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Phenotypic diversity among apricot (*Prunus armeniaca* L.) cultivars growing in west central Tunisia

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ABSTRACT

Purpose: Apricot production extends from the north to the south of Tunisia with many cultivars adapted to different local microclimates. This large extension of apricot is associated with an important genetic diversity, which is threatened to erosion. This study aims to select cultivars with enhanced antioxidant capacity that will benefit consumers with health-promoting properties. **Research Method:** This study was conducted over three growing seasons (2016-2018) in flesh fruits nine apricot cultivars (‘Amor Leuch’, ‘Bakour’, ‘Búlida’, ‘Bayoudhi’, ‘Canino’, ‘Khit eloued’, ‘Khad hlima’, ‘Sayeb’ and ‘Wardi’). The experiment was established in private apricot orchard in the region of Hajeb Laayoun- Kairouan, west central Tunisia. **Findings:** Results showed that the fruit firmness ranged from 20.4 N in the cultivar ‘Sayeb’ to 32.5 N in the cultivar ‘Canino’. The soluble solids content varied from 10.2 °Brix in the cv. ‘Bakour’ to 15.0 °Brix in the cultivar ‘Bayoudhi’. A wide range of variability was found among the apricot cultivars with regard to the phenolic compounds content [32.7-71.5 mg GAE/100 g FW]. The cultivar ‘Khad Hlima’ presented the highest value of relative antioxidant capacity (366.8 µg Trolox Equivalents/g FW). Our study permits to select the cv. ‘Bakour’ with the needed precocity, the cv. ‘Canino’ with high firmness, the cv. ‘Bayoudhi’ with the highest SSC and the cv. ‘Khad Hlima’ with high nutritional quality. **Research limitations**: No limitations were found. **Originality/Value:** This study represents a valuable source of genotypes to be used in apricot breeding programs.

INTRODUCTION

Apricot, (*Prunus armeniaca* L.), is a stone-fruit species that is grown worldwide in all temperate regions. Apricot cultivars are divided into four eco-geographical groups: Central Asian, Irano-Caucasian, European, and Dzhungar-Zailing (Lopes et al., 2002) with the Central Asian group are the oldest one. Apricot production is around 3.7 million tons in a harvested area of around 562475 ha in 2020 (FAOSTAT, 2022). Apricot is an important fruit tree species in Tunisia, the production is around 38000 tons in a harvested area of around 7336 ha in 2020 (FAOSTAT, 2022). However due to the adaptation factors, a strong interaction exists between cultivar and area of cultivation (Krichen et al., 2009). Recent surveys performed in the main areas, lead to the identification of 112 accessions; 76 grafted ones issued for the northern, central and southeastern areas, and 36 seed-propagated ones called "Bargougs" encountered in the oasian areas (Krichen et al., 2009). The Kairouan region is characterized by the great wealth of biodiversity as a source of apricot germplasm, and hence the abundance of different genotypes. In this zone the production is around 12400 tons (45% of the national production) in a harvested area of around 3270 ha.

Apricot is considered one of the most delicious temperate tree fruits with good balance of sugars, acids, fiber, minerals and aroma (Lo Bianco et al., 2010). Besides its delicious taste, excellent flavor and attractive colors, apricot fruits are rich in antioxidants (Hegedús et al., 2010). Fratianni et al. (2022) reported that apricots contain many secondary metabolites, such as phenolic compounds, carotenoids, in particular β-carotene, and ascorbic acid. Apricot fruits show a presence of magnesium, calcium, iron, zinc, and copper in larger quantities (Singh et al., 2014). The people also use it after drying and, due to better rheological and aroma characteristics, process it into jam and fruit juice (Pinar et al., 2013).

The main objective of this work was to evaluate, the existing phenotypic diversity of agronomic and biochemical fruit quality traits among apricot cultivars. The determination of fruit quality attributes of some promising apricot cultivars is important for future breeding programs and consumer acceptance.

MATERIALS AND METHODS

Plant material and experimental design

The study was conducted in a 20-year-old irrigated apricot orchard located in the region of Hajeb Laayoun - Kairouan in west central Tunisia, during three growing seasons (2016-2018). The climate of the study area is typically Mediterranean with irregular rainfall and long dry summer period. The trial was designed as a complete randomized block design with three replications. Each treatment consisted of ten trees. Twenty fruits were considered for each cultivar and served for agronomical and biochemical fruit quality determinations. This study was designed with nine apricot cultivars: 'Amor Leuch', 'Bakour', 'Búlida', 'Bayoudhi', 'Canino', 'Khit eloued', 'Khad hlima', 'Sayeb' and 'Wardi' with the pomological characteristics indicated in Table 1. Trees were grown under standard conditions of irrigation, fertilization and disease control.

Table 1. Origin, size and skin and pulp colour of the studied apricot cultivars

Cultivars	Fruit size	Skin colour	Pulp colour
Amor leuch	Middle	Orange	Yellow
Bakour	Small	Yellow	Yellow
Búlida	Middle	Yellow	Yellow
Bayoudhi	Middle	White	White
Canino	Middle	Yellow	Yellow
Chechi Khit eloued	Middle	Yellow	Yellow
Khad Hlima	Middle	Yellow	White
Sayeb	Small	Yellow	Yellow
Wardi	Small	Orange	Yellow

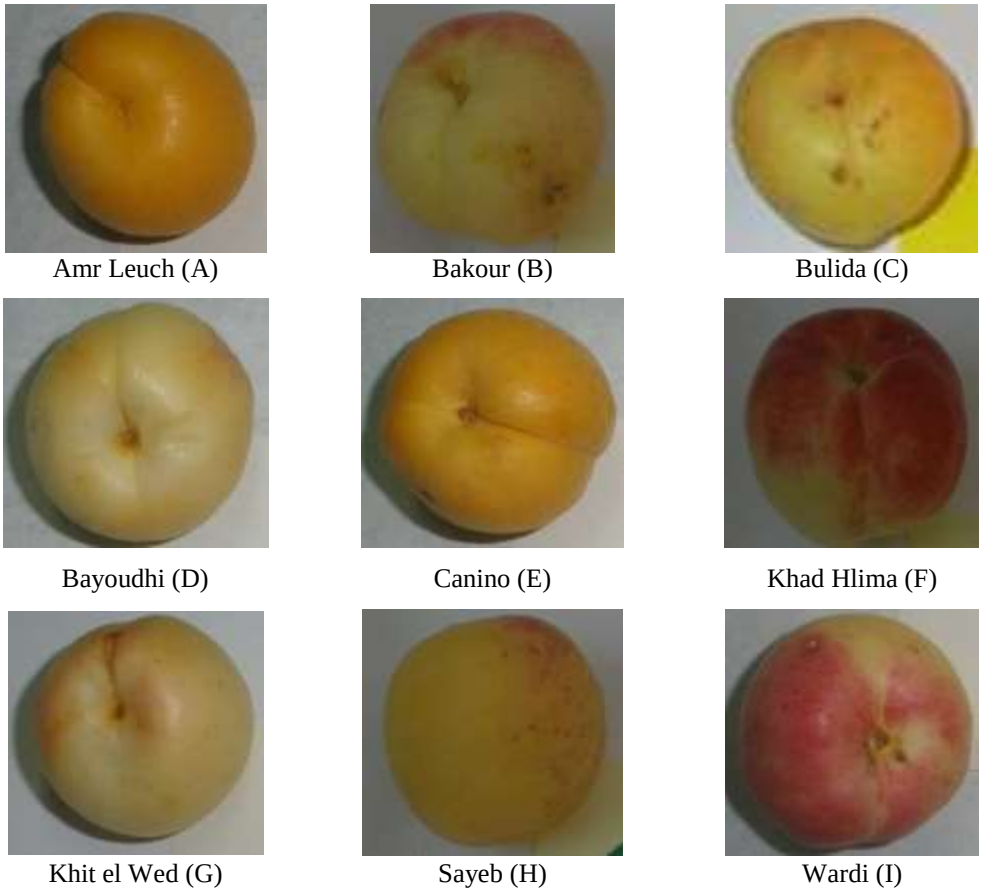

Fig. 1. Apricot studied cultivars: A= Amr Leuch, B= Bakour, C= Bulida, D= Bayoudhi, E= Canino, F= Khad Hlima, G= Khit el Wed, H= Sayeb, I = Wardi**.**

Fruits (Fig. 1) were handpicked at commercial maturity and assessed by peel fruit color and flesh firmness. Fruits were considered ripe in the tree when their growth had stopped, began softening, and were easily detached.

Fruit quality attributes

At least 20 free of defects fruits were carefully hand harvested at commercial maturity stage. Ten fruits of each cultivar were randomly sampled and measured for length and width with a caliper (CD-20B, Mitutoyo Co., Japan). Fruit weight was measured immediately after harvest using an electronic analytical digital scale balance (GT 480, Ohaus, Korea) and the mean of ten fruits samples was reported in grams. Fruit firmness was measured on opposite sides of each fruit by a hand penetrometer with an 8 mm flat probe and expressed in Newton (N). Soluble solids content (SSC) was measured as ºBrix using a handheld refractometer (Atago, Tokyo, Japan). The pH measurements were performed using pHmeter (Thermo Fisher Scientific Inc., Germany). Titratable acidity (TA) of the juice was determined in ten grams of homogenized samples and diluted with 90 g of distilled water, microtitrated with 0.1 N NaOH until a pH of 8.1 and expressed as g malic acid/100 g FW. The ripening index (RI) was calculated based on the SSC/acidity ratio. Color values on the skin of apricot fruits were measured using a CR-200 Minolta Chromameter (Chuo-Ku, Osaka, Japan) in the central region on both sides of ten apricot fruits. Flesh values of L* (brightness or lightness), a* (-a* = greenness, +a* = redness), b* (-b* =blueness, +b* = yellowness), C* (chroma) and h° (lightness's angle) were determined. The colour parameters were measured using equation (1 and 2).

$$C^* = (a^{*2} + b^{*2})^{1/2} \qquad (1)$$

where: C*: chroma is the grade of quantitative difference of hue parameter with reference to grey colour).

$$h^o = (\tan^{-1} b^*/a^*) \qquad (2)$$

where h^o: Hue angle is the qualitative attribute of colour.

Phytochemical extraction

For all assays, 5 g of peeled fruit flesh from 10 representative fruits was immediately frozen in liquid nitrogen and stored at −20 ºC until analysis, except for vitamin C assay where samples were kept in 5mL of 50mL L^{-1} metaphosphoric acid for preservation of ascorbic acid. Samples were homogenized in a polytron for 2 min with 10 mL of extraction solution (0.5 mol L^{-1} HCl in 800 mL L^{-1} methanol) for phenolics and 10 mL of (50mL L^{-1} metaphosphoric) for vitamin C and processed as reported in Abidi et al. (2011).

Antioxidant determination

Anthocyanins, flavonoids, total phenolics, Vitamin C, carotenoids, and relative antioxidant capacity were evaluated with colorimetric methods and measured using a spectrophotometer (Jenway 6300) as described by (Abidi et al., 2015). The total anthocyanins content was evaluated measuring in the hydroalcoholic extract the absorbance at 535 and 700 nm. The anthocyanins concentration was calculated using the molar extinction absorptivity coefficient ε = 25,965/cm M and was expressed in mg of cyanidin 3-glucoside equivalents (C3GE) per kg FW. Total flavonoid content was determined by measuring the absorbance at 510 nm and expressed as mg catechin equivalent (CE) per 100 g FW. Total phenolic content was determined with a colorimetric method based on the chemical reduction of Folin–Ciocalteu reagent. The absorbance at 725 nm was measured and the results were expressed as mg gallic acid equivalent (GAE) per 100 g FW. Vitamin C was measured at 525 nm and expressed as mg ascorbic acid (AsA) per 100 g fresh weight (FW). For the carotenoid content, the extract was diluted with acetone-hexane (4:6), and measured at the absorbances 663, 645, 505 and

453 nm on a spectrophotometer (Jenway 6300). The content of β-carotene was estimated using the equation 3:

β-caroten (mg/100ml) = 0.216×A663 – 1.22×A645 – 0.305×A505 + 0.452×A453 (3)

where A663, A645, A505 and A453 are the absorbance at 663, 645, 505 and 453 nm.
The total β-carotene content was expressed as mg of β-carotene per 100g of dried weight (mg β-carotene /100g FW). Relative antioxidant capacity (RAC) was determined using DPPH (2,2-diphenyl-1-picrylhydrazyl). The absorbance at 515 nm was measured after 10 min of reaction and RAC was expressed as mg Trolox (6-hydroxy-2,5,7,8- tetramethylchromane-2-carboxylic acid) equivalent (TE) kg^{-1} FW.

Statistical analysis
All traits were measured or scored for each cultivar separately. Mean values and mean standard error (SE), were calculated for each studied trait using SPSS 20.0 (SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

Fruit quality attributes
The apricot fruits were analyzed for agronomical and basic biochemical fruit quality traits. The mean values of fruit weight, pulp/stone ratio, pH, firmness, soluble solids content (SSC), pH, titratable acidity (TA) and the ripening index ratio (RI = SSC/TA) were studied in the apricot cultivars (Table 2). The fruit weight varied from 23.5 g in 'Bakour' to 41.24g in 'Khit elwed' showing statistically significant difference ($P<0.05$) among the studied cultivars. The obtained fruit weight results were comparable to a previous study of Asma and Ozturk, (2005) reporting a fruit weight in the range of [25 - 40 g]. The pulp stone ratio also showed high variability among cultivars presenting values in the range of [10.5 – 15.5]. Regarding fruit firmness, values ranged from 20.4 N in the cv. 'Sayeb' to 32.5 N in the cv. 'Canino'. According to Scandella et al. (1998) the quality standards for apricot at harvest maturity, suitable for consumers and the apricot industry, are a firmness value between 3.0 and 0.5 kg cm^{-2}, which was confirmed by the results in this study. In this line, Caliskan et al. (2012) found fruit firmness values between 1–4.3 kg/cm^2 for early apricot cultivars. The SSC content is an important quality attribute, influencing notably the fruit taste. Nevertheless, six cultivars ('Amor Leuch', 'Bayoudhi', 'Bulida', 'Khad Hlima' and 'Wardi') showed SSC values higher than 12 °Brix. Ruiz and Egea, (2008) reported that the soluble solids content is a very important quality attribute, influencing notably the fruit taste and the apricot genotypes which have a SSC of 12 ºBrix were characterized by an excellent gustative quality. Crisosto et al. (2004) reported that in the case of cultivars with SSC <12% and TA > 0.9%, consumer acceptance was controlled by the interaction between SSC and TA rather than SSC alone. Generally, the fruit maturity stage at harvest is the principal factor affecting fruit acidity and soluble solids content (Ruiz & Egea, 2008). The TA varied from 0.65 (%) in the cv. 'Canino' to 0.93 (%) in the cv. 'Amr Leuch'. Our findings are similar to the study of Miloševic et al. (2013) studying the influence of stock on fruit physical and chemical traits of five apricot cultivars. The studied cultivars might be suitable for fresh consumption, fruit drying and transformation or using them as parents in breeding programs for the modification of precocity (cv. 'Bakour'), and SSC (cv. 'Bayoudhi'). Regarding the ripening index (RI) the values observed were lower than those obtained by Hegedűs et al. (2010).

Fruit skin colour parameters presented significant variations among cultivars (Table 3). The cultivars 'Wardi' has the most orange-colored skin (highest a* and lowest L* and hue values), whereas 'Bayoudhi' had the most white-colored skin (lowest a* and highest L* and hue values). The parameter L* of the chromameter (bright to dark) varied from 53.0 (cv. 'Wardi') to 68.7 (cv. 'Bayoudhi'). A decrease in L* value correlated well with an increase in brown pigment concentration in peach and plum pulps (Lozano & Ibarz, 1997).

This darkening was explained by carotenoid accumulation as described in Ruiz et al. (2005). The parameter b* (blue to yellow) varied from 28.9 in cv. 'Bayoudhi' to 52.5 in cv. 'Canino'. Our results are in accordance with the values observed in Piagnani et al. (2013) studying apricot varieties. Cultivars also differed in value a* of fruit ground-colour in the three growing seasons. In general, the decrease in L* and h° reflects the darkening of apricot flesh and a shift from white to orange, respectively. Ruiz et al. (2005) reported that hue angle (h°) is a suitable parameter for estimating the carotenoid content of apricots. Color values coincided with results reported by Ihns et al. (2011) reporting that the average L*, a* and b* color values (52.1-56.9, 24.3-26.7 and 44.5-50.1, respectively) in two different apricot cultivars. Also Akın et al. (2008) reported that the same parameters (L*, a* and b*) were between 52.5-62.2, 10.7-21.1 and 20.4-28.9, respectively. Closer to our results, Hegedús et al. (2010) reported values of (62.63-84.63; 60.15-72.43; 51.66-68.48) for h°, L* and C*, respectively, in fruit flesh of apricot cultivars.

Table 2. Mean and standard error (SE) of agronomical and basic biochemical fruit quality traits in apricot cultivars

Varieties	FW	P/S	Firmness	SSC	pH	TA	RI
Amor Leuch	31.90 ± 1^{b}	11.43 ± 1^{c}	23.0 ± 1^{b}	12.2 ± 1^{b}	2.9 ± 0.5^{b}	0.93 ± 0.6^{a}	13.1 ± 1^{c}
Bayoudhi	35.80 ± 2^{b}	12.70 ± 2^{b}	22.1 ± 2^{b}	15.0 ± 1^{a}	3.2 ± 0.5^{a}	0.92 ± 0.2^{a}	16.3 ± 2^{b}
Búlida	32.50 ± 2^{b}	11.20 ± 2^{c}	21.1 ± 1^{b}	13.2 ± 1^{a}	3.1 ± 0.2^{a}	0.81 ± 0.4^{b}	16.2 ± 1^{b}
Bakour	23.50 ± 2^{c}	10.50 ± 1^{c}	25.5 ± 1^{b}	10.2 ± 1^{c}	3.6 ± 0.3^{a}	0.85 ± 0.1^{b}	12.0 ± 1^{c}
Canino	40.24 ± 2^{a}	13.37 ± 2^{a}	32.5 ± 1^{a}	11.8 ± 1^{b}	2.9 ± 0.4^{b}	0.65 ± 0.6^{c}	18.1 ± 2^{a}
Khad Hlima	32.52 ± 1^{b}	12.81 ± 1^{b}	23.8 ± 3^{b}	12.5 ± 2^{b}	3.3 ± 0.2^{a}	0.73 ± 0.1^{c}	17.1 ± 1^{b}
Khit eloued	41.24 ± 2^{a}	15.50 ± 1^{a}	23.5 ± 2^{b}	13.0 ± 1^{a}	3.7 ± 0.7^{a}	0.82 ± 0.1^{b}	15.8 ± 1^{b}
Sayeb	25.35 ± 3^{c}	14.50 ± 1^{a}	20.4 ± 3^{b}	11.9 ± 1^{b}	3.2 ± 0.2^{a}	0.81 ± 0.7^{b}	14.7 ± 1^{c}
Wardi	30.50 ± 2^{c}	12.00 ± 1^{b}	24.5 ± 1^{b}	12.0 ± 2^{b}	3.5 ± 0.1^{a}	0.86 ± 0.3^{b}	13.9 ± 1^{c}

Units and abbreviations: Fruit weight (g); P/S: Pulp stone ratio; Firmness (N); N = Newtons; SSC = Soluble solids content (°Brix); TA = Titratable acidity (g malic acid/100 g FW); RI = Ripening index (SSC/TA).

Table 3. Fruit colour attributes of studied apricot cultivars

	Colour attributes				
Cultivars	*a**	*b**	*L**	*C**	*h°*
Amor leuch	20.0 b	48.3 a	63.7 b	52.27 a	23.71 c
Bakour	13.9 c	42.9 b	64.7 b	45.09 b	18.54 d
Búlida	27.5 b	46.5 b	63.1 b	54.02 a	33.87 b
Bayoudhi	11.6 c	28.9 c	68.7 a	31.14 c	22.98 c
Canino	24.6 b	52.5 a	64.9 b	57.97 a	26.83 c
khad hlima	20.0 b	42.3 b	60.7 b	46.78 b	27.07 c
Khit eloued	25.6 b	29.9 d	59.4 c	39.36 c	49.04 a
Sayeb	17.3 c	42.9 b	62.8 b	46.25 b	23.09 c
Wardi	31.1 a	37.7 c	53.0 c	48.87 b	47.25 a

Abbreviations: L*= lightness; C*= Chroma; h°= hue

Phytochemical traits

The level of vitamin C, anthocyanins, flavonoids, total phenolics and antioxidant capacity in pulp of apricot fruit showed considerable variability among cultivars (Fig. 2a-f).

Anthocyanins

Anthocyanins varied from 1.0 mg C3GE/kg FW in the cv. 'Bakour' to 4.2 mg C3GE/kg FW in the cv. 'Wardi' (Fig. 1a). The studied cultivars presented lower values of anthocyanins in fresh fruits. This is in accordance with Bureau et al. (2009) reporting that the anthocyanins are present in small amounts in apricot fruits.

Flavonoids

Flavonoids varied from 9.4 mg CE/100 g FW (cv. 'Sayeb') to 32.5 mg CE/100 g FW (cv. 'Canino') as shown in Figure 1b. In the present study, cultivars 'Canino' and 'Khit eloued' are particularly rich in flavonoids. Such results seem to reveal the importance of genotype for the production of flavonoids. Fan et al. (2017) reported that the flavonoids content of flesh fruit ranged from 12.3 to 229.9 mg RE/100 g, with the highest values being found in late-maturing varieties. Carbone et al. (2018) presented total flavonoid content (TFC) in apricot cultivars between 1.9 and 12.0 mg CE/100 g. Wani et al. (2017) found flavonoids values ranging from 12.2 to 36.2 mg/100 g in apricot genotypes.

Total phenolics

A wide range of variability was found among the apricot cultivars with regard to the phenolic compounds content (Fig. 1c). Total phenolics ranged from 38.1 (cv. 'Bayoudhi') to 71.5 mg GAE/100 g FW (cv. 'Khad Hlima'). These results are in accordance with Fan et al. (2017) reporting that total phenolics ranged from 16.6 to 124.7 mg GAE/100 g in flesh of apricot fruits. Caliskan et al. (2012) reported that the levels of total phenolics were in the range of [14.4 - 177.1 mg GAE 100 g^{-1} FW], with a mean value of 64.4 mg GAE 100 g^{-1} FW in apricot cultivars. Hegedűs et al. (2010) reported that high phenolic values may be related in the origin of cultivars, environmental conditions, length of fruit development period and maturity levels of fruits. Dragovic-Uzelac et al. (2007) reported that the phenolic compounds of apricot can change with cultivar, stage of maturity, geographical region, and fruit location on the tree. The total phenolic content in a large number of apricot cultivars grown in Hungary ranged from 12.0 to 89.0 mg GAE/100 g (Hegedus et al., 2010).

Vitamin C

The vitamin C content in the studied apricot cultivars ranged from 3.7 mg AsA/100 g FW in the cv. 'Bakour' to 9.2 mg AsA/100 g FW in the cv. 'Bayoudhi' (Fig. 1d). Hegedús et al. (2010) reported that vitamin C content ranged from 3.04 to 16.17 mg/100 g FW in apricot cultivars. Akin et al. (2008) reported vitamin C content in the range of [4.9 to 11.5 mg/100 g FW] in 11 apricot cultivars. Our results indicate that apricot is a good source of vitamin C and highlight the fact that vitamin C content is an important part of the overall evaluation of apricot fruit quality.

Carotenoids

The carotenoids content (Fig. 2e) in the fresh fruit ranged from 2.1 mg β-carotene /100g FW in the cv. 'Sayeb' to 4.4 mg β-carotene /100g FW in the cv. 'Bùlida' showing statistically significant differences between cultivars. Karatas (2022) reported that total carotenoid content of 10 wild apricot fruits was in the range of 6.15–9.93 mg/100 g, and genotypes exhibited statistically significant differences to each other. Ruiz et al. (2005) reported a total carotenoid

content between 1.5 and 16.5 mg/100 g among diverse apricot cultivars. Gecer et al. (2020) reported total carotenoid content between 1.1 and 12.5 mg/100 g in wild apricots.

Relative antioxidant capacity

The relative antioxidant capacity (RAC) presented large variability between cultivars (Fig. 1f). This parameter varied from 151.2 µg Trolox Equivalents/g FW in the cv. 'Bakour' to 366.8 µg Trolox Equivalents/g FW in the cv. **'**Khad Hlima**'**. Hegedús et al. (2010) reported that early ripening apricot cultivars from different groups and origin had smaller antioxidant potential. Several studies reported that antioxidant capacity depends on the fruit species, cultivars, origin, maturity stage, fruit development period, geographical conditions, harvest year and cultural practices (Hegedús et al., 2010; Leccese et al., 2011).

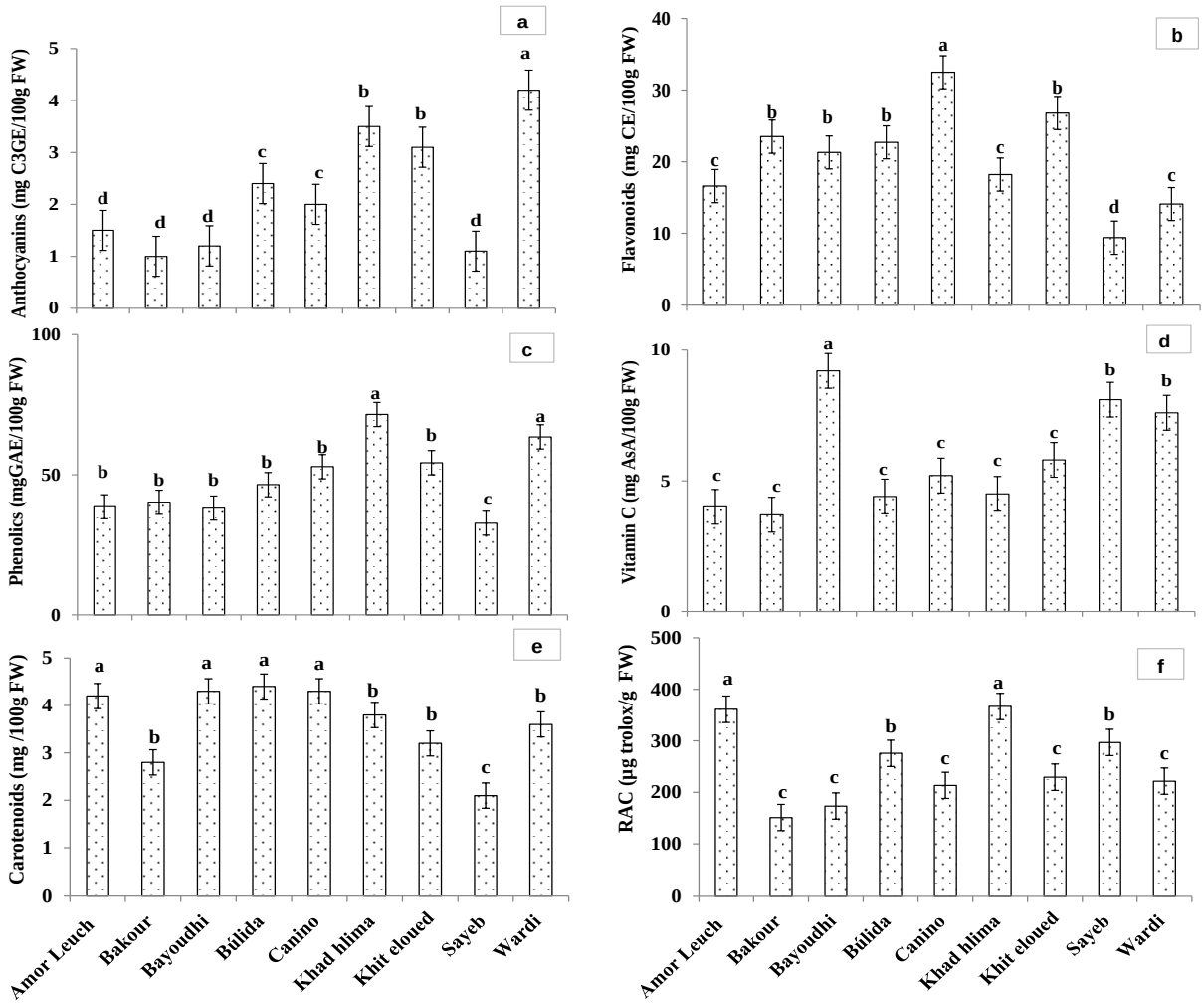

Fig. 2. Biochemical fruit quality traits in apricot cultivars

Units: Vitamin C (mg AsA/100 g FW); Anthocyanins (mg C3GE/kg FW); Flavonoids (mg CE/100 g FW); Total phenolics (mg GAE/100 g FW); RAC; Relative Antioxidant Capacity (µg Trolox Equivalents/g FW). Abbreviations: AsA = Ascorbic acid; C3GE = Cyanidin-3-glucoside equivalents; CE = catechin equivalents; GAE = gallic acid equivalents.

CONCLUSION

The present study provides a detailed data describing the agronomical and nutritional characteristics of nine diverse apricot genotypes growing in west central Tunisia. The apricot cultivars showed wide variation in fruit weight, soluble solids content, firmness, ripening index, color attributes and phenolic compounds content. The cv. 'Bakour' as early apricot cultivar is suitable for fresh consumption although of the small fruit size. The cv. 'Canino' maintained the flesh firmness which make it suitable for apricot drying and processing. The cv. 'Bayoudhi' presented high value of SSC being suitable for fresh consumption and fruit processing. The cv. 'Khad Hlima' presented high nutritional quality with attractive color attributes. Therefore, this work represents a valuable source of genotypes to be used in apricot breeding programs.

Conflict of interest
Authors declare no conflict of interest.

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