OCL 2022, 29, 9
© M. Ibourki et al., Published by EDP Sciences, 2022
https://doi.org/10.1051/ocl/2022002

OCL Oilseeds & fats Crops and Lipids

Available online at:
www.ocl-journal.org

RESEARCH ARTICLE — OPEN ACCESS

Physical fruit traits, proximate composition, fatty acid and elemental profiling of almond [*Prunus dulcis* Mill. DA Webb] kernels from ten genotypes grown in southern Morocco

Mohamed Ibourki[1,2], Hasna Ait Bouzid[1], Laila Bijla[1], Rabha Aissa[3], El Hassan Sakar[4], Tarik Ainane[5], Said Gharby[1,*] and Abdellatif El Hammadi[1]

[1] Physicochemistry Research Team, Laboratory Biotechnology, Materials and Environment (LBME), Faculty Polydisciplinary of Taroudant, Ibn Zohr University, Agadir, Morocco
[2] African Sustainable Agriculture Research Institute (ASARI), Mohammed VI Polytechnic University (UM6P), Laayoune, Morocco
[3] Bioprocesses and Environment Team, Superior School of Technology, Ibn Zohr University, Agadir, Morocco
[4] Laboratory of Applied Botany, FS, Abdelmalek Essaadi University, Tetouan, Morocco
[5] Superior School of Technology, Sultan Moulay Slimane University, Khenifra, Morocco

Received 21 October 2021 – Accepted 23 January 2022

Abstract – This study was carried out with the aim to evaluate physical fruit traits, proximate composition, elemental content, and fatty acid profiling of almond kernels from ten genotypes (sweet and bitter) grown under various agro-ecological conditions (Tafraout, Igherm, Taliouine, Tiznit and Essaouira) in southern Morocco. During the ripening stage, samples (almond kernels) belonging to these genotypes were subjected to physical fruits measurements (weight, length, width, and thickness). Proximate composition determination (crude protein, crude oil, ash and moisture) was carried out on the powder of kernels for each genotype. Carbohydrates as well as energy value were calculated. Elemental profiling of almond kernels consisted of ten macro and microelements was determined as well as the fatty acids composition of almond extracted oil. The results of this study showed wide variations among the investigated genotypes in terms of crude protein (17.14 ± 2.14 to 25.12 ± 1.23 g/100 g), oil content (51.12 ± 2.99 to 56.26 ± 3.22 g/100 g), ash content (5.11 ± 0.45 to 6.79 ± 0.52 g/100 g), moisture content (2.55 ± 0.38 to 4.34 ± 1.16 g/100 g), carbohydrates (13.34 ± 1.54 to 18.59 ± 2.22 g/100 g) and energy value (549.80 ± 37.04 to 591.03 ± 38.56 kcal/100 g DM). A similar trend was observed in the case of mineral profiling. K (9796.08 ± 793.49 to 14 197.84 ± 1150.03 mg/kg) was the major mineral in all genotypes. This was followed by P (8190.75 ± 663.46 to 11 061.68 ± 895.96 mg/kg), Ca (3067.53 ± 248.47 to 5404.93 ± 437.79 mg/kg) and Mg (4002.85 ± 324.22 to 5101.72 ± 413.23 mg/kg), while Na, Cu, Fe, Zn, Mn and B were detected in small quantities. Our results revealed six fatty acids with a dominance of oleic acid, which varied widely among the studied genotypes and extraction technique. Solvent extraction performed better in terms of oil content. The studied genotypes showed a great pomological potential that could be exploited for their fruits such as for breeding purposes.

Keywords: almond kernels / physical traits / minerals / proximate composition / fatty acids

Résumé – Caractéristiques physiques du fruit, composition approximative, profil des acides gras et des éléments minéraux de dix génotypes d'amandier [*Prunus dulcis* Mill. DA Webb] cultivés dans le sud du Maroc. Cette étude a été réalisée dans le but d'évaluer les caractéristiques physiques des fruits, la composition approximative, la teneur en éléments minéraux et le profil en acides gras des amandons de dix génotypes (douce et amer) d'amandier cultivés dans diverses conditions agro-écologiques (Tafraout, Igherm, Taliouine, Tiznit et Essaouira) dans le sud du Maroc. À maturité, des échantillons (amandons) appartenant à ces génotypes ont fait l'objet des mesures physiques des fruits (poids, longueur, largeur et épaisseur). La détermination de la composition approximative (teneur en protéines, la teneur en huile, cendres et humidité) a été effectuée sur la poudre d'amandons pour chaque génotype. Les carbohydrates

*Correspondence: s.gharby@uiz.ac.ma

ainsi que la valeur énergétique ont été calculés. Les éléments minéraux (dix macro et microéléments) d'amandons et la composition en acides gras des huiles extraites ont été déterminés. Les résultats de cette étude ont montré de grandes variations parmi les génotypes étudiés en termes de protéines brutes (17,14 ± 2,14 à 25,12 ± 1,23 g/100 g), la teneur en huile (51,12 ± 2,99 à 56,26 ± 3,22 g/100 g), la teneur en cendres (5,11 ± 0,45 à 6,79 ± 0,52 g/100 g), la teneur en humidité (2,55 ± 0,38 à 4,34 ± 1,16 g/100 g), la teneur en carbohydrates (13,34 ± 1,54 à 18,59 ± 2,22 g/100 g) et la valeur énergétique (549,80 ± 37,04 à 591,03 ± 38,56 kcal/100 g MS). Une tendance similaire a été observée la composition minérale. Le K (9796,08 ± 793,49 à 14 197,84 ± 1150,03 mg/kg) a été le principal minéral de tous les génotypes, suivi par P (8190,75 ± 663,46 à 11 061,68 ± 895,96 mg/kg), Ca (3067,53 ± 248,47 à 5404,93 ± 437,79 mg/kg) et Mg (4002,85 ± 324,22 à 5101,72 ± 413,23 mg/kg). Néanmoins, Na, Cu, Fe, Zn, Mn et B ont été détectés en petites quantités. Nos résultats ont révélé six acides gras avec une dominance d'acide oléique avec une variation considérable entre les génotypes étudiés et la technique d'extraction. L'extraction par solvant a donné de meilleurs résultats de la teneur en huile. Les génotypes étudiés ont montré un grand potentiel pomologique qui pourrait être exploité pour leurs fruits notamment à des fins de sélection.

Mots clés : amandons / caractéristiques physiques / éléments minéraux / composition approximative / acides gras

1 Introduction

Almonds [*Prunus dulcis* Mill. DA Webb] are one of the most important nut trees growing worldwide in terms of commercial production. The top producers are USA and some countries of the Mediterranean basin. Following the latest FAOSTAT's release (FAOSTAT 2021), the almond world production is around 3.5 millions of tons. Morocco is one of the potential producers with a total production of 117 270 tons coming from a harvested area estimated at 190 612 ha. The bitter almond (*Prunus amygdalus, var. amar*) is inedible because of the presence of a glycoside called amygdalin that can be decomposed into glucose, benzaldehyde, and hydrocyanic acid and make the product non-edible. Bitter almond oil has important medicinal properties and it is used in pharmaceutical industry (Čolić *et al.*, 2019). Sweet almond (*Prunus amygdalus, var. dulcis*) is the cultivated for its kernel, which forms the edible part of the nut. Sweet almond oil contains low level of free fatty acids, peroxides and phosphatides (Čolić *et al.*, 2019). Chemical composition of almond kernels is well documented. Almond kernel is known to be of high nutritional value (Yada *et al.*, 2013; Zahedi *et al.*, 2020, Sakar *et al.*, 2021a). Indeed, almond is considered as a valuable source of lipids (44–61% on fresh weight; 20–68% on dry weight), proteins (10 to 35%), dietary fiber, riboflavin, vitamin E, phytosterols, manganese, magnesium, copper, phosphorus and sugars (Roshila *et al.*, 2007; King *et al.*, 2008; Yada *et al.*, 2011, 2013; Prgomet *et al.*, 2017; Socias i Company and Gradziel, 2017; Čolić *et al.*, 2019). It also contains a significant amount of bioactive compounds including flavonoids, phenolics and tannins making it a good natural antioxidant (Čolić *et al.*, 2019). Almond oil has high concentrations of monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs), such as linoleic and oleic acids (Zahedi *et al.*, 2020). Thanks to international breeding programs, several cultivars were released. Delayed blooming time is one the main goal of these breeding programs to overcome frost as the limiting factor for almond production (Sakar *et al.*, 2017a). In modern Moroccan orchards, several commercial cultivars are grown. The most important are "Marcona", "Tuono", "Ferragnès", and "Ferraduel" (Kodad *et al.*, 2015). Following these authors, traditional orchards are dominated by almond seedlings mainly on marginal soils with a low productivity. However, these almond genotypes (seedlings) may offer an important germplasm to select superior genotypes to be included in breeding programs, for instance, owing to their promising pomological features. Little is known about Moroccan genetic diversity of almond genotypes especially in southern Morocco. Hence the originality of this work, which aimed at (i), characterizing pomological and physico-chemical characteristics of some local almond genotypes growing and (ii) comparing sweet and bitter almonds originated from various agro-ecological areas.

2 Material and methods

2.1 Sampling

This study was carried out on ten almond genotypes. For each genotype, three healthy trees were chosen for fruit sampling. Among them, five genotypes are sweet almonds (*Prunus amygdalus* var. dulcis) and the five remaining belong to bitter almonds (*Prunus amygdalus*, var. amara). Fruit sampling was done at full ripening stage (BBCH89) according to Sakar *et al.* (2019a). Fruits (sweet and bitter) were harvested during July in 2019 from five agro-ecological areas of southern Morocco namely (Fig. 1): Tafraout, Igherm, Taliouine, Tiznit, and Essaouira. Geographical position as well as climatic data of these areas are presented in Table 1.

2.2 Sample processing

At the laboratory, collected almond samples were manually cracked to release the kernels (fruit edible part) as described by Sakar *et al.* (2019b). Afterwards, the kernels were crushed using an electric grinder. Finally, the powders were stored in plastic bottles at room temperature until use.

2.3 Chemicals and apparatus

Nitric acid, hydrochloric acid, methanol, potassium hydroxide and hexane were all reagent grade. For each of evaluated elements (Cu, Zn, Fe, B, Mn, Mg, Ca, Na and K), a standard solution of 1000 μg/mL dissolved in 2% (v/v) HNO_3 supplied by Merck Millipore (CertiPUR, Darmstadt, Germany) was used as a stock

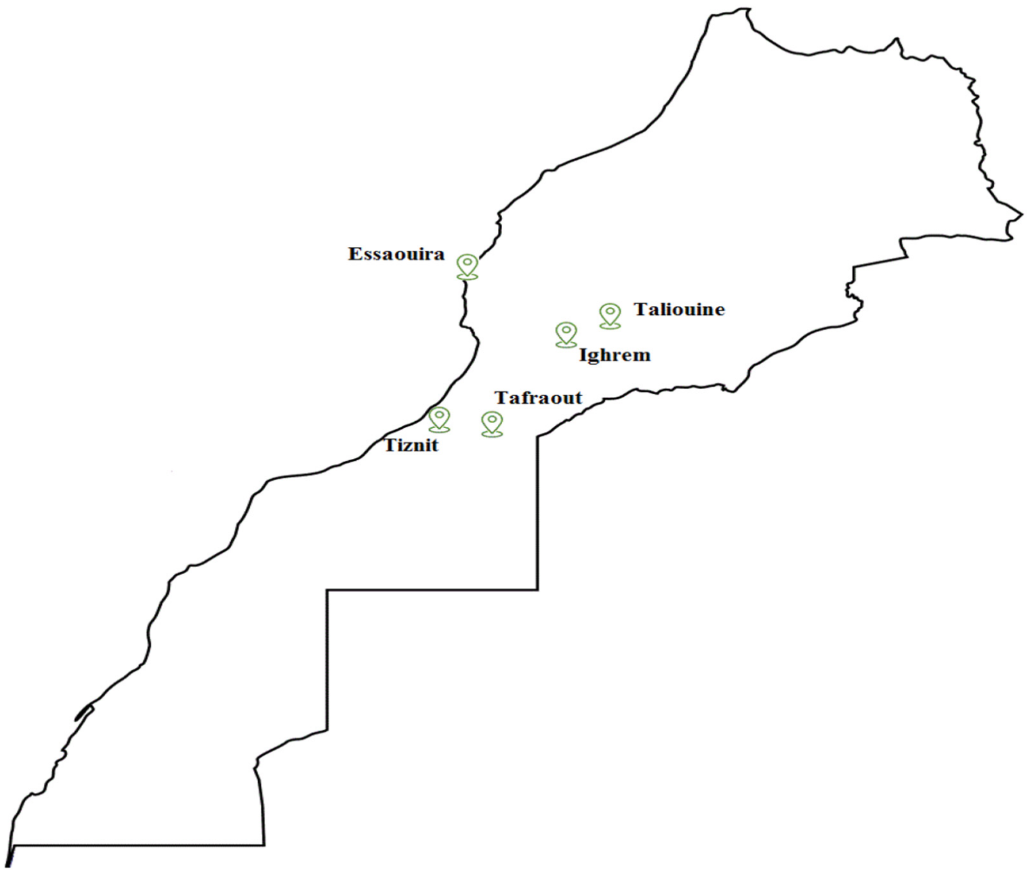

Fig. 1. Location of sampling sites.

Table 1. Geographical and climatic data for the sampling agro-ecological areas.

Agro-ecological area	Geographical coordinates	Altitude (m)	Temperature (°C)
Essaouira	31°30′44″ North 9°46′11″ West	7	10–25
Igherm	30° 5’ 6” North 8° 27’ 54” West	1729	3–38
Tafraout	29°43′28″ North 8°58′28″ West	993	3–30
Taliouine	30° 31’ 52” North 7° 55’ 26” West	1019	2.6–34
Tiznit	29° 40’ 48” North 9° 42’ 53” West	248	3.8–42.2

solution for a calibration purpose. Stock solutions were stored in the fridge at 4 °C. Ultrapure water with maximum resistivity of 18.2 MΩ/cm, obtained from a Milli-Q Millipore system (Darmstadt, Germany) and Argon alpha-gas (purity higher than 99.995) supplied by Air liquid were used. Minerals were determined using a Perkin Elmer Model Optima 8000 DV spectrometer (Waltham, USA), equipped with a charge-coupled device (CCD) detector. A Gem Tip, Cross-Flow II nebulizer coupled with the Scott-chamber was used as a sample introduction system.

2.4 Physical kernel traits measurements

Before starting measurements, broken, damaged or immature almond kernels were removed. Fruit physical traits were carried out on sub-samples of 30 kernels from each genotype. Axial dimensions: length (KL); width (KW), thickness (KT), were measured on individual fruits with a digital caliper reading to 0.01 mm. Similarly, kernel weight (W) was measured using electronic balance with a precision of 0.01 g (Sakar *et al.*, 2019b; Sakar *et al.*, 2020).

Table 2. Fruit physical traits in almond kernels in the studied ten genotypes: weight (KH); length (KL); width (KW); thickness (KT).

Agro-ecological area	Genotype	KH (g)	KL (mm)	KW (mm)	KT (mm)
Igherm	IGs	0.51 ± 0.15	16.47 ± 2.20	10.00 ± 1.30	5.53 ± 0.93
	IGb	0.69 ± 0.13	20.05 ± 2.18	11.45 ± 1.85	5.60 ± 0.83
Tafraout	TFs	0.57 ± 0.07	16.75 ± 2.15	9.96 ± 1.13	5.87 ± 1.06
	TFb	0.58 ± 0.15	19.03 ± 3.68	10.71 ± 1.40	5.48 ± 1.18
Tiznit	Tis	0.57 ± 0.07	15.83 ± 0.65	9.75 ± 0.53	7.31 ± 0.55
	Tib	0.85 ± 0.23	18.90 ± 3.47	11.86 ± 0.90	7.35 ± 0.68
Taliouine	TLs	1.03 ± 0.18	21.27 ± 2.41	13.76 ± 1.05	7.30 ± 1.14
	TLb	0.76 ± 0.18	20.42 ± 1.83	11.87 ± 1.64	5.99 ± 0.45
Essaouira	ESs	0.54 ± 0.13	17.97 ± 2.15	10.68 ± 1.38	5.32 ± 0.49
	ESb	0.55 ± 0.11	17.72 ± 1.41	11.16 ± 0.99	5.28 ± 0.77

Results are mean values ± SD.

2.5 Proximate composition

Proximate composition analysis was carried out on the powder of almond kernels. Moisture content (MC) was determined using an oven. Five grams of powder was placed in a ventilated oven at 103 °C until reaching a constant weight. Nitrogen content was determined by Dumas Method using an elementary analyzer LECO FP628 (LECO Corporation, Saint Joseph, MI, USA), protein content (PC) was estimated by multiplication the nitrogen value obtained by conversion factor 6.25. Ash content (AC) was determined by calcination of 5 g of sample powder in muffle furnace at 550 °C for six hours. Oil content (OC) was determined using two methods firstly; Soxhlet apparatus; 20 g of powder was subjected to extraction with hexane for 8 h. The solvent was partly removed in rotary vacuum evaporator at 45 °C, and also press extractor. The rest of the solvent was removed under stream of nitrogen to a constant weight to determine the OC gravimetrically. The extracted oils were filtered and kept in dark glass bottles at 4 °C until analysis for fatty acids. Carbohydrates content (CC) was obtained according the following equation:

$$CC(g/100g) = 100 - (PC(g/100g) + MC(g/100g) + AC(g/100g) + OC(g/100g)).$$

Energy value (EV) (expressed as kcal/100 g dry basis) was computed from values of MC, AC, PC, OC (Soxhlet extracted), and CC using the following equation:

$$EV(kcal/100g) = (2.62 \times PC) + (8.37 \times OC) + 4.2 \times CC.$$

2.6 Minerals determination

Digestion of plant material was carried out using microwave assisted digestion speed-wave (BERGHOF, Germany). Kernel powder (0.3 g) was weighed in Teflon vessels then 8 mL of nitric acid (HNO_3) (65%) and 2 mL of oxygenated water (H_2O_2) (30%) were added, then inserted in the mineralizer and the mineralization program was launched. A clear solution was obtained at the end of the program was diluted to 25 mL and then injected into ICP-OES.

2.7 Fatty acids composition determination

A mixture consisting of 1 g of oil, 10 mL of methanol, and 0.4 mL of 2 N potassium hydroxide was prepared, esterified by boiling under reflux for 10 minutes and cooled, then 2 mL of hexane were added to the mixture and washed with distillated water. Finally, hexane layer containing fatty acid methyl esters (FAMEs) was collected and analyzed gas chromatography (Agilent-6890). This later were equipped with a capillary column CP-Wax 52CB (30 m × 250 µm i.d., 0.25 µm film thickness). The operating conditions of GC-FID during this study were as follow: helium as carrier gas, 1 mL/min of total gas flow rate, 170 °C was the initial oven temperature and 230 °C was the final, temperature gradient was 4 °C/min, injector and detector temperature was set at 220 °C and the injection volume of the samples was 2 µL in a split mode (split ratio 1:50). The results were expressed as the relative percentage of the area of each fatty acid peaks (Gharby *et al.*, 2020).

2.8 Statistical analysis

All determinations and measurements were performed, at least, in triplicate. The averaged values were calculated, and results were reported as means ± standard deviation (SD). Principal component analysis (PCA) and correlations matrix were carried out on mean values. Cluster analysis was performed on mean values through Euclidean distance to reveal similarity among studied genotypes. All statistical analyses were made through the Statgraphics Centurion XVII (StatPoint Technologies, Inc., Virginia, USA).

3 Results and discussion

3.1 Physical fruit traits

Along with chemical composition, the morphological aspect of an agricultural product is important since it influences consumer acceptance. The most research works focus in almond fruit is devoted to its chemical composition and little is given to physical fruit traits (Sakar *et al.*, 2020). In this study, four morphological aspects; weight, length, width and

Table 3. Moisture content (MC, %), protein content of solvent (PCs, %) and press extracted cake (PCp, %), oil content extracted by solvent (OCs, %) and press extractor (OCp, %), ash content (AC, %), carbohydrate content (CC, %), and energy value (EV, kcal/100 g) of the studied genotypes grown under five different agro-ecological areas.

Origin	Genotype	MC (%)	PCs (%)	PCp (%)	OCs (%)	OCp (%)	AC (%)	CC (%)	EV (kcal/100 g)
Igherm	IGs	2.77 ± 0.04	22.52 ± 2.53	35.19 ± 2.46	52.14 ± 5.25	61.89 ± 0.74	5.11 ± 0.45	17.46 ± 1.45	568.75 ± 37.22
	IGb	2.98 ± 0.08	20.36 ± 1.25	27.72 ± 1.94	51.97 ± 6.03	58.34 ± 9.15	6.10 ± 0.39	18.59 ± 2.22	566.41 ± 35.14
Tafraout	TFs	2.80 ± 0.05	22.05 ± 0.52	33.98 ± 2.37	56.26 ± 3.22	57.96 ± 6.16	5.55 ± 0.33	13.34 ± 1.54	584.70 ± 33.14
	TFb	2.55 ± 0.38	17.14 ± 2.14	10.44 ± 0.73	56.02 ± 2.68	52.42 ± 6.74	5.90 ± 0.36	18.39 ± 3.02	591.03 ± 38.65
Tiznit	Tis	4.34 ± 1.16	25.12 ± 1.23	31.73 ± 2.78	51.12 ± 2.99	36.27 ± 5.20	6.06 ± 0.50	13.36 ± 1.02	549.80 ± 37.04
	Tib	3.00 ± 0.16	24.98 ± 3.01	30.75 ± 2.15	52.17 ± 3.04	52.82 ± 1.06	6.11 ± 0.41	13.74 ± 0.98	559.82 ± 30.55
Talioune	TLs	3.54 ± 0.01	20.05 ± 1.22	34.17 ± 2.39	52.25 ± 4.81	55.35 ± 4.79	5.59 ± 0.44	18.57 ± 2.44	567.86 ± 29.62
	TLb	3.74 ± 0.11	20.27 ± 1.58	27.56 ± 1.92	52.85 ± 5.20	49.52 ± 6.54	6.49 ± 0.51	16.65 ± 2.22	565.39 ± 35.02
Essaouira	ESs	3.69 ± 0.02	19.33 ± 2.03	33.60 ± 2.35	55.09 ± 2.11	52.47 ± 1.27	6.79 ± 0.52	15.10 ± 1.03	575.17 ± 38.33
	Esb	3.77 ± 0.12	19.05 ± 1.85	32.19 ± 2.25	54.73 ± 3.77	53.23 ± 1.62	6.60 ± 0.50	15.85 ± 1.11	574.57 ± 39.11

Results are mean values ± SD.

thickness were investigated, the results are shown in Table 2. The obtained results showed that kernel weight varied slightly from an origin to another, the lowest value was 0.51 ± 0.15 g found in bitter almond from Tiznit and the highest one was 1.03 ± 0.18 g obtained in sweet almond from Taliouine, our results were lower than those reported by Sakar *et al.* (2020) for some commercial cultivars grown in northern Morocco. Length showed also a small variation between the studied agro-ecological areas, and ranged from 15.83 ± 0.65 mm measured for sweet almond from Tiznit to 21.27 ± 2.41 mm measured for sweet almond from Taliouine. For width, the results exhibited a good homogeneity between the obtained values for all the studied areas, and ranged from 9.75 ± 0.53 mm obtained in sweet almond of Tiznit to 13.76 ± 1.05 mm obtained in sweet almond from Taliouine. Regarding thickness the obtained results showed a small variation among studied areas, and from one genotype to another. The lowest value was 5.28 ± 0.77 mm found in bitter almond of Essaouira, and the highest was 7.35 ± 0.68 mm found in bitter almond of Tiznit.

3.2 Proximate composition

The determination of almond chemical composition is of a great importance since it allows consumers to know the nutritional value and the quality of this product. Moisture, protein, oil content and ash were determined in this study, and the obtained results were summarized in Table 3. MC of the studied samples showed relatively small variations between samples and ranged from 2.55 ± 0.38 in bitter almond of Tafraout to 4.34 ± 1.16% in sweet almond of Tiznit with an average of 3.32 ± 0.23%. Indeed, MC values of studied almond genotype showed small variations between sweet and bitter almond. Our results were similar to those found in some Turkish almond genotypes (2.25–3.70) by Simsek *et al.* (2018). PC varied usually from 10% to 35% (Socias i Company and Gradziel, 2017), and almond kernel was considered as a protein-rich food (Roncero *et al.*, 2020). The values obtained in this study ranged from 17.14 ± 2.14% found in bitter almond from Tafraout to 25.12 ± 1.23% found in sweet almond from Tiznit, with an average of 21.08 ± 1.82 g/100 g for solvent extraction. Values obtained for the cake extracted by press were different to those found for solvent extraction. Our results were in line with those reported in previous studies: from 20.81 to 25.99 g/100 g found in samples from Turkey (Simsek and Kizmaz, 2017), 14.1 ± 0.09 to 35.1 ± 1.87 g/100 g found in Moroccan samples (Kodad *et al.*, 2013), and 18.5 to 24.0 g/100 g in samples from California (Yada *et al.*, 2013). According to these results and because of high protein content of almond, this product could be used as a dietary supplement to fight proteins deficiency and also for people suffer from hypertension (Simsek *et al.*, 2018). Regarding crude oil (OC), almond kernel is known to be particularly rich in oil and vary between 48 to 67 g/100 g of kernel dry weight (Abdallah *et al.*, 1998; Kodad and Socias i Company, 2008; Sathe *et al.*, 2008; Sakar *et al.*, 2017b, Simsek *et al.*, 2018). According to our results, solvent extraction showed that all samples were rich in oil with little variations from an origin to another. Sweet almond from Tiznit displayed the lowest value (51.12 ± 2.99 g/100 g), while the highest value (56.26 ± 3.22 g/100 g) was found in sweet almond from Tafraout. These outcomes were consistent with those reported by other authors for almonds from Turkey (43.50 to 55.70 g/100 g) as highlighted by Simsek and Demirkiran (2010) and Özcan *et al.* (2011), Portugal (30.00 to 51.00 g/100 g) as outlined by Martins *et al.* (2000), and Morocco (52.6 to 58.7 g/100 g) reported by Kodad *et al.* (2014). As demonstrated by Kodad *et al.* (2010), while OC is under the genetic dependency, the environment factors (soil and climate) account for significant impacts on its variations. The OC values obtained by press extraction showed wide variations from 36.27 ± 5.20 to 61.89 ± 0.74%. Such variations could be ascribed mainly to kernel moisture level as well as genotype. The results obtained for ash content showed a small variation between the analyzed samples, with lowest value of 5.11 ± 0.45% found in sweet almond of Igherm and the highest value 6.79 ± 0.52% found in sweet almond of Essaouira. The results for AC were higher than those reported by Simsek and Demirkiran (2010) in almond from Turkey (2.45–4.42%), but closer to the values found by Moodley *et al.* (2007) in samples from South Africa (5.0 ± 0.1%). From the results cited above large variations in concentrations were found for oil and proteins content between the studied origins, this could be explained by environmental effect such as climatic conditions including weather and temperature variation, soil characteristics, growing conditions and also agronomic practices. Differences between genotypes of the same origins could be explained differences on the genetic background of each genotype. These findings were in good agreement with other studies, which previously observed differences in proteins and oil content as variety effect (Drogoudi *et al.*, 2013).

Carbohydrates in almonds consist mainly of soluble sugars (mainly sucrose), starch and other polysaccharides such as cellulose and non-digestible hemicelluloses. According to previous studies, almonds are characterized by high carbohydrates content (CC) (Čolić *et al.*, 2019). The total carbohydrates content usually ranged from 14 to 28% (Roncero *et al.*, 2020). The obtained results in our study were calculated using CP and OC obtained by solvent extraction and they show that the analyzed samples were rich in carbohydrates. The carbohydrates content varied among origins and genotypes, the lowest value ($13.34 \pm 1.54\%$) was obtained in sweet almond from Tafraout, while the highest one ($18.59 \pm 2.22\%$) found in bitter almond from Igherm. Our results were lower than those reported in almonds from South Africa ($28.0 \pm 0.6\%$) as reported in Moodley *et al.* (2007). The variation of the carbohydrates content has already been linked to different factors such as cultivar, origin and harvest time (Yada *et al.*, 2013; Roncero *et al.*, 2020). The carbohydrates content determined herein for almond kernels was lower than that reported in previous studies (Moodley *et al.*, 2007; Akpambang *et al.*, 2008).

Energy value (EV) was also estimated during this study. Almost no variations were seen among studied samples, the lowest value was 549.80 ± 37.04 kcal/100 g found in sweet almond from Tiznit, and the highest one (591.03 ± 38.65 kcal/100 g) was recorded in better almonds from Tafraout. Our results were very close to those reported in US Department of Agriculture, Agricultural Research Service (USDA, 2010).

3.3 Mineral composition

Minerals are involved in various metabolic and physiologic processes of living organisms; their proper functioning requires the supply of well-defined quantities of these metals (Williams, 2005; Dronkelaar *et al.*, 2018; Ceccanti *et al.*, 2021). Indeed, insufficient intake or excess of minerals and trace elements may result in an alteration of the immune system and can eventually lead to clinical symptoms; adequate intake is required to preserve a healthy immune system (Wintergerst *et al.*, 2007). In plants, minerals are known to be involved in the synthesis of organic compounds (Özcan, 2006). In almond kernels, minerals have been extensively studied in contrasting geographical regions (Schirra *et al.*, 1994; Özcan, 2006; Özcan *et al.*, 2011; Drogoudi *et al.*, 2013; Yada *et al.*, 2013; Simsek *et al.*, 2018; Ibourki *et al.*, 2019). It is widely evidenced that almond kernel is a good source of minerals (Socias i Company and Gradziel, 2017; Roncero *et al.*, 2020). The amount of the minerals studied in the sweet and bitter almond cultivars are shown in Table 4. According to the obtained results among the major-elements group constituted by K, Ca, P, and Mg following to the high requirements of these elements for plants, K was the most abundant element in all samples with concentration ranged from 9796.08 ± 793.49 mg/kg found in bitter almond of Igherm to $14\,197.84 \pm 1150.03$ mg/kg found in Sweet almond of Essaouira, the same observation has already been noted by Roncero *et al.* (2020). P was the second most abundant element and ranged from 8190.75 ± 663.46 mg/kg found in sweet almond of Tafraout to $11\,061.68 \pm 895.96$ mg/kg found in bitter almond of Tiznit. Ca was in third position and ranged from 3067.53 ± 248.47 mg/kg in bitter almond of Essaouira to 5404.93 ± 437.79 mg/kg found in sweet almond of Tiznit. Mg content was similar to that of Ca and ranged from 4002.85 ± 324.22 mg/kg found in sweet almond of Essaouira to 5101.72 ± 413.23 mg/kg found in bitter almond of Tiznit. The remaining minerals were found in small quantities as follows: Na (150.73 ± 13.18 to 271.64 ± 22.13 mg/kg), Cu (10.96 ± 1.96 to 22.12 ± 1.79 mg/kg), Fe (60.01 ± 5.40 to 85.19 ± 6.90 mg/kg), Zn (56.03 ± 4.53 to 77.53 ± 6.28 mg/kg), Mn (20.73 ± 1.67 to 31.56 ± 2.55 mg/kg), and B (20.47 ± 1.47 to 40.92 ± 3.12 mg/kg). These outcomes were consistent with results reported in other study (Wang *et al.*, 2019). Important variations were seen among genotypes and origins as evidenced in Table 4. Considerable variations were observed for all elements as a function of geographic origin. This was consistent with what was previously reported by other authors for various plants and plant foods (Faez *et al.*, 2013; Ibourki *et al.*, 2021a, 2021b, 2022). These variations could be explained by the diversity of the mineral composition of soils for each origin, ecological factors, agronomic practices, water source, irrigation practices and also fertilizer component (Simsek *et al.*, 2018) as well as the ripening stage (Schirra *et al.*, 1994; Yada *et al.*, 2013). The differences found between the genotypes growing under the same conditions are probably controlled by genetic component (Drogoudi *et al.*, 2013; Yada *et al.*, 2013).

3.4 Fatty acid composition

The fatty acid (FA) composition is an important indication of nutritional value of the oil (Gharby *et al.*, 2017, 2018). In order to highlight the differences between almond FA composition of genotypes obtained from different origin and evaluate the effect of extraction method on this component, we determined the fatty composition profile. Table 5 shows the obtained results of FA composition of different genotypes almond oil obtained by press and solvent. In general, almond oil is known to be rich in unsaturated fatty acids with a high content of oleic acid (63 to 78%) and linolenic acid (12 to 27%) and (Kodad and Socias i Company, 2008). Owing to this composition almond oil is considered very healthy (Barreca *et al.*, 2020). In this study eight fatty acids namely: myristic acid C14:0, palmitic acid C16:0, palmitoleic acid C16:1, stearic acid C18:0, oleic acid C18:1, linoleic acid C18:2, linolenic acid C18:3 and arachidic acid C20:0 were analyzed in almond oil (Tab. 5). The obtained results showed similar fatty acid profiles among almond oil from various genotypes and origins. However, LSD's test revealed significant differences ($p < 0.05$) among some genotypes in terms of the investigated fatty acids. Similarly, important variations were seen among almond oil samples achieved using solvent and press

Table 4. Mineral content (mg/kg) of ten almond kernel flour genotypes grown under five different agro-ecological areas.

Origin	Genotype	Zn	Cu	Na	Fe	B	Mn	Mg	Ca	K	P
Igherm	IGs	72.52 ± 5.87	13.06 ± 1.05	206.66 ± 16.73	72.43 ± 5.86	27.45 ± 2.23	29.15 ± 2.36	4430.64 ± 358.87	4513.88 ± 365.61	13 009.39 ± 1053.76	8756.37 ± 709.27
	IGb	65.81 ± 5.32	14.52 ± 1.17	163.48 ± 13.24	76.01 ± 6.14	24.38 ± 1.97	31.49 ± 2.55	4026.05 ± 326.11	4120.07 ± 333.71	9796.08 ± 793.49	8581.81 ± 695.13
Tafraout	TFs	71.67 ± 5.80	22.12 ± 1.79	174.73 ± 14.15	85.19 ± 6.90	40.92 ± 3.12	25.35 ± 2.05	4628.24 ± 374.86	5359.93 ± 434.15	12 662.57 ± 1025.67	8190.75 ± 663.46
	TFb	74.89 ± 6.06	11.96 ± 0.96	233.87 ± 18.94	63.54 ± 5.14	20.67 ± 1.67	21.83 ± 1.76	4227.96 ± 342.46	4406.27 ± 356.90	10 379.02 ± 840.71	9102.76 ± 737.32
Tiznit	Tis	76.87 ± 6.22	15.21 ± 1.23	237.53 ± 19.23	73.84 ± 5.98	26.82 ± 2.17	31.56 ± 2.55	4847.62 ± 392.65	5404.93 ± 437.79	13 922.77 ± 1127.74	9616.85 ± 778.96
	Tib	77.53 ± 6.28	17.52 ± 1.41	271.64 ± 22.13	72.28 ± 5.85	23.01 ± 1.86	31.21 ± 2.52	5101.72 ± 413.23	4472.32 ± 362.25	13 997.45 ± 1133.78	11 061.68 ± 895.96
Talioune	TLs	76.67 ± 6.80	20.12 ± 1.77	150.73 ± 13.18	75.19 ± 6.90	35.92 ± 2.92	27.30 ± 2.72	4720.05 ± 397.60	5100.33 ± 400.23	12 790.40 ± 1120.44	8256.43 ± 629.51
	TLb	70.89 ± 5.04	10.96 ± 1.96	283.87 ± 18.06	60.01 ± 5.40	20.47 ± 1.47	28.91 ± 2.66	4307.96 ± 342.46	4701.44 ± 379.79	10 360.12 ± 835.50	9206.51 ± 702.51
Essaouira	ESs	73.07 ± 5.91	13.44 ± 1.08	179.97 ± 14.57	63.31 ± 5.12	24.56 ± 1.98	25.06 ± 2.03	4002.85 ± 324.22	4448.94 ± 360.36	14 197.84 ± 1150.03	8283.84 ± 670.98
	ESb	56.03 ± 4.53	11.26 ± 0.91	250.01 ± 20.25	76.74 ± 6.22	23.32 ± 1.88	20.73 ± 1.67	4219.81 ± 341.81	3067.53 ± 248.47	10 401.92 ± 842.56	9422.96 ± 763.23

Results are mean values ± SD.

extractions. Indeed, oleic acid, linoleic acid and palmitic acid were predominant in almond oil regardless of genotype, origin and extraction method, the same findings were already noted in previous study (Kodad *et al.*, 2010). Oleic acid was the most abundant in all genotypes for both kinds of extraction with important variations (64.2–71.1%) for pressured oil and oil extracted by solvent (65.4–73.23%). This is in line published literature regarding the dominance of oleic acid in almond oil (Sakar *et al.*, 2021a) and other vegetable oils such olive oil (Gharby *et al.*, 2021), argan oil (Boukyoud *et al.*, 2021), and date palm seed oil among others (Ibourki *et al.*, 2021b). Linoleic acid was the second most abundant for both oils obtained by press (18.01 to 25.32%) and solvent extracted oil (14.7 to 24.12%). However, the studied almond oil samples contained very small amounts of linolenic acid. It is even absent in some samples. It is a very oxidizable molecule. This fatty acid can be used to detect the adulteration of almond oil with other vegetable oils rich in linolenic acid such as soybean and rapeseed oils (Gharby *et al.*, 2020). Both myristic and arachidic acids were not detected in all studied samples extracted using solvent and press extractions.

The major saturated fatty (SFA) acids, was palmitic acid representing in third position with variation ranges from 6.3 to 7.08% and from 6.5 to 8.1% for pressured oil and that extracted by solvent, respectively. Stearic acid was detected in small amount in press extracted oil (1.8 to 3.1%) as well as solvent extracted oil (2.1 to 3.4%). Palmitoleic acid was found in a very small amount in oil extracted by pressing (0.3 to 0.5%) and in solvent extracted oil (0.3 to 0.67%). These findings showed that extraction type effect was of a lesser magnitude. Regarding origin effect, slight variations were seen between genotypes belonging to the same origin, however, genotypes from different origins showed important variations of FAs content except for C16:1 the content of different origins were very similar. These differences could be explained by climatic conditions and agronomic practices (Sakar *et al.*, 2021a).

3.5 Principal component analysis

PCA was used as a multivariate statistical analysis with the aim to discriminate among genotypes and various origins (sites). The first three components were retained since they explained around 68% of total data variance. As it can be seen in Figure 2A, the five origins were separated through the first two components accounting for about 50%. Figure 2B represents mean values of geographical origins plotted on the surface delimited by PC1 and PC2. Furthermore, Tiznit seemed to interact with higher values of MC, EV, KT, P, Mg, K, Zn, and Mn, while, Tafraout together with Talioune and Essaouira were associated to the best records of AC, Cu, Ca, W, PC. Igherm was characterized by higher levels of CC, OC, and KL. As evidenced in Figures 2C and 2D, the investigated almond genotypes were separated through the second component (PC2 = 21.50%) and the third component (PC3 = 17.05%). Moreover, better almonds were marked by higher levels of MC, OC, CC, AC, EV, KT, Zn, Mg, Na, and P. In contrast, sweet genotypes were linked to great values of PC, KW, KL, W, Fe, K, and B. PCA is widely in use in many fields such as pomological studies, chemometrics, crop physiology

Table 5. Fatty acid profiles of almond oil obtained by press and solvent extraction.

Fatty acids		Igherm		Tafraout		Tiznit		Taliouine		Essaouira	
		IGs	IGb	TFs	TFb	TIs	TIb	TLs	TLb	ESs	ESb
Palmitic acid	Press	7.1 ± 0.1a	6.8 ± 0.1a	6.6 ± 0.1b	6.7 ± 0.1ab	7.1 ± 0.1a	6.9 ± 0.1a	6.8 ± 0.1a	6.6 ± 0.1b	6.8 ± 0.1a	6.4 ± 0.1b
	Solvent	8.1 ± 0.1a	6.5 ± 0.1c	7.0 ± 0.1b	6.6 ± 0.1c	6.8 ± 0.1c	6.8 ± 0.1c	6.8 ± 0.1c	6.6 ± 0.1c	7.5 ± 0.1b	7.3 ± 0.1b
Palmitoleic acid	Press	0.6 ± 0.1a	0.5 ± 0.1ab	0.4 ± 0.1c	0.4 ± 0.1c	0.4 ± 0.1c	0.4 ± 0.1c	0.5 ± 0.1ab	0.5 ± 0.1ab	0.6 ± 0.1a	0.5 ± 0.1ab
	Solvent	0.7 ± 0.1a	0.5 ± 0.1ab	0.4 ± 0.1b	0.4 ± 0.1b	0.3 ± 0.1b	0.4 ± 0.1b	0.5 ± 0.1ab	0.4 ± 0.1b	0.6 ± 0.1a	0.5 ± 0.1ab
Stearic acid	Press	2.7 ± 0.1a	3.0 ± 0.1a	1.8 ± 0.1b	2.1 ± 0.1b	3.1 ± 0.1a	2.9 ± 0.1a	2.4 ± 0.1ab	1.8 ± 0.1b	2.5 ± 0.1ab	2.8 ± 0.1a
	Solvent	2.2 ± 0.1b	3.3 ± 0.1a	2.2 ± 0.1b	2.1 ± 0.1b	3.4 ± 0.1a	2.2 ± 0.1b	2.5 ± 0.1ab	2.2 ± 0.1b	2.1 ± 0.1b	2.1 ± 0.1b
Oleic acid	Press	67.6 ± 0.1a	70.2 ± 0.1ab	71.9 ± 0.1b	70.8 ± 0.1a	64.2 ± 0.1b	67.6 ± 0.1ab	70.2 ± 0.1a	67.9 ± 0.1ab	69.8 ± 0.1a	69.7 ± 0.1ab
	Solvent	73.3 ± 0.1a	70.4 ± 0.1b	71.4 ± 0.1b	71.0 ± 0.1b	65.4 ± 0.1c	70.2 ± 0.1b	69.7 ± 0.1b	70.0 ± 0.1b	70.3 ± 0.1b	69.0 ± 0.1b
Linoleic acid	Press	21.9 ± 0.1b	19.5 ± 0.1c	19.1 ± 0.1d	20.0 ± 0.1c	25.3 ± 0.1a	22.5 ± 0.1b	20.2 ± 0.1c	23.2 ± 0.1b	20.0 ± 0.1c	20.5 ± 0.1c
	Solvent	14.8 ± 0.1c	19.3 ± 0.1b	18.9 ± 0.1b	19.9 ± 0.1b	24.1 ± 0.1a	19.7 ± 0.1b	20.6 ± 0.1b	20.8 ± 0.1b	19.6 ± 0.1b	21.1 ± 0.1b
Linolenic acid	Press	0.1 ± 0.1b	ND	0.2 ± 0.1a	ND	ND	ND	ND	0.2 ± 0.1a	ND	0.1 ± 0.1b
	Solvent	0.1 ± 0.1	ND	ND	ND	0.2 ± 0.1a	0.1 ± 0.1b	0.1 ± 0.1b	0.2 ± 0.1a	ND	ND
SFA*	Press	9.8 ± 0.1	9.8 ± 0.1	8.4 ± 0.1	8.8 ± 0.1	10.2 ± 0.1	9.8 ± 0.1	9.2 ± 0.1	8.4 ± 0.1	9.3 ± 0.1	9.2 ± 0.1
	Solvant	10.3 ± 0.1	9.8 ± 0.1	9.2 ± 0.1	8.7 ± 0.1	10.2 ± 0.1	9.0 ± 0.1	9.3 ± 0.1	8.8 ± 0.1	9.6 ± 0.1	9.4 ± 0.1
USFA**	Press	90.2 ± 0.1	90.2 ± 0.1	91.6 ± 0.1	91.2 ± 0.1	89.9 ± 0.1	90.5 ± 0.1	90.9 ± 0.1	91.8 ± 0.1	90.4 ± 0.1	90.8 ± 0.1
	Solvant	88.9 ± 0.1	90.2 ± 0.1	90.7 ± 0.1	91.3 ± 0.1	90 ± 0.1	90.4 ± 0.1	90.9 ± 0.1	91.4 ± 0.1	90.5 ± 0.1	90.6 ± 0.1

*SFA: Saturated fatty acids; **USFA: Unsaturated fatty acids; ND: Not detected.
Results are presented as mean values followed by standard deviation. For each fatty acid, values followed by the same letter are not significantly different at 5% as a probability level.

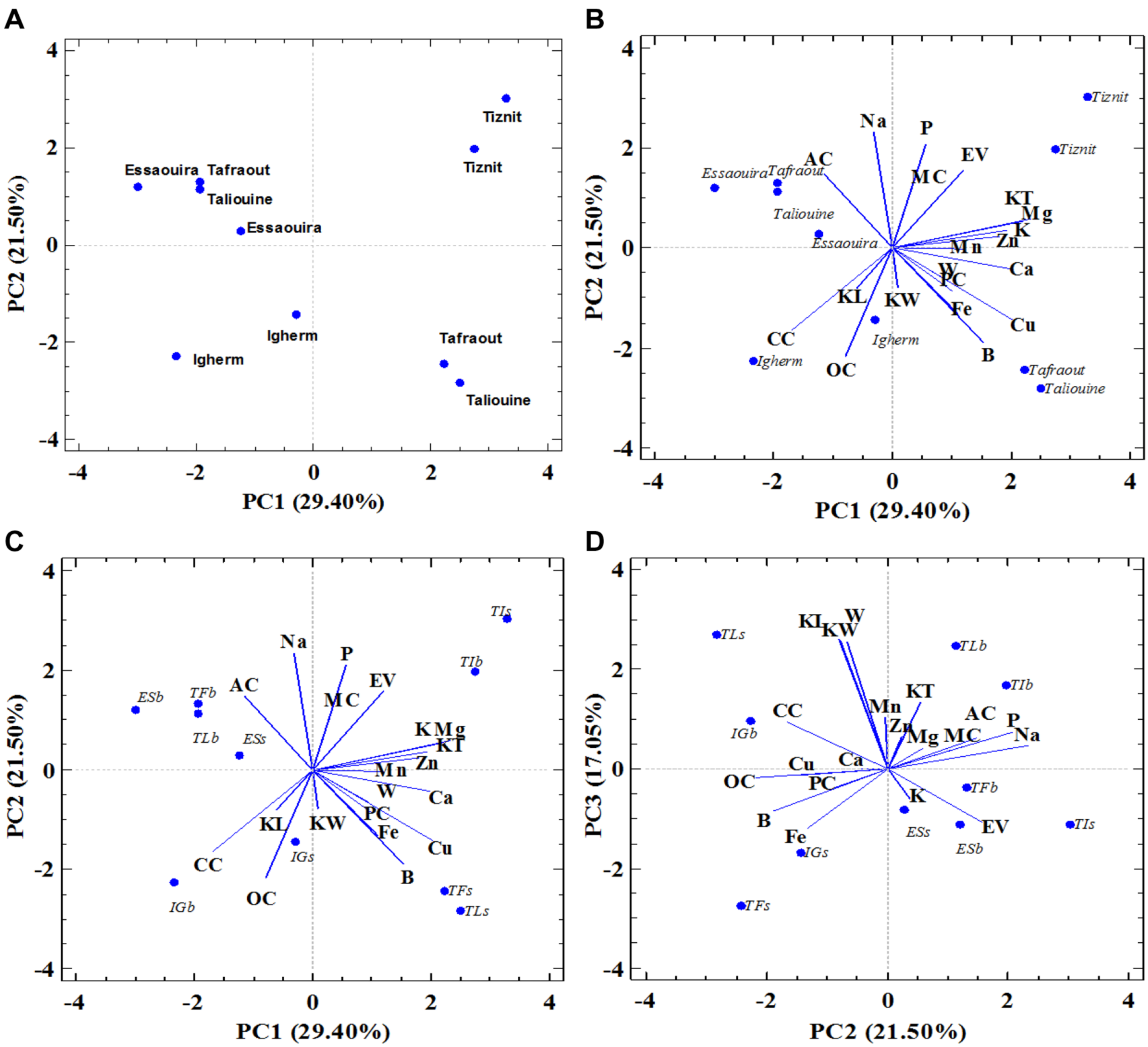

Fig. 2. Principal component projections for the first three components that most impact investigated fruit traits. Blue segments represent dependent variables, while points plotted are mean values. W: weight; KL: kernel weight; KW: kernel weight; KT: kernel thickness; OC: oil content; CC: carbohydrates content; PC: protein content; AC: ash content; EV: energy value.

among others (Boussakouran *et al.*, 2019; El Yamani *et al.*, 2019a, 2019b, 2019c, 2020a, 2020b, 2020c, 2020d; Zeroual *et al.*, 2021; Boussakouran *et al.*, 2021; Sakar *et al.*, 2021a, 2021b; Ibourki *et al.*, 2022).

3.6 Cluster analysis

Cluster analysis was carried out on mean values to examine similarity among investigated genotypes based on their physical fruit traits, proximate composition as well as mineral profiling as illustrated in Figure 3. From these outcomes, our genotypes showed higher diversity. TLs presented higher dissimilarity with the remaining genotypes, IGs and TFs were similar to each other. In a similar way, there were important similarities among TFs, ESb, ESs, TLb, and IGb. In such a context, a genetic study seems to be very useful to compete this pomological study among local almond genotypes in southern Morocco.

3.7 Correlation study

Spearman ranks correlation was performed on mean values to analyze association among studied parameters (Tab. 6). Based on these outcomes, important correlations were highlighted. Axial dimensions (KL, KW, and KT) were linked positively to each other on one hand and associated correlated

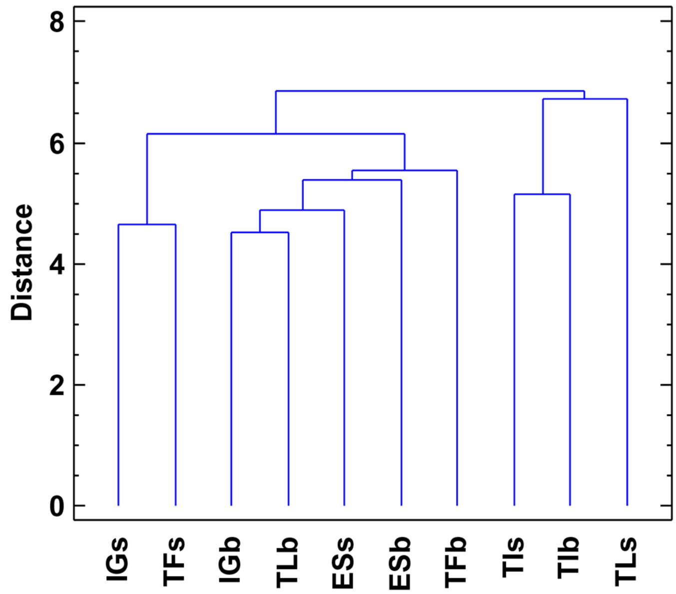

Fig. 3. Dendrogram conceived based on Euclidean distance in studied almond genotypes.

Table 6. Coefficients of correlation among investigate dependent variables.

	W	KL	KW	KT	MC	PC	OC	AC	CC	EV	Zn	Cu	Na	Fe	B	Mn	Mg	Ca	K	P
W		0.77*	0.77*	0.67*	0.02	−0.40	−0.17	0.12	0.05	−0.05	0.32	0.29	0.01	−0.08	−0.27	0.26	0.42	0.16	−0.28	0.09
KL			0.90**	0.13	−0.09	−0.39	−0.03	0.21	0.54	−0.41	−0.07	−0.10	−0.15	−0.27	−0.39	−0.12	−0.18	−0.24	−0.47	−0.2
KW				0.21	0.08	−0.26	0.03	0.28	0.48	−0.43	−0.05	−0.14	0.07	−0.21	−0.43	−0.05	−0.01	−0.27	−0.33	0.05
KT					0.16	−0.07	−0.21	−0.25	−0.31	0.12	0.62	0.56	0.13	−0.04	0.10	0.72*	0.85*	0.68*	0.21	0.26
MC						−0.03	−0.54	0.62	−0.15	−0.03	−0.03	−0.15	0.38	−0.03	−0.11	0.12	0.05	0.16	0.2	0.40
PC							0.58	−0.42	0.02	−0.19	0.04	0.43	−0.49	0.41	0.85*	−0.07	0.19	0.35	0.50	−0.50
OC								−0.48	0.43	−0.49	−0.37	0.28	−0.6	0.58	0.53	0.02	−0.12	−0.2	−0.14	−0.53
AC									0.05	−0.08	−0.21	−0.44	0.45	−0.36	−0.6	−0.21	−0.47	−0.49	0.07	0.38
CC										−0.93**	−0.6	−0.41	−0.28	−0.14	−0.12	0.02	−0.56	−0.33	−0.53	−0.38
EV											0.58	0.21	0.27	0.01	−0.05	−0.21	0.39	0.15	0.37	0.36
Zn												0.49	0.04	−0.32	0.11	0.33	0.68*	0.47	0.67	0.25
Cu													−0.56	0.49	0.71*	0.33	0.56	0.53	0.39	−0.38
Na														−0.47	−0.72*	0.02	0.19	−0.08	0.03	0.85*
Fe															0.6	−0.02	0.12	0.03	−0.2	−0.30
B																0.12	0.26	0.53	0.36	−0.64
Mn																	0.48	0.42	0.12	0.28
Mg																		0.71*	0.37	0.31
Ca																			0.32	−0.15
K																				0.12
P																				

** and * indicate significance at 0.01 and 0.05 a probability levels, respectively.

with kernel weight (W). Likewise, EV had a negative correlation with CC. Also, KT was positively and significantly linked to Mg, Ca, and Mn. B was positively associated to PC and Cu and negatively correlated with Na. Mg had a positive significant correlation with Zn and Ca. P displayed a positive correlation with Na. The remaining correlations were low or insignificant. Similar trends of correlations were highlighted by other authors (Sorkheh *et al.*, 2010; Sakar *et al.*, 2019b). Correlation knowledge is very important for breeders and consumers. For instance, breeding for a desirable trait could foster the appearance or disappearance of another trait because of their correlation.

4 Conclusions

In this study, we investigated the differences between ten almond genotypes (five of bitter and five of sweet almond) originated from five different areas in southern Morocco. The studied genotypes were compared in terms of physical fruits traits, proximate composition, mineral profiling and fatty acid composition. The obtained data exhibited a good homogeneity in terms of physical fruit traits, and slight variations were seen in proximate composition, minerals content. Similar fatty acid profiles were obtained for almond oil from various genotypes, origins and extraction method. The above results showed that investigated genotypes had important protein content, oil content, energy value, mineral composition and fatty acid composition of almond oil. Our genotypes showed promising features that should be considered for consumers and breeding purposes. Likewise, higher variability was highlighted among genotypes as revealed by multivariate statistical approaches (PCA and cluster analysis).

References

Abdallah A, Miguel HA, Thomas MG. 1998. Oil content and fatty acid composition of almond kernels from different genotypes and California production regions. *J Am Soc Hortic Sci* 123(6): 1029–33. https://doi.org/10.21273/JASHS.123.6.1029.

Akpambang V, Amoo I, Izuagie A. 2008. Comparative compositional analysis on two varieties of melon (*Colocynthis citrullus* and *Cucumeropsis edulis*) and a variety of almond (*Prunus amygdalus*). *Res J Agric Biol Sci* 4: 639–642.

Barreca D, Nabavi SM, Sureda A, *et al.* 2020. Almonds (*Prunus dulcis* Mill. D.A. Webb): A source of nutrients and health-promoting compounds. *Nutrients* 12(3). https://doi.org/10.3390/nu12030672.

Boukyoud Z, Ibourki M, Gharby S, *et al.* 2021. Can the water quality influence the chemical composition, sensory properties, and oxidative stability of traditionally extracted argan oil? *Mediterr J Nutr Metab* 4(14): 383–399. https://doi.org/10.3233/MNM-210005.

Boussakouran A, El Hassan S, Mohamed EY, Yahia R. 2019. Morphological traits associated with drought stress tolerance in six Moroccan durum wheat varieties released between 1984 and 2007. *J Crop Sci Biotechnol* 22(4):345–53. https://doi.org/10.1007/s12892-019-0138-0.

Boussakouran A, Mohamed EY, El Hassan S, Yahia R. 2021. Genetic advance and grain yield stability of Moroccan durum wheats grown under rainfed and irrigated conditions. *Int J Agron* 2021: e5571501. https://doi.org/10.1155/2021/5571501.

Ceccanti C, Brizzi A, Landi M, Incrocci L, Pardossi A, Guidi L. 2021. Evaluation of major minerals and trace elements in wild and domesticated edible herbs traditionally used in the Mediterranean area. *Biol Trace Elem Res* 199: 3553–3561. https://doi.org/10.1007/s12011-020-02467-3.

Čolić S, Zec G, Natić M, Fotirić-Akšić M. 2019. Almond (*Prunus dulcis*) oil. In: Ramadan M, ed. *Fruit oils: Chemistry and functionality*. Cham: Springer. https://doi.org/10.1007/978-3-030-12473-1_6.

Drogoudi PD, Pantelidis G, Bacchetta L, *et al.* 2013. Protein and mineral nutrient contents in kernels from 72 sweet almond cultivars and accessions grown in France, Greece and Italy. *Int J Food Sci Nutr* 64(2): 202–9. https://doi.org/10.3109/09637486.2012.728202.

Dronkelaar C, Aafke VV, Maya A, Anouk VDS, Weijs PJS, Tieland M. 2018. Minerals and sarcopenia: The role of calcium, iron, magnesium, phosphorus, potassium, selenium, sodium, and zinc on muscle mass, muscle strength, and physical performance in older adults: A systematic review. *J Am Med Dir Assoc* 19(1): 6–11. e3. https://doi.org/10.1016/j.jamda.2017.05.026.

El Yamani M, El Hassan S, Mansouri F, Caid H, Elamrani A, Rharrabti Y. 2019a. Effect of pigments and total phenols on oxidative stability of monovarietal virgin olive oil produced in Morocco. *Riv Ital Delle Sostanze Grasse* 96: 17–24.

El Yamani M, Sakar EH, Boussakouran A, Benali T, Rharrabti Y. 2019b. Antioxidant activity of phenolic extracts from olive mill wastewater and their influence on virgin olive oil stability. *Moroc J Chem* 7(1): 211–223. https://doi.org/10.48317/IMIST.PRSM/morjchem-v7i1.13835.

El Yamani M, Sakar EH, Boussakouran A, Rharrabti Y. 2019c. Physiological and biochemical responses of young olive trees (*Olea Europaea* L.) to water stress during flowering. *Arch Biol Sci* 71(1): 123–32.

El Yamani M, Sakar EH, Boussakouran A, Ghabbour N, Rharrabti Y. 2020a. Physicochemical and microbiological characterization of olive mill wastewater (OMW) from different regions of northern Morocco. *Environ Technol* 41(23): 3081–93. https://doi.org/10.1080/09593330.2019.1597926.

El Yamani M, El Hassan S, Boussakouran A, Rharrabti Y. 2020b. Leaf water status, physiological behavior and biochemical mechanism involved in young olive plants under water deficit. *Sci Hortic* 261: 108906. https://doi.org/10.1016/j.scienta.2019.108906.

El Yamani M, Sakar EH, Boussakouran A, Rharrabti Y. 2020c. Activity of two natural additives in improving the stability of virgin olive oil quality during storage. *OCL* 27: 44. https://doi.org/10.1051/ocl/2020039.

El Yamani M, Sakar EH, Boussakouran A, Rharrabti Y. 2020d. Influence of ripening index and water regime on the yield and quality of "Moroccan Picholine" virgin olive oil. *OCL* 27: 19. https://doi.org/10.1051/ocl/2020015.

Faez M, Bchitou R, Boulmane M, Bouhaouss A, Guillaume D. 2013. Modeling of the distribution of heavy metals and trace elements in argan forest soil and parts of argan tree. *Nat Prod Commun* 8: 21–23. https://doi.org/10.1177/1934578x1300800105.

FAOSTAT. 2021. FAO Statistical Yearbook. Rome.

Gharby S, Harhar H, Bouzoubaa Z, Asdadi A, El Yadini A, Charrouf Z. 2017. Chemical characterization and oxidative stability of seeds and oil of sesame grown in Morocco. *J Saudi Soc Agric Sci* 16(2): 105–11. https://doi.org/10.1016/j.jssas.2015.03.004.

Gharby S, Harhar H, Farssi M, Ait Taleb A, Guillaume D, Laknifli L. 2018. Influence of roasting olive fruit on the chemical composition and polycyclic aromatic hydrocarbon content of olive oil. *OCL* 25(3): A303. https://doi.org/10.1051/ocl/2018013.

Gharby S, Ravi HA, Guillaume D, Vian MA, Chemat F, Charrouf Z. 2020. 2-methyloxolane as alternative solvent for lipid extraction and its effect on the cactus (*Opuntia ficus-indica* L.) seed oil fractions. *OCL* 27: 27. https://doi.org/10.1051/ocl/2020021.

Gharby S, Hajib A, Ibourki M, *et al.* 2021. Induced changes in olive oil subjected to various chemical refining steps: A comparative study of quality indices, fatty acids, bioactive minor components, and oxidation stability kinetic parameters. *Chem Data Collect* 33: 100702. https://doi.org/10.1016/j.cdc.2021.100702.

Ibourki M, Gharby S, Azoughigh F, El Ghailassi K, Laknifli A, El Hammadi A. 2019. Determination of mineral and trace elements in leaves of four fruit trees (argan, olive, carob and almond tree) by inductively coupled plasma optical emission spectrometer. *Journal of Anal Sci Appl Biotechnol* 1(2): 22–27. https://doi.org/10.48402/IMIST.PRSM/jasab-v1i2.18968.

Ibourki M, Gharby S, Guillaume D, *et al.* 2021a. Profiling of mineral elements and heavy metals in argan leaves and fruit by-products using inductively coupled plasma optical emission spectrometry and atomic absorption spectrometry. *Chem Data Collect* 35: 100772. https://doi.org/10.1016/j.cdc.2021.100772.

Ibourki M, Azouguigh F, Jadouali S, *et al.* 2021b. Physical fruit traits, nutritional composition, and seed oil fatty acids profiling in the main date palm (*Phoenix dactylifera* L.) varieties grown in Morocco. *J Food Qual*. https://doi.org/10.1155/2021/5138043.

Ibourki M, Ait Bouzid H, Bijla L, *et al.* 2022. Mineral profiling of twenty wild and cultivated aromatic and medicinal plants growing in Morocco. *Biol Trace Elem Res*. https://doi.org/10.1007/s12011-021-03062-w.

King JC, Blumberg J, Ingwersen L, Jenab M, Tucker KL. 2008. Tree nuts and peanuts as components of a healthy diet. *J Nutr* 138: 1736S–1740S. https://doi.org/10.1093/jn/138.9.1736S.

Kodad O, Socias i Company R. 2008. Variability of oil content and of major fatty acid composition in almond (*Prunus Amygdalus Batsch*) and its relationship with kernel quality. *J Agric Food Chem* 56(11): 4096–4101. https://doi.org/10.1021/jf8001679.

Kodad O, Estopañan G, Juan T, *et al.* 2010. Plasticity and stability in the major fatty acid content of almond kernels grown under two Mediterranean climates. *J Hortic Sci Biotechnol* 85(5): 381–86. https://doi.org/10.1080/14620316.2010.11512684.

Kodad O, Estopañán G, Juan T, Socias I, Company R. 2013. Protein content and oil composition of almond from Moroccan seedlings: Genetic diversity, oil quality and geographical origin. *J Am Oil Chem Soc* 90(2): 243–52. https://doi.org/10.1007/s11746-012-2166-z.

Kodad O, Estopañán G, Fagroud M, Juan T, Socias i Company R. 2014. Physical and chemical traits of almond kernels of the local almond populations in Morocco: Commercial and industrial end-uses. *Acta Hortic* 1028: 233–38. https://doi.org/10.17660/ActaHortic.2014.1028.37.

Kodad O, Lebrigui L, El-Amrani L, Socias i Company R. 2015. Physical fruit traits in Moroccan almond seedlings: Quality aspects and post-harvest uses. *Int J Fruit Sci* 15(1): 36–53. https://doi.org/10.1080/15538362.2014.924830.

Martins AN, Gomes C, Ferreira L. 2000. Almond production and characteristics in Algarve, Portugal. *NUCIS Newsl* 9: 6–9.

Moodley R, Kindness A, Jonnalagadda SB. 2007. Elemental composition and chemical characteristics of five edible nuts (almond, Brazil, pecan, macadamia and walnut) consumed in Southern Africa. *J Environ Sci Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes* 42(5): 585–59. http://doi.org/10.1080/03601230701391591.

Özcan MM. 2006. Determination of the mineral compositions of some selected oil-bearing seeds and kernels using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). *Grasas y Aceites* 57(2): 211–18. https://doi.org/10.3989/gya.2006.v57.i2.39.

Özcan MM, Ünver A, Erkan E, Arslan D. 2011. Characteristics of some almond kernel and oils. *Sci Hortic* 127(3): 330–33. https://doi.org/10.1016/j.scienta.2010.10.027.

Prgomet I, Gonçalves B, Domínguez-Perles R, Pascual-Seva N, Barros AI. 2017. Valorization challenges to almond residues: Phytochemical composition and functional application. *Molecules* 22(10). https://doi.org/10.3390/molecules22101774.

Roncero JM, Álvarez-Ortí M, Pardo-Giménez A, Rabadán A, Pardo EJ. 2020. Review about non-lipid components and minor fat-soluble bioactive compounds of almond kernel. *Foods* 9(11): 1646. https://doi.org/10.3390/foods9111646.

Roshila M, Kindness A, Jonnalagadda S. 2007. Elemental composition and chemical characteristics of five edible nuts (almond, Brazil, pecan, macadamia and walnut) consumed in Southern Africa. *J Environ Sci Health Part. B, Pesticides, Food Contaminants, and Agricultural Wastes* 42: 585–91. https://doi.org/10.1080/03601230701391591.

Sakar EH, El Yamani M, Rharrabti Y. 2017a. Frost susceptibility of five almond [*Prunus dulcis* (Mill.) D.A. Webb] cultivars grown in North-Eastern Morocco as revealed by chlorophyll fluorescence. *Int J Fruit Sci* 17(4): 415–422. https://doi.org/10.1080/15538362.2017.1345671.

Sakar EH, El Yamani M, Rharrabti Y. 2017b. Variability of oil content and its physico-chemical traits from five almond (*Prunis dulcis*) cultivars grown in Northern Morocco. *J Mater Environ Sci* 8(8): 2679–2686.

Sakar EH, El Yamani M, Boussakouran A, Rharrabti Y. 2019a. Codification and description of almond (*Prunus dulcis*) vegetative and reproductive phenology according to the extended BBCH scale. *Sci Hortic* 247: 224–234. https://doi.org/10.1016/j.scienta.2018.12.024.

Sakar EH, El Yamani M, Rharrabti Y. 2019b. Geometrical traits in almond fruit as affected by genotypic and environmental variations in Northern Morocco. *Erwerbs-Obstbau* 61(2): 103–12. https://doi.org/10.1007/s10341-018-0401-y.

Sakar EH, El Yamani M, Rharrabti Y. 2020. Fruit gravimetrical traits in almond [*Prunus dulcis* (Mill.) D.A. Webb]: Combined effects of genetic control and environmental drivers. *Erwerbs-Obstbau* 62(1): 37–46. https://doi.org/10.1007/s10341-019-00457-x.

Sakar EH, El Yamani M, Boussakouran A, *et al.* 2021a. Variability of oil content and its physicochemical traits from the main almond [*Prunus dulcis* Mill. DA Webb] cultivars grown under contrasting environments in North-Eastern Morocco. *Biocatal Agric Biotechnol* 32: 101952. https://doi.org/10.1016/j.bcab.2021.101952.

Sakar EH, El Yamani M, Boussakouran A, Rharrabti Y. 2021b. Genotypic and environmental variations in kernel color indices in the main almond (*Prunus dulcis* (Mill.) D.A. Webb) cultivars grown in North-Eastern Morocco. *Scientifica* 2021: e9970223. https://doi.org/10.1155/2021/9970223.

Sathe SK, Seeram NP, Kshirsagar HH, Heber D, Lapsley KA. 2008. Fatty acid composition of California grown almonds. *J Food Sci* 73(9): C607–14. https://doi.org/10.1111/j.1750-3841.2008.00936.x.

Schirra M, Mulas M, Nieddu G, Virdis F. 1994. Mineral content in "Texas" almonds during fruit growth and ripening. *Acta Hortic* 373: 207–14. https://doi.org/10.17660/ActaHortic.1994.373.29.

Simsek M, Demirkiran AR. 2010. Determination of superior almond genotypes in Diyarbakir Central Districts. *Agric J* 5(3): 173–80. https://doi.org/10.3923/aj.2010.173.180.

Simsek M, Kizmaz V. 2017. Determination of chemical and mineral compositions of promising almond (*Prunus Amygdalus* L.) genotypes from Beyazsu (Mardin) Region Beyazsu (Mardin) Yöresisindeki Üstün Badem (*Prunus Amygdalus* Batsch) Genotiplerinin Kimyasal ve Mineral Kompozisyonlarının Belirlenmesi. *Int J Agric Wildl Sci (IJAWS)* 2017: 6–11. https://doi.org/10.24180/ijaws.298525.

Simsek M, Arikan B, Yildirim Y, Olmez N, Boguc F. 2018. Fatty acid, mineral and proximate compositions of various genotypes and commercial cultivars of sweet almond from the same ecological conditions. *Appl Ecol Environ Res* 16. https://doi.org/10.15666/aeer/1603_29572971.

Socias i Company R, Gradziel TM. 2017. Almonds: Botany, production and uses. Wallingford: CABI.

Sorkheh K, Shiran B, Khodambashi M, Moradi H, Gradziel TM, Martínez-Gómez P. 2010. Correlations between quantitative tree and fruit almond traits and their implications for breeding. *Sci Hortic* 125 (3): 323–31. https://doi.org/10.1016/j.scienta.2010.04.014.

USDA. 2010. Agricultural Research Service/USDA, National Nutrient Database for Standard Reference, Release 23. Retrieved 10/4/2010.

Wang W, Wang HL, Xiao XZ, Xu XO. 2019. Wild almond (*Amygdalus Pedunculata* Pall.) as potential nutritional resource for the future: studies on its chemical composition and nutritional value. *J Food Measure Charact* 13(1): 250–58. https://doi.org/10.1007/s11694-018-9939-5.

Williams MH. 2005. Dietary supplements and sports performance: Minerals. *J Int Soc Sports Nutr* 2(1): 43. https://doi.org/10.1186/1550-2783-2-1-43.

Wintergerst ES, Maggini S, Hornig DH. 2007. Contribution of selected vitamins and trace elements to immune function. *Ann Nutr Metab* 51(4): 301–23. https://doi.org/10.1159/000107673.

Yada S, Lapsley K, Huang G. 2011. A review of composition studies of cultivated almonds: Macronutrients and micronutrients. *J Food Compos Anal* 24: 469–480. https://doi.org/10.1016/j.jfca.2011.01.007.

Yada S, Huang G, Lapsley K. 2013. Natural variability in the nutrient composition of California-grown almonds. *J Food Compos Anal* 30(2): 80–85. https://doi.org/10.1016/j.jfca.2013.01.008.

Zahedi SM, Abdelrahman M, Hosseini MS, Yousefi R, Tran LMP. 2020. Physical and biochemical properties of 10 wild almond (*Amygdalus scoparia*) accessions naturally grown in Iran. *Food Biosci* 37. https://doi.org/10.1016/j.fbio.2020.100721.

Zeroual A, Sakar EH, Eloutassi N, Mahjoubi F, Chaouch M, Chaqroune A. 2021. Phytochemical profiling of essential oils isolated using hydrodistillation and microwave methods and characterization of some nutrients in Origanum compactum Benth from Central-Northern Morocco. *Biointerf Res Appl Chem* 11. https://doi.org/10.33263/BRIAC112.93589371.

Cite this article as: Ibourki M, Ait Bouzid H, Bijla L, Aissa R, Sakar EH, Ainane T, Gharby S, El Hammadi A. 2022. Physical fruit traits, proximate composition, fatty acid and elemental profiling of almond [*Prunus dulcis* Mill. DA Webb] kernels from ten genotypes grown in southern Morocco. *OCL* 29: 9.