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Morphometric and biochemical characterization of old low-chilling pear cultivars (*pyrus communis l.*) grown in Tunisia

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Abstract

Fruit quality attributes were studied in eight old pear cultivars grown in a Mediterranean climate in the Center-eastern of Tunisia. Fruit quantitative and qualitative morphological parameters, fruit skin color on both sun-exposed and shaded fruit sides, and chemical characteristics in both flesh and peel (titratable acidity, TSS, fructose, glucose, sucrose, total sugars, citric and malic acids) were evaluated. A high variability was found in the set of the evaluated pear cultivars. The fruit weight varied from 22.63 g to 63.72 g and firmness varied from 2.78 kg/cm2 and 4.78 kg/cm2. 'Arbi Sidi Bou Ali' and 'Arbi Bouficha' presented the biggest fruits. However, 'Radsi' tended to have the smallest fruits. 'Jrani' and 'Arbi Chiheb' have shown the lowest values of healthy seeds per fruit. 'Radsi' pears were the most red-colored fruits, while 'Jrani' 'Arbi Chiheb' and 'Arbi Bouficha' produced green-yellowish fruits. Results showed also that pear fruit flesh had more effective sugars and organic acids compared to peel for all cultivars. The TSS ranged from14.6° brix to 19.1°Brix in the flesh and from 12 to 17.1°Brix in the peel. 'Arbi Chiheb' was distinguished by the highest malic acid content in both flesh and peel. Titratable acidity was significantly higher in 'Arbi Sidi Bou Ali', 'Tourki' and 'Meski Arteb' compared to other cultivars. A high correlation was found among some pear quality attributes, which could reduce the number of pomological traits. These results would be a guide in the selection of potential cultivars which are used in food industry and fresh market as well as in breeding programs.

Keywords: Pyrus communis, pomological, biochemical traits, phenotypic variability

Introduction

Pear is one of world's earliest fruit trees cultivated in temperate regions since more than 3000 years (Bell, 1991). It belongs to tribe Pyreae, subfamily of Spiraeoideae in the Rosaceae family (Potter et al., 2007). European pear (Pyrus communis L.) has been widely produced throughout Europe, North and South America, and Africa (Yamamoto and Chevreau, 2009). It is consumed for its juicy delicious taste and rich nutritional composition (Li et al., 2016). In general, it is eaten fresh or used for production of processed foods such as juice, jellies, puree and jams (Lee et al., 2017). In Tunisia, traditional local pear cultivation is very old and encountered in many districts due to its low chilling requirement, its adaptability to different ecological conditions, and its tolerance to drought as compared to introduced foreign varieties (Mars et al., 1994). Most of pear traditional cultivars are found in the centre-east of the country with a substantial genetic diversity (Brini et al., 2008). Although Tunisian local pears present a wide phenotypic diversity, little attention was paid to them and data on their properties are scarce. Therefore, identification of this native material is essential for conservation and management strategies, and for crop improvement programs especially under changing climatic conditions.

In general, genetic diversity can be determined by evaluating morphological, phenological and agronomic characteristics, as well as by biochemical and molecular markers (Höfer et al., 2014). Challice and Westwood (1973) made the first comprehensive study of Pyrus spp variation using morphological and chemical traits to classify 244 individuals into 22 Pyrus species. A descriptor list for pear genetic resources has been developed by the International Board for Plant Genetic Resources (IBPGR) (Thibault et al., 1983). Many researchers have applied these guidelines to characterize cultivated pear cultivars in Turkey (Ozturk et al., 2009; Bayazit et al., 2016), Spain (Pereira-Lorenzo et al., 2012), Iran (Najafzadeh and Arzani, 2015), and to differentiate between various wild pear species in Slovakia (Paganová, 2009) and Georgia (Asanidze et al., 2011).

The present study aims to characterize for the first time eight traditional Tunisian pear cultivars using morphological and chemical traits, in order to investigate the existing phenotypic diversity.

Materials and Methods

Plant material and fruit sampling

Based on preliminary prospection of local pear in center-eastern Tunisia (data being published), eight cultivars (Table 1) were selected for pomological and biochemical fruit analysis. These cultivars were grown in family orchards and home gardens situated in four localities (Bouficha, Sidi Bou Ali, Jammel and Menzel Fersi) characterized by typical Mediterranean climate with warm winter. Fresh fruits were harvested carefully by hand at maturity stage, picked randomly on all sides of the tree, and then immediately transferred to the laboratory in a cooler. Fruits were selected to be representative of the general characteristics of the cultivar and were free from blemishes, diseases and physical abnormalities.

Table 1. Denomination, codes and geographic coordinates of studied Tunisian pear cultivars

Cultivar	Code	Origin	Latitude	Longitude
Tourki	TRK	Menzel Fersi	35° 33' 3.3696'	10°52'13.9722"
Arbi Sidi Bou Ali	ASB	Sidi Bou Ali	35° 57' 30.7254"	10° 28' 34.284"
Meski Arteb	MTB	Sidi Khlifa	36° 14' 50.0064"	10°25'32.2854"
Soukri	SKR	Sidi Bou Ali	35° 57' 30.7254"	10° 28' 34.284"
Arbi Chiheb	AR2J	Jammel	35° 37' 19.3368"	10°46'18.4908"
Jrani	JRN	Jammel	35° 37' 19.3368"	10°46'18.4908"
Radsi	RDS	Sidi Khlifa	36° 14' 50.0064"	10°25'32.2854"
Arbi Bouficha	ABF	Bou Ficha	36° 17' 56.526"	10°27'13.3416"

Determination of pomological parameters

For each cultivar, pomological characterization was performed on a sample of 20 fruits according to IBPGR (1983) and UPOV (2000). A total of 16 phenotypic characteristics were recorded (11quantitative parameters and 5qualitative parameters). Quantitative parameters were (Table 2): fruit fresh weight (FW, g) by an analytical balance with a sensitivity of 0.01 mg, fruit length (FL, mm), maximum diameter (MD, mm), stalk length (SL, mm), stalk thickness (ST, mm), depth of stylar cavity (DS, mm), thickness of the mesocarp (TM, mm), diameter of the outer limit of the carpel (DC, mm) using a digital caliper with a sensitivity of 0.001 mm, total number of seeds (TS), number of empty (aborted) seeds (ES). Also, the fruit firmness (FF, kg/cm2), on opposite fruit sides at the maximum diameter using fruit texture analyzer (ES- 92830 Garches).

To measure the qualitative characteristics which are: density of lenticels (DL), fruit symmetry in longitudinal section (FS), Fruit profile from sides (FP), position of maximum diameter (PD), we attribute character states used as descriptors according to UPOV (2000). For the position of maximum

diameter (PD): (1) in middle, (2) slightly towards calyx, (3) clearly towards calyx. For the profile of sides (FP): (1) concave, (2) straight, (3) convex. For the symmetry in longitudinal section (FS): (1) symmetric, (2) slightly asymmetric, (3) strongly asymmetric and for the density of lenticels (DL): (2) few, (4) medium, (6) many.

Fruit skin color was measured using a colorimeter (Chroma Meter CR-400, Minolta, Japan) based on Hunter System L*, a*, b* (CIELAB) and the measurements were made on both sides of the fruit (the sun exposed and shaded side). The CIELAB color scale is organized in a cube form. The L* axis runs from top to bottom, with the maximum 100, which represents a perfect reflecting diffuser. Lower L* values (with a minimum could be zero) indicate darkness while higher L* values indicate lightness. The a* value measures redness when positive and greenness when negative, whereas the b*value measures yellowness when positive and blueness when negative. The chroma value C, calculated as [C = (a*2 + b*2) 1/2], indicates color intensity saturation. The hue angle H° is a parameter that has been shown to be effective in predicting visual color appearance, was calculated using the formula [H = tan−1 (b*/a*)], where 0° or 360°= red-purple, 90°= yellow, 180°= bluish-green, and 270°= blue (McDonald et al., 1993).

Determination of biochemical parameters

The biochemical characterization was carried out in the two separate tissues (peel and flesh) of fruits. Each pear was peeled and cored manually and then the flesh was divided into eight equal portions, of which two opposite quarters were used. For each cultivar, flesh and peel were ground in liquid nitrogen and stored at -80°C until analysis. Total Soluble Solids (TSS) were determined with a digital refractometer (PR-101 ATAGO, Norfolk, VA, USA) and expressed in °Brix at 20°C. Titratable acidity (TA) was determined by titration up to pH 8.1 with 0.1 mol/L NaOH and expressed in mmol H+ kg-1 fresh weight (FW) using an auto titrator (Methrom, Herisau, Switzerland). Sugars (total sugars, glucose, fructose and sucrose) and organic acids (malic acid and citric acid) were quantified using colorimetric-enzymatic methods (Boehringer Mannheim Co., Mannhein, Germany) and expressed in g kg-1 FW. These measurements were performed with a SAFAS flx-Xenius XM spectrofluorimeter (SAFAS, Monaco).

Data analysis

The means of different fruit characteristics values are given as mean ± standard deviation (SD). Analysis of variance (ANOVA) followed by Duncan's multiple range test were performed using SPSS (Statistical Package for the Social Sciences) Version 18.0. The significance level was set to $P < 0.05$. Pearson's correlation test was carried out using XLSTAT 2016 in order to determine whether there were any significant relationship between morphological and biochemical traits. Statistical significance was given at $P<0.05$.

Results and discussion

Quantitative fruit traits

Fruit morphometric characterization revealed a large variability, and high levels of variation were found. The average values for fruit characteristics were statistically different at $P \leq 0.01$ (Table 2). Number of empty seeds (EM) had the highest coefficient of variation (CV) among all studied traits (51.07 %). The number of total seeds (TS) and the depth of stylar cavity also presented high CV, 44.24% and 43.41%, respectively. The lowest coefficient of variation was observed for fruit length (12.67%). Similar studies

have shown high morphological variation in pear (Pereira-Lorenzo et al., 2012; Selamovska et al., 2015).

Fruit weight (FW) varied in the range of 22.63 - 63.72 g (Table 2). The highest values were observed in 'Arbi Sidi Bou Ali' (63.72 g) and 'Arbi Bouficha' (54.76 g) that were classified as relatively large fruits (> 54 g), while the lowest values were observed in 'Radsi' (22.63 g) considered as small fruit (< 23 g). The cultivars 'Arbi Chiheb', 'Soukri' and 'Jrani' have similar average fruit weight, respectively, 39.01 g, 39.82 g and 40.1 g. They are considered as medium fruits (39-49 g). Similar values were reported for cultivars grown in North Turkey (Bostan, 2009). According to Flaishman et al. (2001) fruit weight becomes extremely important factor for both marketing and economic benefits since consumers prefer large pears.

'Arbi Sidi Bou Ali' and 'Arbi Bouficha' cultivars presented the largest values for fruit length (FL) and fruit maximum diameter (MD), whereas 'Radsi' tended to have the smallest values for both parameters. Fruit length (FL) ranged from 41.88 to 52.94 mm and fruit maximum diameter (MD) varied from 33.41 mm to 49 mm. For a set of Iranian pear cultivars, Najafzadeh and Arzani (2015) have determined that fruit length ranged from 69.9mm to 98.2 mm and fruit maximum diameter was between 46.9 and 71.7mm, which make them bigger compared to Tunisian pears.

'Arbi Chiheb' and 'Jrani' cultivars have the longest fruit stalk (SL), correspondingly, 42.54 mm and 40.73 mm, which makes the harvest of the fruit easy and maintains the fruit's integrity. 'Soukri' has the shortest stalk (22.32 mm) but the wide stalk thickness (ST) (3.32 mm). According to Ait Said et al. (2013) means of stalk length and width of endemic Moroccan pear were about 24.59 mm and 2.12 mm, respectively.

The diameter of the outer limit of the carpel (DC) varied from 10.62 mm for 'Radsi' to 18.03 mm for 'Arbi Sidi Bou Ali'. The later have shown the largest thickness of mesocarp (TM) (13.57 mm) and longest depth of stylar cavity (DS) (5.38 mm). Bostan (2009) reported that average depth of stylar cavity (DS) was 4.95 mm among Turkish pear cultivars. The lowest thickness of mesocarp (TM) was noted in Jrani and Radsi (Table2). Indeed TM varied between 11.07 and 18.07 mm. It has been proven that variations in sizes may be due to differences in cell density per unit area which varies according genotypes (Paulus and Schrevens, 1999).

The mean number of total seeds (TS) and mean number of empty seeds (ES) per fruit varied considerably between cultivars, as can be seen by their respective coefficients of variation (43.41% and 51.07%). 'Soukri' presented the highest value of total seeds per fruit (10.35) of which over 7 seeds were empty or aborted. However, 'Jrani' and 'Arbi Chiheb' have shown the lowest values, respectively, 2.84 and 3.81 seeds per fruit, of which 2.64 and 3.44 were empty seeds. In a study performed on local pear grown in Gumushane (Turkey), the number of seeds ranged from2.76 to 8.06 (Kalkisim et al., 2018). Kratovalieva et al. (2014) noted that the average number of seeds in pear landraces was 2.5 healthy seeds per fruit. The relatively low seed number for 'Jrani' and 'Arbi Chiheb' (0.20 and 0.38 seed/fruit) could be related to their ploidy level since they are triploids as revealed by molecular fingerprints (data being published). These results are similar to those presented by Phillips et al. (2016) on triploid pear cytotypes. In theory, triploids are highly infertile. However, limited fertility and seed production could result from the formation of apomictic embryos or through the union of aneuploid or unreduced gametes (Ramsey and Schemske, 1998; Phillips et al., 2016).

As reported in Table 2, fruit firmness (FF) ranged between 2.78 kg/cm2 and 4.78 kg/cm2. 'Tourki' and 'Jrani' had firmer fruits than the other cultivars. However, 'Radsi' fruits showed relatively low firmness

value. Pereira-Lorenzo et al. (2012) have observed the fruit firmness of local Spanish pears in the range of 3.66 to 8.45kg/cm2. In a similar study, fruit firmness among Kashmiri pear was between 5.30 kg/cm2 and 9.79 kg/cm2 (Jan et al., 2016). These values were quite different from the present study. This suggested that fruits of Tunisian pear cultivars are not so firm but fluctuated between soft and medium. Firmness is an essential parameter in pear quality assessment as it can inform about storage capacity and resistance to manipulation during postharvest life. In general, firmer fruit can be stored longer.

Table 2. Variation of quantitative fruit traits among studied pear cultivars

Cv.	TRK	ASB	MTB	SKR	AR2J	JRN	RDS	ABF	CV%
FW	48,70±7,87c	63,72±16,14a	44,77±8cd	39,82±4,87d	39,01±5,68d	40,1±5,88d	22,63±4,59e	54,76±9,51b	33,94
FL	48,46±3,42c	52,15±6,85ab	50,69±3,45abc	49,65±4,48bc	44,22±4,45d	43,43±3,91d	41,88±4,13d	52,94±4,37a	12,67
MD	44,36±2,63b	49,00±5,63a	40,82±5,59c	42,91±2,38bc	41,96±1,89bc	42,26±3bc	33,41±2,78d	44,49±5,89b	14,02
SL	28,86±4,69de	34,55±4,39bc	31,57±5,03cd	22,32±4,33f	42,55±6,11a	40,73±6,45a	26,94±4,81e	36,14±7,71b	25,13
ST	2,62±0,39bcd	2,46±0,25d	2,81±0,34b	3,32±0.4a	2,54±0.28cd	2,79±0,35b	2,76±0,45bc	2,7±0,24bcd	15,09
DC	15,50±2,34b	18,03±2,2a	15,5±2,2b	15,29±1,61b	12,79±1,2c	13,57±1,81c	10,62 ±2,6d	13,12±2,14c	37,53
DS	4,72±0,58bcd	5,38±1,69a	4,45±0,56cd	3,92±0.51d	5,16±0,84ab	5,37±0,53a	4,45±0,57cd	4,13±0,82cd	44,24
TS	9,04±1,27b	7,24±3,6c	8,71±0,99b	10,35±0,79a	3,81±2,17d	2,84±1,72d	8,96±1,43b	9,6±2,01ab	43,41
ES	7,20±1,89ab	6,68±3,6b	6,57±2,03b	7,47±1.42ab	3,44±1,97cd	2,64±1,63d	4,76±2,44c	8,7±2,13a	51,07
FF	4,78±0,93a	3,37±0,87b	3,68±0.78b	3,54±0,57b	3,62±0,45b	4,63±0,46a	2,78±0,55c	2,94±0,56c	26,56
TM	11,93±1,62bc	13,57±3,41a	13,14±1,21ab	13,22±1,31ab	12,26±1,64abc	11,07±1,97c	11,47±1,81c	13,53±1,62a	17,68

FW: fruit weight, FL: fruit length, MD: maximum diameter, SL: Stalk length, ST: Stalk thikness, DC: diameter of the outer limit of the carpel, DS: depth of stylar cavity, TS: total seeds, ES: empty seeds, FF: fruit firmness, TM: thikness of mesocarp. CV%: coefficient of variation.

Mean values ± standard deviations. Means followed by different letter within a same row indicate significant differences according to Duncan test

Qualitative fruit traits

Large variation was observed for the qualitatively assessed traits (Figure 1). Fruit shape index as indicated by the ratio FL/MD varied from 1.03 to 1.27 with an average of 1.14 which reflected that most of analyzed cultivars presented very short to short fruit. This parameter allows a direct comparison of shape between fruits of differing size. Our cultivars mostly prone to ovate-oblong than pyriform shape, except of 'Meski Arteb' which tended to be relatively pyriform. About 45 % of sampled fruits had a ratio <1.1 giving a very short fruits, essentially cultivars 'Jrani', 'Arbi Sidi Bou Ali' and 'Tourki'. Only 'Radsi' fruits had intermediate shaped fruits. It was already demonstrated that the fruit shape in pears is a polygenic characteristic (Jianet al., 2016). Kappel et al. (1995), reported that ideal pyriform shape ratio ranged from 1.44 to 1.48. Our values were lower than those reported by these authors.

Regarding the density of lenticels, macro-pores on fruits facilitating gas exchange, we noticed that 'Radsi' and 'Arbi Bouficha' showed few ones on their fruit skin (42.51%). However, 'Tourki', 'Soukri' and 'Arbi Sidi Bou Ali' provide fruits with high density of lenticels. Fruits with moderate lenticels density were revealed only in 'Jrani'. Konarska et al. (2013) observed that the number of lenticels in Conference was 23% lower than in Clapp's Favourite, when studying the relationship between the

morphology, structure and fruit quality of these two pear cultivars during their development and maturation.

Across all cultivars, over 67% of the fruits had a concave lateral profile represented principally by 'Radsi' and 'Arbi Bouficha'. Tourki' and 'Arbi Sidi Bou Ali' were quite slight (25% of samples). Only 'Jrani'showed a convex lateral profile.

The position of maximum diameter was evenly distributed over all pear cultivars, around 'Arbi Bouficha', 'Arbi Chiheb', 'Jrani' and 'Tourki' (67.07%) had their maximum diameter slightly towards calyx. In addition, 29.34% had maximum diameter in middle illustrated in 'Arbi Sidi Bou Ali' and 'Radsi'. Only samples belonging to 'Meski Arteb' exhibited maximum diameter clearly towards calyx (6.58%).

With respect to fruit symmetry in longitudinal section, we reported that 'Arbi Sidi Bou Ali', 'Arbi Bouficha' cultivars provided symmetric fruits, followed by 'Radsi' and 'Soukri'. Very few fruits were slightly asymmetric (Figure 1). Therefore, bearing symmetric fruits in longitudinal section is a predominant characteristic among Tunisian cultivars.

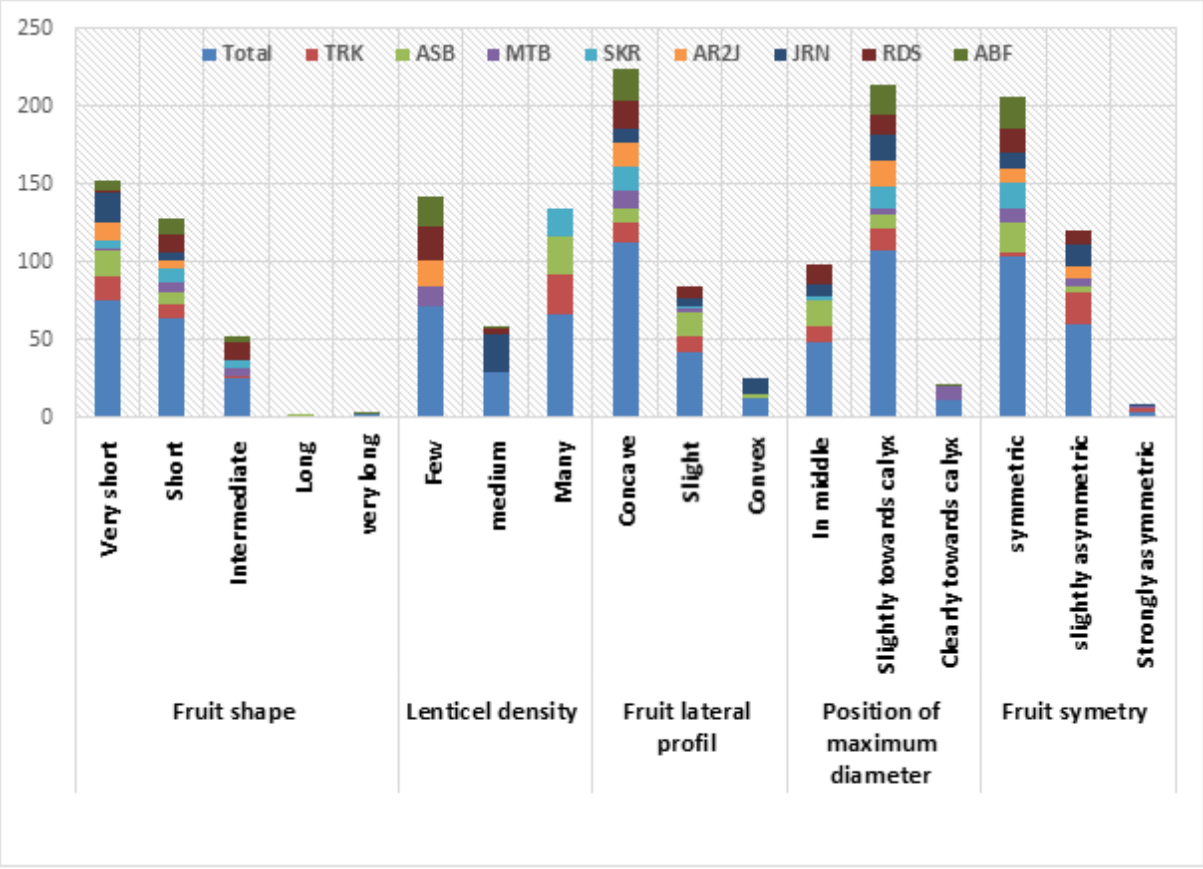

Figure 1. Frequency distribution of the studied cultivars for qualitatively measured traits

Fruit skin color parameters

Fruit skin color is a key characteristic which gives an idea about quality and maturity of fruit (Zhang et al., 2012). It consists also an important quality feature in determining consumer acceptance since the first assessment of fruit by the consumer is of a visual nature (Telias et al., 2011). In addition, peel color

is one of the main traits enabling cultivar discrimination. In the current study, phenotyping by Minolta colorimeter and measuring fruit skin color showed that color indices (C, L*, a*, b* and H°) varied significantly between cultivars, as well as between both of sun-exposed and shaded sides of the fruit (Table 3).

It appears that peel fruit color on the sun-exposed side (F1) was significantly redder than the shaded side (F2) for all studied cultivars. This result is in agreement with the result obtained by Dussie et al. (1997) in colorimetric characterization of pear cultivars. Similarly to pear, Hamadziripi et al. (2014) reported that the apple peel color difference is resulting from canopy microclimate which highly varied with both light and temperature. Our cultivars 'Radsi' and 'Soukri' showed the highest red component a* for the sun-exposed side (F1) indicating a red-blusher color, meanwhile cultivars 'Jrani', Arbi Bouficha' and 'Arbi Chiheb' showed the highest a* in the shaded side (F2). According to Honda et al. (2002), the major determinants of fruit skin reddening are the amount and the composition of anthocyanins. Their biosynthesis is mediated by a number of well-characterized enzymes that are strongly associated to genetic factors (Dondini et al., 2008) and largely affected by variation of light (Sun et al., 2014), temperature (Sivankalyani et al., 2016) and other environmental conditions (Castañeda-Ovando et al., 2009; Carbone et al., 2009). Recently, many studies revealed the complexity of the regulatory expression of the genes encoding these enzymes in fruit skin and investigate the molecular mechanism for red coloration in pear (Xue et al., 2017; Wang et al., 2017) as well in apple (Chen et al., 2017). Values of b* were positive for all cultivars ranging from 37.54 to 49.76 in (F1) and from 43.08 to 52.37 in (F2). Our range of values is in agreement with previous studies in pear (Ozturk et al., 2009; Najafzadeh and Arzani, 2015). L* (light component) values ranged from 57.57 to 69.16 in (F1) and from 60.47 to 73.15 in (F2). L* index was higher in 'Arbi Bouficha' and 'Meski Arteb' cultivars for both fruit faces (F1) and (F2) indicating the brightness of the whole fruit. It was low in 'Arbi Sidi Bou Ali' and 'Arbi Chiheb' cultivars. Hue values (H°) in sun-exposed face (F1) ranged from 115.94 in 'Arbi Sidi Bou Ali', which indicates a whitish color, to 79.69 in 'Radsi' which point out to intense color, and in shaded face (F2) from 115.9 also in 'Arbi Sidi Bou Ali' to 101.79 in 'Jrani'. In both of its (F1) and (F2) faces, 'Tourki' presented the highest chroma C (C*F1=53.55, C*F2=54.22), and higher b*, L* and hue angles of H° values were recorded (b*F1=49.76, b*F2=49.97; L*F1=66.96, L*F2= 65.41; H°F1=111.29, H°F2=112.74) which indicated a homogenous bright yellow saturated color of the whole fruit. On the other hand, 'Radsi' presented the largest difference in a* and b* parameters between (F1) and (F2) surfaces providing fruits with noticeable degree of bi-color which may affect consumer preference. In fact, this cultivar increased notably fruit skin pigmentation on its sunlight side (F1) than the others cultivars. These results confirmed those of Brahem et al. (2017) which indicated that the same cultivar 'Radsi' presented in its peel the highest amounts of both quercetin-3-O-galactoside and quercetin-3-O-glucoside responsible for red color pigmentation in Pomoideae (Tsao et al., 2003) compared to other studied Tunisian and European cultivars. Profiling fruit skin color of these eight cultivars revealed that the highest colored cultivar was 'Radsi' followed by 'Meski Arteb' and 'Soukri', while 'Jrani' 'Arbi Chiheb' and 'Arbi Bouficha' are less colored.

Table 3. Fruit color indices values measured on sun-exposed (F1) and shaded (F2) faces for pear cultivars

Cultivar		L*	a*	b*	C*	H°
TRK	F1	66,96±4,51ab	-19,24±2,99ef	49,76±3,7a	53,55±3,03a	111,29±3,99ab
	F2	65,41±3,51c	-20,77±2,49de	49,97±3,92b	54,22±2,93a	112,74±3,74ab
ASB	F1	60,09±2,94de	-21,75±0,87f	44,97±3,18bc	49,90±2,82bc	115,94±1,63a
	F2	60,47±3,28d	-21,99±0,69e	45,43±2,84de	50,57±2,42b	115,90±1,66a
MTB	F1	66,80± 4,45ab	-15,93±4,21de	49,49±3,05a	52,13±2,7ab	108,10±4,82b
	F2	66,25±3,21bc	-18,61±2,05c	48,22±2,11bc	51,77±1,87b	111,38±3,27bc
SKR	F1	57,57±6,38e	-2,32±12,04b	37,54±6,95d	39,25±7,77e	90,54±17,01d
	F2	67±2,46bc	-20,27±1,06d	46,86±1,71cd	51,07±1,69b	113,40±1,21ab
AR2J	F1	62,15±2,51cd	-11,42±4,83cd	42,04±1,63c	43,80±2,38d	104,92±6,04bc
	F2	62,32±2,28d	-14,51±1,36b	43,08±2,17f	45,48±2,19d	108,62±1,69cd
JRN	F1	64,78±4,56bc	-8,33±2,75c	46,35±2,36b	47,17±2,46cd	100,14±3,28c
	F2	66,89±3,04d	-9,81±2,33a	46,99±1,60cd	48,05±1,6c	101,79±2,79e
RDS	F1	61,39±11,77d	5,89±1,95a	42,65±8c	46,84±7,38cd	79,69±20,83e
	F2	73,15±5,7bc	-15,04±3,56b	52,37±3,4a	53,36±3,19a	103,34±11,19e
ABF	F1	69,16±3,22a	-12,13±4,33cd	45,85±3,51b	50,76±7,53ab	104,99±5,75bc
	F2	68,45±3,23b	-13,97±3,33b	44,77±3,84ef	47,05±3,40c	107,44±4,67d

Mean values ± standard deviations. Means followed by different letter within a same column indicate significant differences according to Duncan test.

Sugars and Total Soluble Solids

Soluble sugars were important components in pears, influencing notably their taste. The average values of fructose, glucose, sucrose, total sugar content and total soluble solids (TSS) of both peel and flesh of the studied pear cultivars are presented in Table 4. Fructose and glucose were identified as the principal monosaccharides in the pear cultivars which was consistent with the results obtained on other pear, apple and loquat varieties in previous studies (Hussain et al., 2015;Yim and Nam, 2016).A large variability was observed in the set of cultivars examined, and significant differences among them were found(Table 4).Sugar analyzes showed significant variation of fructose and sucrose contents depending on part of fruit (flesh or peel) and obtained values were higher in the flesh which is in accordance with previous studies on other pear cultivars (Öztürk et al., 2015).Nevertheless, for glucose there was no difference between flesh and peel for all cultivars. Total sugar content present in the flesh ranged from 4.57 to 8.92 g /100 g FW, while in the peel, it varied from 3.27 to 6.64 g/100 g FW which represented between 36 and 46% of the total sugars of the fruit.

In the fruit flesh, fructose varied from 1.30 g/100 g FW in ‘Arbi Chiheb’ to 5.01 g/100 g FW in ‘Arbi Bouficha’. Glucose varied from 0.73 g/100 g FW for ‘Soukri’ to 2.35 g/100 g FW in ‘Arbi Bouficha’, and sucrose varied from 1.60 to 2.22 g/100 g FW, respectively, in ‘Tourki’ and ‘Jrani’. Chen et al. (2007) reported similar results for six commercial pear cultivars grown in China for fructose and glucose contents, while sucrose amounts were quite lower than in our results (0.21-1.03 g/ 100 g FW). Interestingly, sucrose was the major sugar in the cultivar ‘Arbi Chiheb’ (1.95 g / 100 g FW). Flesh total

sugar concentration means ranged from 4.57 g/100 g FW in‘Arbi Chiheb’to 8.92g/100 g FW in ‘Arbi Bouficha’.

In the fruit peel, ‘Soukri’ had the lowest amount of fructose (1.75 g/100 g FW), glucose (0.82 g/100 g FW) and total sugar (3.27 g/100 g FW), while ‘Arbi Bouficha’ showed the highest content of fructose (3.70 g/100 g FW) and total sugar (6.61 g/100 g FW). The highest glucose amount was found in ‘Jrani’ (2.08 g/100 g FW) followed by ‘Arbi Bouficha’ (2.04 g/100 g FW) and ‘Tourki’ (1.25 g/100 g FW). Sucrose content varied between 0.64 and 1.68g/100 g FW. ‘Radsi’ presented the highest value and ‘Arbi Chiheb’ the lowest one.

It was found that total soluble solids (TSS) in the flesh was higher than in the peel for all cultivars as reported in other pear cultivars by Öztürk et al. (2015). TSS varied in the range of 12.0-19.1°Brix in peel and flesh (Table 4). Đurić et al. (2015) reported similar results among Bosnian and Herzegovinian pears. The cultivar ‘Arbi Bouficha’ showed the highest values both in flesh and peel (respectively 19.1°Brix and 17.1°Brix) which may be due to its higher total sugar content. However, ‘Soukri’ had the lowest TSS in fruit flesh and peel, respectively 14.6°Brix and 12.0°Brix. Compared to results reported in other European and Asian pears (Hussain et al., 2015; Jan et al., 2016), Tunisian cultivars exhibited relatively higher TSS values.

Table 4. Total Soluble Solids (°Brix) and sugar composition of different pear cultivar fruits (g/100 g of fresh weight)

	Fructose		**Glucose**		**Sucrose**		**Total sugar**		**Total Soluble Solids**	
	Flesh	**Peel**	**Flesh**	**Peel**	**Flesh**	**Peel**	**Flesh**	**Peel**	**Flesh**	**Peel**
TRK	3,72±0,18bc	2,62±0,18bc	1,54±0,10b	1,25±0,09b	1,60±0,27d	0,93±0,11bc	6,85±0,17c	4,80±0,23b	16,9±0,22b	15,47±0,9abc
ASB	2,44±0,29d	2,27±0,12cd	1,18±0,16c	1,19±0,14b	1,77±0,14cd	0,71±0,06bc	5,39±0,37de	4,17±0,10bc	14,63±0,53d	13,7±0,49cd
MTB	3,71±0,04bc	3,03±0,42b	1,14±0,13c	1,13±0,09b	2,19±0,12ab	1,56±0,14a	7,04±0,27bc	5,73±0,62a	15,47±0,52cd	14,5±0,83bc
SKR	3,08±0,14cd	1,75±0,22d	0,73±0,02c	0,82±0,15c	1,97±0,06abc	0,70±0,13bc	5,77±0,17d	3,27±0,49c	14,63±0,37d	12±1,02d
AR2J	1,30±0,27e	2,16±0,15cd	1,32±0,09d	1,11±0,11b	1,95±0,21abcd	0,64±0,03c	4,57±0,57e	3,90±0,26bc	16,23±0,47bc	13,7±1,27cd
JRN	4,25±0,79ab	3,57±0,06a	1,49±0,06b	2,08±0,11a	2,22±0,16a	0,98±0,09b	7,96±0,88ab	6,64±0,17a	17,03±0,46b	16,43±1,25ab
RDS	4,87±0,36a	3,68±0,39a	1,35±0,20bc	1,11±0,17b	2,02±0,03abc	1,68±0,28a	8,25±0,27a	6,47±0,81a	14,9±0,94d	15,4±1,61abc
ABF	5,01±0,41a	3,70±0,16a	2,35±0,08a	2,04±0,08a	1,85±0,13bcd	0,87±0,01bc	8,92±0,45a	6,61±0,25a	19,07±0,85a	17,07±0,68a

Mean values ± standard deviations. Means followed by different letter within a same column indicate significant differences according to Duncun test.

Titratable acidity and organic acids

Organic acids are important components for fruit taste, and impact on the overall organoleptic quality of pear (Chen et al., 2006). The titratable acidity (TA) values of studied cultivars ranged from 2.35 to 5.22 meq/100 g FW in the flesh and from 1.41 to 4.68 meq /100 g FW in the peel (Figure 2). It is noteworthy that acidity in the peel was lower compared to the flesh for all cultivars which is not in agreement with previous findings (Öztürk et al., 2015) reported that TA was consistently higher in the peel than in the flesh. The cultivar ‘Arbi Sidi Bou Ali’ has the highest acidity in the flesh (5.22 meq/100 g FW) which is almost twice of that in the peel (2.46 meq/100 g FW). However, ‘Meski Arteb’ has comparable and also higher acidity in both peel and flesh fruit (4.83meq/100 g FW and 4.68meq/100 g

FW). On the other hand, 'ArbiBouficha' produced fruits with low acidity in both flesh and peel (Figure 2) and had an excellent gustative quality.

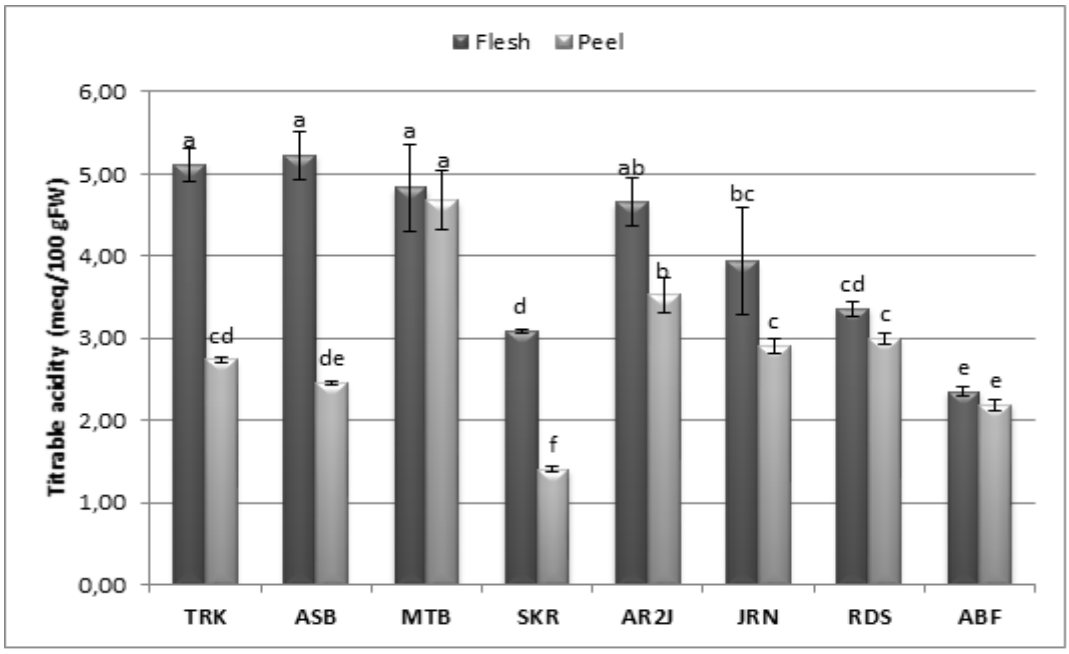

Figure 2. Titrable acidity in fruit flesh and peel of eight pear cultivars

Consistent with the literature and previous data (Đurić et al., 2015), the characterization of organic acid components in the studied cultivars revealed that malic acid and citric acid are the two predominant organic acids. Significant differences were recorded between the cultivars and between the two parts of the fruit (peel and flesh) for malic acid content that was, generally, the predominant acid in local pears. Its concentration was very high in the cultivar 'Arbi Chiheb' (0.36 and 0.25 g/ 100g FW, respectively in the flesh and the peel) (Figure 3). Regarding citric acid, obtained values ranged from 0.06 to 0.24 g/100 g FW in flesh and from 0.06 to 0.11g/100 g FW in the peel. These values were in agreement with previous results of Yim and Nam (2016) for Pyrus pyrifolia, and P. communis varieties Jules d'Airolles and Abate Fetel. Citric acid is more concentrated in the flesh for the studied cultivars, except of 'Arbi Chiheb' and 'Radsi'. Cultivars 'Tourki' and 'Arbi Sidi Bou Ali' had the highest citric acid levels with the flesh contents about 2 times that in the peel.

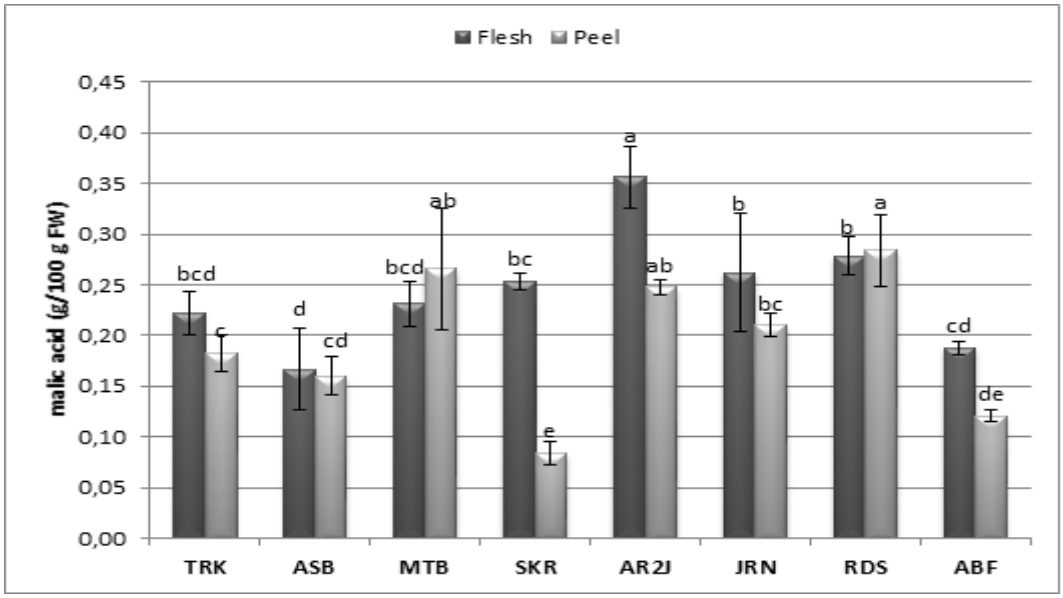

Figure 3. Content of malic acid in fruit flesh and peel of different pear cultivars

Correlations among fruit characteristics

All morphological and biochemical parameters were included in the correlation analysis (Table 5). Highly significant correlations ($p< 0.05$) were found among some pomological traits related to the fruit quality and chemical traits. It was obvious that fruit weight (FW) was highly correlated with fruit diameter (FD) (r=0.95), fruit length (FL) (r=0.81) and diameter of the outer limit of the carpel (DC) (r=0.95), that are also associated with each other. Therefore, these parameters can be used to predict each other. In addition, fruit weight (FW) was correlated to citric acid amount in the flesh (r=0.79). These relationships have been reported also by other authors (Rana et al., 2015; Najafzadeh and Arzani, 2015). Negative correlation (r=-0.78) between stalk thickness (ST) and titratable acidity in the flesh indicated that pears with large stalk have less acidity in their flesh. Results showed also that diameter of the carpel outer limit (DC) was significantly associated with the thickness of mesocarp (TM) (r=0.79) and the citric acid amounts in the flesh (CA1) (r=0.77), but negatively associated with malic acid (MA1) in the flesh (r=-0.78). So, it is possible to infer that fruits with large outer limit of the carpel provide thick mesocarp with more citric acid and less malic acid amounts.

Fruit firmness (FF) was correlated with the total soluble solids in fruit flesh (TSS1) (r=0.86) which means that pear cultivars with high TSS are somehow firmer than other pear fruits. It was found also that total soluble solids in fruit peel (TSS2) was negatively correlated with the thickness of mesocarp (TM) (r=-0.79), but highly correlated with glucose in the flesh (GL1) (r=0.89), glucose in the peel (GL2) (r=0.78), fructose in the peel (FR2) (r=0.87).

Significant correlations were obtained between fruit skin color indices and some of biochemical traits (Figure 4). In fact, the red color content (a*F1) on the sun-exposed face of pear fruit was negatively correlated with flesh titratable acidity(TA1) as well with citric acid (CA1) in the flesh. Sunlight and specifically an increase in the temperature load of the fruit, leads to a corresponding decrease in overall fruit acidity (Sweetman et al., 2014). Nevertheless, (a*F2) on the shaded face showed a positive correlation with glucose amount in the fruit peel (r=0.70). In addition, yellow color values (b*F2) were correlated with sucrose in peel as well with the fructose and total sugar in the flesh (r=0.89, r=0.82). Similar results was reported by Ozturk et al. (2009) indicated that b* component correlated significantly with sugar increase in pear fruits. Light component (L*F2), showed a high correlation with fructose and total sugars in the flesh. In general, color variables have been recommended for prediction of both chemical and quality changes in fruits (Lozano and Ibarz, 1997).

Table 5. Correlation matrix among studied variables

	FW	FL	FD	SL	ST	DC	DS	FF	TM	AT1	GL1	FR1	CA1	SG1	TSS2	FR2	SC2	CA2	SG2	L^*_{F1}	a^*_{F1}	L^*_{F2}	a^*_{F2}
FL	**0,81**	**1,00**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FD	**0,95**	0,72	**1,00**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DC	**0,95**	**0,94**	**0,90**	-0,08	-0,08	**1,00**		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	0,44	-0,15	0,43	**0,87**	**-0,80**	0,14	**1,00**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS	-0,03	0,48	-0,13	**-0,95**	0,46	0,22	**-0,82**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ES	0,43	**0,81**	0,34	**-0,77**	0,29	0,64	-0,58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TM	0,68	**0,91**	0,63	-0,22	0,12	**0,79**	-0,19	-0,24	**1,00**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TSS1	-0,03	-0,38	0,06	0,55	-0,31	-0,18	0,45	**0,86**	-0,57	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT1	0,75	0,48	0,61	0,44	**-0,78**	0,58	0,57	0,35	0,34	**1,00**	-	-	-	-	-	-	-	-	-	-	-	-	-
CA1	**0,79**	0,72	0,65	-0,17	-0,40	**0,77**	0,17	0,34	0,43	0,75	0,17	-0,06	**1,00**	-	-	-	-	-	-	-	-	-	-
MA1	-0,69	-0,73	-0,54	0,35	0,08	**-0,78**	-0,05	-0,11	-0,46	-0,38	0,11	-0,25	**-0,79**	-	-	-	-	-	-	-	-	-	-
SG1	-0,49	-0,43	-0,60	-0,23	0,16	-0,44	-0,15	0,13	-0,67	-0,35	0,41	**0,98**	-0,14	**1,00**	-	-	-	-	-	-	-	-	-
TSS2	-0,22	-0,53	-0,31	0,36	-0,43	-0,37	0,44	0,45	**-0,79**	0,16	**0,89**	0,62	0,04	0,75	**1,00**	-	-	-	-	-	-	-	-
GL2	0,03	-0,40	0,07	0,61	-0,26	-0,12	0,66	0,60	-0,59	0,09	0,65	0,34	-0,09	0,49	**0,78**	-	-	-	-	-	-	-	-
FR2	-0,48	-0,59	-0,62	0,16	-0,19	-0,55	0,18	0,04	-0,75	-0,15	0,62	**0,79**	-0,23	**0,90**	**0,87**	**1,00**	-	-	-	-	-	-	-
SC2	-0,53	-0,27	-0,75	-0,28	0,05	-0,46	-0,33	-0,32	-0,36	-0,20	0,20	**0,76**	-0,16	**0,77**	0,48	**0,78**	**1,00**	-	-	-	-	-	-
SG2	-0,43	-0,53	-0,57	0,18	-0,17	-0,49	0,19	0,11	-0,71	-0,12	0,61	**0,79**	-0,21	**0,90**	**0,88**	**0,99**	**0,77**	0,11	**1,00**	-	-	-	-
a^*_{F1}	**-0,90**	-0,68	**-0,83**	-0,35	0,55	**-0,80**	-0,49	-0,48	-0,51	**-0,93**	-0,20	0,45	**-0,80**	0,43	0,00	0,34	0,39	-0,57	0,28	-0,43	**1,00**	-	-
b^*_{F1}	0,35	0,19	0,16	0,26	-0,53	0,26	0,35	0,55	-0,13	0,71	0,65	0,29	0,60	0,37	0,68	0,46	0,36	0,72	0,50	**0,92**	-0,62	-	-
L^*_{F2}	**-0,85**	-0,57	**-0,89**	-0,50	0,46	-0,72	-0,56	-0,26	-0,62	-0,73	0,05	**0,83**	-0,48	**0,80**	0,35	0,64	0,75	-0,14	0,60	0,03	**0,83**	**1,00**	-
a^*_{F2}	-0,59	**-0,84**	-0,49	0,58	-0,04	-0,71	0,35	0,16	**-0,77**	-0,36	0,46	0,25	-0,74	0,42	0,58	0,62	0,20	-0,57	0,62	0,20	0,46	0,35	**1,00**
b^*_{F2}	-0,47	-0,24	-0,61	-0,63	0,18	-0,36	-0,47	-0,10	-0,47	-0,31	0,24	**0,89**	0,10	**0,82**	0,47	0,62	**0,77**	0,29	0,59	0,27	0,43	**0,82**	-0,04

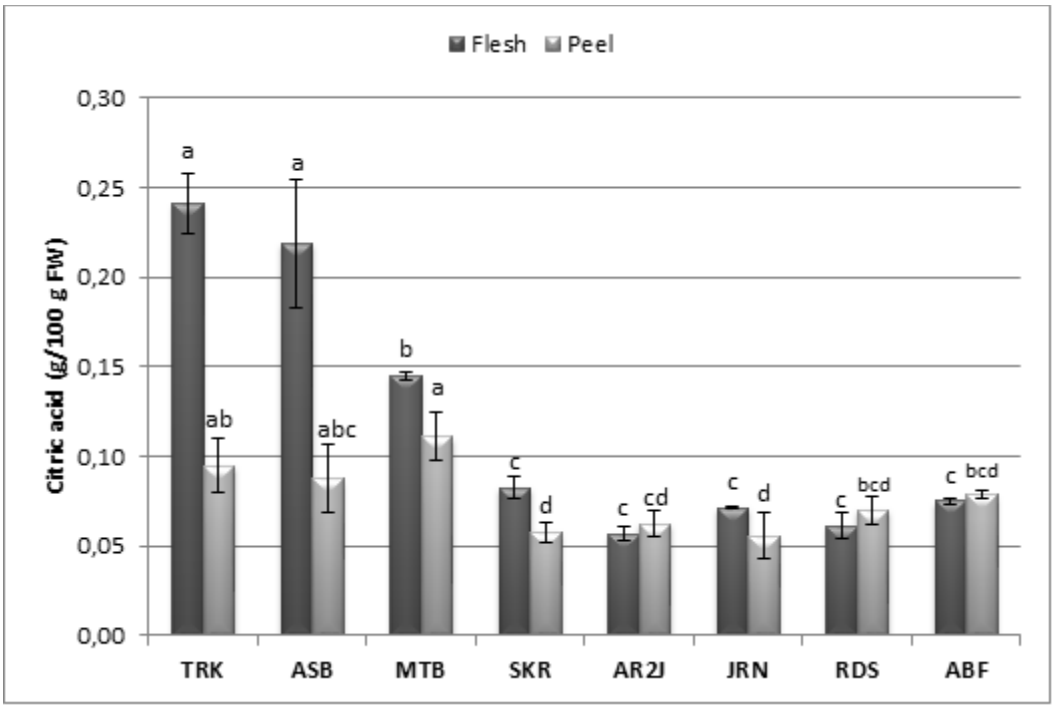

Figure 4. Citric acid content in fruit flesh and peel of different pear cultivars

Conclusion

The study showed the importance of morphological and biochemical traits to the divergence and the genetic variation within the autochthonous pear cultivars. The phenotypic diversity evidence the richness of the local pear germplasm. Compared to other European pear, Tunisian pear cultivars produced mostly small sized fruits, but they exhibited high TSS and total sugars contents which guarantee a good taste. Fruit flesh was richer in sugars and organic acids compared to peel for all cultivars. According to important fruit characteristics, we can identify 'Arbi Bouficha' as one of the best pear cultivars, mainly because of high soluble solids and relatively pyriform fruit shape. 'Radsi' also remains very interesting cultivar with its remarkably bicolored skin and high fructose amounts in both flesh and peel. The obtained results provided us a basic data to effectively characterize those old cultivars and promise new traits of interest that would be beneficial to pear breeding programs.

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