Changes in cell wall neutral sugar composition related to pectinolytic enzyme activities and intra-flesh textural property during ripening of ten apricot clones

Jamal Ayour, Carine Le Bourvellec, Barbara Gouble, Jean-Marc Audergon, Mohamed Benichou, Catherine M.G.C. Renard

Changes in cell wall neutral sugar composition related to pectinolytic enzyme activities and intra-flesh textural property during ripening of ten apricot clones

Jamal Ayour [a, b, c]*, Carine Le Bourvellec [b, c], Barbara Gouble [b], Jean-Marc Audergon [d], Mohamed Benichou [a], Catherine M.G.C. Renard [b, c]

[a] *Food Sciences Laboratory, Faculty of Sciences Semlalia, Cadi Ayyad University, M-40090 Marrakesh, Morocco*

[b] *UMR 408 Safety and Quality of Vegetable Products, INRA, F-84000 Avignon, France*

[c] *University of Avignon and the Pays du Vaucluse, UMR408 Safety and Quality of Vegetable Products, F-84000 Avignon, France*

[d] *INRA, UR1052 Genetic and Improvement of Fruits and Vegetables, F-84143 Montfavet, France*

∗Corresponding author:

E-mail address: jamal.ayour@educagri.fr

Abstract

The changes of texture and cell wall characteristics of apricot were investigated in ten clones at two maturity stages. Fruit firmness, cell wall composition and enzyme activity of three apricot flesh zones were analysed. The AIS (alcohol-insoluble solids) were characterised by high amounts of uronic acid (179-300 mg g^{-1} AIS) and relatively high amounts of cellulosic glucose (118-214 mg g^{-1} AIS). The methylesterification degree varied significantly among the different clones ranging from 58 to 97 in Ab 5 and Mans 15 respectively. Conversely to zones firmness, enzymatic activity was higher in pistil followed by equatorial and peduncle zones. The ripening effect has been observed in firmness evolution according to enzymatic activity. This correlation allowed a classification of clones depending on softening. Among studied clones, Ab 5, Marouch 16, Mans 15 and Cg 2 were less influenced by softening and have the advantage of a technological valorisation for the processing industry.

Keywords: *Prunus armeniaca* L.; sugar; firmness; pectinmethylesterase; β-galactosidase; maturity

1. Introduction

The Marrakesh region is considered the most important apricot growing area in Morocco. However, the traditional varieties are almost the only source of production. Indeed, various renovations have occurred in recent years to introduce new cultivars to meet market requirements and satisfy consumers and industry demands. The National Institute for Agricultural Research in Marrakesh (INRA) has undertaken a research program targeting areas of traditional cultivation of several fruit species including creating a collection of apricot clones. Some of these clones have already been the subject of characterization studies of quality agronomic performance (Ayour et al., 2017).

Beside aroma and sweetness, texture is one of the important quality attributes of apricot fruit; it influences consumer acceptability, postharvest manipulation, shelf-life, microbial susceptibility and suitability for processing into different products (Gatti et al., 2009). Although only little information is available specifically on apricot, texture is often related to cell wall structure and composition. Cell walls are important elements of plant cells and are implicated in evolution of fruit firmness and texture during ripening. The softening of apricot fruit during ripening has been associated with alterations in the cell wall materials (De Martino et al., 2002). Moreover, the soft fruits are easily damaged, including latent damage, but little is known of the mechanism of softening in these fruits. Many studies on fruit texture focused on cell walls since remarkable changes occur in their polysaccharide's composition, structure and organization consecutive to the induction of enzymes and proteins expression on ripening (Brummell, 2006; Goulao & Oliveira, 2008; Renard & Ginies, 2009; Ella Missang et al., 2012; Lahaye et al., 2014; Brahem et al., 2017; Liu et al., 2017). Apricot fruit was characterized by high heterogeneity in its tissue structure (Archibald & Melton, 1987). Ella Missang et al. (2012) reported that in fresh apricot fruit, firmness decreased gradually from the external to the internal tissues. From the peduncle to the pistil, firmness was higher in the peduncle zone, followed by the pistil zone and at last the equatorial zone.

The heterogeneity of apricot texture depends on genetic (Ruiz & Egea, 2008) and tissue type within the fruit (Ella Missang et al., 2011). The latter variations were due to different tissue histology and cell wall polysaccharide characteristics in the different fruit regions. To highlight the importance of the heterogeneity and its influence on the quality of apricot, research work has been carried out in recent years on the relationship between the texture of the fruit and industrial processing (Ella Missang et al., 2012 ; Ayour et al., 2016; Deng et al.,

2018; Deng et al., 2019). Indeed, the rapid loss of texture of the apricot fruit during storage and processing is a limiting factor for its commercialisation and use. To better understand the variability of apricot texture, we have already studied the impact of heat treatment according to the stage of harvesting fruit in a wide range of cultivars. In fact, the tested cultivars had different degrees of sensitivity to heat treatment, probably in relation to their textural characteristics of the fruit. Consequently, we have identified physical criteria for the selection of apricots intended for processing (Ayour et al., 2016).

Recently, physical and chemical analyses conducted by Deng et al. (2018) indicated a strong correlation between the texture loss, the decomposition and the degradation of the pectin polysaccharides of the cell wall in relation to the reduction of the drying time of apricots. In another study, Deng et al. (2019) indicated that this drying time of apricot was influenced by the ripening stage, which is related to changes in the physicochemical and pectic properties in the tissue nanostructure of the fruit. Indeed, it is necessary to choose fruits with an appropriate degree of ripeness to achieve a high drying rate. Lahaye et al. (2014) were able to exploit the cell wall composition heterogeneity in the inner and outer parenchyma tissue to discriminate fruit of nine apricot varieties. Phenotyping and chemotyping of structural characteristics known to contribute to fleshy fruit texture showed several discriminating variables, among which methyl and acetyl groups esterifying cell wall polysaccharides were particularly the better discriminants. Cell walls can be modified by pectinolytic enzymes. In research on texture engineering of fruits and vegetables through pectin modification by endogenous enzymes, most attention has been paid to pectinmethylesterase (PME) and polygalacturonase (PG). PME is one of the key enzymes involved in plant carbohydrate metabolism (Hubbard & Pharr, 1992). It catalyzes the demethylation of the pectin homogalacturonan domain, favoring, if present, the action of PG, which subsequently depolymerizes pectin by cleaving the galacturonan linkages (Duvetter et al., 2009). Further, pectin solubilization by β-galactosidase (β-Gal) is actively involved in fruit softening (Brummell et al., 2001). Rose & Bennet (1999) have correlated the cell wall degradation with β-Gal and other glycosidases, which activities consist in hydrolyzing the glycosidic side chains of pectin. These activities increase during ripening of apricots (Cardarelli et al., 2002). Brummell et al. (2004) have reported that all these enzyme activities lead to the depolymerization and solubilisation of pectin, which are correlated with a decrease in fruit firmness. However, Ribas-Agustí et al. (2017) reported that texture loss of apricots was more correlated to the increased acidity compared to other biochemical parameters

include pectinolytic enzyme activities (Pectinmethylesterase, Polygalacturonase, β-Galactosidase and α-Arabinosidase). Recently, Fan et al. (2019) studied the effect of parietal enzymes on the apricot texture, in particular the degradation of polysaccharides with ultrastructure modification in its cell wall, the main contribution to the softening. To avoid this degradation, they reported the advantages of near freezing temperature (NFT) storage in the inhibition of cell wall modifying enzymes (β-galactosidase, pectin methyl esterase, polygalacturonase and cellulase) and related genes expressions.

Most texture studies on cell wall composition and enzymatic activity are related to whole fruit, mainly concerning physiological and ripening aspects. In terms of food quality, special attention has been given to changes in the cell wall during ripening, in order to optimize the textural attributes of the plant, as well as other quality characteristics dependent on these modifications (Waldron et al., 2003). However, studies on the fine characterization of the intra-flesh texture associated to the cell wall biochemistry, in particular as quality control, are scarce. Fines studies of tissue structure are needed to better understand the underlying biochemical and microstructural phenomena involved in the texture loss, thus making it possible to identify the selection criteria for apricots intended for processing as we reported in a previous study on apricot texture (Ayour et al., 2016).

Therefore, this study concerned to ten apricot clones aimed to: **i)** Characterize the texture changes in relation to cell wall neutral sugar composition and the pectinolytic enzyme activities on three tissue zones of fruit flesh (peduncle zone, equatorial zone, and pistil zone) in order to determine the cell wall composition and its potential variability. **ii)** Investigate the variation in firmness through the different flesh tissue zones according to the pectinolytic enzyme activity during ripening. **iii)** Assess the suitability of apricots for technological purposes, especially for processing to canned halves, an important Agri-food industry in Marrakesh region.

2. Material and methods

2.1.Standards and chemicals

Liquid nitrogen, ethanol and acetone were from Fisher Scientific (Strasbourg, France). Phenol, sulfuric acid, meta-hydroxyphenyl (MHDP) and methanol were from Merck (Darmstadt, Germany). Acetic acid, phosphate buffer, citrate buffer, borate buffer, sodium chloride (NaCl), apple pectin, p-nitrophenyl-β-D-galactopyranoside and p-nitrophenol (Sigma-Aldrich (Darmstadt, Germany). Sugars (glucose, arabinose, fucose, galactose, xylose, mannose and rhamnose) were from Fluka (Buchs, Switzerland). Sodium hydroxide, Methanol-d3 (CD3OH), Potassium hydroxide (KOH) and inositol were from Sigma-Aldrich (Deisenhofen, Germany). Acetonitrile of HPLC grade was obtained from VWR International (Radnor, USA). Polyvinylpolypyrrolidone (PVPP), Triton X-100 were from Sigma-Aldrich, (Saint-Quentin-Fallavier, France).

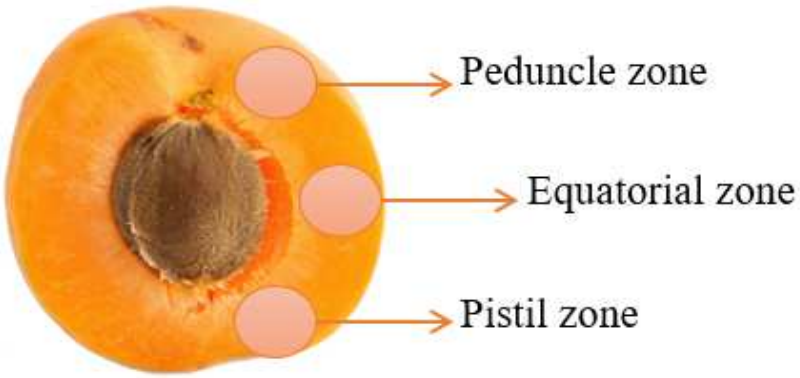
2.2.Fruit and sampling

Apricot fruits from ten clones (Boum A2, Agdez LG1, Marouch 4, Ab 5, Marouch 16, Rtil 4, Clone C, Mans 15, Agdez C2 and Cg 2) were from the apricot collection in Saâda experimental field of the Regional Center for Agricultural Research in Marrakesh, National Institute for Agricultural Research (INRA), Morocco (30◦21_08.4_N 9◦30_29.0_W). All the studied clones were harvested at two stages of maturity (M1: commercially ripe and M2: consumption ripe) based on fruit firmness and surface color.

The fruit is considered commercially ripe when it reached complete size and an intense color (light, orange or red depending on genotype), but still firm to withstand handling, transport and storage conditions. At the consumption stage, the fruit is soft and could easily be detached from the tree. It is the fruit intended for the local market and for consumption almost immediate (ready to be eaten) (Ayour et al., 2017).

Batches of harvested apricots (n=30 per maturity stage) was divided into two groups (n=10 and n=20). The fisrt group was used for the analysis of the firmness by an electronic penetrometer (Petrotest PNR 10, Anton Paar, Villeneuve la Garenne, France) at three tissue zones (peduncle, equatorial and pistil) on the fruit flesh. The second group was used for cell wall composition and enzymatic analysis by corresponding tissue zone (2 replicates of 10

157 units per zone). These apricots were cut into small pieces per tissue zone using a sharp knife
158 and immediately crushed in liquid nitrogen (A11 basic analytic, Ika, Staufen, Germany) and
159 stored at -80 °C until analyses. Samples were identified by repeat number, tissue zone, stage
160 of maturity and clone name. Cell wall composition and enzymatic activities were analysed in
161 duplicate. However, analysis of cell wall composition was performed only on commercial
162 stage fruits (M1).
163
164 *2.3.Texture test of the different fruit zones*
165
166 Sampling was carried out as described in Ribas-Agusti et al. (2017). A tissue slice of
167 about 1.5 cm thick was cut longitudinally using a sharp knife. The three tissue zones defined
168 on the surface section (peduncle, equatorial and pistil) are presented in Figure 1. Firmness at
169 each tissue zone was measured using an electronic penetrometer (Petrotest PNR 10)
170 corresponding to the maximum pressure (Pa).
171 One measurement was made per tissue zone and per fruit; the average value and standard
172 deviation of the 10 fruits were calculated by corresponding zone.
173
174
175
176
177
178
179
180
181



182 **Fig. 1.** Apricot slice showing the three tissue zones included in the experimentation and the
183 penetration points of the texture test.

184 *2.4.Cell wall composition*

185

186 *2.4.1. Cell wall isolation and extraction*

187 Cell wall materials were prepared as alcohol-insoluble solids (AIS) from the different
188 tissue zones according to Renard et al. (1990) and Renard (2005) using hot rinsing method,
189 briefly described below. About 500 mg of apricot homogenate frozen were weighed and
190 suspended in 100 mL of 70 % ethanol and left for 25 min at boiling (temperature: 82–85 °C).
191 The suspension was vigorously mixed and stabilized at room temperature for 1 hour and then
192 filtered with a filtration system using the columns (75 ml empty SPE column (Interchim)
193 equipped with a sinter of 20 µm) and a vaccum system Restek (Restek Corporation,
194 Bellefonte, PA, USA). Subsequently, the insoluble material was resuspended in 70% alcohol.
195 The washings were continued till absence of sugars as shown by absence of color in the
196 phenol sulfuric test (Dubois et al., 1956). Samples were then washed twice with acetone:
197 water: acetic acid (v/v/v 60:39:1) to extract polyphenols (Guyot et al., 1998), afterwards twice
198 with acetone: water solution (v/v 80:20), then with pure acetone until discoloration of the
199 substrate. This solid residue (AIS) was dried at 40 °C overnight and weighed.

200

201 *2.4.2. Analytical methods*

202 Neutral sugars were analysed as alditol acetates after acid hydrolysis by two ways. For
203 glucose from cellulose analysis, the samples (c.a. 10 mg of AIS) were subjected to pre
204 hydrolysis with 250 µL 72% sulfuric acid for 1 h at room temperature (Saeman et al., 1954),
205 then diluted to sulfuric acid (1 mol L^{-1}) by addition of water and internal standard (inositol).
206 However, no pre hydrolysis was carried out for the analysis of neutral sugars (simple
207 hydrolysis), including non-cellulosic glucose, the samples (10 mg) were dissolved in sulfuric
208 acid (1 mol L^{-1}) with internal standard. All samples were placed in an oven at 100 °C for 3 h
209 for hydrolysis, after that they were derivatised to volatile alditol acetates (Englyst et al.,
210 1982). They were injected onto a GC-FID HP 5890 Series II (Agilent, Palo Alto, CA)
211 containing a DB225-MS capillary column (30 m x 0.25 mm i.d. coated with, 0.25 µm film
212 thickness; Agilent). The conditions were: injection temperature 250 °C in split mode (ratio
213 1:25); hydrogen as carrier gas at 45 cm/s (1.3 mL min^{-1}); oven temperature isothermal at 215
214 °C. Uronic acids were measured spectrophotometrically by the *m*-hydroxydiphenyl assay as
215 described by Blumenkrantz & Asboe-Hansen (1973) with galacturonic acid as external
216 standard, expressed as anhydrouronic acids (AUA). Uronic acids were measured after acid

hydrolysis by Saeman procedure as described above. Methanol was determined in AIS as described by Renard and Ginies (2009) by stable isotope dilution assay using headspace-GC–MS after saponification. Degree of methylation (DM) was calculated as the molar ratio of methanol to uronic acids.

2.5.Pectinolytic enzyme activities

2.5.1. Determination of Pectinmethylesterase activity

Pectinmethylesterase (PME) activities were determined by titration as described in Ribas-Agustí et al. (2017) with minor modifications. The extract from apricot powder (1 g) was produced with 1 mL 0.2 mol L^{-1} phosphate buffer, pH 7.0, containing 1 mol L^{-1} NaCl. The mixture was stirred for 2 h at 4 °C and centrifuged for 30 min at 16,000×g and 4 °C to obtain the PME crude extract (clear supernatant). An aliquot of the extract (250 µL) was added to 1 mL of apple pectin (3.5 g L^{-1}) solution (70–75% esterification, Sigma-Aldrich), in 0.12 mol L^{-1} NaCl. The mixture was kept for 30 min at pH 7.0 and 35 °C under stirring in an automatic pH titrator (Metrohm, Herisau, Switzerland). The carboxylic groups liberated by de-esterification of the pectin methyl groups were measured by titration with 0.1 mol L^{-1} NaOH. The amount of carboxylic groups liberated at pH 7.0 and 35 °C was used to define the PME activity. The PME activity was expressed as nkat g^{-1} fruit fresh weight.

2.5.2. Determination of β-Galactosidase activity

β-Galactosidase activities were measured as described by Ribas-Agustí et al. (2017) with some modifications. The enzyme was extracted from 1 g of samples with 1 mL 0.1 mol L^{-1} borate buffer, pH 9.0, containing 1.2 mol L^{-1} NaCl, 10 mL L^{-1} Triton X-100, and 10 g L^{-1} PVPP. The mixture was stirred for 2 h at 4 °C and centrifuged for 30 min at 16,000×g and 4 °C to extract β-galactosidase (clear supernatant).

The incubations were performed in a microplate spectrophotometer (FLX-Xenius, Safas, Monaco), at 37 °C for 60 min. We used 1 mmol L^{-1} *p*-nitrophenyl-β-D-galactopyranoside (Sigma- Aldrich) in 50 mmol L^{-1} citrate buffer (pH 4.4) as substrate. An aliquot of the extracts (10 µL) was added to 190 µL of substrate, and the absorbance was recorded at 400 nm every 1 min to measure the liberation of nitrophenol. The rate of nitrophenol release from the glycosides, at pH 4.4 and 37 °C, was used to define the glycosidase activities. Its quantification was performed using a *p*-nitrophenol standard curve at 0.4 - 1.6 mmol L^{-1}

range (Sigma-Aldrich). The β-galactosidase activity was expressed as nkat g^{-1} fruit fresh weight.

2.6.Statistical analysis

The firmness, cell wall composition and enzymatic activities (dependent variables) data of each apricot clone were statistically evaluated by three-way analysis of variance (ANOVA) using the three independent variables: tissue zone, clone and maturity stage. Cell wall composition was analyzed in duplicate : 2 replicates of 10 plant material units per zone per clone. Firmness was analyzed per zone for 10 fruits per clone and per maturity stage. PME and β-Gal activities were analyzed in duplicate: 2 replicates of 10 plant material units per zone, per maturity stage and per clone. The analytical reproducibility of the results was determined as pooled standard deviations (Pooled SD). This parameter was calculated for each series of replicates per variable using the sum of individual variances weighted by the individual degrees of freedomas described by Kosmala et al. (2013).

Data of measured firmness, cell wall composition and enzyme activities of flesh tissue zones for M1 stage were subjected to multivariate analysis. The objective was to investigate the relationships between apricot texture, cell wall composition and enzyme activities. The Pearson's correlation coefficients between all parameters were calculated. Principal component analysis (PCA) was performed on datasets obtained from apricots using XLSTAT statistical software version 2018.

3. Results and discussion

3.1.Cell wall composition of apricot tissues

Significant differences ($P \leq 0.005$) were observed between apricot clones for the three tissue zones (peduncle, equatorial and pistil). However, less significant difference was observed between the three zones within the same clone. All tissues zones showed relatively high amounts of alcohol insoluble solids expressed by their yields (Table 1). Indeed, the AIS yields were higher than those reported by Ella Missang et al. (2012) which varied between 16 and 17 mg g^{-1} FW for cell wall materials in apricot median tissues. All other data available on apricot cell walls concern only the whole fruit, without distinguishing the different tissue

283 zones. AIS yields found in the present work were close to those reported by Kurz et al. (2008)
284 for some apricot varieties (24.9–25.9 mg g^{-1} FW) and lower than obtained cell wall yields
285 (30.5–52.4 mg g^{-1}) for Canino apricot variety (Femenia et al., 1998). The compositions of the
286 AIS (Table 1) were characterised by high amounts of uronic acid (179 – 300 mg g^{-1} AIS).
287 Glucose (mostly cellulosic, 118-214 mg g^{-1} AIS) was the main neutral sugar in the AIS from
288 apricot flesh, followed by arabinose. This result was in line with previous studies: Ella
289 Missang et al. (2012) report that for all nine fresh tissues, uronic acids (268–338 mg g^{-1} AIS)
290 from pectin was the predominant sugar, followed by glucose (197–217 mg g^{-1} AIS). Lahaye et
291 al. (2014) and Femenia et al. (1998) describe that glucose and uronic acid as the main
292 monosaccharides in apricot AIS. Arabinose, galactose, commonly found in pectin side-chains,
293 and mannose, which is a hemicellulose sugar (mannan), were all present in higher
294 concentrations than reported by previous studies (Ella Missang et al., 2012; Lahaye et al.,
295 2014). The presence of fucose, in addition to relatively high amounts of xylose, suggested the
296 presence of hemicelluloses composed of xyloglucan polymers as found recently in apricot
297 (Liu et al., 2017) and in other Prunus species, such as plum (Nunes et al., 2008; Renard and
298 Ginies, 2009) or peach (Brummell et al., 2004; Yoshioka et al., 2011). This monosaccharide
299 was in the ranges reported by other authors (Femenia et al., 1998; Ella Missang et al., 2012;
300 Lahaye et al., 2014) but lower than in Kurz et al. (2008). Recently, in other fruit specie, Ren
301 et al. (2020) report that glucose was the most abundant component followed by arabinose and
302 galactose in composition of cell-wall polysaccharides of custard apple (*Annona squamosal*).
303 Besides, a small proportion of rhamnose, xylose and mannose occurs .

304 Pectin methyl esterification varied significantly among the different clones ranging from
305 DM = 58 to 97 in Ab 5 and Mans 15 respectively for equatorial zone. These DM were
306 comparable to those reported by Lahaye et al. (2014) (from 46 to 81). Femenia et al. (1998)
307 describe a decrease in methyl esterification of pectin during apricot ripening (from 87 to 60)
308 according to the observed increase in pectin methylesterases gene expression and enzyme
309 activity observed in a large number of ripening fleshy fruits (Brummell, 2006; Goulao &
310 Oliveira, 2008).

311 The cell wall composition depends strongly on apricot structural tissues. In this study
312 the measures were collected in the median tissue of the three zones, which appears quite
313 homogeneous with typical parenchymal cells. These cells are organised relative to the
314 vascular bundles, as illustrated by Archibald & Melton (1987), and have no preferential
315 orientation relative to the fruit structure. Archibald & Melton (1987) report that apricot is

316 characterized by high heterogeneity in its tissue structure, with five layers: an epidermis, a
317 hypodermal layer, a middle layer of thin walled parenchyma cells, a layer of radially
318 elongated cells and a layer of small cells adjacent to the pit. This heterogeneity is already
319 studied (Ayour et al., 2016; Ella Missang et al., 2011) and these five layers have different
320 responses during thermal treatment. The median equatorial zone appears the most
321 representative for texture characterization in the apricot intended for processing. Indeed, this
322 study was carried out on the three median zones in peduncle, equatorial and pistil parts
323 (Figure 1). Meanwhile, changes in the tissue structure, involved in the extensive solubilization
324 and depolymerization of pectin in the middle lamella of cell walls, and the modification of
325 pectin, are related to the ability to bind water and organic molecules (Simal et al., 2005).
326 Moreover, not only the chemical compositions but also the structural polymerization of
327 neutral sugars impact the AIS characteristics. Previous studies have indicated that apricot
328 softening is caused by solubilization of cell wall polysaccharides, which has therefore
329 decreased cell wall strength and intercellular adhesion (Ella Missang et al., 2012; Fan et al.,
330 2017; Deng, et al., 2019; Ren et al., 2020). The ripening induced a softening of the texture,
331 associated with the depolymerized and solubilized pectin. Since then, water-soluble pectin
332 (WSP) content has increased considerably, coupled with the decrease in chelator-soluble
333 pectin (CSP) and Na_2CO_3-soluble pectin (NSP) content. During this time, the structure of
334 pectin is strongly altered during maturation, as observed by AFM. The length of the polymer,
335 the amounts of branching and the size of the aggregates are reduced during the development
336 of maturity (Deng, et al., 2019). Ren et al. (2020) report that molecular weight distribution
337 and monosaccharide composition of cell-wall polysaccharides changed greatly during storage,
338 especially the degradation of pectin polysaccharide. In addition to storage, the genotype
339 represents one of the most influencing factors on the chemical composition of the cell wall. In
340 this study, sugar composition was able to distinguish the different apricot clones and slightly
341 between the flesh zones. Xylose, arabinose, mannose, rhamnose, and uronic acid showed
342 significant differences between the flesh zones belonging in the same clone. The (zone*clone)
343 interaction shows that the difference between the monosaccharide concentrations depend on
344 clone and flesh zone. The apricot clones were found to be relatively rich in AIS according to
345 the literature data, except for Clone C and Agdez C2.

346 **Table 1.** Yields, monosaccharide compositions and DM of alcohol-insoluble solids (AIS) isolated from different tissue zones of fresh apricot fruits of ten apricot clone. 347

Zone	Clone	Yield (mg g^{-1} FW)	Monosaccharide composition (mg g^{-1} AIS)											
			Rha	Fuc	Ara	Xyl	Man	Gal	AUA	Non-cellulosic Glc	Cellulose	Total NS + AUA	MeOH (mg/g)	DM
Peduncle	Boum A2	24	11	4.1	90	39	20	40	241	9	169	612	28	64
	Agdez LG1	15	12	5.4	87	41	18	51	255	14	182	664	32	70
	Marouch 4	20	12	4.2	73	32	19	38	243	16	165	602	31	70
	Ab 5	26	13	3.1	94	35	16	50	229	10	160	610	32	77
	Marouch 16	17	10	4.8	72	34	19	37	274	10	175	634	32	64
	RTil 4	20	12	4.3	82	46	21	37	225	14	193	634	27	66
	Clone C	18	10	4.7	92	34	18	39	204	12	164	577	26	70
	Mans 15	19	12	4.6	83	37	22	38	213	14	194	617	33	86
	Agdez C2	22	14	4.3	77	30	24	40	203	21	182	595	30	82
	Cg 2	27	12	4.5	106	34	18	43	179	10	175	582	26	79
Equatorial	Boum A2	20	12	4.1	82	37	21	40	267	9	180	652	29	59
	Agdez LG1	17	11	4.2	75	37	17	47	262	12	172	637	32	66
	Marouch 4	17	11	4.0	67	35	21	38	276	10	173	635	31	63
	Ab 5	28	10	4.2	95	40	16	48	295	10	154	673	31	58
	Marouch 16	16	14	4.3	68	32	21	39	253	11	189	631	32	70
	RTil 4	20	14	4.1	108	35	20	45	215	9	195	645	27	69.
	Clone C	25	11	3.5	83	28	18	39	184	14	118	498	28	84
	Mans 15	18	11	4.8	77	34	21	38	187	12	187	571	33	97
	Agdez C2	23	13	4.4	68	32	26	38	183	24	175	563	27	80
	Cg 2	26	15	4.0	78	41	24	41	199	11	214	627	30	83
Pistil	Boum A2	23	13	4.7	82	34	21	41	251	10	178	634	29	64
	Agdez LG1	19	9	4.3	72	38	17	43	268	11	157	618	31	64
	Marouch 4	19	12	4.2	63	32	20	35	294	14	169	642	32	60
	Ab 5	27	10	4.0	88	35	16	45	300	9	149	655	33	61
	Marouch 16	20	12	4.0	64	32	21	36	285	14	175	643	34	67
	RTil 4	21	15	4.2	72	37	23	37	262	12	187	649	33	68
	Clone C	20	12	4.3	92	21	6	39	220	11	169	574	32	80
	Mans 15	21	13	4.9	85	37	22	41	215	14	196	627	33	85
	Agdez C2	26	12	4.5	81	33	26	45	183	20	170	574	29	86
	Cg 2	28	10	4.2	107	32	17	40	197	11	165	582	27	76
	Pooled SD	4	1.6	0.3	13	4	4	4	38	6	18	72	7	11
ANOVA	Clone	15***	6***	6***	19***	20***	36***	10***	15***	6***	9***	35**	23**	16***
	Tissue Zone	6**	4*	1	6**	13***	7**	1	5*	2*	1	9*	8**	1
	Clone*Zone	5*	5*	2	6**	9**	7**	2	1	1	3*	4*	7**	1

Rha: rhamnose, Fuc: fucose, Ara: arabinose, Xyl: xylose, Man: mannose, Gal: galactose, Glc: glucose, Cellulose: calculated by glucose from Saeman hydrolysis – glucose (No-cellulosic Glc) from simple hydrolysis, AUA: anhydrouronic acids, MeOH: methanol, DM: degree of methylation. Pooled SD: pooled standard deviation, Fisher's Value F value, $P \leq 0.05$: *, $P \leq 0.01$: **, $P \leq 0.001$: ***.

351 *3.2.Changes of apricot flesh firmness*

352

353 Firmness varied significantly (Table 2 and Table 3) between apricot clones according to
354 flesh zones and maturity stages. The fruit firmness was significantly higher in apricots harvested
355 at the commercial stage (M1) than in those harvested at the consumption stage (M2). The same
356 pattern of maturity evolution was found among all apricot clones, as found by Sharma et al.
357 (2011) who reported that harvest maturity significantly influences the firmness of some Japanese
358 prunus. Deng et al. (2019) reported that texture of apricot was strongly dependent on the
359 maturation stages, the hardness decreased considerably ($P \leq 0.05$) with advance in the maturity
360 of apricots. Indeed, softening during ripening has been confirmed in other reports on apricots
361 (Ayour et al., 2016; Fan et al., 2017; Amoriello et al., 2018;), mango (Cárdenas-Pérez et al.,
362 2018) and bananas (Yap et al., 2017).

363 Agdez C2 and Ab 5 were the firmest and the least firm clones respectively. Our results
364 were consistent with the study by Caliskan et al. (2012) which reported values from 11 10^4 to 47
365 10^4 Pa (exactly from 107873 to 470719 Pa) in firmness measurements on whole apricots.
366 Firmness was monitored from the peduncle to the pistil zone (Table 2). For most clones, the
367 firmness was higher in the peduncle, followed by the equatorial and at last the pistil zone. All
368 differences were significant, in agreement with Ella Missang et al. (2012) who report higher
369 firmness in the peduncle tissue followed by the equatorial and pistil zones. However, the
370 equatorial zone is the most homogeneous flesh part among the clones, such that low differences
371 in firmness values were observed between studied apricots compared to both other zones. The
372 apricot is also characterized by a great texture heterogeneity of these tissues (Ella Missang et al.,
373 2012).

374 Recently, Zhang et al. (2018) indicated that weight loss and firmness were the major
375 factors affecting the quality of apricots. To cope with this physiological problem related to the
376 maturation of the fruit, the authors studied the advantages of a biological treatment which
377 prevented the decrease in firmness and benefited the textural properties of the tissue, namely: An
378 edible coating of protein isolate soybeans (SPI) and chitosan which has been used to extend the
379 shelf life of apricots stored at 2 °C.

380

381 *3.3.Changes in Pectinmethylesterase activity*

382

383 Significant effects were found for clone, ripening stage, tissue zone and their interactions

on PME activity (Table 2 and Table 3). Significant differences in enzyme activities were observed between the apricot clones in both ripening stages. The highest enzyme activity was found in Agdez LG1 and the lowest level was determined for Cg 2. Higher PME activity was observed with ripening for all studied clones, except for Agdez LG1 and Marouch 16 and more pronounced in Ab 5, Mans 15 and Cg 2. These results highlight the importance of cultivar and ripening stage for PME activity in apricot fruit. Similar results were found in other works with different apricot cultivars, who also reported that PME activity increased during the maturity stages (Arancibia & Motsenbocker, 2004; Lohani et al., 2004; Deng et al., 2005; Abaci & Asma, 2014). The apricot clones were characterized by low PME activity values, compared to Abaci & Asma (2014) who found a significant difference in enzyme activity between the unripe and ripe fruits of six apricot cultivars. Even higher activities were reported in other apricot cultivars (Cardarelli et al., 2002; Botondi et al., 2003). The effect of the tissue zone was different concerning the different clones and the ripening stages: For most clones, PME activity was higher in the pistil and equatorial zones. Similar result was found by Ribas-Agustí et al. (2017) who reported lowest PME activity in the peduncle, followed by the equatorial and highest activity in the pistil zone.

Fan, et al. (2019) reported that the degradation of polysaccharides in the cell wall is a consequence of the synergy between several key enzymes that modify the cell wall, including PME, PG, β-GAL and CEL. In accordance with our study and other reports (Carvajal et al., 2015; Liu et al., 2016) the parietal enzymatic activities of apricot increased during the fruit ripening process. The use of NFT storage suppressed increases in these enzymes activities according to Fan et al. (2019). Indeed, PME activity in apricots increased rapidly at the start of storage at 5 °C, while the increase in this enzymatic activity was effectively inhibited by storage at 0 °C and NFT. Compared to storage at 0 °C, NFT storage suppressed the activity of the apricot enzyme at lower levels. The activity of the PME in the apricots stored at the NFT were respectively 88% of that of the apricots stored at 0 °C on the 60^{th} day.

3.4.Changes in β-Galactosidase activity

Significant effects were found for clone, ripening stage, tissue zone and their interactions on β-galactosidase activity (Table 2 and Table 3). Agdez LG1 and Boum A2 had the highest levels of β-Gal activities while the lowest level was determined for Cg 2. Increased activity was observed with ripening for most studied clones, this agreed with various studies which have

417 indicated that activity of β-galactosidase increased during ripening of many fruits (Golden et al.,
418 1993; Lazan et al., 2004).
419 However, the effect of maturity stage was not significant on the β-Galactosidase activity,
420 in fact few differences have been found between M1 and M2, compared to PME activity (Table
421 3). For most clones, β-Gal activity was higher in the pistil zone followed by both other zones
422 (equatorial and peduncle), with relative order depending on clone. Ribas-Agustí et al. (2017) also
423 reported an increasing trend of β-galactosidase activity with ripening, and from peduncle to pistil
424 zones. These results highlight the important implication of genotype and tissue zone in evolution
425 of β-Gal activity in apricot fruit. Indeed, earlier reports (Gulzar & Amin, 2012; Ribas-Agustí et
426 al., 2017) indicate that the β-galactosidases may be involved in the modification of the tissues
427 structure and cell wall polysaccharides of apricot fruits, suggesting its important role in
428 softening.
429 As for the PME activity, Fan et al. (2019) reported that β-GAL activity in apricots
430 increased rapidly at the start of storage at 5 °C, while the increase in this enzymatic activity was
431 effectively inhibited by storage at 0 °C and NFT. Compared to storage at 0 °C, NFT storage
432 suppressed the activity of the apricot enzyme at lower levels. The activity of β-GAL in apricots
433 stored at NFT was 74% respectively of that of apricots stored at 0 °C on the 60th day. Moreover,
434 changes in enzymatic activities in apricots have shown similar trends for all cell wall enzymes
435 (Fan, et al., 2019).

	Firmness (kPa)						PME (nkat g^{-1})						β-Gal (nkat g^{-1})					
	M1			M2			M1			M2			M1			M2		
Clone	Ped	Equ	Pis	Ped	Equ	Pis	Ped	Equ	Pis	Ped	Equ	Pis	Ped	Equ	Pis	Ped	Equ	Pis
Boum A2	183	162	113	159	153	99	10	27	25	10	27	27	12	12	14	12	8	20
Agdez LG1	173	162	110	164	146	109	33	39	45	33	40	43	9	11	13	10	15	21
Marouch 4	215	164	167	157	152	105	4	8	10	5	6	12	6	4	9	6	8	7
Ab 5	154	124	41	108	101	88	7	18	20	23	18	24	4	7	7	10	7	7
Marouch 16	209	206	195	186	177	119	4	16	8	4	9	6	4	8	7	4	8	7
RTil 4	158	116	117	98	67	37	5	18	18	5	23	22	4	3	14	6	12	11
Clone C	263	270	161	191	147	102	13	14	12	13	14	16	3	9	5	4	4	7
Mans 15	265	154	190	206	178	131	14	23	19	22	25	22	6	7	6	8	6	7
Agdez C2	295	217	186	179	165	140	22	38	40	25	38	42	6	6	17	8	10	15
Cg 2	259	201	192	202	192	142	0.1	3	3	1	6	6	4	3	5	5	5	6

436 **Table 2.** Changes of firmness, pectinmethylesterase (PME) and β-galactosidase (β-Gal) activities of apricots clones in different zones of flesh during ripening.

437 PME: Pectinmethylesterase, BetaGal: β-Galactosidase.
438 M1: commercial stage; M2: consumption stage.
439 Ped: Peduncle, Equ: Equatorial, Pis: Pistil.
440
441 **Table 3.** Three-way ANOVA analysis of firmness, pectinmethylesterase and β-galactosidase in studied apricot.

442
443
444
445
446
447
448

Variable	ANOVA							
	Pooled SD	Clone	Maturity	Zone	Clone*Maturity	Clone*Zone	Maturity*Zone	Clone*Maturity*Zone
Firmness	19	10***	17***	14***	19***	19***	10**	16**
PME	10	7***	8**	3***	11**	10*	8*	10*
BetaGal	7	2***	5*	3***	4**	5**	7	5*

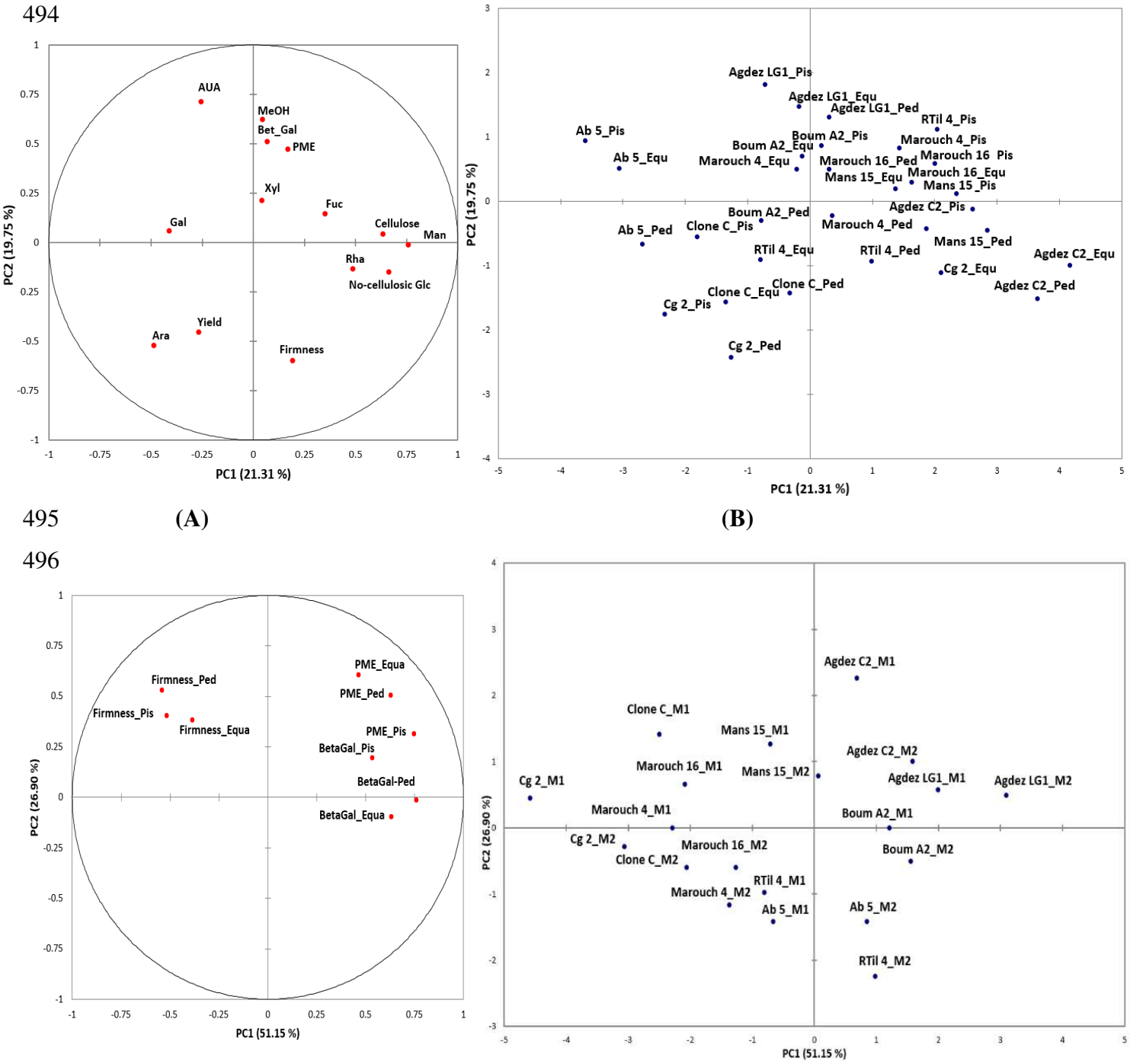
449 Pooled SD: pooled standard deviation, Fisher's Value F value, $P \leq 0.05$: *, $P \leq 0.01$: **, $P \leq 0.001$: ***.
450 PME: Pectinmethylesterase, BetaGal: β-Galactosidase.

451 *3.5.Multivariate analysis data of firmness and cell wall composition*

452

453 According to the Pearson correlation coefficients, the yields were not significantly
454 correlated with neutral sugars, except for arabinose, which showed significant positive
455 correlation coefficient (0.501). Among the positive correlations, cellulosic glucose was found
456 correlated with rhamnose (0.624), non-cellulosic glucose with mannose (0.512) and arabinose
457 with galactose (0.497). Uronic acid content was not correlated with neutral sugars but correlated
458 with methanol (0.541) and firmness (-0.574). However, no significant correlation was found
459 between cell wall AIS parameters and enzyme activities. The firmness was found negatively
460 correlated with PME (-0.502) and β-Gal (-0.472). These correlations showed the implication of
461 enzymes activities in degradation of the pectin and its participation in loss of apricot firmness.
462 The Principal Components Analysis (PCA) was used to illustrate the relationships among
463 studied parameters, also to analyze the implication of cell wall composition and pectinolytic
464 enzyme activities in the evolution of apricot texture considering the clone, tissue zone and
465 ripening effects. The principal found correlations were plotted and shown in Figure 2.
466 A first PCA was carried out using all studied parameters for M1 stage. More than 41 % of the
467 total variance was explained by the first both principal components (Fig. 2A and 2B). The
468 dispersion of the individuals (clone linked to zone) on the factorial map (Fig. 2B) showed the
469 important impact of the genotype on cell wall composition and on enzyme activities compared to
470 tissue zone. Therefore, the parietal composition of studied apricots varies significantly with
471 clone compared to tissue zone, while there is no link with a precise tissue zone.
472 To highlight the impact of ripening stage on apricot texture, a reanalysis of the results with
473 firmness and enzyme activities data for both maturity stages (M1 and M2) allowed better
474 mapping of studied clones with a high variability (Fig. 1C and 1D). More than 78 % of the total
475 variance was explained by the first both principal components (Fig. 2C and 2D). The negative
476 correlation between firmness and enzymatic activities was shown on the factor map as a function
477 of the tissue zones. This correlation is explained by the PC1 axis with 51.15% of the total
478 variability on both sides of the PC origin. In addition, the three tissue zones are grouped for each
479 measured parameter, indeed, they don't have a significant effect on apricot texture compared
480 also to maturity stage. The distribution of individuals (Fig. 1D) distinguished the apricot clones
481 according to a major impact of maturity stage. The factorial map (Fig. 1 D) indicated that
482 ripening effect was related to the enzyme activities. M2 stage was characterized by a higher
483 enzymatic activity compared to M1 stage and vice versa for apricots firmness.

Among studied clones, Adez LG2, Boum A2 and Agdez C2 were characterized a loss of firmness between M1 and M2, explained by high enzymatic activity observed for the two maturity stages. These results are supported with previous studies (Lazan et al., 2004; Arancibia & Motsenbocker, 2004; Lohani et al., 2004; Deng et al., 2005; Abaci et al., 2014; Ribas-Agustí et al., 2017) which reported the impact of ripening process in enzymatic activity increasing. However, Ab 5, Marouch 16, Mans 15 and Cg 2 (Fig. 3) were less influenced by the softening by looking at their firmness and the effect of the enzymatic activity both ripening stages. Hence the importance of these apricot clones which can represent a technological solution for the processing industry especially to canned halves, an important industry in Marrakesh region, whose apricot texture is the key element of the transformation.



(A) **(B)**

(C) **(D)**

Fig. 2. Principal component analysis of firmness, cell wall composition and pectinolytic enzyme changes in different tissue zones of ten apricot clones:
(A) and **(B)** Representation of all variables and segregation of 10 apricot clones according to tissue zones.
(C) and **(D)** Representation of firmness and pectinolytic enzyme variables and segregation of 10 apricot clones according to maturity stages.
Ped: Peduncle, Equ: Equatorial, Pis: Pistil
Rha: rhamnose, Fuc: fucose, Ara: arabinose, Xyl: xylose, Man: mannose, Gal: galactose, Glc: glucose, Cellulose: difference between total glucose measured after Saeman hydrolysis and readily hydrolysable glucose (No-cellulosic Glc) measured after 1M H_2SO_4 hydrolysis. AUA: anhydrouronic acids, MeOH: methanol, PME: Pectinmethylesterase, BetaGal: β-Galactosidase, M1: commercial stage; M2: consumption stage.

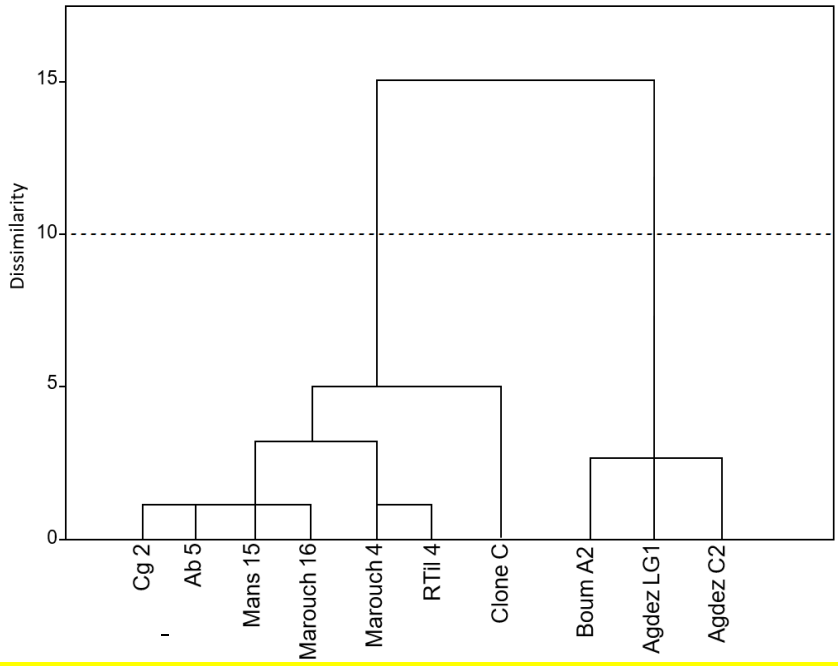


Fig. 3. Cluster dendrogram realized on firmness and enzyme activity variables for ten apricot clones at two maturity stages.

4. Conclusion

Apricot texture was characterized with high heterogeneity between studied clones. Apricots showed different texture profiles according to their cell wall composition and changes. Indeed, the results could help to illustrate the fundamental of changes of apricot texture according to tissue zone, genotype and ripening stage.

Apricot cell walls contained relatively high levels of neutral sugars such as glucose, arabinose, xylose and galactose. Rhamnose, mannose and fucose were also found to be present in small amounts. Also, studied apricots showed higher levels of uronic acid and of degree of methylation. This composition depends especially to clone and to tissue zone. The measurement of flesh firmness allowed a significant difference between the three tissue zones (peduncle, equatorial and pistil). The ripening effect was observed in the evolution of firmness as a function of enzymatic activity, in particular the increased PME activity with the maturity stage.

These associations allowed us to classify apricot clones according to the evolution of softening. A group of clones constituted by Ab 5, Marouch 16, Mans 15 and Cg 2 were less influenced by softening and have the advantage of a technological valorisation for processing industry, especially for canned halves, thanks to the texture of fruit apricots of these clones which is decisive in the production of apricot canned halves.

Acknowledgements

The authors thank Line Touloumet, Marielle Bogé and Albert Ribas-Agusti for their technical help in UMR 408 of INRA in Avignon. They also thank the technical staff of Saâda experimental field of INRA, Regional Center for Agricultural Research in Marrakech for their precious cooperation.

References

Abaci, Z. T., & Asma, B. M. (2014). Changes in some enzymatic parameters of six apricot cultivars during ripening. *Anadolu Journal of Agricultural Sciences*, 29, 174-178.

Amoriello, T., Ciccoritti, R., Paliotta, M., & Carbone, K. (2018). Classification and prediction of early-to-late ripening apricot quality using spectroscopic techniques combined with chemometric tools. *Scientia Horticulturae*, 240, 310–317.

Arancibia, R. A., & Motsenbocker, C. E. (2004). Pectin ultra-degradation decreases the force required to detach ripe fruit from the calyx in tabasco pepper. *Journal of the American Society for Horticulture Science*, 129, 642-648.

Archibald, R. D., & Melton, L. D. (1987). The anatomy of the fleshy pericarp of maturing Moorpark apricots, *Prunus armeniaca*. *New Zealand Journal of Botany*, 25, 181-184.

Ayour, J., Gouble, B., Reling, P., Ribas-Agustí, A., Audergon, J. M., Maingonnat, J. F., & Renard, C. M. (2016). Impact of cooking on apricot texture as a function of cultivar and maturity. LWT – *Food Science and Technology*, 85, 385–389.

Ayour, J., Sagar, M., Harrak, H., Alahyane, A., & Benichou, M. (2017). Evolution of some fruit quality criteria during ripening of twelve new Moroccan apricot clones (*Prunus armeniaca* L.) *Scientia Horticulturae* 215, 72-79.

Botondi, R., DeSantis, D., Bellincontro, A., Vizovitis, K., & Mencarelli, F. (2003). Influence of ethylene inhibition by 1-methylcyclopropene on apricot quality, volatile production, and glycosidase activity of low- and high-aroma varieties of apricots. *Journal of Agriculture and*

Food Chemistry, 51, 1189–1200.

Brahem, M., Renard, C. M. G. C., Gouble, B., Bureau, S., & Le Bourvellec, C. (2017). Characterization of tissue specific differences in cell wall polysaccharides of ripe and overripe pear fruit. *Carbohydrate Polymers*, 156, 152–164.

Brummell, D. A. (2006). Cell wall disassembly in ripening fruit. *Functional Plant Biology*, 33, 103–119.

Brummell, D. A., & Harpster, M. H. (2001). Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants. *Plant Molecular Biology*, 47, 311-340.

Brummell, D. A., Dal Cin, V., Crisosto, C. H., & Labavitch, J. M. (2004). Cell wall metabolism during maturation, ripening and senescence of peach fruit. *Journal of Experimental Botany*, 55, 2029–2039.

Caliskan, O., Bayazit, S., & Sumbul, A. (2012). Fruit quality and phytochemical attributes of some apricot (*Prunus armeniaca* L.) cultivars as affected by genotypes and seasons. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 40, 284-294.

Cardarelli, M., Botondi, R., Vizovitis, K., & Mencarelli, F. (2002). Effects of exogenous propylene on softening, glycosidase, and pectinmethylesterase activity during postharvest ripening of apricots. *Journal of Agriculture and Food Chemistry*, 50, 1441–1446.

Cárdenas-Pérez, S., Chanona-Pérez, J. J., Güemes-Vera, N., Cybulska, J., Szymanska-Chargot, M., & Chylinska, M. (2018). Structural, mechanical and enzymatic study of pectin and cellulose during mango ripening. *Carbohydrate Polymers*, 196, 313–321.

Carvajal, F., Palma, F., Jamilena, M., & Garrido, D. (2015). Cell wall metabolism and chilling injury during postharvest cold storage in zucchini fruit. *Postharvest Biology and Technology*, 108, 68–77.

De Martino, G., Massantini, R., Botondi, R., & Mencarelli, F. (2002). Temperature affects impact injury on apricot fruit. *Postharvest Biology and Technology*, 21, 331–339.

583 Deng, Y., Wu, Y., & Li, Y. (2005). Changes in firmness, cell wall composition and cell wall
584 hydrolases of grapes stored in high oxygen atmospheres. *Food Research International*, 38,
585 769–776.
586 Deng, L. Z., Mujumdar, A. S., Yang, X. H., Wang, J., Zhang, Q., Zheng, Z. A. (2018). High
587 humidity hot air impingement blanching (HHAIB) enhances drying rate and softens texture of
588 apricot via cell wall pectin polysaccharides degradation and ultrastructure modification. *Food*
589 *Chemistry*, 261, 292–300.
590 Deng, L.Z., Pan, Z., Zhang, Q., Liu, Z.L., Zhang, Y., Meng, J.S., Gao, Z.J., & Xiao, H.W.
591 (2019). Effects of ripening stage on physicochemical properties, drying kinetics, pectin
592 polysaccharides contents and nanostructure of apricots. *Carbohydrate Polymers*, 222, 114980.
593 Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric
594 method for determination of sugars and related substances. *Analytical Chemistry*, 28, 350-
595 356.
596 Duvetter, T., Sila, D. N., Van Buggenhout, S., Jolie, R., Van Loey, A., & Hendrickx, M. (2009).
597 Pectins in processed fruit and vegetables: part I-stability and catalytic activity of pectinases.
598 *Comprehensive Reviews in Food Science and Food Safety*, 8, 75–85.
599 Ella Missang, C., Maingonnat., J. F., Renard, C. M. G. C., & Audergon, J. M. (2011). Texture
600 variation in apricot: Intra-fruit heterogeneity, impact of thinning and relation with the texture
601 after cooking. *Food Research International*, 44, 46-53.
602 Ella Missang, C., Maingonnat, J. F., Renard, C. M. G. C., & Audergon, J. M. (2012). Apricot
603 cell wall composition: Relation with the intra-fruit texture heterogeneity and impact of
604 cooking. *Food Chemistry*, 133, 45-54.
605 Englyst, H., Wiggins, H., & Cummings, J. (1982). Determination of the non-
606 starchpolysaccharides in plant foods by gas-liquid chromatography of constituent sugars as
607 alditol acetates. *Analyst*, 107, 307–318.

608 Fan, X., Zhao, H., Wang, X., Cao, J., & Jiang, W. (2017). Sugar and organic acid composition of
609 apricot and their contribution to sensory quality and consumer satisfaction. *Scientia*
610 *Horticulturae*, 225, 553–560.
611 Fan, X., Jiang, W., Gong, H., Yang, Y., Zhang, A., Liu, H., Cao, J., Guo, F., Cui, K. (2019). Cell
612 wall polysaccharides degradation and ultrastructure modification of apricot during storage at a
613 near freezing temperature. *Food Chemistry*, 300, 125194.
614 Femenia, A., Sanchez, E. S., Simal, S., & Rosello, C. (1998). Developmental and ripening-
615 related effects on the cell wall of apricot (*Prunus armeniaca*) fruit. *Journal of the Science of*
616 *Food and Agriculture*, 77, 487-493.
617 Gatti, E., Defilippi, B. G., Predieri, S., & Infante, R. (2009). Apricot (*Prunus armeniaca* L.)
618 quality and breeding perspectives. *Journal of Food, Agriculture & Environment*, 7, 573-580.
619 Golden, K. D., John, M. A., & Kean, E. A. (1993). β-Galactosidase from *Coffea arabica* and its
620 role in fruit Ripening. *Phytochemistry*, 34, 355-360.
621 Goulao, L. F., & Oliveira, C. M. (2008). Cell wall modifications during fruit ripening: When a
622 fruit is not the fruit. *Trends in Food Science and Technology*, 19, 4–25.
623 Gulzar, S., Amin, S. (2012). Kinetic studies on β-Galactosidase isolated from apricots (*Prunus*
624 *armeniaca kaisa*). *American Journal of Plant Sciences*, 3, 636-645.
625 Guyot, S., Marnet N., Laraba D., Sanoner P., & Drilleau J. F. (1998). Reversed-phase HPLC
626 following thiolysis for quantitative estimation and characterization of the four main classes of
627 phenolic compounds in different tissue zones of French cider apple variety (*Malus domestica*
628 *var Kermerrien*). *Journal of Agricultural and Food Chemistry*, 46, 1698-1705.
629 Hubbard, N. L., & Pharr, O. M. (1992). Developmental changes in carbohydrate concentration
630 and activities of sucrose metabolizing enzymes in fruits of two *Capsicum annuum* L.
631 genotypes. *Plant Science*. 86: 33-39.
632 Kosmala, M., Milala, J., Kołodziejczyk, K., Markowski, J., Zbrzeźniak, M., & Renard, C. M.

(2013). Dietary fiber and cell wall polysaccharides from plum (*Prunus domestica* L.) fruit, juice and pomace: Comparison of composition and functional properties for three plum varieties. *Food research international*, 54(2): 1787-1794.

Kurz, C., Carle, R., & Schieber, A. (2008). Characterisation of cell wall polysaccharide profiles of apricots (*Prunus armeniaca* L.), peaches (*Prunus persica* L.), and pumpkins (*Cucurbita* sp.) for the evaluation of fruit product authenticity. *Food Chemistry*, 106, 421-430.

Lahaye, M., Falourd, X., Quemener, B., Devaux, M. F., & Audergon, J. M. (2014). Histological and cell wall polysaccharide chemical variability among apricot varieties. *LWT - Food Science and Technology*, 58, 486-496.

Lazan, H., Ng, S. Y., Goh, L. Y., & Ali, Z. M. (2004). Papaya β-Galactosidase/Galactanase isoforms in differential cell wall hydrolysis and fruit softening during ripening. *Plant Physiology and Biochemistry*, 42, 847-853.

Liu, K., Liu, J., Li, H., Yuan, C., Zhong, J., & Chen, Y. (2016). Influence of postharvest citric acid and chitosan coating treatment on ripening attributes and expression of cell wall related genes in cherimoya (*Annona cherimola* Mill.) fruit. *Scientia Horticulturae*, 198, 1–11.

Liu, H., Chen, F., Lai, S., Tao, J., Yang, H., & Jiao, Z. (2017). Effects of calcium treatment and low temperature storage on cell wall polysaccharide nanostructures and quality of postharvest apricot (*Prunus armeniaca*). *Food Chemistry*, 225, 87–97

Lohani, S., Trivedi, P.K., & Nath, P. (2004). Changes in activities of cell wall hydrolases during ethylene-induced ripening in banana: effect of 1-MCP, ABA and IAA. *Postharvest Biology and Technology*, 31, 119-126.

Nunes, C., Saraiva, J. A., & Coimbra, M. A. (2008). Effect of candying on cell wall polysaccharides of plums (*Prunus domestica* L.) and influence of cell wall enzymes. *Food Chemistry*, 111, 538–548.

Ren, Y., Sun, P., Wang, X., & Zhu, Z. (2020). Degradation of cell wall polysaccharides and

change of related enzyme activities with fruit softening in *Annona squamosa* during storage. *Postharvest Biology and Technology*, 166, 111203.

Renard, C. M. G. C. (2005). Variability in cell wall preparations: quantification and comparison of common methods. *Carbohydrate Polymers*, 60, 515-522.

Renard, C. M. G. C., Voragen, A. G. J., Thibault, J. F. & Pilnik, W. (1990). Studies on apple protopectin I: Extraction of insoluble pectin by chemical means. *Carbohydrate Polymers*, 12: 9–25.

Renard, C. M. G. C., & Ginies, C. (2009). Comparison of the cell wall composition for flesh and skin from five different plums. *Food Chemistry*, 114, 1042–1049.

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.

Rose, J. K., & Bennett, A. B. (1999). Cooperative disassembly of the cellulose-xyloglucan network of plant cell walls: parallels between cell expansion and fruit ripening. *Trends in Plant Science*, 4, 176-183.

Ruiz, D., & Egea, J. (2008). Phenotypic diversity and relationships of fruit quality traits in apricot (*Prunus armeniaca* L.) germplasm. *Euphytica*, 163, 143–158.

Saeman, J. F., Moore, W. E., Mitchell, R. L. & Millet, M. A. (1954). Techniques for the determination of pulp constituents by quantitative paper chromatography. *Tappi Journal*, 37, 336-343.

Sharma, S. K., Chaudhary, S. P., Rao, V. K., Yadav, V. K., & Bisht, T. S. (2011). Standardization of technology for preparation and storage of wild apricot fruit bar. *Journal of Food Science and Technology*, 48, 675–681.

Simal, S., Femenia, A., Cárcel, J. A., & Rosselló, C. (2005). Mathematical modelling of the drying curves of kiwi fruits: Influence of the ripening stage. *Journal of the Science of Food*

and Agriculture, 85(3), 425–432.

Waldron, K. W., Park, M. L., & Smith, A. C. (2003). Plant cell walls and food quality. *Comprehensive Reviews in Food Science and Food Safety*, 2, 101-119.

Yap, M., Fernando, W. M., Brennan, C. S., Jayasena, V., & Coorey, R. (2017). The effects of banana ripeness on quality indices for puree production. *LWT-Food Science and Technology*, 80, 10–18.

Yoshioka, H., Hayama, H., Tatsuki, M., & Nakamura, Y. (2011). Cell wall modifications during softening in melting type peach ‘‘Akatsuki’’ and non-melting type peach ‘‘Mochizuki’’. *Postharvest Biology and Technology*, 60, 100–110.

Zhang, L., Chen, F., Lai, S., Wang, H., & Yang, H. (2018). Impact of soybean protein isolate-chitosan edible coating on the softening of apricot fruit during storage. *LWT Food Science and Technology*, 96, 604–611.