mg g^{-1} FW. The GJ syrup is derived from a clarified-concentrated grape juice, where the tartaric acid appears as a major organic acid. The diffusion of tartaric acid from the canning medium (GJ) into the peach flesh is feasible via the established osmotic equilibrium of the can contents upon storage; instead, no tartaric acid in both fresh and canned peach fruit in LS was detected (Durst and Weaver, 2013, Sharma et al., 2002).

The concentration of total acids in GJ ranged from 2.6 mg g^{-1} FW in 'Romea' to 4.0 mg g^{-1} FW in 'Fercluse®', while the content in LS ranged from 1.8 mg g^{-1} FW in 'Fercluse®' to 3.1 mg g^{-1} FW in 'VLG'. In general, canning considerably reduced the

content of organic acids in both syrups as compared to fresh fruit; the ‘VLG’ registered the higher retention of organic acids following canning and storage. Possible reasons for organic acid depletion in thermally treated peach fruit could be explained by either organic acids thermal decomposition or the involvement of these compounds as reactants in Maillard reactions or diffusion in the packing media following osmotic equilibrium (Nicoli et al., 1999, Aktas and Yildiz, 2011).

Table 4.2: Content of total and individual organic acids (malic, citric and shikimic acids) of canned peaches of seven non-melting peach cultivars, filled with LS and GJ, after 6 months of storage at room temperature.

Cultivar	Canned fruit type	Organic acid content (mg g^{-1} FW)			
		Malic acid	**Citric acid**	**Shikimic acid**	**Total acids**
Romea	LS	1.4 ± 0.1 de	0.5 ± 0.2 f	0.2 ± 0.1 j	2.1 ± 0.1 gh
	GJ	1.6 ± 0.1 bc	0.6 ± 0.4 de	0.3 ± 0.4 i	2.6 ± 0.2 f
Catherina	LS	1.6 ± 0.1 b	0.3 ± 0.1 g	0.3 ± 0.1 h	2.2 ± 0.1 g
	GJ	1.9 ± 0.12 a	0.5 ± 0.2 ef	0.4 ± 0.1 g	2.8 ± 0.1 de
Mirel®	LS	1.2 ± 0.1 f	0.5 ± 0.1f	0.4 ± 0.1 g	2.1 ± 0.1 g
	GJ	1.8 ± 0.1 a	0.5 ± 0.1 f	0.6 ± 0.1 c	3.0 ± 0.1 cd
Fercluse®	LS	0.9 ± 0.1 g	0.6 ± 0.04 ef	0.4 ± 0.1 fg	1.8 ± 0.03 h
	GJ	1.9 ± 0.1 a	0.7 ± 0.3 d	1.1 ± 0.2 a	4.0 ± 0.1 a
Everts	LS	1.3 ± 0.1 ef	0.9 ± 0.1 bc	0.4 ± 0.1 g	2.6 ± 0.02 f
	GJ	1.5 ± 0.1 cd	1.1 ± 0.1 a	0.6 ± 0.1 d	3.2 ± 0.1 bc
Ferlate®	LS	1.5 ± 0.1 bcd	0.8 ± 0.1 c	0.4 ± 0.3 g	2.7 ± 0.1 ef
	GJ	1.8 ± 0.1 a	0.9 ± 0.1 b	0.5 ± 0.1 ef	3.2 ± 0.1 b
VLG	LS	1.5 ± 0.1 bcd	1.1 ± 0.1 a	0.5 ± 0.2 e	3.1 ± 0.1 bc
	GJ	1.9 ± 0.1 a	1.0 ± 0.1 a	0.7 ± 0.1 b	3.7 ± 0.1 a
Effect summary[+]					
Cultivar (C)		***	***	***	***
Canned fruit type (CFT)		***	***	***	***
C X CFT		***	***	***	***

Two-way ANOVA was performed by the linear model on raw data followed by Tukey's honest significant difference (HSD) multiple comparison test for permitting the comparison of any treatment combination. Values are means ± standard error (n=3). Values in the same column followed by different letters are significantly different at $p < 0.05$. [+] ANOVA p-values *** indicates $p < 0.001$.

4.3.3. The effect of storage duration, genotype and packing medium on textural and other quality attributes of canned peaches

During storage, fruit tissues undergo physicochemical and biochemical changes that affect their final texture and quality features of the processed fruits. To our knowledge, there are no available data regarding the evolution of such properties over extensive storage of canned peaches. Thus, textural properties and other quality traits of the canned peach samples in either LS or GJ over 24 months of storage were examined.

Some of the quality attributes (SSC, TA, and colour parameters) remained unaffected or slightly changed between canned peaches of the same cultivar that were stored for 6 or 24 months (

Supplementary Table S 2); Miranda et al. (2012) also reported constant SSC and TA values for strawberries canned in syrup during storage. The mean concentration of soluble sugars of the examined cultivars ranged from 14.4 to 18.5 °Brix in LS, while in GJ the content varied within 12.0 and 13.4 °Brix. For the GJ packed products, the lower values were expected as the °Brix of the diluted grape juice concentrate used as packing medium was already less than that of the sugar syrup when the fruit was canned. Among the studied cultivars, 'Fercluse®' registered the highest SSC in both syrups. On the other hand, TA mean values ranged from 3.3 to 4.9 (g malic

acid L^{-1}) in peach halves stored in light syrup and 3.2 to 4.3 (g malic acid L^{-1}) in diluted grape juice concentrate. The colour parameters (L and h°) of all examined cultivars also remained practically unaffected between 6 and 24 months of storage (*

Supplementary Table S 2). Occasionally, based on the cultivar considered, a slight decrease of L values with a concomitant increment of the hue angle after 24 months of storage was noted. Notably, canned samples for all cultivars presented lower L* values and higher h° values compared to fresh mesocarp (Table 4.1 &*

Supplementary Table S 2**)**. The decrease in L* reflects the darkening of flesh colour, potentially implying the presence of non-enzymatic browning reaction products during processing-storage (Ahmed et al., 2012). Furthermore, canned peach halves get a darker colour when heated due to pigment destruction (chlorophylls and carotenoids), as it occurs with the peach puree (Avila and Silva, 1999).

Opposite to the above-mentioned quality attributes, the textural properties were greatly affected upon storage, being dependent on cultivar and syrup type used. A decrease in all textural parameters (puncture firmness, TPA hardness and chewiness, Kramer hardness and total hardness) was noted for both types of canned products (LS and GJ) between 6 and 24 months of storage for all cultivars (Figure 4.2). Table 4.3 provides information regarding the main effects/interactions and the associated p-values. The three-way interaction (cultivar x syrup type x storage time) was only significant for the TPA-Chewiness. The storage time effect was highly significant depending on the cultivar consider. The two-way interaction (cultivar x storage time) was always significant, exception made for Kramer shear hardness. The canned peaches of most cultivars packed

in GJ registered higher puncture firmness than in LS, while 'VLG' exhibited the higher loss in both syrups after 24 months of storage. Accordingly, packing of canned peaches in grape juice resulted in relatively greater retention of hardness and chewiness (both evaluated with the TPA test) compared to canned peaches in light syrup throughout the storage period. Among the tested cultivars, a notable reduction in tissue firmness (~ 50%) was recorded for cultivar 'VLG', while 'Mirel®' appeared more resistant to firmness loss after 24-month storage. Low chewiness values were recorded for all cultivars in both syrups, with the exemption of 'Catherina' in LS that remained unaffected. Other TPA texture parameters, namely springiness and cohesiveness remained unaffected over 24 months of storage for both canning media (Supplementary Table S 3). Hardness values, as determined with the employment of the Kramer shear test (hardness and total hardness), were high for 'Ferlate®', 'Mirel®' and 'Fercluse®'. The greatest hardness retention after 24 months of storage was registered in 'Fercluse®' canned fruit packed in LS (73% and 67%) and in 'Ferlate®' canned fruit packed in GJ (72% and 70%), for the two aforementioned KST parameters, respectively.

Overall, the data reported herein indicate that significant textural changes in canned clingstone peaches occur upon extended storage, leading to significant firmness losses. Such losses have been attributed to turgor pressure loss and/or residual pectin methyl-esterase activity (PME) affecting the cell wall polysaccharide matrix and thereby the structural integrity of the fruit tissue (Terefe and Versteeg, 2011, Greve et al., 1994). Among the examined cultivars, 'Ferlate®' exhibited the highest values of the mechanical and textural properties tested in both packing media; with 'Mirel®' samples in GJ at 6

months storage were the firmest as recorded by the Kramer shear testing. The late harvested cultivar ‘VLG’ was generally characterised by reduced retention of most textural properties tested compared to all other examined cultivars. On the other hand, ‘Mirel®’ in LS and ‘Fercluse®’ in GJ registered the higher retention of TPA hardness after a 24-month storage period. To what extent, a peach product can maintain appreciable textural attributes needs to be further explored through definition of appropriate quality thresholds for a given attribute in relation to consumer’s acceptability for this line of processed products.

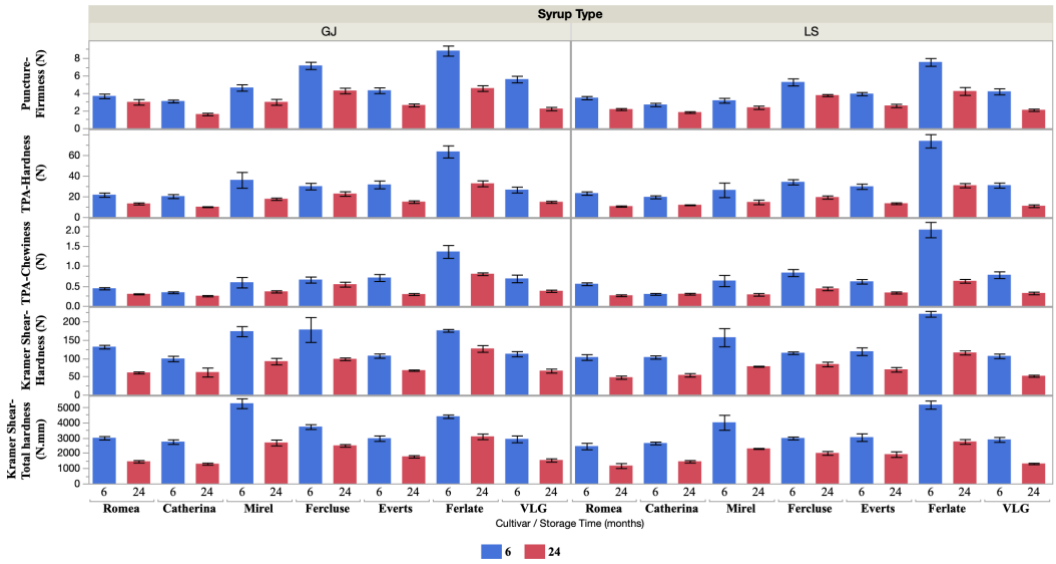


Figure 4.2: Storage effect on five textural properties measured by three large deformation mechanical tests (puncture, TPA and KST) of seven clingstone peach cultivars canned in light syrup and grape juice following 6 and 24 months of storage. The legend under the graph describes the overlay levels of storage time; the data with the blue colour correspond to 6 months of storage and those with red colour to 24 months of storage.

Table 4.3: The main effects/interactions of the model for the three-way ANOVA and the associated p-values.

Effect summary	Textural properties p-values				
	Puncture Firmness (N)	**TPA-Hardness (N)**	**TPA-Chewiness (N)**	**Kramer Shear-Hardness (N)**	**Kramer Shear-Total hardness (N.mm)**
Cultivar (C)	***	***	***	***	***
Syrup Type (SYT)	***	NS	**	NS	*
C x SYT	*	NS	***	***	***
Storage Time (ST)	***	***	***	***	***
C x ST	***	***	***	NS	*
SYT x ST	**	NS	**	NS	NS
C x SYT x ST	NS	NS	**	NS	NS

*p < 0.05; **p < 0.01; ***p < 0.001; NS indicates not significant

4.3.4. The effect of cultivar and packing medium on sensorial attributes of canned peaches

In the current study, cultivars packed in LS showed significant differences for nine attributes (Figure 4.3A), but not for the residual peel, blemished, acidity, astringency, fruitiness and off-flavour. When GJ was used as filling medium, the cultivars exhibited significant differences for all tested attributes (Figure 4.3B); numerical values of all sensory data are included in

Supplementary Table S 4. No residual peel and blemished fruit in both syrups for all examined cultivars were registered, implying proper inspection practices throughout the canning process. The absence of blemished flesh and residual peel is a prerequisite for the canning industry in terms of fresh fruit handling as well as at the various processing stages (Metheney et al., 2002). In general, a different pattern for the scores of sensory descriptors was noted between LS and GJ samples.

The odour profile of the canned samples in LS was characterized by higher intensity scores for the peach aroma compared to GJ. The scoring of odour ranged from 5.1 ('Romea') up to 6.9 ('Fercluse®') in LS, while the GJ samples scored lower values, but showing great varietal differences spanning from 2.8 ('Romea', 'VLG') up to 6.2 ('Everts').

A significant variation of the colour parameters, such as intensity, uniformity and brightness, among the cultivars was also recorded. The colour profile of canned samples in both syrups (LS and GJ), as perceived by the panellists, can be categorised into the following groups: orange for 'Fercluse®' (8.7) and 'Mirel®' (8.3); yellow-orange for 'Romea' (7.1) and 'Catherina' (6.9); and yellow for 'Everts' (5.6), 'Ferlate®' (5.5), and 'VLG' (5.1) (Figure 4.1). Interestingly, the early-ripening cultivars ('Romea' and 'Catherina') were characterized by yellow-orange flesh, the mid-ripening cultivars ('Mirel®' and 'Fercluse®') by orange flesh and the late-ripening cultivars ('Everts', 'Ferlate®', 'VLG') by yellow flesh. To what extent the fruit ripening process has an impact on the colour of the canned product for clingstone peaches needs to be further elaborated.

In general, the taste profile descriptive analysis showed clear differences between the LS- and GJ-packed samples (Figure 4.3). The panellists scored the LS samples as significantly more sweet, fruity, 'peachy' (having more the typical taste of fresh peach) and less sour. The astringency, bitter taste, as well as the off-taste attributes were scored relatively low (<5.0 in the point structured rating scale) for all samples, being always higher in the case of GJ samples. Panellists also expressed a general dislike for the canned peach samples in GJ, with some panellists reporting as general remark that the samples had 'strange taste', resembling 'fermented grapes' and 'excessive bitterness'. 'Romea', 'Mirel®', 'Fercluse®' and 'VLG' canned in GJ registered the higher scores (intensity) regarding acidity, astringency, bitterness and off-flavour. This is possibly due to the tartness of grape juice, mostly caused by tartaric acid, which has been 'detected' by the panellists in the processed products of these specific cultivars.

Texture profiling by sensorial means revealed moderate to high intensity (5.0-8.1) scores in terms of hardness and difficulty in chewiness (Figure 4.4). The highest firmness values (hardness) were registered for 'Mirel®' and 'Ferlate®' in both syrups. The remaining samples of the other cultivars exhibited significantly lower hardness values (5.4-6.3 in LS and 5.0-5.9 in GJ).

Grape juice has been reported as a rich source of phenolic antioxidants, exhibiting beneficial effects on human health (Toscano et al., 2017) and that grape polyphenols contribute to the astringency and bitterness, and depending on their concentration can be perceived in high intensities (Dinnella et al., 2011, Lesschaeve and Noble, 2005). Nevertheless, it is important to note that the overall sensorial perception of canned peach

fruit, packed in GJ, is above the threshold set by the consumers for product acceptability. To the best of our knowledge, this is the first comprehensive sensory study that includes a comparative quality assessment of canned peaches derived from seven different non-melting clingstone cultivars.

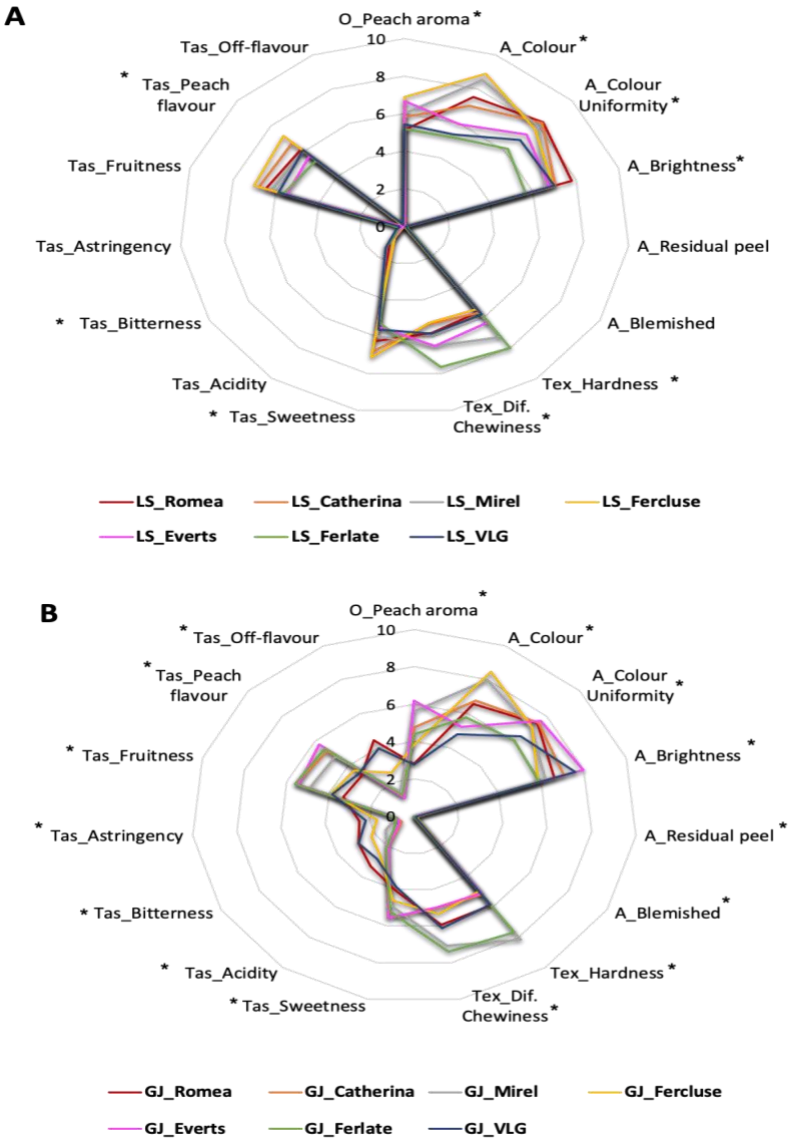


Figure 4.3: Sensory evaluation of seven non-melting peach cultivars packed in light syrup (A) and grape juice syrup (B). The data obtained refer to 15 examined attributes as scored by the sensory panel. For each sensory attribute the perceived mean intensity increases outward from the centre point. Attributes with asterisk (*) indicate significant differences ($p < 0.05$) between the cultivars of each packing medium. The abbreviations (O), (A), (Tex) and (Tas) stand for odour, appearance, texture and taste, respectively.

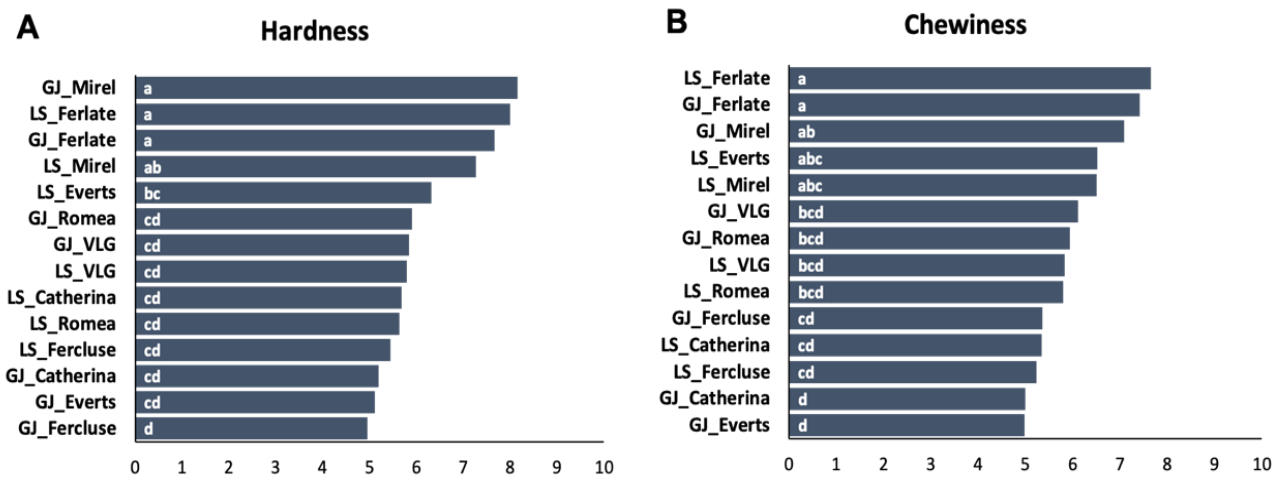


Figure 4.4: The texture (hardness and chewiness) intensity profile of descriptive analysis within cultivars and packing media. Different letters indicate significant differences ($p < 0.05$) of mean panel data scores between the cultivars and two packing media.

4.3.5. Correlations between sensorial and instrumental measurements

The analytical (objective measurements) data by instrumental testing (I) showed positive correlations with respective sensorial measurements (S) of the four grouped attributes (hardness, chewiness, sweetness and acidity) (Table 4.4). In particular, instrumental testing of the hardness parameter showed significant correlation ($r = 0.67$; $p < 0.05$) with the corresponding sensorial characteristic; a significant correlation between the sensorial and instrumental chewiness was also registered ($r = 0.68$; $p < 0.05$). The highest significant correlation ($r = 0.97$; $p < 0.05$) was determined between instrumental hardness and instrumental chewiness, with the 'Ferlate®' canned peaches showing the highest performance in accordance with the sensorial analysis (Figure 4.4).

The perceived sweetness by the panellists also exhibited significant correlation ($r = 0.79$; $p < 0.05$) with SSC, while a fairly weak correlation ($r = 0.34$) was registered for acidity. A significant negative relationship ($r = -0.92$; $p < 0.05$) was observed between sensorial acidity and sensorial sweetness, as expected, since sweetness intensity can be modulated (masked) by high concentrations of acids that dim the perception of sweetness (Bento et al., 2020). No correlation between sweetness and hardness from the instrumental measurements was noted. Collectively, a positive yet not highly linear correlations among instrumental and sensorial analyses were monitored, particularly for the sweetness, hardness and chewiness attributes.

Table 4.4: Correlation matrix between sensorial (S) and instrumental (I) data of four grouped properties (hardness, chewiness, sweetness and acidity).

	S_Hardness	**I_Hardness**	**S_Chewiness**	**I_Chewiness**	**S_Sweetness**	**I_Sweetness**	**S_Acidity**	**I-Acidity**
S_Hardness	1							
I_Hardness	0.67*	1						
S_Chewiness	0.94*	0.75*	1					
I_Chewiness	0.58*	0.97*	0.68*	1				
S_Sweetness	-0.15	-0.09	-0.30	-0.08	1			
I_Sweetness	-0.01	0.00	-0.07	0.10	0.79*	1		
S_Acidity	-0.08	-0.04	0.04	-0.08	-0.92*	-0.83*	1	
I-Acidity	0.21	0.37	0.36	0.44	-0.47	-0.20	0.34	1

Values with asterisk (*) indicates significant at $p < 0.05$

4.4. Conclusions

Over the past years, the canning industry was dominated by few peach cultivars that their ripening period was coinciding; as a result, there has been an urgent request by the peach industry to seek for alternative approaches towards extension of the non-melting peach campaign. However, the processed end products may vary considerably in their sensorial properties and storability, being highly affected by the cultivar considered. The results reported herein indicate that all examined cultivars exhibited appreciable quality attributes after canning and at certain cases such properties were maintained even after a 24-month storage of the canned product. 'Ferlate®' and 'Mirel®' appear to have a great potential towards production of an added-value canned product. Canned peaches composed of diluted clarified concentrated grape juice, prepared with the main general objective that fits the new market trends towards more "natural" products, showed inferior sensorial attributes for an array of taste descriptors, namely bitterness, astringency and off-taste.

5. Profiling phytochemicals in fresh and canned fruit of non-melting peach cultivars: impact of genotype and canning process on their content

Abstract

The aim of the study was the estimation of total carotenoids, total phenolics and total antioxidant capacity of methanolic extracts, along with identification and quantification of individual phenolic and carotenoid compounds by LC-MS/MS, were made to evaluate the compositional variability and impact of processing on the bioactive compound profile of eight non-melting peach cultivars, both in fresh and canned forms, with either light syrup or grape juice as packing media. Data showed that individually quantified phytochemicals, as identified in fresh fruit, differ significantly among the tested cultivars, with the widely grown 'Andross' cultivar demonstrating the highest contents. In terms of the phytochemical profile upon canning as a preservation method, the use of grape juice, a liquid matrix higher in bioactives content, compared to pure sugar syrup, resulted in the reduction of losses of bioactive compounds by balancing out diffusion processes between fruit tissue and packing medium. Grape juice also supplies a good source of polyphenols while sugar syrup does not. Overall, the current study demonstrated that the phytochemical profile of peach fruit is primarily genotype dependent, as is its ability to retain the bioactives upon canning and storage of the processed fruit. Heat treatment differentially affected individual carotenoids and phenolic compounds. Total and individual bioactive content showed that peach carotenoids and α-tocopherol, with the

exemption of β-carotene, were more stable than phenolic compounds upon thermal treatment and subsequent storage. The sum of zeaxanthin and lutein was relatively unaffected by the preservation technique compared to β-carotene. All phenolic compounds including neochlorogenic acid, chlorogenic acid, procyanidin B1 and catechin decrease significantly following canning and storage.

Keywords: phenolics, carotenoids, nutrition, *Prunus persica*, processing, clingstone

5.1. Introduction

Peach is a widely consumed fruit as fresh and in processed forms (canned, frozen, juice, etc.). It is considered an agricultural product of high commercial value due to its nutritional profile and multi-sensory quality attributes. Human consumption of peaches has been reported to exhibit a protective effect towards an array of chronic diseases by modulating cellular oxidative stress caused by free radicals (Cevallos-Casals et al., 2006).

The nutritional value of peaches is mainly driven by their chemical constituents. Several studies have characterized peaches as being rich in major nutrients, mostly digestible and non-digestible carbohydrates, as well as a wide range of physiologically active micronutrients, including various bioactive compounds (Giorgi et al., 2005, Gecer, 2020, Remorini et al., 2008, Gil et al., 2002). Notably, they are rich in natural metabolites and phytochemical compounds, mostly of small molecular weight, with enhanced antioxidant properties.

An array of such bioactive compounds have been identified in different peach cultivars including phenolics (catechin, epicatechin, chlorogenic and neochlorogenic acids) (Chang et al., 2000, Mokrani et al., 2016, Tomás-Barberán et al., 2001b, Loizzo et al., 2015), and carotenoid compounds, (β-carotene, lutein and zeaxanthin) (Dabbou et al., 2017, Brown et al., 2014, Di Vaio et al., 2008). Polyphenols and carotenoids, being the main phytochemicals in this fruit, contribute both to the flavour (astringency, bitter taste) and to the yellow-orange colour of the peach. The peach fruit is also considered an important source of vitamins such as A, C and E, as well as other minerals and fibers (Liu et al., 2015, Campbell and Padilla-Zakour, 2013, Davidovic et al., 2013). The respective concentrations of these phytochemicals are highly dependent on the cultivar (genetic makeup), as well as on the cultivation practices and the fruit maturity stage upon harvest (Gil et al., 2002).

The identification of two distinct horticultural types of the fruit, known as (a) "clingstones", where the mesocarp adheres to the endocarp, characterized by a non-melting firm flesh (desired characteristic for processed products), and (b) "freestones", where their mesocarp is easily separated from the endocarp, thus characterised by a melting flesh texture (desired characteristic in the fresh fruit market) (Bassi and Monet, 2008), allows for the production of high quality produce both in the fresh and preserved forms. For the latter, peaches are often subjected to canning as a means of preservation. In this context, thermal processing, being a critical step in the canning process, can significantly impact the composition of the phytochemical profile of the final product.

Indeed, variations in phenolic composition due to cultivar or processing treatments have previously influenced peach antioxidant capacity. Nonetheless, there have been relatively few studies on the effect of processing on individual phenolic constituents (Asami et al., 2003). At the same time, Oliveira et al. (2012) reported that pasteurization of fresh peaches results in a significant reduction of carotenoid content, except for zeaxanthin. In contrast, Campbell and Padilla-Zakour (2013) reported that processed clingstone peaches contained higher quantities of bioactive compounds than fresh fruit, while Durst and Weaver (2013) showed that canned peaches are nutritionally equivalent to fresh produce and even had enhanced contents of vitamins A and C after the canning process.

The majority of previous relevant studies on the phytochemical profile of peach fruit has been limited to a small number of cultivars, with most of them focusing on a single cultivar. Consequently, the aim of the present work was to determine the carotenoid and phenolic composition of methanolic extracts from both fresh and canned peach fruit of eight commercially important non-melting clingstone cultivars to assess the effect of both genotype and thermal processing-storage on the phytochemical content of peach fruit. Our results unravelled stark differences among cultivars, highlighting the strong impact of genotype. At the same time, the effect of thermal processing and storage on the content of individual carotenoid and phenolic compounds has also been elucidated.

5.2. Materials and Methods

5.2.1. Reagents and standards

For spectrophotometric analyses, gallic acid, β-carotene, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), Folin-Ciocalteu phenol reagent, sodium carbonate, sodium acetate, butylated hydroxytoluene (BHT) and 2,4,6-tripyridyl-s-triazine (TPTZ) were obtained from Sigma-Aldrich (Steinheim, Germany). For quantification of individual phenolic compounds, the following standards (analytical grade) were used: neochlorogenic acid, chlorogenic acid, (+)-catechin, (−)-epicatechin, procyanidin B1 and procyanidin B2 from Sigma (St. Louis, MO, USA), caffeic acid, quercetin 3-glucoside from Fluka (Buchs, Switzerland), whereas 2.5-dihydrohybenzoic acid and rutin were obtained from Sigma-Aldrich. To quantify other carotenoids, zeaxanthin and lutein (purity > 95%) were acquired from Extrasynthese (Lyon, France), whereas trans-β-Apo-8′-carotenal used as an internal standard was purchased from Sigma-Aldrich. To quantify vitamin E (VE), DL-a-tocopherol and vitamin E acetate (VEAC, internal standard), these compounds were obtained from Sigma-Aldrich. All organic solvents were of analytical grade: methanol (MeOH) and acetonitrile (ACN) were purchased from Merck (Darmstadt, Germany). Formic acid was acquired from LGC Standards (Germany) and LC-MS grade water was obtained from Fischer Scientific (UK). Unless otherwise stated, all reagents and chemicals were of analytical grade and double-distilled water was used in the entire study.

5.2.2. Fresh and canned fruit material

Eight non-melting peach cultivars (‘Romea’, ‘Catherina’, ‘Mirel®’, ‘Fercluse®’, ‘Andross’, ‘Everts’, ‘Ferlate®’, ‘VLG’) were harvested as described in §2.1 and in a companion work of our group §4.2.2. Subsequently, the harvested fruit were segregated into two lots.

One lot of 30 representative fruits per cultivar (divided in three 10-fruit sublots to represent the biological replications) was selected. Two wedged-shaped slices from the intact peach fruit were dissected, the exocarp was removed, and were crashed into smaller pieces, using liquid nitrogen and a pestle and mortar. Samples were immediately stored at -20 °C.

Another lot of fresh fruit (*ca.* 40 kg) was used for the canning process. Canned peach halves were prepared both in light syrup (LS, initial of ~20.0 °Brix) and grape juice syrup (GJ, initial of ~16.0 °Brix); grape juice is used as an alternative filling medium of less caloric content (Christofi et al., 2021b). All cans were stored at ambient conditions (23 ± 2 °C) for 6 months before subjected to further analysis in order osmotic equilibrium among all components present within the cans to be attained. After the processing, the canned products of the two-packing media (LS and GJ) were sorted in three replicates of one metal can (~ 820 g net weight each can) per cultivar and packing medium. Initially, canned halved fruit were washed with distilled water for 2 min and were drained prior to analysis. Subsequently, the peach halves of three cans per packing medium were homogenized in a laboratory blender (model: ES3, EZ600 black, Blendtec) at high speed for 2 min and the resulting puree was stored at -20 °C until needed.

Both fresh and canned peach tissue, as described previously were subsequently freeze-dried in a lyophilizer (Christ Alpha 1-2 LDplus, Germany). The freeze-dried peach samples obtained were grounded into a fine powder to ensure uniformity and kept at -20 °C until needed for the phytochemical analysis as reported below.

5.2.3. Methodology

The extraction and determination of total and individual phytochemical content in fresh and canned tissue were carried out following the methodology previously analytically described in the following sections §2.7-2.8.

5.2.4. Statistical analysis

Results are presented as mean values. The effect of genotype and canning process, including their interactions and relative importance of both factors, were examined using two-way ANOVA, with the employment of JMP Pro software (Version 15.2, SAS Institute, Cary, NC); differences were considered as significant at $p < 0.05$. The prediction profiler function displaying the models and settings contributing to achieving the overall maximum desirability in terms of total and individual phytochemical content was also implemented using the JMP Pro software (Version 15.2, SAS Institute, Cary, NC). The overall desirability for all responses has been automatically calculated by the geometric mean of the desirability functions for the individual responses.

5.3. Results and Discussion

5.3.1. Antioxidant capacity

The antioxidant activity of the eight peach cultivars, both fresh and canned products, was determined in methanol-resuspended dried extracts of ripe fresh and processed fruit. The effect of genotype as well as the impact of the applied preservation method on the antioxidant activity was prominent (Figure 5.1**,** Table 5.1). The total antioxidant capacity (TAC) of the dried extracts from fresh fruit evaluated with the FRAP assay was significantly higher in 'Andross' (most desirable) (Figure 5.2**,**

Cultivar	**Fruit Type**	**TPC** **F-C (μg GAE/g DW)**	**TAC** **FRAP (μg TE/g DW)**	**TC** **TC (μg β-carotene/g DW)**
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5

	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9
	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5) and ‘Ferlate’ cultivars, while intermediate values were observed for ‘Catherina’, ‘Mirel’, ‘Fercluse’, ‘Everts’ and ‘VLG’. The lowest TAC values were recorded for ‘Romea’ (Figure 5.1**,** Figure 5.2,

Cultivar	Fruit Type	TPC F-C (µg GAE/g DW)	TAC FRAP (µg TE/g DW)	TC TC (µg β-carotene/g DW)
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5
	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9

	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5, Supplementary Table S 6). Tavarini et al. (2008) also reported high antioxidant capacity for 'Andross' and low for 'Romea'. The results showed that amongst the examined peach cultivars, considerable variances occur in the amounts of endogenous antioxidant compounds. Apparently, the antioxidant capacity of fruit is manifested by the synergistic action of an array of biochemical components which include but are not limited to carotenoids, polyphenols, and tocopherols. Therefore, it is probable that the displayed genetic diversity, as it concerns the antioxidant capacity, possibly reflects variations in the abundance of different bioactive constituents present in each type of cultivar examined (García-Alonso et al., 2004, Ding et al., 2020). Notably, no correlation between antioxidant capacity with either the flesh color or the ripening season, thus suggesting a rather additive genetic impact on the fruit tissue compositional make-up of the examined samples.

Preservation of the fresh peaches through canning significantly affected their antioxidant capacity. Specifically, substantial variation among cultivars was noted in the extent of antioxidant capacity reduction when the fruit was canned in light syrup compared to their fresh counterparts, with ‘Romea’ demonstrating the highest (26-fold) decrease and ‘Ferlate’ the lowest (6-fold) (Figure 5.1,

Cultivar	**Fruit Type**	**TPC**	**TAC**	**TC**
		F-C (µg GAE/g DW)	**FRAP (µg TE/g DW)**	**TC (µg β-carotene/g DW)**
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5
	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1

	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9
	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5). The latter variance could be attributed to thermal processing and storage on compounds responsible for antioxidant activity. A decrease in the antioxidant activity of unpeeled peach puree pasteurized at 100 °C for 30 min has also been reported (Talcott et al., 2000) with study of Oliveira et al. (2012) demonstrating a 20% decrease in antioxidant activity upon pasteurization. Interestingly, when grape juice was used as a packing medium in the canning process, the loss of antioxidant capacity was less prominent, attaining a range of reductions between 2-fold (‘Romea’) and 15-fold (‘Mirel’) (Figure 5.1,

Cultivar	Fruit Type	TPC F-C (µg GAE/g DW)	TAC FRAP (µg TE/g DW)	TC TC (µg β-carotene/g DW)
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5
	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9

	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5). In a recent work that studied the effect of thermal processing as part of the canning process on the antioxidant capacity of mangos and pineapple, according to reported experimental findings, the authors insinuated "antioxidant leaching" between the fruit tissue material and the liquid medium (Arampath and Dekker, 2021). They have also demonstrated that the degradation and diffusion of the antioxidant vitamin C in canned pineapple pieces endured stepwise increases, parallel with the rise in internal temperature. In contrast, the vitamin C content in the sugar syrup of pineapple cans gradually increased, possibly due to fruit cell membrane destruction caused by the thermal processing allowing for diffusion of bioactive compounds to the liquid medium surrounding the fruit pieces. Hence, the lower loss of antioxidant capacity observed in the present study when grape juice was used as the liquid matrix, it is plausible to be caused by the fact that grape juice is a medium rich in phenolic compounds (Vinson

et al., 2000, Burin et al., 2010), thus allowing for a bidirectional balance of bioactive compounds between the fruit tissue and the liquid matrix.

Figure 5.1: Total phenolics content (A) antioxidant capacity (B) and total carotenoids (C) evaluated for fresh and canned peach fruit in two packing media (light syrup and grape juice) of eight non-melting peach cultivars. Lower-case letters indicate significant differences and interactions from the ANOVA models among type, and cultivar values respectively (Tukey's post-hoc test, $p < 0.05$).

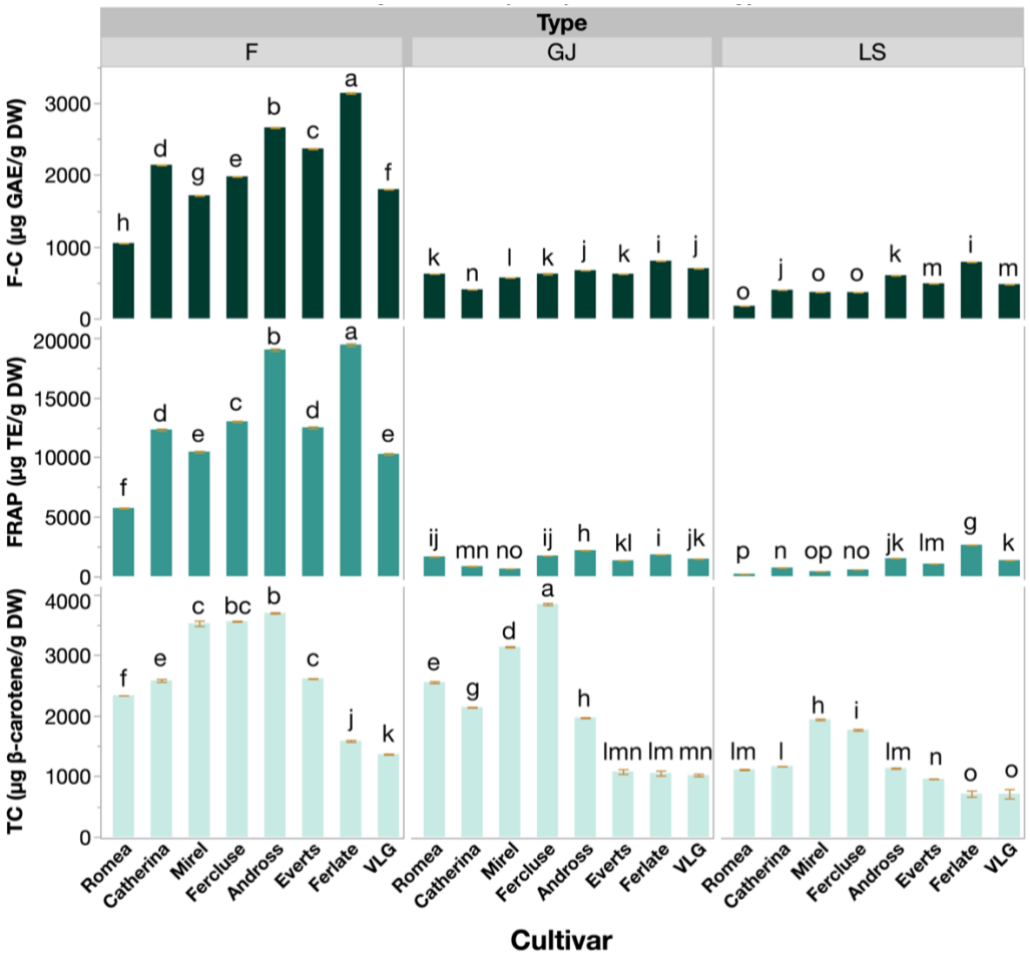


Table 5.1: Effect summary of the impact of product type (T), cultivar (C) and type x cultivar interaction (T x C) on total phenolic content, antioxidant capacity and total carotenoids of eight non-melting peach cultivars, fresh and preserved.

Source	Log Worth		P-Value
Type (T)	97.097		0.00000
Cultivar (C)	73.102		0.00000
T x C	67.929		0.00000

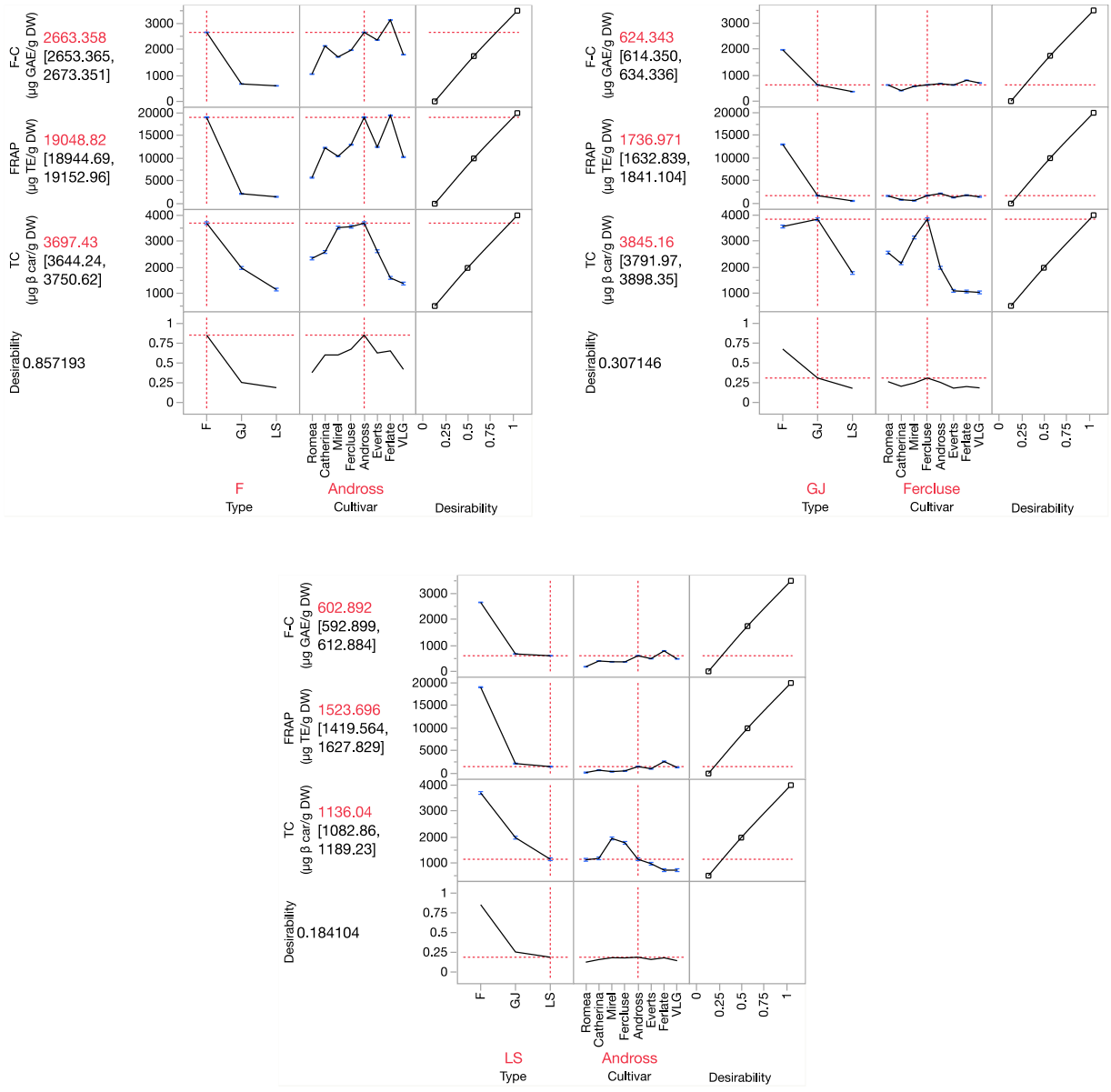


Figure 5.2: Prediction profile of optimum total phytochemical content (F-C, FRAP and TC) between the eight peach cultivars of each product type (F, GJ and LS) for maximizing desirability score. Vertical dash line represents the product type and cultivar, whereas the horizontal line represents values obtained at conditions that result in the highest desirability score. The right-hand row is scaled as 0 (undesirable) to 1 (most desirable).

5.3.2. Total phenolic content

The rich phenolic content of peaches has been widely recorded (Aleixandre-Tudó et al., 2013, Tomás-Barberán et al., 2001b, Vizzotto et al., 2007). Despite a rather extensive assessment of total phenolics content (TPC) for individual cultivars, there has been a somewhat limited number of studies that targeted the evaluation of total phenolics content on a comparative cultivar basis (Di Vaio et al., 2015). In this context, the TPC of the eight peach cultivars examined as study materials in the present work was assessed in methanol-solubilized dry extracts, using the Folin-Ciocalteu assay. The values obtained varied significantly between 1051.4 and 3143.1 μg GAE/g DW (Figure 5.1**,**

Cultivar	**Fruit Type**	**TPC** **F-C (μg GAE/g DW)**	**TAC** **FRAP (μg TE/g DW)**	**TC** **TC (μg β-carotene/g DW)**
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5

	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9
	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5). ‘Andross’, ‘Ferlate’ and ‘Everts’ were found to have the highest TPC levels with values of μg GAE/g, at 3143, 2663 and 2370, respectively, while ‘Romea’ demonstrated the lowest content of TPC with a value of 1051 μg GAE/g. No significant variation on TPC of ‘Mirel’, ‘VLG’, ‘Catherina’ and ‘Fercluse’ cultivars were noted, presenting intermediate concentrations. The results are following the findings of a

previous study that designated ‘Romea’ as a cultivar low in TPC (Mokrani et al., 2016). In addition, and by the current study, it was also shown that in fresh peach fruit, the total phenolics content of the mesocarp is highly cultivar dependent. The present study's findings further provide a good indication for the interrelation between phenolics content and the antioxidant activity of the peach cultivars, thus pointing to phenolic compounds as major contributors to the antioxidant capacity of fruit extracts, without any notable link however, with the flesh color.

Measuring the TPC in canned peaches demonstrated that both cultivar and liquid packing medium (light syrup or grape juice) significantly impacted the total concentration of phenolic compounds (Table 5.1). Irrespective of the packing medium applied, the canned products exhibited lower total phenolics values than their fresh counterparts (Figure 5.1**,**

Cultivar	**Fruit Type**	**TPC** **F-C (μg GAE/g DW)**	**TAC** **FRAP (μg TE/g DW)**	**TC** **TC (μg β-carotene/g DW)**
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6

	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5
	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9
	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5). The total phenolics content (TPC) of canned peaches in light syrup ranged between 276.1 – 494.4 μg GAE /g DW, which is comparable to the findings

reported both by Oliveira et al. (2012) (328–385 μg/g), and by Asami et al. (2003) (314–398 μg/g). Furthermore, canning in light syrup induced a pronounced TPC reduction ranging from 28-fold (VLG) to 49-fold ('Romea'). In contrast, canning the fruit in grape juice resulted in smaller TPC reductions, with a range of 7-fold ('Romea') to 43-fold ('Catherina'). Most cultivars presented a ~ 21-fold decrease, considerably less than the 35-fold decrease noted when the light syrup was chosen as packing medium. As was first observed by Hong et al. (2004),), there is a substantial diffusion of phytochemicals, specifically hydrophilic compounds such as phenolics, from the fruit to the preservation medium following canning and storage due to osmotic equilibration between the fruit tissue and the packing medium. According to Chaovanalikit and Wrolstad (2004), for canned cherries, there is a significant amount of ~ 50 % of phenolic compounds that can be lost from the fruit into the syrup due to diffusion processes occurring upon canning.

Similarly, Oliveira et al. (2012) assessed the contribution of syrup to the total phytochemical content of the canned peaches in the jar. They resulted in a 34-38 % loss of TPC, 48–52 % of antioxidants and only 0.5–1 % total carotenoids after processing due to diffusion. Overall, the findings from previous studies and those of the present work indicate substantial losses of phenolic compounds and antioxidants in the syrup if no consideration for their presence in the packing medium is taken into account to include analytical measurement in the liquid phase well (Gil et al., 2002, Wu et al., 2010). Such a disposition of the bioactive compounds between the fruit pieces and the liquid matrix can provide an explanation to the concentration changes illustrated in Figure 5.1, where 'Romea' is following the same ranking trend (least desirable) for both the fresh and the

canned product in light syrup, whereas when canned in grape juice, the desirability of 'Romea' increases substantially (Supplementary Table S 6). The latter observation might be attributed to the presence of similar bioactive compounds in the natural grape juice and a tissue structure more easily permeable by small molecular weight compounds, and thus counter-balancing their dispensation within and outside the canned fruit pieces upon equilibration. Nonetheless, as the liquid medium is omitted during analysis, further studies are needed to explore the nature and distribution pattern (kinetic responses and equilibrium concentrations) of individual small molecular weight bioactive compounds between the solid and liquid phases in the osmotically modified fruit tissues from different cultivars, and thereby unravel all factors affecting the intercultivar differentiation in phytochemical losses, when canned in different packing media (syrups vs. natural juices).

5.3.3. Total carotenoids

Total carotenoids (TC) content in yellow-fleshed peach genotypes with mid to late ripening demonstrated variability ranging from 1366.7 to 3697.5 μg β-carotene/g DW. In contrast, the carotenoid content found in yellow-orange-fleshed early-ripening cultivars ('Romea' 2336.2 and 'Catherina' 2584.1 μg β-carotene/g DW) showed no statistically significant variability (Figure 5.1,

Cultivar	Fruit Type	TPC	TAC	TC

		F-C (µg GAE/g DW)	FRAP (µg TE/g DW)	TC (µg β-carotene/g DW)
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5
	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9
	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4

	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 5). The highest values of TC was found for the yellow-fleshed 'Andross' (3697.4 μg β-carotene/g DW) cultivar and the lowest content for the yellow-fleshed 'VLG' (1366.7 μg β-carotene/g DW), indicating that flesh color is not an indicator per se for the carotenoid content of a given cultivar. Unlike the marked reduction in phytochemical compounds noted in terms of total phenolics content and antioxidant capacity upon canning of the fresh fruit, in either light syrup or grape juice, the total carotenoids content remained relatively unchanged. Given the general insolubility of carotenoids in water, it is plausible to suggest very little diffusion if any occurs between the fruit tissue and the preservation medium and that the 0.5 - 1 % total carotenoids present in the packing medium reported by Oliveira et al. (2012) could largely originate from dispersed plant material particles in the medium (Campbell and Padilla-Zakour, 2013).

From the results of the total phytochemical content, it can be deduced that in terms of phytochemical profile preservation upon canning, the use of grape juice should be preferable (desirability 0.3 compared to 0.18 for light syrup), as it is a liquid matrix higher in bioactive compounds compared to a sugar syrup and therefore restrains the losses of phenolics and antioxidant capacity by balancing out the diffusion processes between fruit tissue and the packing medium.

Prediction profile statistics suggest that ‘Andross’ has the highest overall desirability in fresh (0.857) and canned in light syrup (0.184) types. At the same time, the most desirable cultivar when the canned product was filled with grape juice, in terms of retention of its total phytochemical content, was ‘Fercluse’ (0.307) (Figure 5.2, Supplementary Table S 6).

Conclusively, assessing all the studied peach cultivars for their composition – bioactivity potential (fresh) and susceptibility to total bioactive components diffusion and/or degradation, concerning the packing medium, the following rankings from more to less desirable in terms of phytochemical content (fresh fruit) and less to more susceptible to phytochemical content loss (processed fruit) are registered: ‘Andross’ > ‘Fercluse’ > ‘Ferlate’ > ‘Everts’ > ‘Mirel’ > ‘Catherina’ > ‘VLG’ > ‘Romea’ for fresh fruit, and ‘Fercluse’ > ‘Romea’ > ‘Andross’ > ‘Mirel’ > ‘Catherina’ > ‘Ferlate’ > ‘VLG’ > ‘Everts’ when peaches were canned with grape juice. The respective ranking when canning was performed with light syrup is ‘Andross’ > ‘Mirel’ > ‘Ferlate’ > ‘Fercluse’ > ‘Everts’ > ‘Catherina’ > ‘VLG’ > ‘Romea’.

5.3.4. Individual phenolic compounds

LC-ESI-MS/MS analysis identified and quantified two hydroxycinnamates and two flavan-3-ols (

Table 5.2). Besides the apparent effect from the different cultivars, the relatively small number of individual phenolic compounds quantified in the flesh of the eight varieties of peach is attributed to the fact that irrespective of the ripening stage, the identified phenolics (hydroxycinnamic acids, total flavonols, and total anthocyanins) in the flesh are in about half the amount compared to the fruit peel (Gil et al., 2002, Tomás-Barberán et al., 2001b, Campbell and Padilla-Zakour, 2013). Two isomeric hydroxycinnamates were identified in the fresh mesocarp tissues of all examined cultivars. Both e isomers showed the same $[M - H]^-$ ion at m/z 354, indicating two components of the same molecular weight, as well as the $[\text{quinic} - H]^-$ ion at m/z 194 and the $[\text{caffeic} - H]^-$ ion at m/z 182. The two components identified were neochlorogenic acid (NCHLA) and chlorogenic acid (CHLA), respectively, based on pure chemical standards analyzed in parallel with the study materials. In general, the fresh fruit extracts contained higher amounts of the individual phenolics than their preserved counterparts, with CHLA exhibiting the highest concentrations compared to the other phenolic compounds detected in all product types (Figure 5.3, Supplementary Table S 7). The high CHLA content in peach fruit has also been previously demonstrated (Rossato et al., 2009, Tomás-Barberán et al., 2001b, Zhao et al., 2015, Manganaris et al., 2017). The CHLA contents varied from 77.7 μg/g DW ('Romea') to 372.2 μg/g DW ('Fercluse') in fresh fruit, 12.5 μg/g DW ('Romea') to 106.5 ('Ferlate') μg/g DW when peaches were canned in light syrup, and from 7.8 μg/g DW ('Romea') to 108.6 ('Ferlate') μg/g DW for the products canned in grape juice. For some cultivars, following thermal processing and storage (6 months), the marked decrease of CHLA concentrations in the canned products, compared with the fresh fruit, indicated

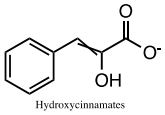
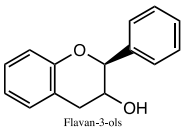
differences when the packing media was considered (e.g., ‘Catherina’, ‘Mirel’, ‘Fercluse’). At the same time, the rest showed no differences in the extent of concentration reductions (i.e., ‘Romea’, ‘Andross’, ‘Everts’, ‘Ferlate’, and ‘VLG’). The contents in NCHLA also demonstrated a considerablevariation among the examined cultivars ranging from 13.3 μg/g DW (‘Romea’) to 92.9 μg/g DW (‘Ferlate’) for the fresh fruit (Figure 5.3), undetectable (‘Romea’) to 18.1 μg/g DW (‘Ferlate’) in fruit canned in light syrup, and 0.6 μg/g DW (‘Romea’) to 18.1 μg/g DW (‘Ferlate’) in fruit canned in grape juice. Evidently and in stark contrast to the CHLA concentration responses, the calculated % differences (comparison between the fresh product and those packed in the two liquid media) indicated that diffusion of NCHLA from the raw fruit tissues to the preservation medium was much greater when canning was with light syrup rather than grape juice, except for ‘Catherina’ that presented similar responses in concentration reductions for both packing media. In agreement with other relevant studies on nectarine and other peach cultivars, examined by Tomás-Barberán et al. (2001b) and Ceccarelli et al. (2016), the content of both hydroxycinnamic acids among orange- and yellow- fleshed peaches was not significantly different (Tomás-Barberán et al., 2001b, Ceccarelli et al., 2016).

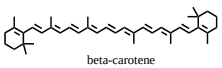
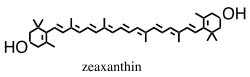
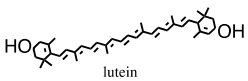
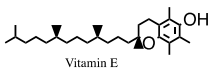
In terms of flavan-3-ols, the $[M - H]^-$ ion at m/z 290 suggested the presence of a monomeric flavanol, while the $[M - H]^-$ ion at m/z 578 pointed towards the molecular weight of a procyanidin dimer with a B-type interflavanoid linkage. However, the presence of the fragment at m/z 426 suggested a typical retro Diels-Alder fission of the heterocyclic rings in dimeric procyanidins, resulting in the detection of only one of the dimers (Zhao et al., 2015). Further analyses were conducted using chemical standards,

identifying the two flavan-3-ols as catechin (CAT) and procyanidin B1 (PB1), respectively. The range of variation in PB1 concentration in fresh fruit was broad, with values of 17.2 μg/g DW (‘Romea’) up to 282.3 μg/g DW (‘Ferlate’). The decrease in PB1 content upon preservation was also high (Supplementary Table S 7). Thermal processing of peaches results in a loss of ~ 21 % of total procyanidins, with some of these losses being attributed to the diffusion of these low molecular weight compounds into the packing medium (Hong et al., 2004). When packed in light syrup, the ‘Romea’, ‘Mirel’ ‘Fercluse’ and ‘VLG’ canned products showed non-detectable amounts of PB1, while in the cultivars where PB1 was detectable in the fresh product, pronounced decreases were noted. The loss of PB1 upon canning was even more pronounced when the grape juice was used as a preservation medium. Specifically, only ‘Ferlate’ demonstrated substantial amounts of PB1, with an 84-fold decrease, however, compared to the respective levels of fresh fruit.

The concentration of CAT was quite low in fresh fruit, ranging from almost undetectable levels (‘Romea’) up to 41.2 μg/g DW (‘Ferlate’). Similarly to PB1, no detectable amounts of CAT were found in the cultivars ‘Romea’, ‘Catherina’, ‘Mirel’, ‘Fercluse’, ‘Andross’, ‘Everts’ and ‘VLG’, in products of both packing media. At the same time, again, ‘Ferlate’ was the only cultivar that maintained some of its flavan-3-ols, specifically catechin (CAT), after canning and 6-months storage (Supplementary Table S 7).

Table 5.2: Chromatographic data (peak number, retention time and ionization mode) and MS² m/z values (molecular and fragment ions) of peach (A) individual phenolic compounds and (B) individual carotenoids and tocopherols

(A) Chemical Structures	Compound	No.	t_R (min)	MH (Frag. MS^2 *m/z*)	Ionization Mode
	Hydroxycinnamates				
 Hydroxycinnamates	Neochlorogenic acid	1	5.6	354 (194, 182)	ESI, [M - H]-
	Chlorogenic acid	3	7.6	354 (194)	ESI, [M - H]-
	Flavan-3-ols				
 Flavan-3-ols	Procyanidin B1	2	7	578 (426)	ESI, [M - H]-
	Catechin	4	7.9	290 (247, 208, 205)	ESI, [M - H]-

(B) Chemical Structures	Compound	No.	t_R (min)	MH (Frag. MS^2 *m/z*)	Ionization Mode
	Carotenoids				
 beta-carotene	β-Carotene	3	14.3	537 (177, 137)	APCI, $[M+H]^+$
 zeaxanthin					
 lutein	zeaxanthin - lutein	1	5.3	569 (175, 135)	APCI, $[M+H]^+$
	lutein - zeaxanthin	1	5.3	569 (119, 93)	APCI, $[M+H]^+$
 Vitamin E	Tocopherols				
	a-tocopherol	2	7.6	431 (165, 137)	APCI, $[M+H]^+$

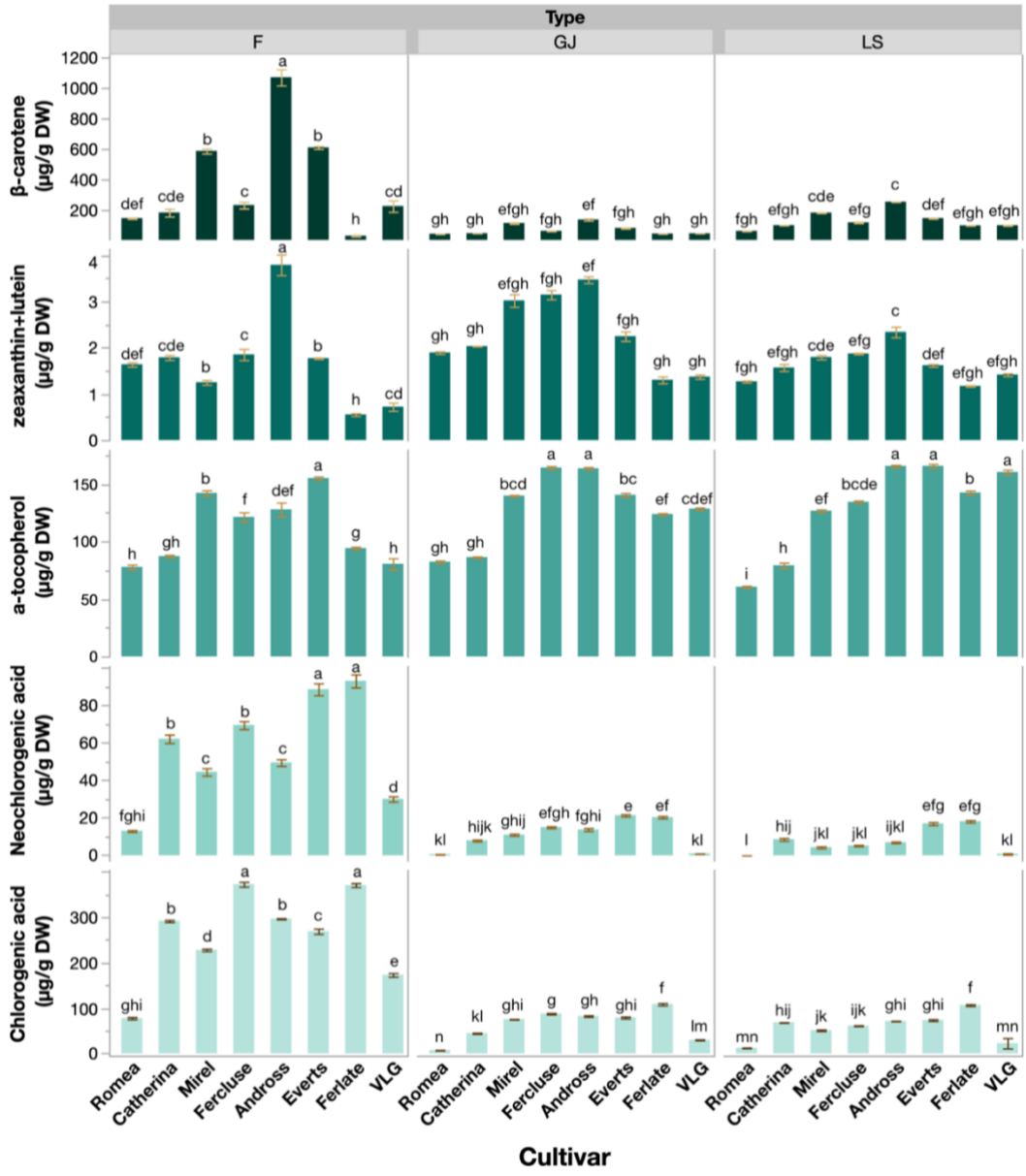


Figure 5.3: Individual phenolic compounds (neochlorogenic acid and chlorogenic acid), carotenoids (β-carotene and zeaxanthin+lutein) and tocopherols (α-tocopherol) evaluated and quantified for fresh and canned peach fruit in two packing media (light syrup and grape juice) of eight non-melting peach cultivars. Lower-case letters indicate significant differences and

interactions from the ANOVA models among product type, and cultivar values, respectively (Tukey's post-hoc test, $p < 0.05$).

5.3.5. Individual carotenoid compounds

In agreement with previous reports (Campbell and Padilla-Zakour, 2013, Zaghdoudi et al., 2015), the most abundant carotenoid in the examined peach cultivars was β-carotene (BCAR). However, remarkable differences were noted for the fresh tissues among the studied peach cultivars, spanning from 33.4 μg/g DW in 'Ferlate' up to 1069.6 μg/g DW in 'Andross' (Figure 5.3, Supplementary Table S 7). The xanthophylls lutein and zeaxanthin (ZELUT) were also identified and quantified and are reported here as their sum, ranging from 0.6 μg/g DW in 'Ferlate' up to 3.6 μg/g DW in 'Andross' for the fresh fruit tissues (Figure 5.3, Supplementary Table S 7). The quantitative distribution of ZELUT in the extracts from the canned peaches resembled those of their fresh counterparts. It is difficult to determine the actual losses of such compounds due to processing and subsequent storage. What can be discerned though, is that although the predominant carotenoids (CAR) found in the peach fruit under study are hydrocarbons, which are known to be heat resistant, ZELUT, mostly xanthophylls, also seemed to be unaffected by canning-storage, compared to BCAR. This observation agrees with the findings of Lessin et al. (1997), revealing a decrease in total β-carotene following canning of peaches. In contrast, increases in other horticultural commodities (i.e., carrots, collard greens, spinach, and sweet potatoes) have been noted, indicating that the effect of thermal treatment on carotenoids depends on the nature of the food matrix itself. Apparently, canning has been suggested to improve extractability of carotenoids from some cellular-

type matrices (Le Bourvellec et al., 2018), resulting in higher detectable levels upon extraction of thermally processed products. This effect can explain the higher concentrations of ZELUT observed in both canned types of peaches, compared to the respective fresh fruit tissues (Supplementary Table S 7).

The DL-α-tocopherol (ATOC) was also detected and quantified in all types of fruit products (fresh and canned), with the fresh fruit demonstrating an average concentration of 77.9 μg/g DW to 155.2 μg/g DW; 'Romea' showed the lowest value and 'Everts' the highest. Most of the examined cultivars displayed non-significant variation between fresh and preserved fruit (canned in either medium), except for 'Ferlate' and 'VLG', which demonstrated significant concentration increases in the canned products (Figure 5.3**,** Supplementary Table S 7). Although studies focusing on the effects of canning on ATOC in fruit are limited since canned products like peaches are not considered significant sources of ATOC (Rickman et al., 2007), the observed conservation of this group of bioactives, and even the increase in ATOC content of the canned peaches, is consistent with the findings for other canned vegetables (Abushita et al., 2000). Specifically, studies on tomatoes demonstrated that upon canning, the levels of ATOC remained similar or higher than the amount present in the fresh tissue. To explain this phenomenon, it has been suggested that ATOC, being entrapped in the cellular tissues of fresh produce, is released during thermal processing due to cell wall degradation; however, once the maximum amount is released from the disintegrated cells, the ATOC content will decline due to thermal degradation and oxidation events occurring in the processed product upon

storage (Abushita et al., 2000). Nevertheless, further research is needed to fully understand the effect of canning on ATOC in thermally processed peaches.

Comparatively, with a critical assessment of the results of the results of the present study on individual bioactive compounds content, as identified and quantified for the eight peach cultivars, fresh and canned products, it can be deduced that peach carotenoids and tocopherols are more stable than phenolic compounds upon thermal treatment and storage; i.e., while carotenoids and tocopherols, in their majority, tend to either remain stable or even exhibit increased concentrations following thermal processing, the polyphenols are more prone to thermal degradation and diffusion into the liquid medium. Statistically, both the cultivar and the type of fruit product (fresh and canned in the two media), as well as their interaction, showed a significant impact on the extent of these effects (Table 5.3). Estimating the proportion of losses in individual phytochemicals due to thermal degradation and/or migration from the food matrix to the liquid medium and hence the desirability index, requires quantification of all nutritionally important phytochemicals in the fresh produce as well as in both the processed fruit tissues and the liquid medium. Since quantification in the present study was only performed for the fruit tissues, a statistical prediction profile was calculated to assess the desirability of the canning type and cultivar. As depicted in Figure 5.4, in terms of retention of individual phytochemicals in the differently packed peach product, the highest desirability seems to be the processed products with the grape juice as a liquid medium, while in terms of cultivar's impact, the most desirable cultivar in terms of richness in phytochemical content, appears to be 'Andross' across all three types of fruit products examined.

Overall, the resulting desirability rankings per type of product, based on their richness in individual bioactive compounds for the eight peach cultivars studied in the present work, are defined as follows: ‘Andross’ > ‘Everts’ > ‘Fercluse’ > ‘Mirel’ > ‘Catherina’ > ‘Ferlate’ > ‘VLG’ > ‘Romea’ for fresh produce, and ‘Andross’ > ‘Fercluse’ > ‘Mirel’ > ‘Everts’ > ‘Ferlate’ > ‘Catherina’ > ‘VLG’ > ‘Romea’ when peaches were canned in grape juice. The respective ranking order when canning was performed with light syrup is ‘Andross’ > ‘Everts’ > ‘Ferlate’ > ‘Mirel’ > ‘Fercluse’ > ‘VLG’ > ‘Catherina’ > ‘Romea’ (Supplementary Table S 8).

Table 5.3: Effect summary of the impact of product type (T), cultivar (C) and type x cultivar interaction (T x C) on quantified individual phenolic compounds, carotenoids and tocopherols of eight non-melting peach cultivars, fresh and preserved.

Source	**Log Worth**		**P-Value**
Type (T)	62.023		0.00000
Cultivar (C)	45.669		0.00000
T x C	34.485		0.00000

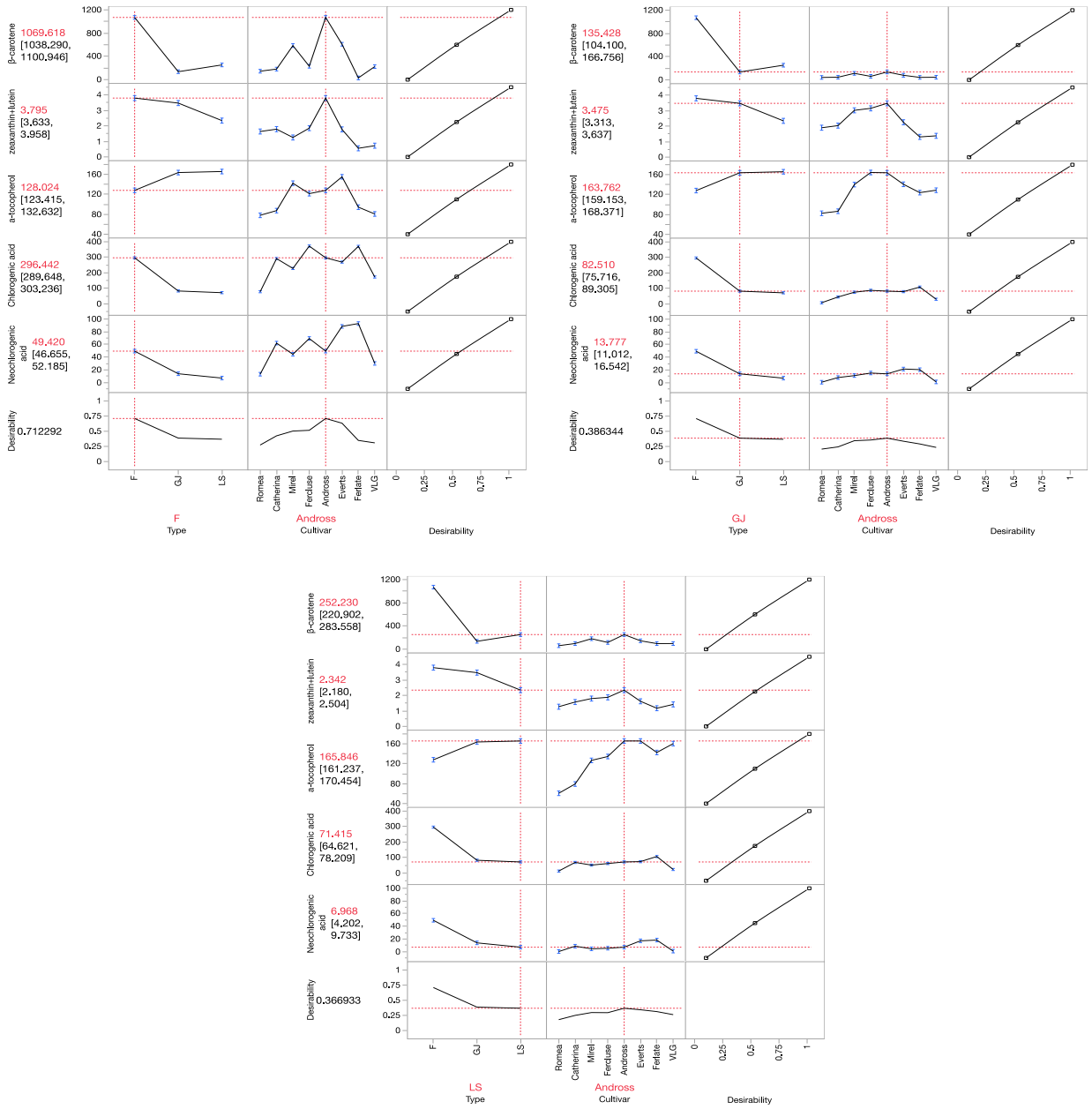


Figure 5.4: Prediction profile of optimum individual phytochemical content (individual phenolic and carotenoid compounds) between the eight peach cultivars of each product type (F, GJ and LS) for maximizing desirability score. Vertical dash line represents the product type and cultivar, whereas the horizontal line represents values obtained at

conditions that result in the highest desirability score. The right-hand row is scaled as 0 (undesirable) to 1 (most desirable).

5.4. Conclusions

The cellular matrix of peach fruit contains an abundance of bioactive compounds. Destruction of the cells of the fruit flesh, diffusion of biochemical components into the preservation (packing) medium, both during heating and osmotic equilibration on storage, are the most common encountered in canned peach products. This study has demonstrated that the phytochemical profile of peach fruit is primarily genotype dependent, as is its ability to retain this profile during thermal processing and storage. Heat treatment differentially affected individual carotenoids and phenolic compounds. Total and individual bioactive content showed that peach carotenoids and α-tocopherol, with the exemption of β-carotene, were more stable than phenolic compounds upon thermal treatment and subsequent storage. The sum of zeaxanthin and lutein was found unaffected by the preservation processing compared to β-carotene. All phenolic compounds, including neochlorogenic acid, chlorogenic acid, procyanidin B1 and catechin, decrease significantly upon canning and storage.

Oligomeric and polymeric proanthocyanidins, which are relevant phenolics in peach, were not studied in the present project as they were not extracted with the solvents used. The present study was focused on those phenolic that could be absorbed in the small intestine and therefore can have direct systemic effects. However, these should be studied in future work, as they interact with gut microbiota and are relevant (poly)phenols

regarding health effects. Moreover, the unique cellular matrix of individual peach fruit cultivars seems to modulate the degree of loss of bioactive compounds as well as the cellular degradation of the fruit tissues and thereby affecting the diffusion of biochemical components into the liquid media, thus rendering certain cultivars and packing liquids more appropriate for canning.

6. General Conclusions /Future perspectives

Responding to the need to explore the different quality disciplines of canned peach fruit, this research study tried to shed some light in the sensorial attributes, textural properties and phytochemical composition of canned fruit from eight commercially important non-melting clingstone peach cultivars, used in Greece. Such cultivars, namely 'Romea', 'Catherina, 'Mirel®', 'Fercluse®', 'Andross', 'Everts', 'Ferlate®' and 'VLG' exhibited on-tree ripening in succession over a period spanning from July until mid-September have been examined regarding the aforementioned properties both as fresh and after canning process.

The current study yields useful and meaningful knowledge to diffuse in industrial, scientific and consumer community: (i) canning industry would be favoured for providing the comprehensive standardized protocols (sensory and texture analyses) to establish accurate qualitative tests to determine the desired end-product quality characteristics and monitor the shelf life of canned fruit products, (ii) peach breeders would be privileged on such protocols to select and evaluate new candidate clingstone cultivars suitable for canning, and (iii) consumers would benefit in terms of continuous research on canned products (available all-year round) on their compositional characteristics and additional nutritional value; being a healthy choice.

On the one hand, taking all into consideration, it could be suggested to the researchers and food processing industries to use the current knowledge for the development of new or optimizing existing technologies alternative to conventional

thermal processing (canning process); aiming to an augmented ‘value-added’ form of processed fruit. From the other hand, the current knowledge on objective analytical determinations coupled with subjective evaluations of critical components as well as the phytochemical content is expected to be further exploited, allowing to obtain products with an overall superior quality.

Future outlooks can be referred to optimizing peach pasteurization process using Ohmic technology; this equipment is already installed at the premises of Venus Growers. Ohmic heating is a novel thermal processing method which is based on generating heat inside the food product by applying an electric field. It has been recently studied and used by researchers and food processing industries as a potential promising method alternative to conventional methods. However, there is limited research in the literature regarding the nutrients and bioactive content and the effects of Ohmic heating on specific compounds. With the aim to optimize (selecting the most appropriate operating conditions such as the electric field frequency, voltage, end-point temperature, treatment time) the processing of peach fruit to maintain its nutritional value. Furthermore, the bioactive profile of processed peach upon Ohmic heating can be compared with the bioactive content of processed peach during canning (the results of the current study) and the sensorial and mechanical protocols can be additionally applied.

7. References

Abushita, A., Daood, H. & Biacs, P. 2000. Change in carotenoids and antioxidant vitamins in tomato as a function of varietal and technological factors. *Journal of Agricultural and Food Chemistry,* 48**,** 2075-2081.

Ahmed, L., Patras, A., Martin-Diana, A. B., Rico, D. & Barry-Ryan, C. 2012. The effect of delactosed whey permeate on phytochemical content of canned tomatoes. *Food Chemistry,* 134**,** 2249-2256.

Aktas, E. T. & Yildiz, H. 2011. Effects of electroplasmolysis treatment on chlorophyll and carotenoid extraction yield from spinach and tomato. *Journal of Food Engineering,* 106**,** 339-346.

Aleixandre-Tudó, J. L., Alvarez, I., Lizama, V., GarcíA, M. a. J., Aleixandre, J. L. & Du Toit, W. J. 2013. Impact of caffeic acid addition on phenolic composition of tempranillo wines from different winemaking techniques. *Journal of Agricultural and Food Chemistry,* 61**,** 11900-11912.

Ames, B. N., Shigenaga, M. K. & Hagen, T. M. 1993. Oxidants, antioxidants, and the degenerative diseases of aging. *Proceedings of the National Academy of Sciences of the United States of America,* 90**,** 7915-7922.

Apostolopoulos, C. & Brennan, J. G. 1994. Interrelationships between sensory and mechanical characteristics of canned peaches. *Journal of Texture Studies,* 25**,** 191-206.

Aprea, E., Corollaro, M. L., Betta, E., Endrizzi, I., Demattè, M. L., Biasioli, F. & Gasperi, F. 2012. Sensory and instrumental profiling of 18 apple cultivars to investigate the relation between perceived quality and odour and flavour. *Food Research International,* 49**,** 677-686.

Arampath, P. C. & Dekker, M. 2021. Thermal effect, diffusion, and leaching of health-promoting phytochemicals in commercial canning process of mango (Mangifera indica l.) and pineapple (ananas comosus l.). *Foods,* 10**,** 46.

Asami, D. K., Hong, Y. J., Barrett, D. M. & Mitchell, A. E. 2003. Processing-induced changes in total phenolics and procyanidins in clingstone peaches. *Journal of the Science of Food and Agriculture,* 83**,** 56-63.

Aubert, C., Bony, P., Chalot, G., Landry, P. & Lurol, S. 2014. Effects of storage temperature, storage duration, and subsequent ripening on the physicochemical characteristics, volatile compounds, and phytochemicals of western red nectarine (Prunus persica L. Batsch). *Journal of Agricultural and Food Chemistry,* 62**,** 4707-4724.

Avila, I. & Silva, C. 1999. Modelling kinetics of thermal degradation of colour in peach puree. *Journal of Food Engineering,* 39**,** 161-166.

Ayour, J., Gouble, B., Reling, P., Ribas-Agustí, A., Audergon, J.-M., Maingonnat, J.-F., Benichou, M. & Renard, C. M. 2017. Impact of cooking on apricot texture as a function of cultivar and maturity. *LWT-Food Science and Technology,* 85**,** 385-389.

Badenes, M. L., Cambra, M., López, M., Batlle, I., Iglesias, I., Aranzana, M., López, E., Vives, C., Garcia Brunton, J. & Romeu, J. 2015. A peach germplasm collection for increasing the genetic diversity in European breeding programs. *Acta Horticulturae***,** 125-129.

Barrett, D. M., Somogyi, L. & Ramaswamy, H. S. 2004. *Processing fruits: science and technology*, CRC press.

Bassi, D. & Monet, R. 2008. Botany and Taxonomy. *In:* Layne, D. R. & Bassi, D. (eds.) *The peach: Botany, Productin and Uses.* Oxfordshire, UK: CABI.

Belisle, C., Phan, U. T., Adhikari, K. & Chavez, D. J. 2018. A fruit quality survey of peach cultivars grown in the southeastern United States. *HortTechnology,* 28**,** 189-201.

Bento, C., Goncalves, A. C., Silva, B. & Silva, L. R. 2018. Assessing the phenolic profile, antioxidant, antidiabetic and protective effects against oxidative damage in human erythrocytes of peaches from Fundão. *Journal of Functional Foods,* 43**,** 224-233.

Bento, C., Gonçalves, A. C., Silva, B. & Silva, L. R. 2020. Peach (*Prunus persica*): Phytochemicals and Health Benefits. *Food Reviews International***,** 1-32.

Bett-Garber, K. L., Watson, M. A., Lea, J. M., Champagne, E. T. & Lamikanra, O. 2010. Effect of combined underwater processing and mild precut heat treatment on the sensory quality and storage of fresh-cut cantaloupe melon. *Journal of Food Quality,* 33**,** 424-438.

Biesalski, H.-K., Dragsted, L. O., Elmadfa, I., Grossklaus, R., Müller, M., Schrenk, D., Walter, P. & Weber, P. 2009. Bioactive compounds: Definition and assessment of activity. *Nutrition,* 25**,** 1202-1205.

Bonneau, A., Boulanger, R., Lebrun, M., Maraval, I., Valette, J., Guichard, É. & Gunata, Z. 2018. Impact of fruit texture on the release and perception of aroma compounds during in vivo consumption using fresh and processed mango fruits. *Food Chemistry,* 239**,** 806-815.

Boriss, H. & Brunke, H. 2006. Commodity Profile: Peaches and Nectarines. *Agricultural Marketing Resource Center, University of California*.

Bourles, E., Mehinagic, E., Courthaudon, J.-L. & Jourjon, F. 2009. Impact of vacuum cooking process on the texture degradation of selected apple cultivars. *Journal of Food Science,* 74**,** E512-E518.

Bourne, M. 2002. *Food texture and viscosity: concept and measurement,* Elsevier.

Brown, A. F., Yousef, G. G., Guzman, I., Chebrolu, K. K., Werner, D. J., Parker, M., Gasic, K. & Perkins-Veazie, P. 2014. Variation of carotenoids and polyphenolics in peach and implications on breeding for modified phytochemical profiles. *Journal of the American Society for Horticultural Science,* 139**,** 676-686.

Burin, V. M., Falcão, L. D., Gonzaga, L. V., Fett, R., Rosier, J. P. & Bordignon-Luiz, M. T. 2010. Colour, phenolic content and antioxidant activity of grape juice. *Food Science and Technology,* 30**,** 1027-1032.

Burrell, R. E. & Reighard, G. L. 2017. Late dormant pruning affects split pit incidence in peach. *Acta Horticulturae* 1177**,** 157-164.

Byrne, D. H. 2005. Trends in stone fruit cultivar development. *HortTechnology,* 15**,** 494-500.

Byrne, D. H., Nikolic, A. N. & Burns, E. E. 1991. Variability in sugars, acids, firmness, and color characteristics of 12 peach genotypes. *Journal of the American Society for Horticultural Science,* 116**,** 1004-1006.

Byrne, D. H., Raseira, M. B., Bassi, D., Piagnani, M. C., Gasic, K., Reighard, G. L., Moreno, M. A. & Pérez, S. 2012. Peach. *In:* Badenes, M. L., Byrne, D.H., (ed.) *Fruit breeding*, *Handbook of Plant Breeding*. Boston, MA, USA,: Springer.

Campbell, O. E. & Padilla-Zakour, O. I. 2013. Phenolic and carotenoid composition of canned peaches (*Prunus persica*) and apricots (*Prunus armeniaca*) as affected by variety and peeling. *Food Research International,* 54**,** 448-455.

Canet, W., Alvarez, M. D., Luna, P. & Fernández, C. 2004. Reprocessing effect on the quality of domestically cooked (boiled/stir-fried) frozen vegetables. *European Food Research and Technology,* 219**,** 240-250.

Cantín, C. M., Gogorcena, Y. & Moreno, M. A. 2010. Phenotypic diversity and relationships of fruit quality traits in peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies. *Euphytica,* 171**,** 211-226.

Cantín, C. M., Moreno, M. A. & Gogorcena, Y. 2009. Evaluation of the antioxidant capacity, phenolic compounds, and vitamin C content of different peach and nectarine [*Prunus persica* (L.) batsch] breeding progenies. *Journal of Agricultural and Food Chemistry,* 57**,** 4586-4592.

Cardoso, J. M. P. & Bolini, H. M. A. 2008. Descriptive profile of peach nectar sweetened with sucrose and different sweeteners. *Journal of Sensory Studies,* 23**,** 804-816.

Causse, M., Saliba-Colombani, V., Lesschaeve, I. & Buret, M. 2001. Genetic analysis of organoleptic quality in fresh market tomato. 2. Mapping QTLs for sensory attributes. *Theoretical and Applied Genetics,* 102**,** 273-283.

Ceccarelli, D., Simeone, A. M., Nota, P., Piazza, M. G., Fideghelli, C. & Caboni, E. 2016. Phenolic compounds (hydroxycinnamic acids, flavan-3-ols, flavonols) profile in fruit of Italian peach varieties. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology,* 150**,** 1370-1375.

Cevallos-Casals, B. A., Byrne, D., Okie, W. R. & Cisneros-Zevallos, L. 2006. Selecting new peach and plum genotypes rich in phenolic compounds and enhanced functional properties. *Food Chemistry,* 96**,** 273-280.

Chang, S., Tan, C., Frankel, E. N. & Barrett, D. M. 2000. Low-density lipoprotein antioxidant activity of phenolic compounds and polyphenol oxidase activity in selected clingstone peach cultivars. *Journal of Agricultural and Food Chemistry,* 48**,** 147-151.

Chaovanalikit, A. & Wrolstad, R. 2004. Total anthocyanins and total phenolics of fresh and processed cherries and their antioxidant properties. *Journal of Food Science,* 69**,** FCT67-FCT72.

Charrier, G., Ngao, J., Saudreau, M. & Améglio, T. 2015. Effects of environmental factors and management practices on microclimate, winter physiology, and frost resistance in trees. *Frontiers in Plant Science,* 6.

Chaunier, L., Courcoux, P., Della Valle, G. & Lourdin, D. 2005. Physical and sensory evaluation of cornflakes crispness. *Journal of Texture Studies,* 36**,** 93-118.

Chen, L. & Opara, U. L. 2013. Texture measurement approaches in fresh and processed foods—A review. *Food Research International,* 51**,** 823-835.

Christofi, M., Mauromoustakos, A., Mourtzinos, I., Lazaridou, A., Drogoudi, P., Theodoulidis, S., Biliaderis, C. G. & Manganaris, G. A. 2021a. The effect of genotype and storage on compositional, sensorial and textural attributes of canned fruit from commercially important non-melting peach cultivars. *Journal of Food Composition and Analysis,* 103**,** 104080.

Christofi, M., Mourtzinos, I., Lazaridou, A., Drogoudi, P., Tsitlakidou, P., Biliaderis, C. G. & Manganaris, G. A. 2021b. Elaboration of novel and comprehensive protocols toward determination of textural properties and other sensorial attributes of canning peach fruit. *Journal of Texture Studies,* 52**,** 228-239.

Chuo, S. C., Nasir, H. M., Mohd-Setapar, S. H., Mohamed, S. F., Ahmad, A., Wani, W. A., Muddassir, M. & Alarifi, A. 2020. A Glimpse into the extraction methods of active compounds from plants. *Critical Reviews in Analytical Chemistry***,** 1-30.

Ciacciulli, A., Chiozzotto, R., Attanasio, G., Cirilli, M. & Bassi, D. 2018. Identification of a melting type variant among peach (P. persica L. Batsch) fruit textures by a digital penetrometer. *Journal of Texture Studies,* 49**,** 370-377.

Cirilli, M., Bassi, D. & Ciacciulli, A. 2016. Sugars in peach fruit: A breeding perspective. *Horticulture Research,* 3.

Citadin, I., Raseira, M. D. C., Herter, F. G. & Da Silva, J. B. 2001. Heat requirement for blooming and leafing in peach. *HortScience,* 36**,** 305-307.

Civille, G. V. & Oftedal, K. N. 2012. Sensory evaluation techniques—Make "good for you" taste "good". *Physiology & Behavior,* 107**,** 598-605.

Colaric, M., Veberic, R., Stampar, F. & Hudina, M. 2005. Evaluation of peach and nectarine fruit quality and correlations between sensory and chemical attributes. *Journal of the Science of Food and Agriculture,* 85**,** 2611-2616.

Contador, L., Díaz, M., Hernández, E., Shinya, P. & Infante, R. 2016. The relationship between instrumental tests and sensory determinations of peach and nectarine texture. *European Journal of Horticultural Science,* 81**,** 189-196.

Couvillon, G. & Krewer, G. 2018. The peach, the nectarine, and the plum. *Quality and Preservation of Fruits.* CRC Press.

Crisosto, C. H. 1999. Optimum procedures for ripening stone fruit. *Management of Fruit, Ripening. University of California, Davis, Postharvest Horticulture Series,* 9**,** 28-30.

Crisosto, C. H. & Crisosto, G. M. 2005. Relationship between ripe soluble solids concentration (RSSC) and consumer acceptance of high and low acid melting flesh peach and nectarine (Prunus persica (L.) Batsch) cultivars. *Postharvest Biology and Technology,* 38**,** 239-246.

Crisosto, C. H., Day, K. R., Crisosto, G. M. & Garner, D. 2001. Quality attributes of white flesh peaches and nectarines grown under California conditions. *Journal-American Pomological Society,* 55**,** 45-51.

Crisosto, C. H., Valero, C. & Slaughter, D. C. 2007. Predicting pitting damage during processing in Californian clingstone peaches using color and firmness measurements. *Applied Engineering in Agriculture,* 23**,** 189-194.

Dabbou, S., Maatallah, S., Castagna, A., Guizani, M., Sghaeir, W., Hajlaoui, H. & Ranieri, A. 2017. Carotenoids, phenolic profile, mineral content and antioxidant properties in flesh and peel of Prunus persica fruits during two maturation stages. *Plant Foods for Human Nutrition,* 72**,** 103-110.

Dardick, C. & Callahan, A. M. 2014. Evolution of the fruit endocarp: molecular mechanisms underlying adaptations in seed protection and dispersal strategies. *Frontiers in Plant Science,* 5**,** 284.

Das, B., Ahmed, N. & Singh, P. 2011. Prunus diversity-early and present development: a review. *International Journal of Biodiversity and Conservation,* 3**,** 721-734.

Davidovic, S. M., Veljović, M. S., Pantelić, M. M., BaošIć, R. M., Natić, M. M., Dabić, D. C., Pecić, S. P. & Vukosavljević, P. V. 2013. Physicochemical, antioxidant and

sensory properties of peach wine made from redhaven cultivar. *Journal of Agricultural and Food Chemistry,* 61**,** 1357-1363.

De Roeck, A., Mols, J., Duvetter, T., Van Loey, A. & Hendrickx, M. 2010. Carrot texture degradation kinetics and pectin changes during thermal versus high-pressure/high-temperature processing: A comparative study. *Food Chemistry,* 120**,** 1104-1112.

Delgado, C., Crisosto, G. M., Heymann, H. & Crisosto, C. H. 2013. Determining the primary drivers of liking to predict consumers' acceptance of fresh nectarines and peaches. *Journal of Food Science,* 78**,** S605-S614.

Delwiche, M. J. 1988. Maturity standards for processing clingstone peaches. *Journal of Food Process Engineering,* 10**,** 269-284.

Deman, J. M., Voisey, P. W., Rasper, V. F. & Stanley, D. W. 1976. *Rheology and texture in food quality*, Westport, Connecticut, Avi.

Denoya, G. I., Polenta, G. A., Apóstolo, N. M., Budde, C. O., Sancho, A. M. & Vaudagna, S. R. 2016. Optimization of high hydrostatic pressure processing for the preservation of minimally processed peach pieces. *Innovative Food Science and Emerging Technologies,* 33**,** 84-93.

Di Vaio, C., Graziani, G., Marra, L., Cascone, A. & Ritieni, A. 2008. Antioxidant capacities, carotenoids and polyphenols evaluation of fresh and refrigerated peach and nectarine cultivars from Italy. *European Food Research and Technology*, 227**,** 1225-1231.

Di Vaio, C., Marallo, N., Graziani, G., Ritieni, A. & Di Matteo, A. 2015. Evaluation of fruit quality, bioactive compounds and total antioxidant activity of flat peach cultivars. *Journal of the Science of Food and Agriculture,* 95**,** 2124-2131.

Ding, T., Cao, K., Fang, W., Zhu, G., Chen, C., Wang, X. & Wang, L. 2020. Evaluation of phenolic components (anthocyanins, flavanols, phenolic acids, and flavonols) and their antioxidant properties of peach fruits. *Scientia Horticulturae,* 268**,** 109365.

Dinnella, C., Recchia, A., Tuorila, H. & Monteleone, E. 2011. Individual astringency responsiveness affects the acceptance of phenol-rich foods. *Appetite,* 56**,** 633-642.

Dragovic-Uzelac, V., Levaj, B., Mrkic, V., Bursac, D. & Boras, M. 2007. The content of polyphenols and carotenoids in three apricot cultivars depending on stage of maturity and geographical region. *Food Chemistry,* 102**,** 966-975.

Drogoudi, P., Gerasopoulos, D., Kafkaletou, M. & Tsantili, E. 2017. Phenotypic characterization of qualitative parameters and antioxidant contents in peach and nectarine fruit and changes after jam preparation. *Journal of the Science of Food and Agriculture,* 97**,** 3374-3383.

Drogoudi, P., Pantelidis, G. E., Goulas, V., Manganaris, G. A., Ziogas, V. & Manganaris, A. 2016. The appraisal of qualitative parameters and antioxidant contents during postharvest peach fruit ripening underlines the genotype significance. *Postharvest Biology and Technology,* 115**,** 142-150.

Drogoudi, P., Tsipouridis, C. & Pantelidis, G. 2009. Effects of crop load and time of thinning on the incidence of split pits, fruit yield, fruit quality, and leaf mineral contents in 'Andross' peach. *The Journal of Horticultural Science and Biotechnology,* 84**,** 505-509.

Drogoudi, P. & Tsipouridis, C. G. 2007. Effects of cultivar and rootstock on the antioxidant content and physical characters of clingstone peaches. *Scientia Horticulturae,* 115**,** 34-39.

Durst, R. W. & Weaver, G. W. 2013. Nutritional content of fresh and canned peaches. *Journal of the Science of Food and Agriculture,* 93**,** 593-603.

Eduardo, I., Chietera, G., Bassi, D., Rossini, L. & Vecchietti, A. 2010. Identification of key odor volatile compounds in the essential oil of nine peach accessions. *Journal of the Science of Food and Agriculture,* 90**,** 1146-1154.

Engindeniz, S., Cukur, F. & Yucel, D. 2003. The economic and technical analysis of peach growing: a case study for Turkey. *Journal of Applied Horticulture,* 5**,** 114-118.

Eskin, N. a. M. 1991. The peach, the nectarine and the plum. *In:* COUVILLON, G. O. & KREWER, G. (eds.) *Quality and Preservation of Fruits.* CRC Press.

Esti, M., Messia, M. C., Sinesio, F., Nicotra, A., Conte, L., La Notte, E. & Palleschi, G. 1997. Quality evaluation of peaches and nectarines by electrochemical and multivariate analyses: relationships between analytical measurements and sensory attributes. *Food Chemistry,* 60**,** 659-666.

Fadón, E., Herrera, S., Guerrero, B. I., Guerra, M. E. & Rodrigo, J. 2020. Chilling and heat requirements of temperate stone fruit trees (Prunus sp.). *Agronomy,* 10**,** 409.

Faostat. Available: http://www.fao.org/faostat/en/#data/QCL [Accessed 23 August 2021].

Farina, V., Lo Bianco, R. & Mazzaglia, A. 2019. Evaluation of late-maturing peach and nectarine fruit quality by chemical, physical, and sensory determinations. *Agriculture (Switzerland),* 9.

Felts, M., Threlfall, R. T. & Worthington, M. L. 2019. Physicochemical and descriptive sensory analysis of arkansas-grown peaches and nectarines. *HortScience,* 54**,** 226-235.

Ferrer, A., Remón, S., Negueruela, A. I. & Oria, R. 2005. Changes during the ripening of the very late season Spanish peach cultivar Calanda: feasibility of using CIELAB coordinates as maturity indices. *Scientia Horticulturae,* 105**,** 435-446.

Florkowski, W. J., Shewfelt, R. L., Brueckner, B. & Prussia, S. E. 2014. *Postharvest Handling, Third Edition: A Systems Approach*, Academic Press.

Font I Forcada, C., Gradziel, T. M., Gogorcena, Y. & Moreno, M. Á. 2014. Phenotypic diversity among local Spanish and foreign peach and nectarine [Prunus persica (L.) Batsch] accessions. *Euphytica,* 197**,** 261-277.

Fraser, P. D. & Bramley, P. M. 2004. The biosynthesis and nutritional uses of carotenoids. *Progress in Lipid Research,* 43**,** 228-265.

Fuentes-Pérez, M. D. C., Nogales-Delgado, S., Ayuso, M. C. & Bohoyo-Gil, D. 2014. Different peach cultivars and their suitability for minimal processing. *Czech Journal of Food Sciences,* 32**,** 413-421.

Gangwar, L., Singh, D. & Mandal, G. 2008. Economic evaluation of peach cultivation in North Indian plains. *Agricultural Economics Researh Review,* 21**,** 123-129.

García-Alonso, M. A., De Pascual-Teresa, S., Santos-Buelga, C. & Rivas-Gonzalo, J. C. 2004. Evaluation of the antioxidant properties of fruits. *Food Chemistry,* 84**,** 13-18.

Gazzani, G., Papetti, A., Massolini, G. & Daglia, M. 1998. Anti- and Prooxidant Activity of Water Soluble Components of Some Common Diet Vegetables and the Effect of Thermal Treatment. *Journal of Agricultural and Food Chemistry,* 46**,** 4118-4122.

Gecer, M. K. 2020. Biochemical content in fruits of peach and nectarine cultivars. *Turkish Journal of Agriculture and Forestry,* 44**,** 500-505.

Génard, M. & Souty, M. 1996. Modeling the peach sugar contents in relation to fruit growth. *Journal of the American Society for Horticultural Science,* 121**,** 1122-1131.

Gil, M. I., Tomás-Barberán, F. A., Hess-Pierce, B. & Kader, A. A. 2002. Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and plum cultivars from California. *Journal of Agricultural and Food Chemistry,* 50**,** 4976-4982.

Giorgi, M., Capocasa, F., Scalzo, J., Murri, G., Battino, M. & Mezzetti, B. 2005. The rootstock effects on plant adaptability, production, fruit quality, and nutrition in the peach (cv.'Suncrest'). *Scientia Horticulturae,* 107**,** 36-42.

Giuffrida, D., Torre, G., Dugo, P. & Dugo, G. 2013. Determination of the carotenoid profile in peach fruits, juice and jam. *Fruits,* 68**,** 39-44.

González-Buesa, J., Arias, E., Salvador, M. L., Oria, R. & Ferrer-Mairal, A. 2011. Suitability for minimal processing of non-melting clingstone peaches. *International Journal of Food Science and Technology,* 46**,** 819-826.

Gradzie, T. M. & Thorpe, M. A. 2010. 'Goodwin' peach: A processing clingstone peach ripening in the 'Dixon'-'Andross' maturity season. *HortScience,* 45**,** 1901-1903.

Gradziel, T. & Mccaa, J. 2008. Processing peach cultivar development. *The peach: botany, production and uses. Oxfordshire: CABI***,** 175-92.

Greve, L. C., Shackel, K. A., Ahmadi, H., Mcardle, R. N., Gohlke, J. R. & Labavitch, J. M. 1994. Impact of heating on carrot firmness: contribution of cellular turgor. *Journal of Agricultural and Food Chemistry,* 42**,** 2896-2899.

Gunness, P., Kravchuk, O., Nottingham, S. M., D'arcy, B. R. & Gidley, M. J. 2009. Sensory analysis of individual strawberry fruit and comparison with instrumental analysis. *Postharvest Biology and Technology,* 52**,** 164-172.

Habib, S. 2015. Peach: Queen of fruits. *Pakistan food journal***,** 26-27.

Haleema, R., Shenoy, A. & Shabaraya, A. R. 2020. A Review on Pharmacological Activities of Prunus persica. *International Journal of Pharmaceutical Sciences Review and Research,* 60**,** 38-40.

Harker, F. R., Redgwell, R. J., Hallett, I. C., Murray, S. H. & Carter, G. 2010. Texture of fresh fruit. *In Horticultural Reviews*

Hart, D. J. & Scott, K. J. 1995. Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. *Food Chemistry,* 54**,** 101-111.

Hassan, R. B. A. 2012. Vitamins (Importance and Toxicity). *Pharmaceutica Analytica Acta,* 3.

Haug, M. T., King, E. S., Heymann, H. & Crisosto, C. H. 2013. Sensory profiles for dried fig (Ficus Carica L.) cultivars commercially grown and processed in California. *Journal of Food Science,* 78**,** S1273-S1281.

Hilaire, C. 2003. The peach industry in France: State of art, research and development. *In First Mediterranean Peach Symposium***,** 27-34.

Hong, Y.-J., Barrett, D. M. & Mitchell, A. E. 2004. Liquid chromatography/mass spectrometry investigation of the impact of thermal processing and storage on peach procyanidins. *Journal of Agricultural and Food Chemistry,* 52**,** 2366-2371.

Huang, H., Cheng, Z., Zhang, Z. & Wang, Y. 2008. History of cultivation and trends in China. *The peach: botany, production and uses,* 1.

Hui, Y. H. 2006. *Handbook of fruits and fruit processing*, John Wiley & Sons.

Iglesias, I. 2013. Peach production in Spain: current situation and trends, from production to consumption. *Proceedings of the 4th Conference on Innovations in Fruit Growing.*

Iglesias, I. & Echeverría, G. 2021. Overview of the peach industry in the European Union, with special reference to Spain. *Acta Horticulturae 1304, 163-176.*

Igual, M., García-Martínez, E., Camacho, M. & Martínez-Navarrete, N. 2010. Effect of thermal treatment and storage on the stability of organic acids and the functional value of grapefruit juice. *Food Chemistry,* 118**,** 291-299.

Jaeger, S. R., Rossiter, K. L., Wismer, W. V. & Harker, F. R. 2003. Consumer-driven product development in the kiwifruit industry. *Food Quality and Preference,* 14**,** 187-198.

Jaworska, G., Bernaś, E., Biernacka, A. & Maciejaszek, I. 2010. Comparison of the texture of fresh and preserved Agaricus bisporus and Boletus edulis mushrooms. *International Journal of Food Science and Technology,* 45**,** 1659-1665.

Jordheim, M. 2007. Isolation, identification and properties of pyranoanthocyanins and anthocyanin forms. https://bora.uib.no/bora-xmlui/handle/1956/2331

Jowitt, R. 1974. The terminology of food texture. *Journal of Texture Studies,* 5**,** 351-358.

Jun, J., Kwon, J., Nam, E., Chung, K., Yoon, I., Yun, S. & Kim, S. 2016. Trends in public and private peach breeding in the Republic of Korea. *Journal of the American Pomological Society,* 70**,** 180-186.

Kant, R., Shukla, R. K. & Shukla, A. 2018. A review on Peach (Prunus persica): an asset of medicinal phytochemicals. *Int J Res App Sci Eng Technol,* 6**,** 2186-2200.

Keogh, R. C., Robinson, A. P. W. & Mullins, I. J. 2008. Pollination Aware: Peaches and Nectarines. *Pollination Aware – The Real Value of Pollination in Australia.*

Kerr, W. L., Ward, C. D. W., Mcwatters, K. H. & Resurreccion, A. V. A. 2001. Milling and particle size of cowpea flour and snack chip quality. *Food Research International,* 34**,** 39-45.

Khalil, I., Idrees, M., Rabi, F., Rehman, S. & Bostan, N. 2014. An investigation into the problems of peach growers in district Swat. *Journal of Agricultural and Biological Science,* 9**,** 427-434.

Kris-Etherton, P. M., Lefevre, M., Beecher, G., Gross, M., Keen, C. L. & Etherton, T. D. 2004. Bioactive compounds in nutrition and health-research methodologies for establishing biological function: the antioxidant and anti-inflammatory effects of flavonoids on atherosclerosis. *Annual Review of Nutrition,* 24**,** 511-538.

Kuden, A. B., Comlekcioglu, S., Sarier, K., Imrak, B. & Kuden, A. 2018. Peach breeding studies in Turkey and the evaluation of peach and nectarine hybrids. *Breeding and Health Benefits of Fruit and Nut Crops,* 47.

Lachkar, A., Attia, I. B. & Amor, Y. 2020. Morphological and chemical analysis of peach fruits in three different farming systems. *Organic Agriculture,* 10**,** 49-61.

Lawless, H. T. & Heymann, H. 2010. Sensory Evaluation of Food: Principles and Practices. 2 ed. New York: Springer-Verlag

Layne, R. 1997. Peach and nectarine breeding in Canada: 1911 to 1995. *Fruit varieties journal (USA).*

Le Bourvellec, C., Gouble, B., Bureau, S., Reling, P., Bott, R., Ribas-Agusti, A., Audergon, J.-M. & Renard, C. M. 2018. Impact of canning and storage on apricot carotenoids and polyphenols. *Food Chemistry,* 240**,** 615-625.

Legua, P., Hernández, F., Díaz-Mula, H. M., Valero, D. & Serrano, M. 2011. Quality, bioactive compounds, and antioxidant activity of new flat-type peach and nectarine cultivars: a comparative study. *Journal of Food Science,* 76**,** C729-C735.

Lesschaeve, I. & Noble, A. C. 2005. Polyphenols: factors influencing their sensory properties and their effects on food and beverage preferences. *The American Journal of Clinical Nutrition,* 81**,** 330S-335S.

Lessin, W. J., Catigani, G. L. & Schwartz, S. J. 1997. Quantification of cis-trans isomers of provitamin A carotenoids in fresh and processed fruits and vegetables. *Journal of Agricultural and Food Chemistry,* 45**,** 3728-3732.

Li, X.-W., Meng, X.-Q., Jia, H.-J., Yu, M.-L., Ma, R.-J., Wang, L.-R., Cao, K., Shen, Z.-J., Niu, L. & Tian, J.-B. 2013. Peach genetic resources: diversity, population structure and linkage disequilibrium. *BMC genetics,* 14**,** 1-16.

Lieb, V. M., Esquivel, P., Cubero Castillo, E., Carle, R. & Steingass, C. B. 2018. GC–MS profiling, descriptive sensory analysis, and consumer acceptance of Costa Rican papaya (Carica papaya L.) fruit purees. *Food Chemistry,* 248**,** 238-246.

Liu, H., Cao, J. & Jiang, W. 2015. Evaluation and comparison of vitamin C, phenolic compounds, antioxidant properties and metal chelating activity of pulp and peel from selected peach cultivars. *LWT - Food Science and Technology,* 63**,** 1042-1048.

Llácer, G., Batlle, I., Iglesias, I., Mota, M. & Oliveira, C. M. 2009. Temperate fruits and nuts: Iberian diversity. *Chronica Horticulturae-Subscription,* 49**,** 20-23.

Loizzo, M. R., Pacetti, D., Lucci, P., Núñez, O., Menichini, F., Frega, N. G. & Tundis, R. 2015. *Prunus persica* var. platycarpa (Tabacchiera Peach): Bioactive Compounds

and Antioxidant Activity of Pulp, Peel and Seed Ethanolic Extracts. *Plant Foods for Human Nutrition,* 70**,** 331-337.

Lombardo, V. A., Osorio, S., Borsani, J., Lauxmann, M. A., Bustamante, C. A., Budde, C. O., Andreo, C. S., Lara, M. V., Fernie, A. R. & Drincovich, M. F. 2011. Metabolic profiling during peach fruit development and ripening reveals the metabolic networks that underpin each developmental stage. *Plant Physiology,* 157**,** 1696-1710.

Ma, R., Yu, M. & Shen, Z. 2007. Progress on the Research of Peach Germplasm Resources and Breeding in China. *Asian and Australasian Journal of Plant Science and Biotechnology,* 1**,** 29-32.

Macdougall, D. 2002. Colour measurement of food: Principles and practice. *Colour in food: improving quality.* 1 ed.: CRC Press.

Magness, J. R. 1951. How fruit came to America. *National Geographic.*

Manganaris, G. A., Drogoudi, P., Goulas, V., Tanou, G., Georgiadou, E. C., Pantelidis, G. E., Paschalidis, K. A., Fotopoulos, V. & Manganaris, A. 2017. Deciphering the interplay among genotype, maturity stage and low-temperature storage on phytochemical composition and transcript levels of enzymatic antioxidants in Prunus persica fruit. *Plant Physiology and Biochemistry,* 119**,** 189-199.

Manganaris, G. A., Vasilakakis, M., Diamantidis, G. & Mignani, I. 2005. Effect of calcium additives on physicochemical aspects of cell wall pectin and sensory attributes of canned peach (Prunus persica (L) Batsch cv Andross). *Journal of the Science of Food and Agriculture,* 85**,** 1773-1778.

Metheney, P. D., Crisosto, C. H. & Garner, D. 2002. Developing canning peach critical bruising thresholds. *Journal American Pomological Society,* 56**,** 75-78.

Minas, I. S., Blanco-Cipollone, F. & Sterle, D. 2021. Accurate non-destructive prediction of peach fruit internal quality and physiological maturity with a single scan using near infrared spectroscopy. *Food Chemistry,* 335**,** 127626.

Miranda, T. G., Lafeta, B. O., Dessimoni-Pinto, N. a. V. & Vieira, G. 2012. Evaluation of strawberry in syrup under different concentrations of sugar and packaging/Avaliacao do morango em calda submetido a diferentes concentracoes de acucar e condicoes de armazenamento. *Alimentos e Nutricao (Brazilian Journal of Food and Nutrition),* 23**,** 307-316.

Mokrani, A., Krisa, S., Cluzet, S., Da Costa, G., Temsamani, H., Renouf, E., Mérillon, J. M., Madani, K., Mesnil, M., Monvoisin, A. & Richard, T. 2016. Phenolic contents and bioactive potential of peach fruit extracts. *Food Chemistry,* 202**,** 212-220.

Morgutti, S., Negrini, N., Nocito, F. F., Ghiani, A., Bassi, D. & Cocucci, M. 2006. Changes in endopolygalacturonase levels and characterization of a putative endo-PG gene during fruit softening in peach genotypes with nonmelting and melting flesh fruit phenotypes. *New Phytologist,* 171**,** 315-328.

National Agriculture, F. a. F. 2012. A profile of the South African peach market value chain.

Nayak, B., Liu, R. H. & Tang, J. 2015. Effect of processing on phenolic antioxidants of fruits, vegetables, and grains—a review. *Critical Reviews in Food Science and Nutrition,* 55**,** 887-918.

Nguyen, L. T., Tay, A., Balasubramaniam, V., Legan, J., Turek, E. J. & Gupta, R. 2010. Evaluating the impact of thermal and pressure treatment in preserving textural quality of selected foods. *LWT-Food Science and Technology,* 43**,** 525-534.

Nicoli, M. C., Anese, M. & Parpinel, M. 1999. Influence of processing on the antioxidant properties of fruit and vegetables. *Trends in Food Science & Technology,* 10**,** 94-100.

Noratto, G., Martino, H. S., Simbo, S., Byrne, D. & Mertens-Talcott, S. U. 2015. Consumption of polyphenol-rich peach and plum juice prevents risk factors for obesity-related metabolic disorders and cardiovascular disease in Zucker rats. *The Journal of Nutritional Biochemistry,* 26**,** 633-641.

Obi, V. I., Barriuso, J. J. & Gogorcena, Y. 2018. Peach brown rot: still in search of an ideal management option. *Agriculture,* 8**,** 125.

Okie, W., Bacon, T. & Bassi, D. 2008. Fresh market cultivar development. *Peach Bot. Prod. Uses,* 139.

Oliveira, A., Coelho, M., Alexandre, E. M. & Pintado, M. 2017. Impact of storage on phytochemicals and milk proteins in peach yoghurt. *Journal of Food Measurement and Characterization,* 11**,** 1804-1814.

Oliveira, A., Pintado, M. & Almeida, D. P. F. 2012. Phytochemical composition and antioxidant activity of peach as affected by pasteurization and storage duration. *LWT - Food Science and Technology,* 49**,** 202-207.

Oliver, P., Cicerale, S., Pang, E. & Keast, R. 2018. Developing a strawberry lexicon to describe cultivars at two maturation stages. *Journal of Sensory Studies,* 33.

Orazem, P., Stampar, F. & Hudina, M. 2011. Quality analysis of 'Redhaven' peach fruit grafted on 11 rootstocks of different genetic origin in a replant soil. *Food Chemistry,* 124**,** 1691-1698.

Ortiz, A., Le Meurlay, D., Lara, I., Symoneaux, R., Madieta, E. & Mehinagic, E. 2017. The effects of sous-vide cooking parameters on texture and cell wall modifications in two apple cultivars: A response surface methodology approach. *Food Science and Technology International,* 23**,** 99-109.

Paiva, S. A. & Russell, R. M. 1999. β-carotene and other carotenoids as antioxidants. *Journal of the American College of Nutrition,* 18**,** 426-433.

Pascal, T. & Monteux-Caillet, R. 1998. Peach breeding in France. *Acta Horticulturae.*

Péneau, S., Brockhoff, P. B., Escher, F. & Nuessli, J. 2007. A comprehensive approach to evaluate the freshness of strawberries and carrots. *Postharvest Biology and Technology,* 45**,** 20-29.

Pérez-González, S. Importance of Brazilian peach germplasm for the Mexican subtropics. VI International Symposium on Temperate Fruit Growing in the Tropics and Subtropics 565, 2000. 75-78.

Pieterse, W.-M. The SA processing peach breeding programme: introducing molecular techniques. XIII Eucarpia Symposium on Fruit Breeding and Genetics 976, 2011. 445-447.

Ramming, D. W. 1991. Genetic control of a slow-ripening fruit trait in nectarine. *Canadian Journal of Plant Science,* 71**,** 601-603.

Rao, S. N. & Barringer, S. A. 2006. Calcification of diced tomatoes by liquid dipping versus electrostatic powder coating. *Journal of Food Processing and Preservation,* 30**,** 71-78.

Raseira, M., Franzon, R., Pereira, J. & Scaranari, C. The first peach cultivars protected in Brazil. *Acta Horticulturae* 1084, 2013. 39-43.

Reig, G., Alegre, S., Gatius, F. & Iglesias, I. 2013a. Agronomical performance under Mediterranean climatic conditions among peach [*Prunus persica* L. (Batsch)] cultivars originated from different breeding programmes. *Scientia Horticulturae,* 150**,** 267-277.

Reig, G., Iglesias, I., Gatius, F. & Alegre, S. 2013b. Antioxidant capacity, quality, and anthocyanin and nutrient contents of several peach cultivars [*Prunus persica* (L.) Batsch] grown in Spain. *Journal of Agricultural and Food Chemistry,* 61**,** 6344-6357.

Reiger, M. 2004. Mark's Fruit Crops Homepage. Available: http://www.uga.edu/fruit.

Remorini, D., Tavarini, S., Degl'innocenti, E., Loreti, F., Massai, R. & Guidi, L. 2008. Effect of rootstocks and harvesting time on the nutritional quality of peel and flesh of peach fruits. *Food Chemistry,* 110**,** 361-367.

Ribas-Agustí, A., Gouble, B., Bureau, S., Maingonnat, J. F., Audergon, J. M. & Renard, C. M. G. C. 2017. Towards the use of biochemical indicators in the raw fruit for

improved texture of pasteurized apricots. *Food and Bioprocess Technology*, 10**,** 662-673.

Rickman, J. C., Bruhn, C. M. & Barrett, D. M. 2007. Nutritional comparison of fresh, frozen, and canned fruits and vegetables II. Vitamin A and carotenoids, vitamin E, minerals and fiber. *Journal of the Science of Food and Agriculture*, 87**,** 1185-1196.

Rodriguez, C. E., Bustamante, C. A., Budde, C. O., Müller, G. L., Drincovich, M. F. & Lara, M. V. 2019. Peach fruit development: A comparative proteomic study between endocarp and mesocarp at very early stages underpins the main differential biochemical processes between these tissues. *Frontiers in Plant Science*, 10**,** 715-715.

Rolle, L., Siret, R., Segade, S. R. S., Maury, C., Gerbi, V. & Jourjon, F. 2012. Instrumental texture analysis parameters as markers of table-grape and winegrape quality: A review. *American Journal of Enology and Viticulture*, 63**,** 11-28.

Ross, C. F. 2009. Sensory science at the human-machine interface. *Trends in Food Science and Technology*, 20**,** 63-72.

Rossato, S. B., Haas, C., Raseira, M. D. C. B., Moreira, J. C. F. & Zuanazzi, J. a. S. 2009. Antioxidant potential of peels and fleshes of peaches from different cultivars. *Journal of Medicinal Food*, 12**,** 1119-1126.

Ruiz-Altisent, M., Lleó, L. & Riquelme, F. 2006. Instrumental quality assessment of peaches: Fusion of optical and mechanical parameters. *Journal of Food Engineering*, 74**,** 490-499.

Sansavini, S., Gamberini, A. & Bassi, D. 2006. Peach breeding, genetics and new cultivar trends. *Acta Horticulturae 713***,** 23-48.

Sawamura, Y., Suesada, Y., Sugiura, T. & Yaegaki, H. 2017. Chilling requirements and blooming dates of leading peach cultivars and a promising early maturing peach selection, Momo Tsukuba 127. *Horticulture Journal*, 86**,** 426-436.

Scorza, R., Mehlenbacher, S. & Lightner, G. 1985. Inbreeding and coancestry of freestone peach cultivars of the eastern United States and implications for peach germplasm improvement. *Journal of the American Society for Horticultural Science (USA)*.

Selli, R. & Bassi, D. 1990. Evaluation of fruit quality in peach and apricot. *Evaluation of fruit quality in peach and apricot***,** 1000-1006.

Shahidi, F. & Yeo, J. 2016. Insoluble-bound phenolics in food. *Molecules,* 21**,** 1216.

Sharma, B. D., Rana, J. C. & Yadav, S. K. 2001. A glance at temperate fruits gene bank. NBPGR, Regional Station, Shimla.

Sharma, K., Kaushal, M. & Kaushal, B. 2002. Canning of peach-halves in fruit juice.

Shuoli, Z., Chengyan, Y., James, L., Karina, G., Vicki, M., James, M. & Desmond, R. L. 2017. U.S. Peach producer preference and willingness to pay for fruit attributes. *HortScience,* 52**,** 116-121.

Siddiq, M., Liavoga, A. & Greiby, I. 2012. Peaches and Nectarines. *Handbook of Fruits and Fruit Processing: Second Edition.*

Slaughter, D. C., Crisosto, C. H., Hasey, J. K. & Thompson, J. F. 2006. Comparison of instrumental and manual inspection of clingston peaches. *Applied Engineering in Agriculture,* 22**,** 883-889.

Sousa, M. B., Canet, W., Alvarez, M. D. & Fernández, C. 2007. Effect of processing on the texture and sensory attributes of raspberry (cv. Heritage) and blackberry (cv. Thornfree). *Journal of Food Engineering,* 78**,** 9-21.

Sridhar, A., Ponnuchamy, M., Kumar, P. S., Kapoor, A., Vo, D.-V. N. & Prabhakar, S. 2021. Techniques and modeling of polyphenol extraction from food: a review. *Environmental Chemistry Letters***,** 1-35.

Stojanovic, B. T., Mitic, S. S., Stojanovic, G. S., Mitic, M. N., Kostic, D. A., Paunovic, D. D. & Arsic, B. B. 2016. Phenolic profile and antioxidant activity of pulp and peel from peach and nectarine fruits. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca,* 44**,** 175-182.

Strada, G. D. & Fideghelli, C. 2003. Le cultivar di drupacee introdotte dal 1991 al 2001. *Informatore Agrario,* 59**,** 65-72.

Sturtevant, E. L. 1919. *Sturtevant's notes on edible plants*, JB Lyon Company, state printers.

Szczesniak, A. S. 2002. Texture is a sensory property. *Food quality and preference,* 13**,** 215-225.

Talcott, S., Howard, L. & Brenes, C. 2000. Contribution of periderm material and blanching time to the quality of pasteurized peach puree. *Journal of Agricultural and Food Chemistry,* 48**,** 4590-4596.

Tanriver, E. & Küden, A. Breeding studies with'Üstün'peach. XI Eucarpia Symposium on Fruit Breeding and Genetics 663, 2003. 733-738.

Tavarini, S., Degl'innocenti, E., Remorini, D., Massai, R. & Guidi, L. 2008. Antioxidant capacity, ascorbic acid, total phenols and carotenoids changes during harvest and after storage of Hayward kiwifruit. *Food chemistry,* 107**,** 282-288.

Techakanon, C., Smith, G. M., Jernstedt, J. & Barrett, D. M. 2017. The effect of high pressure processing on clingstone and freestone peach cell integrity and enzymatic browning reactions. *Innovative Food Science and Emerging Technologies,* 39**,** 230-240.

Terefe, N. & Versteeg, C. 2011. Texture and microstructure of fruits and vegetables. *W: Practical Food and Research***,** 89-115.

Thiele-Wittig, M. & Claus, P. 2003. Plant variety protection—A fascinating subject. *World Patent Information,* 25**,** 243-250.

Tomás-Barberán, F. A. & Ferreres, F. 2012. Analytical Methods of Flavonols and Flavones. *Analysis of Antioxidant-Rich Phytochemicals.*

Tomás-Barberán, F. A., Gil, M. I., Cremin, P., Waterhouse, A. L., Hess-Pierce, B. & Kader, A. A. 2001a. HPLC - DAD - ESIMS analysis of phenolic compounds in

nectarines, peaches, and plums. *Journal of Agricultural and Food Chemistry,* 49**,** 4748-4760.

Tomás-Barberán, F. A., Gil, M. I., Cremin, P., Waterhouse, A. L., Hess-Pierce, B. & Kader, A. A. 2001b. HPLC− DAD− ESIMS analysis of phenolic compounds in nectarines, peaches, and plums. *Journal of Agricultural and Food Chemistry,* 49**,** 4748-4760.

Toscano, L. T., Silva, A. S., Toscano, L. T., Tavares, R. L., Biasoto, A. C. T., De Camargo, A. C., Da Silva, C. S. O., Gonçalves, M. D. C. R. & Shahidi, F. 2017. Phenolics from purple grape juice increase serum antioxidant status and improve lipid profile and blood pressure in healthy adults under intense physical training. *Journal of Functional Foods,* 33**,** 419-424.

Trejo Araya, X. I., Smale, N., Zabaras, D., Winley, E., Forde, C., Stewart, C. M. & Mawson, A. J. 2009. Sensory perception and quality attributes of high pressure processed carrots in comparison to raw, sous-vide and cooked carrots. *Innovative Food Science and Emerging Technologies,* 10**,** 420-433.

Tsvakirai, C. 2017. The role of plant breeders' rights in an evolving peach and nectarine fresh fruit sector. *South African Journal of Science,* 113**,** 1-6.

Tsvakirai, C. Z. 2015. *An economic evaluation of South Africa's peach and nectarine research.* University of Pretoria.

Umar Lule, S. & Xia, W. 2005. Food phenolics, pros and cons: a review. *Food Reviews International,* 21**,** 367-388.

Usda 2020. Stone Fruit Annual: Turkey.

Usda, F. a. S. 2019. Stone Fruit Annual.

Valero, C., Crisosto, C. H., Metheney, D. & Bowerman, E. Developing Critical Pitter Thresholds for Canning Peaches Using a Nondestructive Firmness Sensor. International Conference on Quality in Chains. An Integrated View on Fruit and Vegetable Quality 604, 2003. 811-815.

Van Buren, J. 1979. The chemistry of texture in fruits and vegetables. *Journal of Texture Studies,* 10**,** 1-23.

Vinson, J. A., Yang, J., Proch, J. & Liang, X. 2000. Grape juice, but not orange juice, has in vitro, ex vivo, and in vivo antioxidant properties. *Journal of Medicinal Food,* 3**,** 167-171.

Vizzotto, M., Cisneros-Zevallos, L., Byrne, D. H., Ramming, D. W. & Okie, W. 2007. Large variation found in the phytochemical and antioxidant activity of peach and plum germplasm. *Journal of the American Society for Horticultural Science,* 132**,** 334-340.

Walter, W. M., Truong, V. D. & Espinel, K. R. 2002. Textural measurements and product quality of restructured sweetpotato French fries. *LWT - Food Science and Technology,* 35**,** 209-215.

Wang, L. & Weller, C. L. 2006. Recent advances in extraction of nutraceuticals from plants. *Trends in Food Science and Technology,* 17**,** 300-312.

Wanpeng, X., Zheng, Q., Juanfang, L. & Junping, Q. 2017. Comparative analysis of three types of peaches: Identification of the key individual characteristic flavor compounds by integrating consumers' acceptability with flavor quality. *Horticultural Plant Journal,* 3**,** 1-12.

Wu, R., Frei, B., Kennedy, J. A. & Zhao, Y. 2010. Effects of refrigerated storage and processing technologies on the bioactive compounds and antioxidant capacities of ‘Marion’and ‘Evergreen’blackberries. *LWT-Food Science and Technology,* 43**,** 1253-1264.

Yamamoto, T., Mochida, K. & Hayashi, T. 2003. Shanhai Suimitsuto, one of the origins of Japanese peach cultivars. *Journal of the Japanese Society for Horticultural Science,* 72**,** 116-121.

Zaghdoudi, K., Pontvianne, S., Framboisier, X., Achard, M., Kudaibergenova, R., Ayadi-Trabelsi, M., Kalthoum-Cherif, J., Vanderesse, R., Frochot, C. & Guiavarc’h, Y.

2015. Accelerated solvent extraction of carotenoids from: Tunisian Kaki (*Diospyros kaki* L.), peach (*Prunus persica* L.) and apricot (*Prunus armeniaca* L.). *Food chemistry,* 184**,** 131-139.

Zhang, F., Dong, P., Feng, L., Chen, F., Wu, J., Liao, X. & Hu, X. 2012. Textural changes of yellow peach in pouches processed by high hydrostatic pressure and thermal processing during storage. *Food and Bioprocess Technology*, 5**,** 3170-3180.

Zhang, G., Zong, X., Shen, Y., Zuo, Q., Zhu, G. & Li, C. 1990. New canning peach variety" Zhenghuang 4". *Journal of Fruit Science*, 17**,** 176-178.

Zhang, Y. J., Yao, J., Zhang, Y. & Hu, X. S. 2014. Study on the effect of high hydrostatic pressure on the texture of canned yellow peach of different varieties. *Gaoya Wuli Xuebao/Chinese Journal of High Pressure Physics*, 28**,** 232-238.

Zhao, X., Zhang, W., Yin, X., Su, M., Sun, C., Li, X. & Chen, K. 2015. Phenolic composition and antioxidant properties of different peach [*Prunus persica* (L.) Batsch] cultivars in China. *International journal of molecular sciences*, 16**,** 5762-5778.

Zheng, Y., Crawford, G. W. & Chen, X. 2014. Archaeological evidence for peach (*Prunus persica*) cultivation and domestication in China. *PLoS ONE,* 9.

Zhu, G.-R., Wang, L.-R. & Fang, W.-C. 2003. The status of peach production in China and development strategies. *Deciduous Fruits 4***,** 14-16.

Zuhua, W., Zhenxiang, L. & Zhengling, H. 1989. Advances and achievements of scientific research on peach breeding and culture in China. *China Fruits,* 4**,** 1-5.

Zwingelstein, M., Draye, M., Besombes, J.-L., Piot, C. & Chatel, G. 2020. Viticultural wood waste as a source of polyphenols of interest: Opportunities and perspectives through conventional and emerging extraction methods. *Waste Management*, 102**,** 782-794.

8. Supplementary Material

Supplementary Table S 1: Individual organic sugars and acids contents in mesocarp fresh tissue of the examined cultivars.

Quality attributes	**Cultivar**						
	Romea	**Catherina**	**Mirel**	**Fercluse**	**Everts**	**Ferlate**	**VLG**
Sugars (mg g^{-1} FW)							
Sucrose	40.3 ± 1.2 a	40.9 ± 0.7 a	36.0 ± 0.6 ab	31.7 ± 0.4 abc	28.6 ± 0.3 bcd	24.4 ± 3.9 cd	21.4 ± 3.7 d
Glucose	24.2 ± 2.8 ab	25.4 ± 0.1 a	28.8 ± 0.01 a	22.4 ± 0.1 ab	21.5 ± 0.2 ab	17.8 ± 3.6 b	16.0 ± 3.5 b
Fructose	8.7 ± 0.2 abc	9.6 ± 0.5 a	11.5 ± 0.4 a	10.1 ± 0.2 ab	7.5 ± 0.2 bc	6.7 ± 0.9 c	8.3 ± 1.2 bc
Organic acids (mg g^{-1} FW)							
Malic acid	6.9 ± 0.1 a	6.6 ± 0.02 b	7.0 ± 0.02 a	5.3 ± 0.02 d	6.1 ± 0.03 c	6.1 ± 0.1 c	4.5 ± 0.02 e
Citric acid	2.0 ± 0.04 b	1.6 ± 0.01 c	2.2 ± 0.03 a	0.8 ± 0.01 e	1.1 ± 0.01 d	1.6 ± 0.03 c	1.1 ± 0.02 d
Shikimic acid	1.1 ± 0.03 de	1.1 ± 0.02 e	2.5 ± 0.02 b	1.6 ± 0.02 c	2.9 ± 0.02 a	2.6 ± 0.1 b	1.2 ± 0.01 d

One-way ANOVA was performed by the linear model on raw data followed by Tukey's honest significant difference (HSD) multiple comparison test. Values are means ± standard error (SE); N=3 for individual organic acids and sugars. Means followed by the same letters are not significantly different ($p < 0.05$).

Supplementary Table S 2: Quality traits (SSC, TA, L and h°) of canned peaches derived from the examined cultivars packed in LS and GJ, after 6 and 24 months of storage.*

Quality traits	Storage (months)	Cultivar													
		Romea	**(%)**	**Catherina**	**(%)**	**Mirel**	**(%)**	**Fercluse**	**(%)**	**Everts**	**(%)**	**Ferlate**	**(%)**	**VLG**	**(%)**
Light syrup (LS)															
SSC (°Brix)	6	16.5 ± 0.2	100	15.8 ± 0.1	103	16.4 ± 0.1	101	18.7 ± 0.1	97	14.4 ± 0.1	102	15.0 ± 0.1	100	14.7 ± 0.1	95
	24	16.6 ± 0.1		16.4 ± 0.1		16.7 ± 0.1		18.3 ± 0.1		14.7 ± 0.1		15.0 ± 0.1		14.0 ± 0.1	
TA (g malic acid L^{-1})	6	3.9 ± 0.1	100	3.2 ± 0.1	103	3.5 ± 0.1	94	3.7 ± 0.1	105	3.8 ± 0.1	97	4.4 ± 0.1	100	4.7 ± 0.1	106
	24	3.9 ± 0.1		3.3 ± 0.1		3.3 ± 0.1		3.9 ± 0.1		3.7 ± 0.1		4.4 ± 0.1		5.0 ± 0.1	
L*	6	47.9 ± 0.4	99	55.0 ± 0.6	98	52.7 ± 0.7	92	54.1 ± 0.6	94	49.4 ± 0.3	97	53.6 ± 0.3	100	50.8 ± 0.5	93
	24	47.6 ± 0.5		54.0 ± 0.5		48.4 ± 0.5		50.8 ± 0.4		48.2 ± 0.4		53.8 ± 0.4		47.1 ± 0.5	
h°	6	90.1 ± 0.3	102	86.8 ± 0.3	103	83.4 ± 0.3	105	80.0 ± 0.4	105	90.7 ± 0.5	102	89.6 ± 0.4	101	91.6 ± 0.5	103
	24	92.0 ± 0.3		89.9 ± 0.4		87.5 ± 0.4		84.1 ± 0.3		92.1 ± 0.5		90.9 ± 0.3		94.8 ± 0.4	
Grape juice syrup (GJ)															
SSC (°Brix)	6	12.1 ± 0.1	100	12.1 ± 0.3	99	13.1 ± 0.1	98	13.5 ± 0.1	98	12.8 ± 0.1	102	13.1 ± 0.1	100	13.1 ± 0.2	100
	24	12.2 ± 0.1		12.0 ± 0.1		12.9 ± 0.1		13.3 ± 0.1		13.1 ± 0.1		13.1 ± 0.1		13.2 ± 0.1	
TA (g malic acid L^{-1})	6	4.1 ± 0.1	102	3.2 ± 0.1	96	4.0 ± 0.1	92	3.8 ± 0.1	105	4.1 ± 0.1	93	4.0 ± 0.1	95	4.2 ± 0.1	104
	24	4.2 ± 0.1		3.1 ± 0.1		3.7 ± 0.1		4.0 ± 0.1		3.8 ± 0.1		3.8 ± 0.1		4.4 ± 0.1	
L*	6	55.3 ± 0.5	99	58.0 ± 0.5	95	56.0 ± 0.4	92	56.7 ± 0.5	95	51.1 ± 0.3	96	54.5 ± 0.3	100	53.1 ± 0.5	93
	24	54.7 ± 0.5		55.3 ± 0.6		51.5 ± 0.5		53.8 ± 0.5		49.0 ± 0.4		54.5 ± 0.3		49.5 ± 0.8	
h°	6	84.8 ± 0.2	102	85.1 ± 0.4	103	82.8 ± 0.4	103	79.9 ± 0.3	105	89.7 ± 0.4	102	89.2 ± 0.4	100	89.4 ± 0.5	103
	24	86.5 ± 0.4		88.3 ± 0.4		85.4 ± 0.5		83.9 ± 0.5		91.6 ± 0.4		89.7 ± 0.3		92.6 ± 0.6	

Values are means ± standard error (n=3). Values next to each cultivar column represent percent retention (%) between 6 and 24 months of storage.

Supplementary Table S 3: Other textural (TPA) properties of canned peaches derived from the examined cultivars packed in LS and GJ, after 6 and 24 months of storage.

Textural properties	Storage (months)	Cultivar													
		Romea	**(%)**	**Catherina**	**(%)**	**Mirel**	**(%)**	**Fercluse**	**(%)**	**Everts**	**(%)**	**Ferlate**	**(%)**	**VLG**	**(%)**
Light syrup (LS)															
TPA Springiness	6	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.1	100	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100
	24	0.2 ± 0.02		0.2 ± 0.01		0.2 ± 0.03		0.2 ± 0.01		0.2 ± 0.02		0.2 ± 0.01		0.2 ± 0.01	
TPA Cohesiveness	6	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100
	24	0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01	
Grape juice syrup (GJ)															
TPA Springiness	6	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100	0.2 ± 0.01	100
	24	0.2 ± 0.01		0.2 ± 0.01		0.2 ± 0.02		0.2 ± 0.01		0.2 ± 0.02		0.2 ± 0.01		0.2 ± 0.02	
TPA Cohesiveness	6	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100	0.1 ± 0.01	100
	24	0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01		0.1 ± 0.01	

Values are means ± standard error (n=3). Values next to each cultivar column represent percent retention (%) between 6 and 24 months of storage

Supplementary Table S 4: Sensory data mean score values obtained between cultivars and packing media from Senpaq software.

Sensory attributes	**GJ_Catherina**	**GJ_Everts**	**GJ_Fercluse**	**GJ_Ferlate**	**GJ_Mirel**	**GJ_Romea**	**GJ_VLG**	**LS_Catherina**	**LS_Everts**	**LS_Fercluse**	**LS_Ferlate**	**LS_Mirel**	**LS_Romea**	**LS_VLG**
O_Peach aroma	4.75	6.17	3.81	4.38	5.63	2.81	2.77	5.83	6.67	6.90	5.17	6.02	5.15	5.44
A_Colour	6.77	5.23	8.48	5.77	8.00	6.56	4.79	7.04	5.96	8.90	5.21	8.52	7.56	5.38
A_Colour Uniformity	7.48	7.63	7.13	6.04	7.08	7.44	6.42	8.23	7.31	7.77	6.19	7.96	8.29	6.90
A_Brightness	7.06	7.98	5.85	5.90	6.21	6.60	7.60	7.02	6.75	6.96	5.65	6.54	7.79	7.00
A_Residual peel	0.04	0.04	0.21	0.08	0.00	0.00	0.13	0.00	0.04	0.00	0.08	0.06	0.02	0.04
A_Blemished	0.08	0.04	0.17	0.00	0.04	0.00	0.08	0.04	0.08	0.00	0.13	0.00	0.08	0.04
Tex_Hardness	5.19	5.10	4.96	7.67	8.15	5.90	5.83	5.69	6.31	5.44	8.00	7.27	5.63	5.79
Tex_Dif. Chewiness	5.00	4.98	5.35	7.42	7.08	5.94	6.10	5.33	6.52	5.23	7.65	6.50	5.79	5.83
Tas_Sweetness	5.58	5.56	4.63	5.19	4.90	4.06	3.88	6.81	5.48	7.15	5.29	5.98	6.25	5.60
Tas_Acidity	1.98	1.90	2.58	2.08	2.10	3.29	2.83	0.83	1.33	0.75	1.44	0.88	1.13	1.42
Tas_Bitterness	0.63	0.75	2.21	0.96	1.46	2.90	2.90	0.10	0.13	0.04	0.29	0.08	0.08	0.46
Tas_Astringency	0.83	0.77	1.67	0.79	0.79	2.46	2.17	0.06	0.08	0.04	0.29	0.04	0.02	0.21
Tas_Fruitness	5.58	5.48	3.90	5.60	4.92	3.35	3.85	6.79	5.50	7.02	5.65	6.21	6.48	5.88
Tas_Peach flavour	5.23	5.75	3.63	5.40	4.77	3.19	3.35	6.67	5.65	7.21	5.25	6.02	6.17	6.04
Tas_Off-flavour	1.23	1.04	2.54	1.23	1.40	4.46	3.96	0.00	0.02	0.00	0.13	0.00	0.00	0.13

Supplementary Table S 5: Spectrophotometric determination of total phenolics content (TPC), total antioxidant capacity (TAC) and total carotenoids (TC) of eight non-melting peach cultivars in fresh and canned peach fruit preparations.

Cultivar	Fruit Type	TPC F-C (µg GAE/g DW)	TAC FRAP (µg TE/g DW)	TC TC (µg β-carotene/g DW)
Romea	Fresh	1051.4±3.2	5737.3±42.9	2336.2±1.3
	Canned in LS	176.9±1.6	207.2±10.2	1113.3±9.5
	Canned in GJ	623.2±1.2	1662.7±20.8	2554±15.9
Catherina	Fresh	2141.5±5.9	12330.6±86.9	2584.1±24.8
	Canned in LS	400.2±2.1	732.6±20.2	1169.5±2.6
	Canned in GJ	406.2±1.6	846.4±31.7	2142.1±6.3
Mirel®	Fresh	1716.3±5.5	10468.3±73.2	3526.1±44.1
	Canned in LS	368.9±2.2	419.5±10.8	1939.6±13.5
	Canned in GJ	570.7±1.5	647.3±8.7	3138.6±9.4
Fercluse®	Fresh	1979.8±4.4	13013.4±61.2	3560.3±8.7
	Canned in LS	366.8±2.6	573.8±12.6	1768.9±14.1
	Canned in GJ	624.3±10.3	1737±4.2	3845.2±17.7
Andross	Fresh	2663.4±7.9	19048.8±102.9	3697.4±11.3
	Canned in LS	602.9±3.8	1523.7±24.8	1136±10.7
	Canned in GJ	673.2±2.4	2188.3±21.6	1969±8.1
Everts	Fresh	2369.6±7.4	12506.4±86.6	2615.5±4.9
	Canned in LS	489.7±3.5	1057.9±14.6	961.1±5.2
	Canned in GJ	622.6±3.3	1337.7±25.7	1078.9±39.2
Ferlate®	Fresh	3143.1±10.5	19462.7±126.6	1585±15.6
	Canned in LS	790.1±4.5	2642.1±21.8	713.9±51.4
	Canned in GJ	805.1±4.4	1831.7±19.3	1054.1±42.6
VLG	Fresh	1802.4±4.1	10281.8±76.6	1366.7±9.3
	Canned in LS	479.3±5.2	1355.4±15.9	713±76.7
	Canned in GJ	699.8±3.7	1472.9±19.7	1020.7±20.7

Supplementary Table S 6: Ranking of peach cultivars based on their calculated maximum overall desirability in terms of total phytochemical content for each product type, by transformation of the response variable to a 0 (undesirable) up to 1 (most desirable) scale.

Desirability						
Type	**Cultivar**	**F-C (µg GAE/g DW)**	**FRAP (µg TE/g DW)**	**TC (µg β-carotene/g DW)**	**Overall**	**Ranking**
F	Romea	0.3235	0.3118	0.5264	0.3759	8
F	Catherina	0.6044	0.6089	0.5931	0.6021	6
F	Mirel®	0.4912	0.5215	0.8520	0.6021	5
F	Fercluse®	0.5608	0.6415	0.8614	0.6767	2
F	Andross	0.7485	0.9359	0.8991	0.8572	1
F	Everts	0.6669	0.6172	0.6017	0.6280	4
F	Ferlate®	0.8828	0.9559	0.3322	0.6545	3
F	VLG	0.5137	0.5129	0.2782	0.4185	7
GJ	Romea	0.2187	0.1376	0.5850	0.2602	2
GJ	Catherina	0.1658	0.1026	0.4749	0.2006	5
GJ	Mirel®	0.2059	0.0940	0.7450	0.2434	4
GJ	Fercluse®	0.2190	0.1408	0.9397	0.3071	1
GJ	Andross	0.2309	0.1601	0.4297	0.2514	3

GJ	Everts	0.2186	0.1237	0.2077	0.1778	8
GJ	Ferlate®	0.2631	0.1449	0.2017	0.1974	6
GJ	VLG	0.2374	0.1295	0.1936	0.1812	7
LS	Romea	0.1097	0.0750	0.2161	0.1211	8
LS	Catherina	0.1643	0.0977	0.2299	0.1545	6
LS	Mirel®	0.1567	0.0842	0.4221	0.1772	2
LS	Fercluse®	0.1562	0.0908	0.3785	0.1751	4
LS	Andross	0.2138	0.1317	0.2217	0.1841	1
LS	Everts	0.1862	0.1117	0.1790	0.1550	5
LS	Ferlate®	0.2594	0.1795	0.1187	0.1768	3
LS	VLG	0.1836	0.1245	0.1184	0.1394	7

Supplementary Table S 7: Quantification of individual phenolic (NCHLA, CHLA, PB1 and CAT), carotenoid (BCAR and ZELUT) and tocopherol (ATOC) compounds (µg/g DW) as found in eight peach cultivars (fresh and canned in two packing media, light syrup 'LS' and grape juice 'GJ').

LC-MS								
		Individual Phenolic Compounds				**Individual Carotenoids/Tocopherols**		
Cultivar	**Fruit Type**	**NCHLA**	**CHLA**	**PB1**	**CAT**	**BCAR**	**ZELUT**	**ATOC**
Romea	Fresh	13.3±0.7	77.7±2.5	17.2±0.3	ND	144.4±4.1	1.6±0.0	77.9±2.1
	Canned in LS	ND	12.5±0.8	ND	ND	60.2±1.3	1.3±0.0	60.6±1.1
	Canned in GJ	0.6±0.1	7.4±0.6	ND	ND	41.5±1.5	1.9±0.0	82.4±1.2
Catherina	Fresh	62.1±2.2	291.5±2.5	130.5±1.4	12.8±0.6	204.4±14.8	1.8±0.1	87.3±1.2
	Canned in LS	8.6±0.7	68.3±0.6	18.7±0.9	ND	98.1±0.5	1.6±0.1	79.3±2.5
	Canned in GJ	7.9±0.5	44.7±1.0	ND	ND	45.7±0.5	2.0±0.0	86.5±0.7
Mirel®	Fresh	44.5±2.1	227.9±2.7	56.3±1.2	3.2±0.1	585.3±16.2	1.3±0.1	142.4±2.3
	Canned in LS	4.3±0.6	51.1±1.7	ND	ND	180.5±2.5	1.8±0.0	126.8±1.4
	Canned in GJ	11.0±0.6	75.4±0.6	ND	ND	112.0±4.6	3.0±0.1	140±0.6
Fercluse®	Fresh	69.4±2.1	372.2±5.3	92.7±1.7	1.3±0.1	230.1±22.1	2.0±0.0	121.4±4.1

	Canned in LS	5.3±0.3	61.2±0.9	ND	ND	116.3±4.4	1.9±0.0	134.6±1.2
	Canned in GJ	15.0±0.5	87.7±1.4	ND	ND	60.4±1.5	3.1±0.1	164.4±1.4
Andross	Fresh	49.4±1.8	296.4±1.2	102.0±1.8	7.1±0.3	1069.6±52.9	3.6±0.1	128±6.2
	Canned in LS	7.0±0.4	71.4±0.6	9.1±0.3	ND	252.2±1.4	2.3±0.1	165.8±1.3
	Canned in GJ	13.8±0.8	82.5±1.7	ND	ND	135.4±6.9	3.5±0.1	163.8±1.2
Everts	Fresh	88.5±3.1	268.8±5.7	91.7±2.0	7.9±0.4	608.7±9.6	1.8±0.0	155.2±1.5
	Canned in LS	17.0±0.8	73.5±2.3	0.5±0.1	ND	144.7±3.2	1.6±0.0	165.9±1.9
	Canned in GJ	21.3±0.6	79.2±2.1	ND	ND	79.6±3.5	2.3±0.1	140.7±1.8
Ferlate®	Fresh	92.9±3.5	370.5±4.2	282.3±3.5	41.2±0.6	33.4±1.7	0.6±0.0	94.3±1.3
	Canned in LS	18.1±0.6	106.5±1.9	48.2±0.8	7.4±0.2	96.6±0.8	1.2±0.0	142.7±1.8
	Canned in GJ	20.4±0.7	108.6±2.6	29.9±0.2	5.5±0.3	43.3±1.1	1.3±0.1	123.9±0.9
VLG	Fresh	30.3±2.4	174.1±6.6	103±2.6	9.8±0.4	259.0±19.2	0.8±0.0	85.3±2.4
	Canned in LS	0.8±0.4	33.9±1.3	ND	ND	97.7±2.9	1.4±0.0	160.5±2.2
	Canned in GJ	1.0±0.1	30.1±1.2	ND	ND	45.0±0.1	1.4±0.0	128.7±1.2

Supplementary Table S 8: Overall ranking of eight peach cultivars based on their calculated maximum overall desirability in terms of individual phytochemical content for each product type, by transformation of the response variable to a 0 (undesirable) up to 1 (most desirable) scale.

		Desirability						
Type	**Cultivar**	**BCAR**	**ZELUT**	**ATOC**	**NCHLA**	**CHLA**	**Overall**	**Ranking**
F	Romea	0.1695	0.3791	0.2982	0.3092	0.2452	0.2707	8
F	Catherina	0.1954	0.4086	0.3562	0.7465	0.6460	0.4241	5
F	Mirel®	0.4888	0.3044	0.7195	0.6098	0.4955	0.5035	4
F	Fercluse®	0.2304	0.4212	0.5759	0.9220	0.7102	0.5160	3
F	Andross	0.8763	0.8293	0.6205	0.7572	0.5370	0.7123	1
F	Everts	0.5066	0.4054	0.8094	0.6973	0.8799	0.6335	2
F	Ferlate®	0.0867	0.1721	0.3995	0.9182	0.9196	0.3470	6
F	VLG	0.2257	0.2040	0.3147	0.4957	0.3786	0.3068	7
GJ	Romea	0.0959	0.4294	0.3257	0.1756	0.1489	0.2037	8
GJ	Catherina	0.0989	0.4569	0.3507	0.2463	0.2060	0.2405	6
GJ	Mirel®	0.1464	0.6618	0.7032	0.3048	0.2297	0.3433	3
GJ	Fercluse®	0.1095	0.6890	0.8733	0.3283	0.2610	0.3551	2
GJ	Andross	0.1631	0.7594	0.8691	0.3184	0.2512	0.3863	1
GJ	Everts	0.1232	0.5003	0.7078	0.3120	0.3101	0.3350	4
GJ	Ferlate®	0.0972	0.3148	0.5925	0.3686	0.3024	0.2891	5
GJ	VLG	0.0984	0.3280	0.6254	0.2186	0.1520	0.2319	7

LS	Romea	0.1093	0.3080	0.1926	0.1853	0.1443	0.1769	8
LS	Catherina	0.1364	0.3662	0.3066	0.2912	0.2108	0.2481	7
LS	Mirel®	0.1951	0.4099	0.6122	0.2585	0.1779	0.2954	4
LS	Fercluse®	0.1494	0.4252	0.6658	0.2776	0.1852	0.2934	5
LS	Andross	0.2461	0.5188	0.8836	0.2972	0.1984	0.3669	1
LS	Everts	0.1697	0.3753	0.8838	0.3012	0.2760	0.3420	2
LS	Ferlate®	0.1354	0.2895	0.7217	0.3646	0.2851	0.3117	3
LS	VLG	0.1361	0.3362	0.8464	0.2045	0.1503	0.2601	6

Cover page of publication: "Elaboration of novel and comprehensive protocols toward determination of textural properties and other sensorial attributes of canning peach fruit"