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Fatty acids composition and physical characteristics of chickpea seeds

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Abstract

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Cicer arietinum L. is the second most widely grown legume crop in the world. Although it cannot be referred to oil-bearing seeds, its seeds are rich in nutritionally important unsaturated fatty acids, i.e. the chickpea diversity is worth evaluating for fatty acid composition. The goal was to evaluate some chemical and physical characteristics of chickpea seeds from the collection of the National Center for Plant Genetic Resources of Ukraine (NCPGRU). To accomplish this, the following objectives were solved: determination of the total lipid content and geometrical characteristics of the NCPGRU's collection chickpea seeds as well as screening them for fatty acid profiles. Twenty-eight chickpea accessions were grown in the eastern forest-steppe of Ukraine and harvested in 2018, 2019, and 2020. On average across the study years, the oil content was 6.94±0.48% and 5.91±0.98% in *kabuli* and *desi* seeds, respectively, with a significant difference between *kabuli* and *desi* types. The oil content in Ukrainian accessions ranged from 5.64±1.02% (*desi* chana) to 7.58±0.39% (*kabuli* chana). The total oil content was not significant correlated with the seed size or with the sphericity of seeds for the *kabuli* accessions, but it was strongly positively correlated with the seed size and sphericity for the *desi* ones. Five major peaks were detected in *C. arietinum* oil: palmitic, stearic, oleic, linoleic and linolenic acids. Five minor fatty acids were also detected: myristic, palmitoleic, eicosanoic, eicosenoic, and behenic. They are ranked in order of decreasing levels as follows: linoleic > oleic >palmitic > linolenic > stearic > palmitoleic/behenic > eicosanoic > eicosenoic/myristic. The total amount of monounsaturated fatty acids was on average higher in the *kabuli* type (27.7±1.71% vs. 24.3±2.98% in *kabuli* and *desi* chana, respectively), while the total amount of polyunsaturated fatty acids was on average higher in the *desi* type (59.5±1.42% vs. 62.4±2.78% *kabuli* and *desi* chana, respectively). The other oil quality indices (desirable fatty acids [DFA], undesirable hypercholesterolemic fatty acids [UHFA], unsaturated/saturated coefficient, omega-6: omega-3 ratio, omega-9/saturated fatty acids ratio, DFA: UHFA ratio, and atherogenicity index) did not differ between *kabuli* and *desi* types. A Spanish *kabuli* accession, Garbanzo 2, had the best combination of these indices.

Keywords: chickpea; fatty acids; oil quality indices; seed size

Introduction

The chickpea (chana) (*Cicer arietinum* L.) is grown in over 50 countries, being the second most widely grown legume crop in the world (FAOSTAT, 2018). There are two distinct types of chickpea called *desi* and *kabuli* that differ primarily in size, color and surface of seeds. The *kabuli* chana has large round light seeds with smooth coats. The *desi* chickpeas are characterized by small angular seeds of various dark colors, with wrinkled testas.

It is a well studied plant for its nutritional value (Wallace et al., 2016) and is important in Indian, Mediterranean and Middle Eastern cuisines. Recent research suggests that chickpeas may play a beneficial role in weight control, regulation of glucose and insulin levels, as well as positively affect some markers of cardiovascular diseases (Pittaway et al., 2008; Mollard et al., 2012; O'Neil et al., 2014). It is not only a cheap source of high quality protein, but also a good source of carbohydrates, minerals and trace elements (Wallace et al*.,* 2016). The essential fatty acids containing in its oil are other important organic components of chickpeas (Gul et al., 2008). *C. arietinum* cannot be referred to oil-bearing seeds, as the oil content in chickpea seeds is reported to be relatively low and vary within 2.05-10.20% in different studies (Kaur et al., 2005; Alajaji et al., 2006; Wood & Grusak, 2007; Shad et al., 2009). However, chickpea oil is not only of nutritional but also of medicinal importance (Abbasifardab et al., 2020). Its seeds are rich in nutritionally important unsaturated fatty acids like linoleic and oleic acid. On the other hand, unsaturated fatty acids make legume products susceptible to oxidative processes leading to undesirable odor formation. Being better for the human health, polyunsaturated acids are more prone to lipid peroxidation, which shortens the shelf life of polyunsaturated oils (Gibson, 2018). Bearing in mind all effects of the oil composition, one should comprehensively investigate vegetable oils, including chickpea one.

As the chickpea is a key component of plant production in Asia and Africa, recently published studies of chickpea oil were conducted on Indian or Pakistan cultivars. However cultivars originating from other regions may differ in the seed quality, including fatty acid levels. In addition, basic studies were carried out decades ago, and the oil composition could be changed over such a long period.

The genetic diversity is indispensable to successful breeding and growing of any crop. Crop collections are bases for selection and crossing all over the world. The chickpea collection of the National Center for Plant Genetic Resources of Ukraine (NCPGRU) boasts 1,970 accessions (49% of accessions are *kabuli* chana) from 55 countries. It is well characterized for protein content, but little is known about oil from the collection chickpea accessions. Vus et al. (2021) started screening the NCPGRU's chickpea collection for the total lipids. However, there is no available information on fatty acids in chickpea seeds of the NCPGRU's collection. Therefore, a goal was set to evaluate some chemical and physical characteristics of chickpea seeds from the NCPGRU's chickpea collection. To accomplish this, the following objectives were solved: determination of the total lipid content and geometrical characteristics of the NCPGRU's collection chickpea seeds as well as screening them for fatty acid profiles.

Materials and Methods

Test accessions: *C. arietinum* accessions were kindly provided by the National Center for Plant Genetic Resources of Ukraine. Twenty-eight chickpea accessions, which were considered as well-adapted to Ukrainian conditions and are being extensively involved in crossing and breeding, were studied. Although chickpeas are traditionally classified as *kabuli* chana or *desi* chana based on seed size, shape, and color, there are modern *kabuli* cultivars with relatively small seeds as well as large-seeded *desi* cultivars. Hence, the chana categorization in this study was based primarily on color of seeds and 17 *kabuli* and 11 *desi* accessions were studied. As to origin, 10 accessions were Ukrainian; 4 – Canadian; 3 – Spanish; 2 – Israeli; 2 – Russian; 2 – Kazakh; 1 – Syrian; 1 – Croatian; 1 – Azerbaijani; 1- Georgian; and 1 – Nepalese (Table 1).

C. arietinum was grown in experimental plots of the Plant Production Institute named after V.Ya. Yuriev of NAAS (eastern forest-steppe of Ukraine; Kharkivska Oblast, Kharkivskyi District; N 49°59′39″, E 36°27′09″) in compliance with conventional farming techniques. The record plot area was 5 m^2, in three replications each year. Seeds were harvested in 2018, 2019, and 2020. Whole seeds were milled on a laboratory mill LZM (Olis, LLC, Ukraine). Freshly harvested seeds were used for analyses.

Seed size: To determine the average seed size (geometric mean diameter D_g) and sphericity (Sph), 10 seeds were randomly picked and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured using a sliding calliper with an accuracy of 0.1 mm. D_g was calculated by using the following formula: $D_g = (L\times W\times T)^{1/3}$. Sph was calculated as D_g/L (Mohsenin, 1986).

Total lipid content: Three samples of each accession were analyzed for each year. Lipids were extracted from dried (to the constant weight) whole chickpea seeds (700-800 mg in two replications) by Soxhlet technique (Juhaimi et al., 2019). Oil was repeatedly washed (percolated) with petroleum ether of boiling range between 40-60°C. The Soxhlet extractor (Cordial, China) was heated to 40°C (hot extraction). After 6-hour incubation at 40°C, the solvent was evaporated under vacuum using a rotary evaporator (Ika, Germany). The percentage of oil in the initial sample was calculated using the following formula:

Total lipids (crude oil), % = weight of obtained oil ′ 100/ weight of absolutely dry milled seeds used in a run.

Gas chromatography: Three samples of each accession were analyzed for each year. Fatty acid methyl esters were prepared by the modified Peisker method (Peisker, 1964). Chloroform-methanol-96% sulfuric acid mixture in a ratio of 100:100:1 was used for methylation. 30 – 50 µl of lipid extract was placed in a glass ampoule; 2.5 ml of methylation mixture was added, and the ampoule was sealed. Ampoules were incubated in a thermostat at 105°C for 3 hours. After methylation, ampoules were opened, the contents were transferred to test tubes, a pinch of powdered zinc sulfate was added, and then 2 ml of distilled water and 2 ml of hexane were poured to extract methyl esters. After thoroughly stirring and settling, the hexane extracts were filtered and analyzed by gas chromatography (Prokhorova, 1982).

Fatty acid composition was determined using a gas chromatograph Selmikhrom 1 (OAO SELMI, Ukraine) equipped with a flame ionization detector (FID). The stainless steel column, 2.5 m length × 4 mm i.d., was packed with a stationary phase, Inerton AW-DMCS (0.16-0.20 mm) processed with 10% diethylene glycol succinate. 2 ml of hexane solution of fatty acid methyl esters was injected. Gas chromatography was operated under the following conditions: nitrogen flow 30 mL/min; hydrogen flow 30-35 mL/min; air flow 300 mL/min; column temperature 180°C; injector temperature 230 °C and FID temperature 220°C. The chromatograph had the standard deviation of peak retention time (standard deviation of output signal) of 0.6%; the temperature control quality was as follows: the accuracy was ±0.7^{o}C and the instrumental error was 0.3% for the thermostat; the instrumental error was 0.3% for the FID. The fatty acids were identified by comparing the retention time of sample with those of reference fatty acid methyl esters (Sigma-Aldrich, US).

Statistical analysis: The percentages of fatty acid methyl esters were calculated by internal normalization. The data

Table 1. Chickpea seed characteristics (mean ± standard deviation)

Registration number	Country of origin	Accession	Oil content,%	Seed size, mm	Sphericity
kabuli					
UD0500424	Ukraine	Rozanna	7.15±0.74	7.91±0.34	0.93±0.03
UD0500264	Ukraine	Dniprovskyi 1	6.54±0.32	7.40±0.34	0.92±0.03
UD0500240	Syria	ILC 3279	6.88±0.59	7.77±0.36	0.94±0.04
UD0502196	Kazakhstan	Kamyla 1255	6.73±0.71	7.33±0.52	0.92±0.03
UKR001: 0502102	Spain	Garbanzo 2	6.39±0.17	8.69±0.43	0.85±0.03
UKR001: 0502064	Israel	Zehavit	7.49±0.49	8.71±0.33	0.90±0.04
UD0502097	Ukraine	Luh 99/11	6.43±0.06	7.88±0.38	0.93±0.04
UD0502099	Ukraine	Luh 101/11	6.53±0.07	8.03±0.38	0.88±0.03
UKR001: 0502095	Spain	Alcazaba	7.10±0.29	6.44±0.55	0.86±0.03
UKR001: 0502116	Croatia	–	7.17±0.12	8.39±0.49	0.89±0.03
UKR001: 0502106	Spain	Garbanzo 3	6.28±0.35	7.67±0.62	0.90±0.03
UKR001: 0502076	Ukraine	L 273-18	7.44±0.60	7.43±0.35	0.93±0.02
UKR001: 0502080	Ukraine	L 279-18	7.58±0.39	8.51±0.48	0.91±0.05
UKR001: 0502090	Ukraine	L 292-18	7.10±0.29	8.07±0.48	0.91±0.04
UD0500196	Azerbaijan	–	6.24±0.79	7.26±0.45	0.93±0.04
UD0502194	Kazakhstan	Luch	7.25±0.17	7.47±0.59	0.94±0.08
UD0502200	Canada	B-90	7.71±0.55	7.67±0.30	0.91±0.05
		Mean	6.94±0.48	7.80±0.58	0.91±0.03
UD0502201	Canada	CDC Vanguard	6.82±0.17	7.17±0.49	0.91±0.06
UKR001: 0502059	Ukraine	–	6.47±0.39	7.19±0.36	0.89±0.04
UKR001: 0502061	Ukraine	–	6.76±0.44	6.91±0.40	0.89±0.02
UKR001: 0502111	Russian Federation	Avatar	5.91±0.14	7.79±0.33	0.86±0.03
UD0500263	Ukraine	Chornyi	5.64±1.02	7.93±0.35	0.89±0.04
UD0500022	Georgia	–	4.49±0.13	6.23±0.60	0.76±0.05
UD0500101	Russian Federation	Krasnokutskiy 123	6.72±0.22	8.69±0.61	0.84±0.05
UKR001: 0501960	Nepal	–	7.35±0.25	8.28±0.52	0.84±0.05
UD0502195	Israel	–	4.76±0.45	6.23±0.27	0.81±0.07
UD0502198	Canada	CDC Ebony	4.97±0.38	6.43±0.42	0.80±0.05
UD0502199	Canada	CDC Jade	5.06±0.19	7.06±0.40	0.71±0.04
		Mean	5.91±0.98	7.26±0.82	0.84±0.05

were statistically processed in STATGRAPHICS PLUS, using the Fisher's LSD test or Mann-Whitney test for comparisons. The results are presented as mean ± standard deviation (SD) and reported to three significant figures.

The oil quality indices were calculated using the following formulae (Ulbricht & Southgate, 1991; Rhee, 1992):

Desirable fatty acids (DFA) = (UFA + C18:0);

Undesirable hypercholesterolemic fatty acids (UHFA) = (C14:0 + C16:0);

Atherogenicity index (AI) = (4 × C14:0 + C16:0)/ (UFA), where UFA is the total amount of unsaturated fatty acids.

Results and Discussion

Total lipid content: The chickpea exhibits higher oil content than other legumes, and Yegrem (2021) demonstrated a wide genotypic variation of this trait across chickpea accessions. The total lipid concentration in seeds of Ethiopian chickpeas ranged from 3.77% to 7.41%. *Kabuli* seeds were reported to contain more total lipids than *desi* seeds (3.40-8.83% vs. 2.90-7.42%) (Kinfe, 2015). Vus et al. (2021) reported that, on average across the study years, the oil content was 7.08% (range 5.22 -8.69%) and 6.05% (range 4.40- 7.26%) in *kabuli* and *desi* seeds, respectively. This parameter was little variable with coefficient of variation of 6.88–15.04% and 8.98–14.15% for *kabuli* and *desi* chana, respectively. *Kabuli* seeds contained more oil, regardless of the growing conditions. Earlier, similar data were published by Ravi & Harte (2008). We also found similar differences: on average across the study years, the oil content was 6.94±0.48% (from 6.24±0.79% in UD0500196 to 7.71±0.55% in B-90) and 5.91±0.98% (from 4.49±0.13% in UD0500022 to 7.35±0.25% in UKR001:0501960) in *kabuli* and *desi* seeds, respectively, with a significant difference between *kabuli* and *desi* types ($p<0.05$) (Table 1). The oil content in Ukrainian accessions ranged from 5.64±1.02% (in an old Ukrainian *desi* cultivar, Chornyi) to 7.58±0.39% (in a *kabuli* line, L279-18).

The coefficient of variation was also comparable with that reported by Vus et al. (2021): approximately 6.89% and 16.6% for *kabuli* and *desi* chana, respectively. There was no significant correlation between the total oil content and the seed size or between the total oil content and sphericity of seeds for the *kabuli* accessions, but there were strong positive correlations between the total oil content and the seed size ($r=0.70$) and between the total oil content and sphericity of seeds ($r=0.69$) for the *desi* ones. Reviewing literature, we can conclude that this relationship is not universal for different crops. In red wheat varieties, concentrations of lipids were higher in small than in large kernels (Chiu & Pomeranz, 2006). In the safflower, a negative correlation between the grain oil content and the mean geometric diameter or sphericity of the grain was reported (Cerrotta et al., 2020). According to Baker & McKenzie's study (1972), the oil content was not significantly correlated with the kernel size in the oats. However, a direct correlation between the grain size and oil content in grain was observed in wild oats species (Loskutov, 2000). The seed size was significantly positively correlated with the crude fat content in castor accessions (Huang et al., 2015). Even within one crop, data may be controversy. In the soybean, the relationship between the 100-seed weight and oil content was weak and time-variable (Marega et al., 2001). Nevertheless, *GmSWEET10a* a pleiotropic gene, was revealed to simultaneously affect the seed size and oil content in soybean lines, and lines with higher 100-seed weight contained more oil and vice versa (Wang et al., 2020). De Man & Bruyneel (1987) reported that smaller barley grains contained as much fatty acids as the bigger ones. Gordon et al. (2018) also believed that grain size was not related to lipids in barley. Still, Ay et al. (2018) found a weak ($r=-0.17$), but significant, negative correlation between the lipid content and thousand kernel weight in barley lines. In maize, the oil content in the whole grain was not related to either the grain shape or to the size (Raju et al., 2007). Hence, it seems that relationship between the oil content and seed size or its sphericity is not a common feature for different crops or even for different chickpea types.

Fatty acid composition: Gas chromatography of the fatty acid methyl esters was able to detect five major peaks in oil from *C. arietinum* accessions: palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2) and linolenic (C18:3) acids, which is consistent with other researchers' data (Table 2), except for Zia-Ul-Haq et al. (2007), who determined a surprisingly low content of linolenic acid and a surprisingly high content of palmitic acid. We also detected five minor fatty acids: myristic (14:0), palmitoleic (16:1), eicosanoic or arachidic (20:0), eicosenoic or gadoleic (20:1), and behenic (22:0) acids. They are ranked in order of decreasing levels as follows: linoleic > oleic > palmitic > linolenic > stearic > palmitoleic/behenic > eicosanoic > eicosenoic/myristic. We did not find auric or eicosadienoic, or erucic, or lignoceric acids, though small amount of these fatty acids were reported (Wang & Daun, 2004).

Palmitic acid is considered to contribute to development of cardiovascular diseases (Shramko et al., 2020) and cancer (Binker-Cosen et al., 2017; Bojková et al., 2020). However, recent research has demonstrated that the negative effects of palmitic acid could "shadow" its multiple crucial physiological functions, as under normal physiological conditions,

Table 2. Fatty acid profiles and oil quality indices in chickpea seeds (literature data)

Reference	Fatty acid contents, % of the oil yield														Nutrition and dietetic value				
	Lauric C12:0	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1 (omega-7)	Stearic C18:0	Oleic C18:1 (omega-9)	Linoleic C18:2 (omega-6)	Linolenic C18:3 (omega-3)	Eicosanoic (arachidic) C20:0	Eicosenoic (gadoleic) C20:1 (omega-11)	Eicosadienoic C20:2 (omega-6)	Behenic C22:0	Erucic C22:1 (omega-9)	Lignoceric C24:0	Unsaturated/ Saturated coefficient	Approximate omega-6:Omega-3 ratio	AI	Approximate omega-9/ SFA ratio	DFA:UHFA
Baker *et al.* (1961) (wt-% of total elute; chickpea type is not specified).	NR	0.3	12.7	0.1	1.5	19.3	62.9	3.3	Traces	ND	ND	ND	NM	ND	5.9	19:1	0.16	1:1	6.70
Wang and Daun (2004) (% of the oil yield)	ND (*kabuli*) 0.02 (*des*)	0.21 (*kabuli*) 0.22 (*desi*)	9.41 (*kabuli*) 9.09 (*desi*)	0.30 (*kabuli*) 0.26 (*desi*)	1.42 (*kabuli*) 1.16 (*desi*)	32.56 (*kabuli*) 22.31 (*desi*)	51.20 (*kabuli*) 61.62 (*desi*)	2.69 (*kabuli*) 3.15 (*desi*)	0.66 (*kabuli*) 0.51 (*desi*)	0.57 (*kabuli*) 0.50 (*desi*)	0.06 (*kabuli*) 0.12 (*desi*)	0.42 (*kabuli*) 0.37 (*desi*)	0.07 (*kabuli*) 0.13 (*desi*)	0.17 (*kabuli*) ND (*desi*)	7.1 (*kabuli*) 7.7 (*desi*)	19:1(*kabuli*) 20:1 (*desi*)	0.12 (*kabuli*) 0.11 (*desi*)	3:1 (*kabuli*) 2:1 (*desi*)	9.24 (*kabuli*) 9.59 (*desi*)
Zia-Ul-Haq et al. (2007) (means ± SD on dry weight basis; *desi*)		NR	From 17.8 ± 0.1 to 21.5 ± 0.1	From 0.3 ± 0.1 to 0.9 ± 0.0	From 0.9 ± 0.1 to 1.0 ± 0.0	From 20.9 ± 0.1 to 24.4 ± 0.2	From 52.9 ± 0.2 to 55.2 ± 0.2	From 0.3 ± 0.1 to 1.0 ± 0.1	From 1.0 ± 0.0 to 1.8 ± 0.0	NR	NR	NR	NR	NR	From 3.1 to 3.8	From 36:1 to 79:1	From 0.23 to 0.28	1:1	From 3.57 to 4.54
Khrisanapant et al. (2019) (g/100g lipids ; *kabuli)*		NR	10.94 ± 0.20	NR	1.80 ± 0.16	37.87 ± 0.16	45.78 ± 0.42	2.33 ± 0.05	NR	NR	NR	NR	NR	NR	6.8	20:1	0.13	3:1	8.02
Grela et al. (2017) (100 g^{-1} **fat;** chickpea type is not specified)		0.19	9.77	0.09	1.88	33.6	50.6	2.42	0.78	0.52	NR	0.03	NR	0.02	6.9	21:1	0.12	3:1	8.95
USDA (2018) (g 100-g;)	ND	0.19[a]	10.8[a]	0.26[a]	1.83[a]	28.9[a]	55.9[a]	2.17[a]	ND	ND	NM	NM	NM	NM	6.8	26:1	0.13	2:1	8.10

[a] calculated from available data.

Note: ND-measured but not detected; NM-not measured; NR-not reported

Table 3. Fatty acid profiles and oil quality indices in the *kabuli* accessions under investigation

Accession	Fatty acid contents, % of the oil yield														Nutrition and dietetic value				
	Lauric C12:0	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1 (omega-7)	Stearic C18:0	Oleic C18:1 (omega-9)	Linoleic C18:2 (omega-6)	Linolenic C18:3 (omega-3)	Eicosanoic (arachidic) C20:0	Eicosenoic (gadoleic) C20:1 (omega-11)	Eicosadienoic C20:2 (omega-6)	Behenic C22:0	Erucic C22:1 (omega-9)	Lignoceric C24:0	Unsaturated/Saturated coefficient	Approximate omega-6:Omega-3 ratio	AI	Approximate omega-9/ SFA ratio	DFA:UHFA
Rozanna	ND	0.11±0.01	10.2±0.13	0.39±0.05	1.58±0.24	24.9±1.12	59.2±1.04	2.93±0.06	0.33±0.06	0.12±0.02	ND	0.38±0.16	ND	ND	6.9	20:1	0.12	2:1	8.64
Dniprovskyi 1	ND	0.08±0.01	10.1±0.41	0.47±0.04	1.14±0.10	28.1±1.21	56.7±1.09	2.77±0.07	0.27±0.04	0.12±0.02	ND	0.28±0.09	ND	ND	7.4	21:1	0.12	2:1	8.77
ILC 3279	ND	0.09±0.02	10.5±0.11	0.44±0.08	1.58±0.25	27.3±2.82	56.6±2.81	2.77±0.20	0.35±0.08	0.11±0.02	ND	0.32±0.14	ND	ND	6.8	20:1	0.12	2:1	8.39
Kamyla 1255	ND	0.07±0.01	10.9±0.17	0.51±0.08	1.39±0.11	27.6±3.76	55.6±3.82	3.02±0.28	0.33±0.05	0.14±0.02	ND	0.41±0.04	ND	ND	6.6	18:1	0.13	2:1	8.05
Garbanzo 2	ND	0.09±0.01	9.70±0.29	0.48±0.10	1.14±0.13	28.8±4.40	56.0±4.30	2.98±0.31	0.29±0.03	0.12±0.03	ND	0.34±0.10	ND	ND	7.6	19:1	0.11	2.5:1	9.14
Zehavit	ND	0.09±0.02	10.4±0.44	0.48±0.15	1.40±0.14	27.8±2.65	56.2±2.50	2.80±0.20	0.34±0.06	0.11±0.03	ND	0.29±0.09	ND	ND	7.0	20:1	0.13	2:1	8.46
Luh 99/11	ND	0.09±0.01	10.1±0.25	0.44±0.06	3.36±0.46	24.0±2.02	58.0±2.40	2.85±0.17	0.63±0.17	0.12±0.02	ND	0.42±0.11	ND	ND	5.9	20:1	0.12	2:1	8.71
Luh 101/11	ND	0.08±0.02	11.0±0.13	0.61±0.08	1.45±0.21	26.9±2.44	56.3±2.30	3.01±0.06	0.32±0.08	0.12±0.02	ND	0.31±0.14	ND	ND	6.6	19:1	0.13	2:1	7.98
Alcazaba	ND	0.10±0.02	11.3±0.29	0.52±0.03	1.41±0.07	22.6±2.33	60.1±2.42	3.37±0.34	0.32±0.03	0.12±0.03	ND	0.24±0.10	ND	ND	6.5	18:1	0.13	2:1	7.73
UKR001: 0502116	ND	0.09±0.12	11.0±0.47	0.51±0.09	1.57±0.21	26.4±2.95	57.0±2.44	2.70±0.21	0.30±0.04	0.12±0.03	ND	0.34±0.16	ND	ND	6.5	21:1	0.13	2:1	7.96
Garbanzo 3	ND	0.08±0.01	10.6±0.53	0.50±0.11	1.20±0.09	28.2±2.67	55.5±2.94	3.31±0.39	0.27±0.06	0.11±0.03	ND	0.32±0.09	ND	ND	7.0	17:1	0.12	2:1	8.32
L 273-18	ND	0.07±0.02	10.1±0.23	0.50±0.12	1.19±0.10	28.7±3.13	56.0±3.24	2.67±0.14	0.28±0.07	0.14±0.05	ND	0.35±0.12	ND	ND	7.3	21:1	0.12	2:1	8.77
L 279-18	ND	0.08±0.01	11.0±0.43	0.45±0.09	1.51±0.05	28.3±1.68	55.0±2.06	2.88±0.09%	0.32±0.03	0.13±0.03	ND	0.34±0.13	ND	ND	6.5	19:1	0.13	2:1	7.97
L 292-18	ND	0.08±0.01	11.3±0.52	0.51±0.11	1.41±0.11	27.9±1.45	55.3±2.12	2.70±0.11	0.31±0.06	0.16±0.03	ND	0.46±0.09	ND	ND	6.4	21:1	0.13	2:1	7.73
UD0500196	ND	0.08±0.01	10.8%±0.50	0.46±0.16	1.33±0.17	27.5±4.09	56.3%±3.90	2.88±0.24	0.33±0.05	0.12±0.03	ND	0.35±0.11	ND	ND	6.8	20:1	0.13	2:1	8.14
Luch	ND	0.09±0.01	11.1±0.08	0.72±0.04	1.55±0.06	26.9±0.77	56.1±0.66	2.90±0.07	0.35±0.03	0.10±0.01	ND	0.24±0.02	ND	ND	6.5	19:1	0.13	2:1	7.89
B-90	ND	0.09±0.01	10.3±0.79	0.72±0.06	1.43±0.09	27.4±2.21	57.0±1.18	2.54±0.31	0.28±0.04	0.13±0.01	ND	0.25±0.06	ND	ND	7.1	22:1	0.12	2:1	8.59
Mean	-	0.09±0.01	10.6±0.48	0.51±0.09	1.51±0.50	27.0±1.69	56.6±1.35	2.89±0.21	0.33±0.08	0.12±0.01	–	0.33±0.06	–	–	6.8	19:1	0.13	2:1	8.29

Note: ND – measured but not detected.

Table 4. Fatty acid profiles and oil quality indices in the *desi* accessions under investigation

Accession	Fatty acid contents, % of the oil yield															Nutrition and dietetic value				
	Lauric C12:0	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1 (omega-7)	Stearic C18:0	Oleic C18:1 (omega-9)	Linoleic C18:2 (omega-6)	Linolenic C18:3 (omega-3)	Eicosanoic (arachidic) C20:0	Eicosenoic (gadoleic) C20:1 (omega-11)	Eicosadienoic C20:2 (omega-6)	Behenic C22:0	Erucic C22:1 (omega-9)	Lignoceric C24:0	Unsaturated/Saturated coefficient	Approximate omega-6:Omega-3 ratio	AI	Approximate omega-9/ SFA ratio	DFA:UHFA
CDC Vanguard	ND	0.08±0.01	9.60±0.70	0.49±0.04	1.38±0.13	27.8±4.31	57.4±4.37	2.43±0.07	0.28±0.05	0.11±0.01	ND	0.36±0.06	ND	ND	7.5	24:1	0.11	2:1	9.26
UKR001: 0502059	ND	0.09±0.02	11.3±0.46	0.47±0.08	1.38±0.06	23.8±0.59	58.6±1.07	3.67±0.18	0.33±0.06	0.12±0.03	ND	0.41±0.12	ND	ND	6.4	16:1	0.13	2:1	7.73
UKR001: 0502061	ND	0.09±0.01	11.0±0.46	0.47±0.11	1.36±0.13	23.9±0.82	58.6±1.32	3.70±0.29	0.34±0.07	0.11±0.02	ND	0.41±0.07	ND	ND	6.6	16:1	0.13	2:1	8.22
Avatar	ND	0.10±0.01	10.9±0.36	0.49±0.10	1.33±0.08	24.9±1.45	58.1±1.70	3.31±0.16	0.34±0.05	0.12±0.03	ND	0.44±0.06	ND	ND	6.6	18:1	0.13	2:1	8.02
Chornyi	ND	0.12±0.02	11.6±0.31	0.53±0.05	1.31±0.06	22.4±2.67	60.0±2.79	3.16±0.07	0.35±0.09	0.12±0.03	ND	0.43±0.18	ND	ND	6.3	19:1	0.14	1.5:1	7.47
UD0500022	ND	0.11±0.01	11.7±0.38	0.84±0.12	1.18±0.07	19.2±0.62	62.2±0.24	4.08±0.09	0.37±0.05	0.10±0.01	ND	0.20±0.06	ND	ND	6.4	15:1	0.14	1.5:1	7.42
Krasnokutskiy 123	ND	0.09±0.02	11.3±0.37	0.72±0.09	1.61±0.13	29.1±1.00	54.1±0.65	2.39±0.07	0.40±0.03	0.11±0.03	ND	0.20±0.06	ND	ND	6.4	23:1	0.13	2:1	7.73
UKR001: 0501960	ND	0.09±0.02	11.2±0.10	0.75±0.05	1.51±0.09	24.4±0.67	58.6±0.71	2.75±0.07	0.34±0.04	0.09±0.02	ND	0.28±0.09	ND	ND	6.5	21:1	0.13	2:1	7.80
UD0502195	ND	0.13±0.02	13.1±0.47	0.83±0.10	1.41±0.05	20.7±0.36	59.0±0.94	4.14±0.10	0.39±0.04	0.10±0.02	ND	0.23±0.05	ND	ND	5.6	14:1	0.16	1.5:1	6.51
CDC Ebony	ND	0.11±0.01	12.8±0.24	0.82±0.05	1.41±0.10	20.6±0.91	59.9±1.04	3.57±0.24	0.33±0.02	0.15±0.01	ND	0.34±0.04	ND	ND	5.7	17:1	0.16	1.5:1	6.70
CDC Jade	ND	0.09±0.01	10.1±0.23	0.74±0.06	0.87±0.09	21.3±1.41	63.0±1.20	3.37±0.19	0.25±0.04	0.11±0.02	ND	0.22±0.06	ND	ND	7.7	19:1	0.12	2:1	8.77
Mean	–	0.10±0.02	11.3±1.02	0.65±0.16	1.34±0.19	23.5±3.06*	59.1±2.36*	3.33±0.60	0.34±0.04	0.11±0.02		0.32±0.10	–	–	6.5	18:1	0.13	2:1	7.72

* – significant differences between *kabuli* and *desi* types ($p<0.05$)

Note: ND-measured but not detected.

palmitic acid accumulation is prevented by enhanced delta 9 desaturation to palmitoleic acid and/or elongation to stearic acid and further delta 9 desaturation to oleic acid (Carta et al., 2017). Thus, in physiology, consumption of palmitic acid should be considered together with metabolic peculiarities of an individual, and increased amounts of palmitic acid are not necessarily detrimental. The palmitic acid content in chickpeas was lower than in other legumes (cowpea, lentil, mung bean, fava bean, navy bean, kidney bean, black bean, adzuki bean) (Table 2; Khrisanapant et al., 2019) and slightly changed across accessions, regardless of *kabuli* or *desi* type (Table 2). We determined that among the *kabuli* accessions the palmitic acid content varied from 9.70±0.29% in Garbanzo 2 to 11.3±0.29% in Alcazaba (Table 3). As to *desi* type, the palmitic acid content ranged 9.60±0.70% in CDC Vanguard to 13.1±0.47% in UD0502195 (Table 4). Although different researchers report acid contents in different units (means ± SD on dry weight basis or in % of the oil yield), which makes comparisons less informative and means that they should be interpreted with caution), in general, our results were in agreement with the published data. We also found that the palmitic acid content was little variable (the coefficient of variation [%CV] was from 0.89% in IR0501960 (*desi*) to 7.73% in B-90 (*kabuli*).

Linoleic acid (omega-6) is an essential fatty acid; therefore, the consumption of linoleic acid is vital to proper health (Whelan & Fritsche, 2013). The linoleic acid content in chickpeas was higher than that in lentil, cowpea, pea, navy bean, kidney bean, black bean, mung bean or in adzuki bean (Table 2; Khrisanapant et al., 2019). Among the *desi* accessions, the linoleic acid content was maximum in CDC Jade (63.0±1.20%) and minimum in Krasnokutskiy 123 (54.1±0.65%) (Table 4). As to the *kabuli* accessions, the linoleic acid content was maximum in Alcazaba (60.1±2.42%) and minimum in L 279-18 (55.0±2.06%), though there were a number of accessions, which had similar values without significant differences between each other (Table 3). It should be noted that linoleic acid was one of two fatty acids, the mean contents of which differed significantly between *kabuli* and *desi* chana (56.6±1.35 vs. 59.1±2.36%, respectively), and *desi* seeds contained more linoleic acid than *kabuli* ones. This is in agreement with other researchers' data (Jukanti et al., 2012; Wang & Daun, 2004). The linoleic acid content was also little variable: CV ranged 0.38% in UD0500022 (*desi*) to 7.68% in Garbanzo 2 (*kabuli*).

Stearic acid is one of the useful types of saturated fatty acids (Hunter et al., 2010). Higher levels of circulating stearic acid were demonstrated to be associated with a lower risk of atrial fibrillation (Fretts et al., 2014). Stearic acid ingestion causes a drop in circulating long-chain acylcarnitines, suggesting enhanced fatty acid beta-oxidation. This could partly explain differences between palmitic acid and stearic acid, as the former increases cardiovascular and cancer risk whereas the latter decreases both (Senyilmaz-Tiebe et al., 2018). The stearic acid content in chickpeas was significantly lower than in other legumes (Table 2; Khrisanapant et al., 2019). The stearic acid content ranges were between 1.14±0.10%/1.14±0.13% (in Dniprovskyi 1 and Garbanzo 2) and 3.36±0.46% (surprisingly high value in Luh 99/11) and between 0.87±0.09% (unusually low value in CDC Jade) and 1.61±0.13% (in Krasnokutskiy 123) for the *kabuli* and *desi* accessions, respectively (Tables 3 and 4). However, there were no statistically significant differences in the mean values of stearic acid content between the *kabuli* and *desi* accessions. The stearic acid content was medium variable (CV was between 3.36% in L 279-18 (*kabuli*) and 15.7% in ILC 3279 (*kabuli*).

Oleic acid (omega-9) is recognized as vasoprotective, hypotensive and lipid profile-improving (anti-atherogenic) (Massaro & De Caterina, 2002). The oleic acid content in the chickpea accessions under investigation was similar to that in lentil and fava bean, higher than in cowpea, navy bean, kidney bean, black bean, mung bean or in adzuki bean, but lower than in pea (Table 2; Khrisanapant et al., 2019). Oleic acid was the other fatty acid, the amounts of which significantly differed between *kabuli* and *desi* chana: the range was between 22.6±2.33% (Alcazaba) and 28.8±4.40% (Garbanzo 2) for the *kabuli* type (Table 3) and between 19.2±0.62% (UD0500022) and 29.1±1.00% (Krasnokutskiy 123) for the *desi* type (Table 4), i.e., on average the oleic acid level was higher in the *kabuli* accessions. This finding is in line to other authors' results as they reported similar patterns in oleic acid levels in chickpea cultivars (Jukanti et al., 2012; Wang & Daun, 2004). There were moderate variations in the oleic acid content in the accessions under investigation: CV was from 1.72% in UD0502195 (*desi*) to 15.5% in CDC Vanguard (*desi*).

The linolenic acid (omega-3) is an essential fatty acid (Lands, 2016). Its content in chickpeas was slightly lower than that in fava bean or considerably lower in comparison with data reported for other legumes (Table 2; Khrisanapant et al., 2019). The linolenic acid content varied from 2.54±0.31% (B-90) to 3.37±0.34 (Alcazaba) in the *kabuli* types (Table 3) and from 2.39±0.07% (Krasnokutskiy 123) to 4.14±0.10% (UD0502195) in the *desi* types (Table 4). The linolenic acid content was also characterized by moderate variations: CV ranged 1.84% in Luh 101/11 (*kabuli*) to 12.3% in B-90 (*kabuli*).

As to minor acids, there were studies, in which higher levels of erythrocyte and circulating very-long-chain saturated fatty acids (lignoceric (24:0), behenic (22:0) and eicosanoic (20:0)) were revealed to be associated with lower risk of heart failure, atrial fibrillation and sudden cardiac arrest (Fretts et al., 2014*;* Lemaitre et al., 2014; Lemaitre et al., 2018). No or very small amounts of these acids are found in chickpeas, so their effects on human health may be negligible. We did not detect lignoceric acid at all; Wang & Daun (2004) found around 0.17% of lignoceric acid in *kabuli* chickpeas and none in *desi* type, and Grela et al. (2017) detected only 0.02% (Table 2). The amount of eicosanoic acid did not exceed 0.63% (Luh 99/11; *kabuli*) (Table 3) or 0.40% (Krasnokutskiy 123; *desi*) (Table 4), which is generally in line with other researchers' results (Table 2), except for the study (Zia-Ul-Haq et al., 2007), where as high as 1.8% of eicosanoic acid was detected in a *desi* accession. The amount of behenic acid did not exceed 0.46% (L 292-18; *kabuli*) or 0.44% (Avatar; *desi*). Other researchers either detected no behenic acid at all (Table 2), or found trace amounts of this fatty acid (the average values were 0.42% and 0.37% in *kabuli* and *desi* cultivars, respectively) (Wang & Daun, 2004).

In addition to fatty acid levels, a number of indices are used to characterize oil quality: the total amount of monounsaturated fatty acids (MUFA), the total amount of polyunsaturated fatty acids (PUFA), unsaturated/saturated coefficient, omega-6: omega-3 ratio, omega-9/saturated fatty acids (SFA) ratio, the total amount of desirable fatty acids (DFA), the total amount of undesirable hypercholesterolemic fatty acids (UHF*A),* and atherogenicity index (AI). Garbanzo 2 had the best combination of these indices (Table 3).

The total MUFA amount varied from 23.2% in Alcazaba to 29.4% in Garbanzo 2 (*kabuli* type) and from 20.1% in UD0500022 to 29.9% in Krasnokutskiy 123. These values are in line with published data on *desi* seeds (21.4-25.1% (Wang & Daun, 2004; Zia-Ul-Haq et al., 2007), but as to *kabuli* type, the total MUFA content in our accessions was somewhat lower in comparison with values reported by other researchers (33.5% (Wang & Daun, 2004) and even 37.9% (Khrisanapant et al., 2019)).

The total PUFA amount varied from 57.9% in L 279-18 to 63.5% in Alcazaba (*kabuli* type) and from 56.5% in Krasnokutskiy 123 to 66.4% in CDC Jade (*desi* type). Wang & Daun (2004) determined that the total PUFA content was around 54% and 64% in *kabuli* and *desi* types, respectively. The total PUFA amount in *kabuli* seeds was the lowest in Khrisanapant et al.'s study (48.1%) (Khrisanapant et al., 2019). Zia-Ul-Haq et al. (2007) found that *desi* cultivars contained 54%-56% of PUFA. Thus, the total PUFA amount in the *kabuli* and *desi* accessions under investigation was higher than or similar to the published data. It is of note that the total MUFA amount was on average higher in the *kabuli* type (27.7±1.71% vs. 24.3±2.98% in *kabuli* and *desi* chana, respectively; $p < 0.05$), while the total PUFA amount was on average higher in the *desi* type (59.5±1.42% vs. 62.4±2.78% *kabuli* and *desi* chana, respectively; $p < 0.05$).

Of the *kabuli* accessions, Luh 99/11 had the lowest unsaturated/saturated coefficient (5.9), and Garbanzo 2 – the highest (7.6) (Table 3). In the *desi* accessions, the unsaturated/saturated coefficient ranged from 5.6 in UD0502195 to 7.7 in CDC Jade (Table 4). It is evident that neither of types is superior in terms of the unsaturated/saturated coefficient. These findings are generally consistent with the values calculated from literature data (see Table 2; Baker et al., 1961; Wang & Daun, 2004; Grela et al., 2017; USDA, 2018; Khrisanapant et al., 2019), though some researchers provided the data, from which the unsaturated/saturated coefficient turned out to be much lower (3.1 – 3.8; [Zia-Ul-Haq et al., 2007]). This is explained by a lower level of linolenic acid and a higher content of eicosanoic acid in their accessions. Eicosanoic acid is a very-long-chain saturated fatty acid, but it is not necessarily harmful (see above). It is a matter of argument if these considerations should be taken into account when chickpea seed quality is evaluated, given a very small amount of eicosanoic acid in chickpea seeds.

Grela et al. (2017) found a low AI of 0.12 in chickpea compared to that of common bean (0.26) (Table 2). Similar AI values were reported by (Wang & Daun, 2004; USDA, 2018; Khrisanapant et al., 2019). The AI calculated from an old study of chickpea was slightly higher (0.16; [Baker et al*.,* 1961]). Basing on Zia-Ul-Haq et al.'s data (2007), we obtained much higher values of 0.23-0.28. Our own data (Tables 3 and 4) were closer to the figures reported by (Wang & Daun, 2004; Grela et al., 2017; USDA, 2018; Khrisanapant et al., 2019) (Tables 2), except for two *desi* accessions (UD0502195 and CDC Ebony) with AI of 0.16. The AI did not differ between *kabuli* and *desi* types.

Recent research has suggested that excessive levels of omega-6 fatty acids relative to omega-3 fatty acids may increase the risk of certain diseases (Hibbeln et al., 2006; Candela et al., 2011). Modern Western diets typically have ratios of omega-6/omega-3 of 20:1 or even 30:1, with the average of 15–17, mainly from vegetable oils, whereas the optimal ratio is thought to be 4:1 or even lower – 1:1 (Simopoulos, 2002; DiNicolantonio & O'Keefe, 2018). As far as this indicator is concerned, none of the studied accessions can be recommended as breakthrough advantageous because of the omega-6/omega-3 ratios of not lower than 15:1 (in UD0502195) (Table 2). Neither of types is better by this parameter. Our results on the omega-6/omega-3 ratios (Tables

3 and 4) are in agreement with the values calculated from the published data (Table 2).

Unlike omega-3 fatty acids or omega-6 fatty acid, omega-9 fatty acids are not classed as essential ones, because they can be synthesized in the human body from other unsaturated fatty acids. We found no available scientific well-grounded data on a desirable omega-9/SFA ratio, though a ratio of 6:1 is mentioned as a well-balanced value (Lederer, 2021). None of the studied accessions had the omega-9/SFA ratios higher than 2.5:1 (Garbanzo 2; see Table 3), which is consistent with the ratios calculated from other researchers' data (Wang & Daun, 2004; Zia-Ul-Haq et al., 2007; Grela et al., 2017; USDA, 2018; Khrisanapant et al., 2019) (Table 2). The significance of this index is dubious, as at least one saturated fatty acid (stearic) is good for health.

The most favorable DFA:UHFA ratio was found for Garbanzo 2 (9.14, *kabuli* type; see Table 3) and CDC Vanguard (9.26, *desi* type; see Table 4), which is slightly higher than that in Grela el al.'s study (2017) (8.94) and than the ratios calculated from Khrisanapant et al.'s (2019) data and the USDA's data (2018) on chickpea nutrients, significantly higher than the ratios calculated from Baker et al.'s (1961) and especially from Zia-Ul-Haq et al.'s (2007) data and in line with the ratios calculated from Wang & Daun's data (2004) (Table 2). The unbeneficial DFA: UHFA ratios in Zia-Ul-Haq et al.'s study (2007) are accounted for an unusually high content of palmitic acid and a lower content of oleic acid in comparison with other studies.

Conclusions

On average across the study years, the oil content was 6.94±0.48% and 5.91±0.98% in *kabuli* and *desi* seeds, respectively, with a significant difference between *kabuli* and *desi* types. The oil content in Ukrainian accessions ranged from 5.64±1.02% (in a *desi* cultivar, Chornyi) to 7.58±0.39% (in a *kabuli* line, L279-18). The total oil content was not significant correlated with the seed size or with the sphericity of seeds for the *kabuli* accessions, but it was strongly positively correlated with the seed size and sphericity for the *desi* ones. Five major peaks were detected in *C. arietinum* oil: palmitic, stearic, oleic, linoleic and linolenic acids. We also detected five minor fatty acids: myristic, palmitoleic, eicosanoic, eicosenoic, and behenic. They are ranked in order of decreasing levels as follows: linoleic > oleic >palmitic > linolenic > stearic > palmitoleic/behenic > eicosanoic > eicosenoic/myristic. The total MUFA amount was on average significantly higher in the *kabuli* type (27.7±1.71% vs. 24.3±2.98% in *kabuli* and *desi* chana, respectively), while the total PUFA amount was on average significantly higher in the *desi* type (59.5±1.42% vs. 62.4±2.78% *kabuli* and *desi* chana, respectively). The other oil quality indices did not differ between *kabuli* and *desi* types. A *kabuli* accession, Garbanzo 2, had the best combination of these indices.

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