FATTY ACID PROFILES OF UNDERUTILIZED EIGHT ETHIOPIAN OKRA (*ABELMOSCHUS ESCULENTUS)* PODS AND SEEDS ACCESSIONS

Habtamu Fekadu **Gemede**
Department of Food Technology and Process Engineering, Wollega University, P.O. Box: 395, Nekemte, Ethiopia
E-mail:fekadu_habtamu@yahoo.com

Abstract
Fatty acid profile of the pods and seeds of eight indigenous Ethiopian okra accessions were studied for the first time in order to identify the possible sources of fatty acid and oil quantity. In the studied pods and seeds of the eight okra accessions, only five fatty acids were identified and quantified. Palmitoleic, linolenic, arachidic and behenic acids were not detected in any of the studied pods and seeds of okra accessions. The study revealed that the fatty acid composition (%) of pods and seeds of okra accessions were significantly (P<0.05) varied and had respective ranges of myristic acid 4.43-6.85 and 3.35-7.75; for palmitic acid were 19.76-24.71 and 13.24-22.26; for stearic acid were 2.35-3.01 and 2.26-10.93; for oleic acid were 10.35-14.66 and 13.90-24.07; for linoleic acid were 8.70-23.38 and 35.31-43.93. The total saturated, monounsaturated, polyunsaturated and unsaturated fatty acid of the pods and seeds of okra accessions were also significantly (P<0.05) varied and ranged from 28.18-36.04 and 20.62-34.97; 11.15-14.95 and 13.90-25.81; 8.70-23.38 and 35.31-43.93; 21.41-36.96 and 51.09-63.54, respectively. In the seeds of okra accessions, the total unsaturated fatty acid was higher than total saturated fatty acid. The crude oil yield of the seeds of eight okra accessions were significantly (P<0.05) varied and ranged from 19.25-38.19%. Comparing with other vegetable oils, the present study revealed that okra seeds could be considered as a potential sources of edible oil. Okra seeds, especially OPA#3 accessions, could be a good source of essential fatty acids such as oleic and linoleic acid. Overall results suggest that okra seed oil may be considered as a new candidate and valuable source of edible oil and can be utilized as multipurpose products for industrial and nutritional purposes and need to be improved through selection and breeding.

Keywords: Okra, Seed, Pod, Accessions, Oil, Fatty Acid

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1. INTRODUCTION

Vegetable oils are important sources of nutritional oils (FAO, 2009), industrial raw materials (Ramadan *et al*., 2006) and pharmaceutical significance (Nzikou *et al*., 2010). Their usefulness in various applications aside from edible purpose depends on their yields, different compositions and their physical and chemical properties (Aluyor & Ori-Jesu, 2008). These factors rely heavily on the crop species or cultivar and upon the environmental conditions in which the crop is grown (Velasco *et al*., 2005). Indeed, no oil from a single source has been found to be suitable for all purposes because oils from different sources generally differ in their composition (Mohammed & JorfThomas, 2003) and this necessitates the search for new sources of novel oils.

In addition, at present, a few vegetable crops such as soybean, cottonseed, peanuts, rapeseed and sunflower dominate the international edible oilseed market (Diemeleou *et al*., 2014; Sorkheh *et al*., 2016). The world consumption of this dominated vegetable oil by soybean, palm, rapeseed, and sunflower oils are 31.6, 30.5, 15.5, and 8.6 million tons per year, respectively (Stevenson *et al*., 2007). The demand for vegetable oils for food purposes has entailed a considerable expansion of oilseed crops production (Camas *et al*., 2007).
A high consumption of vegetable oils has been also reported (Ayerza & Coastes, 2005; Dubois *et al*., 2007; Rezanka & Singler, 2009; Ixtaina *et al*., 2011) which has greatly increased the demand for alternative plant based oils which are low in saturated fats, high in mono-unsaturated and better sources of omega-3 fatty acid. However, these conventional sources of

vegetable oil no longer meet the ever increasing demands of domestic and industrial sectors (Idouraine *et al*., 1996, Sorkheh *et al*., 2016). Therefore, to meet the demand, there is a need not only to increase the production of the major oilseed crops but also to diversify the sources by exploring and increasing the production of minor and neglected crops such as okra vegetable oils is of much concern.

Okra is native vegetable crop in Ethiopia (Kumar *et al*., 2013) and commonly grown for domestic consumption in the tropical and sub-tropical countries of the world (Ogungbenle & Omosola, 2015). Okra seeds contain about 20 to 40% oil (Benchasri, 2012; MEF, 2013). Okra has a potential for cultivation as an oilseed crop because its mature pods contain high quantity of seeds containing considerable amount of oil which could be characterized and utilized for commercial purposes (Anwar *et al*., 2011). Okra seed oil yield is comparable to most oil seed crops except palm and soybean oil (Kumar *et al*., 2010). Moreover, okra seed oil has potential hypocholesterolemic effect. The potential for wide cultivation of okra for edible oil as well as for cake is very high (Kumar *et al*., 2010). Okra seed is rich in unsaturated fatty acids (Oyelade *et al*., 2003); mainly consists of linoleic acid (up to 47.4%), a polyunsaturated fatty acid essential for human nutrition (Andras *et al*., 2005). Fatty acids, especially unsaturated fatty acids are important as nutritional substances and metabolites in living organisms (Sánchez-Salcedo *et al*., 2016).

The fatty acid composition of oils from vegetable sources varies depending on plant origin, genetic factors, ripening grade of fruits and specific climatic conditions (Velasco *et al*., 2005), and plant response to diverse environmental stresses, including pathogen attack (Feussner & Wasternack, 2002). Although a number of studies have been reported on the characteristics of the oil and other components of okra vegetables (Camciuc *et al*., 1998; Pham *et al*., 2003; Ndangui *et al*., 2010; Jarret *et al*., 2011; Ogungbenle & Omosola, 2015). However, there is no published report currently available in the literature on fatty acid profile of Ethiopian okra vegetables. On this basis, the aim of this study was to evaluate fatty acid profile and oil composition of underutilized Ethiopian pods and seeds of okra accessions in order to identify its quantity and quality for consumption and industrial use.

2. MATERIALS AND METHODS

Sample collection and preparation

The pods (immature fruit) and seeds (fully mature fruit) of eight okra accessions (OPA#1, OPA#2, OPA#3, OPA#4, OPA#5, OPA#6, OPA#7 and OPA#8) grown under the same conditions were harvested randomly from Assosa Agricultural Research Center farm, Benishangul Gumuz Regional State, Ethiopia in the 2014 harvesting seasons. The pods and seeds of each okra accessions were coded, packed in polyethylene bags, kept in an ice box (to prevent moisture loss), and transported to Food Technology and Process Engineering Research laboratory of Wollega University, Ethiopia. Once the samples arrived the laboratory, each of the pod accessions were washed by distilled water and sliced to uniform thickness of 5 mm using a stainless steel knife. The moisture content of the pods were determined immediately after slicing to uniform thickness. The seeds were manually removed from the pods, sorted and sun dried. The sliced okra pods were sun dried and then followed by oven drying at 45 ^{o}C. The dried pods and seeds were milled separately into fine powder using an electric grinder until could to pass through 0.425 mm sieve size. Finally, the powder was packed into airtight polyethylene plastic bags and were stored in a desiccator until required for further analysis. All chemicals used were of analytical grades.

Determination of fatty acid profile

Fatty acids were extracted according to Blye & Dyer extraction method (Manirakiza *et al*., 2001). An Eppendorf tube (2 ml) containing 25 mg of sample was added to 330 µl of 4M HCl to disrupt the cell biomass and was incubated at

80 ^{0}C for 1 hour in water bath (Yu *et al*., 2015). After the incubation period, it was centrifuged at 6000 rpm for 5 minutes and the supernatant was discarded.. To the residual biomass, 200 µl of methanol (MeOH) and 100 µl of chloroform ($CHCl_3$) were added and the mixture was vortexed for 2 min. About 100 µl chloroform was added again and the mixture was shaken vigorously for 2 min. About 180 µl of distilled water was added and the mixture was vortexed again for 2 min. The layers were separated after centrifugation for 10 min at 6000 rpm. The lower layer was transferred to a pre-weighed Eppendorf tube. To the upper layer, 200 µl of 10% (v/v) MeOH solution in $CHCl_3$ was added and second extraction was carried out by vortexing for 2 min. After centrifugation at 6000 rpm, once again the lower layer $CHCl_3$ phase was taken out and added to the pre-weighed tube containing the extract from the previous extraction (i.e. the chloroform layer from the first extraction). The collected $CHCl_3$ containing the analyte was then kept in oven at 100 ^{0}C to evaporate $CHCl_3$ completely. Finally, the tube was allowed to cool and was reweighed. The amount of the total lipid was determined by the difference between the initial and the final weight of the tube.

The amount of lipid present in the tube (approximately 5 mg) was dissolved in 0.20 ml of toluene and the mixture was vortexed for 2 min. To this solution, 1.5 ml of methanol and 0.3 ml of 8% w/v HCl solution were added to it and vortexed for two minutes. The solution was then heated at 100 ^{0}C for one hour and cooled for 15 mins. Then 1 ml of hexane and 1 ml of distilled water was added and vortexed for 2 mins and centrifuged at 6000 rpm. Finally, approximately 500 µl of the upper part of hexane layer was collected for GC analysis.

Fatty acid methyl esters were quantified by gas chromatography equipped with a flame ionization detector using a polar column (TG WaxMS A; 30 m x 0.25 umx 0.25 um). Helium was used as a carrier gas (maintained at 1 ml/min constant flow rate and linear velocity of 30 cm/s, Split ratio was 50:1). Oven temperature gradient was maintained at 100 ^{o}C (0.25min), 30^{o}C/min, 220 ^{o}C (0 mins) and 10^o C/min, 250 ^{o}C (3mins). Air flow of 350 ml/min, H_2 at 35 ml/min, and N_2 at 40 ml/min were used throughout the run. The peaks of individual fatty acids were identified by comparing with retention times with those of standard fatty acids. Quantification of individual fatty acids (%) was carried out by dividing each individual peak areas to the total areas of corresponding fatty acids. In addition, sums of total SFA, MUFA, PUFA, UFA, UFA: SFA and Linoleic: Oleic ratios have been calculated.

Extraction of okra seed oil

The soxhlet extractor method described by AOAC (2000) was used for the extraction and determination of the percentage of the oil yields. About 50.000g of okra seed powders was extracted for 4 hrs with 300 ml of n-hexane (40-60°C) in a Soxhlet extractor. Then the solvent was distilled off at 40^{o}C under vacuum in a rotary evaporator (Model N-1Eyela, Tokyo Rikakikal Co.Ltd. Japan). The extracted oil was weighed to determine the oil content of the seed. The extracted crude oils were stored under refrigerator (4^{o}C) in air tight brown sterile glass bottles (Ejikeme *et al*., 2010) for subsequent physicochemical analyses. The percentage yield of the extracted oil was calculated by using the following formula.

$$\text{Yield of oil}\,(\%) = \frac{\text{Weight of oil}}{\text{Initial weight of sample}} \text{ x } 100$$

Statistical analysis

In the present experiment, the completely randomized design (CRD) was used with two replicates. All the statistical analyses were performed for the result obtained using SPSS version 20.0 for windows. Data were evaluated by using one way analysis of variance (ANOVA). Means were separated by the Duncans multiple range test and the result was reported as mean ± standard error (SE). Statistical significant difference was stated at p-value of 0.05 or less than 0.05.

3. RESULTS AND DISCUSSION

Fatty acid profiles

The fatty acid composition is an essential indicator of the nutritional value of oil. The result of the fatty acid concentration (%) of the pods and seeds of eight okra accessions is shown in Tables 1. The percentage of five fatty acids (namely: palmitic, stearic, oleic, linoleic and linolenic acids) were identified and quantified in pods and seeds of eight okra accessions. The concentration of myristic acid ($C_{14:0}$) ranged from 4.43% to 6.85% in the pods and from 3.35% to 7.75% in the seeds. The myristic acid concentration of the pods of OPA#8 was high (6.65%) but did not differ significantly ($P<0.05$) from OPA#1 (6.44%) and OPA#6 (6.41%) whereas OPA#2 (4.87%), OPA#3 (4.48%) and OPA#5 (4.43%) accessions were low (Table 1).

The myristic acid concentration of the seeds of OPA#3 (7.75%) and OPA#4 (7.47%) was significantly ($P<0.05$) high while it was low in OPA#1 (3.47%) and OPA#5 (3.35%) accessions (Table 1). The mean myristic acid concentration of the pod (5.70%) was higher than the seeds (5.40%) of okra accessions (Figure 1). The mean of myristic acid concentration (5.40%) of the seed was higher than those reported for okra seeds vegetables by Ndangui *et al*. (2010) (0.38%), Jarret *et al*., (2011) (0.3115%), De Sousa Ferreira Soares *et al*. (2012) (0.19%) and Ogungbenle & Omosola (2015) (0.2787%).

Palmitic acid ($C_{16:0}$) concentration of the pods varied from 19.76% (OPA#6) to 27.19% (OPA#4) and in the seeds, it varied from 13.24% (OPA#1) to 22.66% (OPA#7) accessions. The palmitic acid concentration of the pods was significantly ($P<0.05$) high in OPA#4 (27.19%) while OPA#6 was the low (19.76 %) but did not differ significantly ($P<0.05$) from OPA#8 (20.93%) and OPA#3 (21.30%) accessions (Table1). In the seeds, the level of palmitic acid was significantly ($P<0.05$) high in OPA#2 (22.03%) and OPA#7 (22.26%) and was followed by OPA#4 (21.00%), OPA#8 (19.67%) and OPA#3 (19.97%) while low in OPA#1 (13.24%) accession (Table 1).

The mean palmitic acid concentration of the pods (22.96%) was higher than the seeds (18.86%) of okra accessions (Figure 1). The mean palmitic acid concentration (18.86%) of the seeds was lower than those reported by Ndangui *et al*. (2010) (25.85%) and Jarret *et al*. (2011) (30.42%) for okra seed vegetables but was higher than the value reported by Ogungbenle & Omosola, (2015) (0.2673%) for okra seeds. Palmitic acid is a major fatty acid that promotes natural oil regeneration and an important component of the skin to retain its protective barrier. With too little oil, the skin will crack and bleed, resulting in a greater risk of infection and disease (Sami *et al*., 2013).

The concentration of stearic acid was ranged from 2.35% (OPA#8) to 3.01% (OPA#5) in the pods and from 2.26% (OPA#2) to 10.93% (OPA#6) in the seed of okra accessions. The stearic acid concentration of the pod was significantly ($P<0.05$) high in OPA#5 (3.01%) and OPA#4 (2.96%) and was followed by OPA#2 (2.68%) and OPA#7 (2.63%) and was low in OPA#8 (2.35%) and OPA#3 (2.40%) accessions (Table 1). The level of stearic acid was significantly ($P<0.05$) high in the seeds of OPA#6 (10.93%) and was followed by the seeds of OPA#4 (8.29%), OPA#7 (8.11%) and OPA#8 (7.90%). The seeds of OPA#2 (2.26%) were the lowest in their level of stearic acid (Table 1). The mean stearic acid concentration of the pods (2.64%) was lower than the seeds (6.27%) of okra accessions (Figure 1). The mean stearic acid level (6.27%) of the seeds of okra accessions was higher than those reported by Berry (1980) (3.80%), Savello *et a*l. (1980) (3.28%), Al-Wandawi (1983) (4.19%), Camciuc *et al*. (1998), Ndangui *et al*. (2010) (2.64%) and Ogungbenle & Omosola (2015) (5.39%) for okra seeds.

Oleic acid content among the accessions of okra varied from 10.35% to 14.95% in the pods and from 13.90% to 25.81% in the seeds. The oleic acid concentration of the pods was significantly ($P<0.05$) high in OPA#4 (14.95%), OPA#2 (14.66%) and OPA#5 (14.37 %) and low in OPA#3 (11.37%), OPA#7 (11.32 %) and OPA#8 (11.15 %) accessions (Table 1).

Table 1 Fatty acid compositions (%) of pods and seeds of eight okra accessions

Accessions		Fatty Acid								
		$C_{14:0}$	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	$C_{20:0}$	$C_{22:0}$
Pods	OPA#1	6.44 ± 0.12^{ab}	24.71 ± 0.06^{b}	ND	2.54 ± 0.05^{c}	13.58 ± 0.31^{b}	23.38 ± 0.35^{a}	ND	ND	ND
	OPA#2	4.87 ± 0.21^{d}	23.00 ± 0.16^{bc}	ND	2.68 ± 0.03^{b}	14.66 ± 0.31^{a}	17.92 ± 0.23^{c}	ND	ND	ND
	OPA#3	4.48 ± 0.08^{d}	21.30 ± 0.37^{cde}	ND	2.40 ± 0.01^{de}	11.37 ± 0.15^{c}	19.93 ± 0.52^{b}	ND	ND	ND
	OPA#4	5.89 ± 0.15^{c}	27.19 ± 0.59^{a}	ND	2.96 ± 0.04^{a}	14.95 ± 0.14^{a}	8.70 ± 0.03^{h}	ND	ND	ND
	OPA#5	4.43 ± 0.24^{d}	24.67 ± 0.12^{b}	ND	3.01 ± 0.04^{a}	14.37 ± 0.06^{a}	14.34 ± 0.03^{d}	ND	ND	ND
	OPA#6	6.41 ± 0.20^{abc}	19.76 ± 0.50^{e}	ND	2.52 ± 0.04^{cd}	10.35 ± 0.04^{d}	12.51 ± 0.09^{e}	ND	ND	ND
	OPA#7	6.22 ± 0.08^{bc}	22.10 ± 0.04^{cd}	ND	2.63 ± 0.00^{bc}	11.32 ± 0.03^{c}	10.09 ± 0.01^{g}	ND	ND	ND
	OPA#8	6.85 ± 0.04^{a}	20.93 ± 1.43^{de}	ND	2.35 ± 0.06^{e}	11.15 ± 0.07^{c}	11.61 ± 0.13^{f}	ND	ND	ND
Seeds	OPA#1	3.47 ± 0.00^{e}	13.24 ± 0.24^{f}	ND	4.08 ± 0.04^{d}	18.63 ± 0.32^{d}	39.95 ± 0.17^{b}	ND	ND	ND
	OPA#2	6.36 ± 0.31^{b}	22.03 ± 0.27^{a}	ND	2.26 ± 0.05^{e}	17.78 ± 0.43^{de}	43.93 ± 0.37^{a}	ND	ND	ND
	OPA#3	7.75 ± 0.17^{a}	19.97 ± 0.36^{c}	ND	3.62 ± 0.08^{d}	24.07 ± 0.11^{b}	39.47 ± 0.23^{b}	ND	ND	ND
	OPA#4	7.47 ± 0.10^{a}	21.00 ± 0.24^{b}	ND	4.97 ± 0.02^{c}	17.91 ± 0.13^{de}	35.31 ± 0.29^{c}	ND	ND	ND
	OPA#5	3.35 ± 0.05^{e}	14.71 ± 0.38^{e}	ND	8.29 ± 0.58^{b}	25.81 ± 0.68^{a}	35.89 ± 0.74^{c}	ND	ND	ND
	OPA#6	4.89 ± 0.12^{cd}	18.01 ± 0.08^{d}	ND	10.93 ± 0.00^{a}	16.89 ± 0.11^{e}	43.71 ± 0.56^{a}	ND	ND	ND
	OPA#7	4.61 ± 0.11^{d}	22.26 ± 0.41^{a}	ND	8.11 ± 0.06^{b}	13.90 ± 0.50^{f}	37.19 ± 0.41^{c}	ND	ND	ND
	OPA#8	5.27 ± 0.17^{c}	19.67 ± 0.17^{c}	ND	7.90 ± 0.03^{b}	22.59 ± 0.13^{c}	36.43 ± 1.43^{c}	ND	ND	ND

Means not followed by the same uppercase superscript letters in each column of the pods and seeds are significantly different ($P<0.05$) from each other. Data are expressed as mean ± standard deviation of two replicate analysis (n=2). Where: $C_{14:0}$, myristic acid; $C_{16:0}$, palmitic acid; $C_{16:1}$, palmitoleic acid; $C_{18:0}$, stearic acid; $C_{18:1}$, oleic acid; $C_{18:2}$, linoleic acid; $C_{18:3}$, linolenic acid; $C_{20:0}$, arachidic acid; $C_{22:0}$, behenic acid. ND: Non-detected.

In the seeds, the level of oleic acid concentration was significantly ($P<0.05$) high in OPA#5 (25.81%) and was followed by OPA#3 (24.07%) and OPA#8 (22.59%) and was low in OPA#7 (13.90%) accessions (Table 1).

The mean oleic acid concentration of the pods (12.72%) was lower than the seeds (19.70%) of okra accessions (Figure 1).

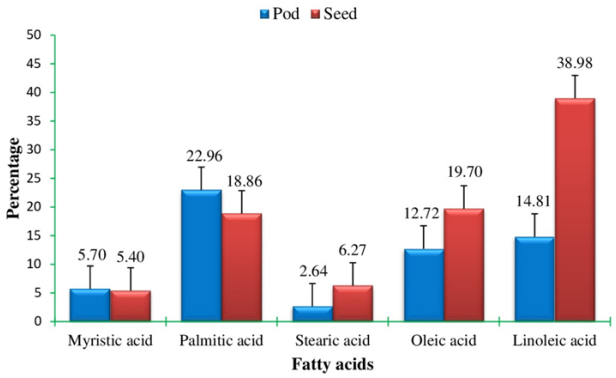


Figure 1 Mean fatty acid composition (%) of the pods and seeds of eight okra accessions

The mean oleic acid concentration (19.70%) in the seeds was in agreement with the value reported for okra seeds by Berry (1980) (19.72%), Savello *et al*. (1980) (17.88%) and De Sousa Ferreira Soares *et al*. (2012) (20.38%). However, it was lower than the result reported by Al-Wandawi (1983) (55.92%), Ndangui *et al*. (2010) (24.61%), Jarret *et al*. (2011) (21.085%), and Ogungbenle & Omosola, (2015) (29.13%) and was higher than the value reported by Camciuc *et al*. (1998) (16.23%) for okra seeds.

Vegetable oils contained high content of oleic acid and hence, reviving much attentions for nutritional and industrial applications (Sharafi *et al*., 2015). Okra seed oil showed similarities to certain oils industrially used for their oleic acid content (corn: 24.8%; linseed: 18.9%; poppy seed: 22.3%; soybean: 23.2%; sunflower seed: 17.7%; walnut kernel: 18.5%) (Demirbaş, 1998).

The result showed that okra is a good source of linoleic acid concentration which varied from 10.09% (OPA#7) to 23.38% (OPA#1) in the pods and in the seeds it varied from 35.89% (OPA#4) to 43.93% (OPA#6). The level of linoleic acid concentration of the pods was significantly ($P<0.05$) high in OPA#1(23.38%) and was followed by OPA#3 (19.93%), OPA#2 (17.92%) and OPA#5 (14.34%) and was low in OPA#4 (8.70%) (Table 1). In the seeds, the level of linoleic acid was significantly ($P<0.05$)

high in OPA#2 (43.93%) and OPA#6 (43.71%) and was low in OPA#4 (35.31%), OPA#5 (35.89%), OPA#7 (37.19%) and OPA#8 (36.43%) (Table 1).

The mean linoleic acid concentration of the pods (14.81%) was lower than the seeds (38.98%) of okra accessions (Figure 1). The mean linoleic acid concentration (38.98%) of the seeds obtained in this study was lower than the values reported for okra seeds by Berry (1980) (44.21%), Camciuc *et al*. (1998) (50.62%), Ndangui *et al*. (2010) (43.40% and 42.15% by Blye and Dyer and Soxlhet, respectively) but was higher than the value reported by Jarret *et al*. (2011) (37.782%) and Ogungbenle & Omosola, (2015) (30.93%). Linoleic acid is one of the most important polyunsaturated fatty acids in human food because of its prevention of distinct heart and vascular diseases. Apart from preventing cardiovascular disorders such as coronary heart diseases and atherosclerosis; linoleic acid prevents high blood pressure. Also linoleic derivatives serve as structural components of the plasma membrane and as precursors of some metabolic regulatory compounds (Matos *et al*., 2009; Bello *et al*., 2011). Linoleic acid is a member of the group of essential fatty acids called omega-6 fatty acids, so called because they are an essential dietary requirement for all mammals and promote the biosynthesis of arachidonic acid, and thus, some prostaglandins.

Linoleic acid is also used in making soaps, emulsifiers, and quick-drying oils. It has become increasingly popular in the cosmetics industry because of its beneficial properties on the skin, including anti-inflammatory, acne-reduction, and moisture-retention properties (Darmstadt *et al*., 2002). Linoleic acid having two double bonds is more susceptible to oxidative rancidity than oleic acid and the saturated fatty acids (Kratz *et al*., 2002). The rancidity of oil is due to the reaction of oxygen with the double bonds of unsaturated fatty acids resulting in the products having unpleasant odor and flavor.

Total saturated fatty acid (SFA) concentration of the pods and seeds of okra accessions are shown in Table 2. The total saturated fatty acid concentration of the accessions was significantly ($P<0.05$) varied from 28.18% (OPA#3) to 36.04% (OPA#4) in the pods however, in the seeds, it varied from 20.62% (OPA#1) to 34.97% (OPA#7). The mean total saturated fatty acid concentration of the pods (31.29%) was relatively similar to the seeds (31.29%) of okra accessions (Figure 1).

Table 2 shows the total monounsaturated fatty acid (MUFA) concentrations of the pods and seeds of okra accessions. The total MUFA concentrations among okra accessions varied from 11.15% (OPA#8) to 14.95% (OPA#4) in the pods and from 13.90% (OPA#7) to 25.81% (OPA#5) in the seeds. The level of total MUFA concentrations of the pods was significantly ($P<0.05$) high in OPA#2 (14.66%), OPA#4 (14.95%) and OPA#5 (14.37%) however, it was low in OPA#3 (11.37%), OPA#7 (11.32%) and OPA#8 (11.15%). In the seeds, OPA#5 was significantly ($P<0.05$) high (25.81%) in its MUFA content and OPA#7 was the lowest (13.90%) on a dry weight basis. The mean total MUFA level of the pods (12.72%) was relatively similar to the seeds (19.70%) (Figure 2).

The total polyunsaturated fatty acid (PUFA) contents of the pods and seeds of okra accessions are given in Table 2. The total PUFA concentration of the pods was significantly ($P<0.05$) high in OPA#1 (23.38%) and low in OPA#4 (8.70%). In the seeds, it was significantly ($P<0.05$) high in OPA#2 (43.93) and low in OPA#4 (35.31%). The mean total PUFA concentration of the pods and seeds were 14.81% and 38.98%, respectively, which implies that the mean total PUFA in the seeds are higher by three folds than the pod of okra accessions (Figure 2).

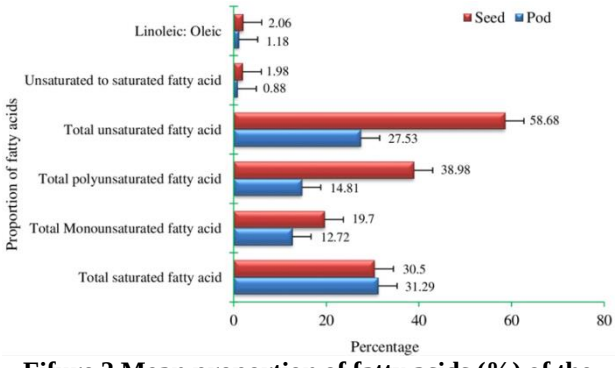
The result of total unsaturated fatty acid (UFA) level of the pods and seeds of okra accessions are presented in Table 2.

Table 2 Proportion of unknown, saturated, monounsaturated and polyunsaturated fatty acids (%) of the pods and seeds of eight okra accessions

	Accessions	Unknown FA	Total SFA	Total MUFA	Total PUFA	Total UFA	UFA: SFA	Linoleic: Oleic
Pods	OPA#1	29.35 ± 0.08^{d}	33.69 ± 0.11^{b}	13.58 ± 0.31^{b}	23.38 ± 0.35^{a}	36.96 ± 0.04^{a}	1.10 ± 0.01^{a}	1.72 ± 0.07^{a}
	OPA#2	36.87 ± 0.31^{c}	30.55 ± 0.39^{cd}	14.66 ± 0.31^{a}	17.92 ± 0.23^{c}	32.58 ± 0.08^{b}	1.07 ± 0.02^{a}	1.22 ± 0.04^{b}
	OPA#3	40.53 ± 0.06^{b}	28.18 ± 0.43^{e}	11.37 ± 0.15^{c}	19.93 ± 0.52^{b}	31.30 ± 0.37^{c}	1.11 ± 0.03^{a}	1.75 ± 0.07^{a}
	OPA#4	40.30 ± 0.36^{b}	36.04 ± 0.47^{a}	14.95 ± 0.14^{a}	8.70 ± 0.03^{h}	23.66 ± 0.11^{e}	0.66 ± 0.01^{e}	0.58 ± 0.01^{e}
	OPA#5	39.19 ± 0.22^{b}	32.11 ± 0.31^{bc}	14.37 ± 0.06^{a}	14.34 ± 0.03^{d}	28.70 ± 0.10^{d}	0.89 ± 0.01^{b}	1.00 ± 0.00^{cd}
	OPA#6	48.45 ± 0.61^{a}	28.69 ± 0.74^{de}	10.35 ± 0.04^{d}	12.51 ± 0.09^{e}	22.86 ± 0.13^{f}	0.80 ± 0.03^{c}	1.21 ± 0.00^{bc}
	OPA#7	47.64 ± 0.06^{a}	30.95 ± 0.03^{c}	11.32 ± 0.03^{c}	10.09 ± 0.00^{g}	21.41 ± 0.02^{g}	0.69 ± 0.00^{de}	0.89 ± 0.00^{d}
	OPA#8	47.12 ± 1.21^{a}	30.13 ± 1.41^{cde}	11.15 ± 0.07^{c}	11.61 ± 0.13^{f}	22.76 ± 0.20^{f}	0.76 ± 0.04^{cd}	1.04 ± 0.01^{c}
Seeds	OPA#1	20.80 ± 0.12^{a}	20.62 ± 0.04^{e}	18.63 ± 0.32^{d}	39.95 ± 0.17^{b}	58.58 ± 0.15^{c}	2.84 ± 0.10^{a}	2.15 ± 0.04^{c}
	OPA#2	7.65 ± 0.82^{c}	30.65 ± 0.02^{c}	17.78 ± 0.43^{de}	43.93 ± 0.37^{a}	61.71 ± 0.81^{ab}	2.01 ± 0.03^{c}	2.47 ± 0.04^{b}
	OPA#3	5.11 ± 0.06^{c}	31.34 ± 0.28^{c}	24.07 ± 0.11^{b}	39.47 ± 0.23^{b}	63.54 ± 0.34^{a}	2.03 ± 0.03^{c}	1.64 ± 0.00^{e}
	OPA#4	13.34 ± 0.51^{b}	33.45 ± 0.35^{b}	17.91 ± 0.13^{de}	35.31 ± 0.29^{c}	53.21 ± 0.15^{d}	1.59 ± 0.01^{e}	1.97 ± 0.03^{d}
	OPA#5	11.95 ± 2.32^{b}	26.35 ± 0.90^{d}	25.81 ± 0.68^{a}	35.89 ± 0.74^{c}	61.70 ± 1.41^{ab}	2.34 ± 0.03^{b}	1.39 ± 0.01^{f}
	OPA#6	5.58 ± 0.65^{c}	33.82 ± 0.21^{ab}	16.89 ± 0.11^{e}	43.71 ± 0.56^{a}	60.60 ± 0.45^{bc}	1.79 ± 0.00^{d}	2.59 ± 0.05^{ab}
	OPA#7	13.94 ± 0.34^{b}	34.97 ± 0.57^{a}	13.90 ± 0.50^{f}	37.19 ± 0.41^{c}	51.09 ± 0.91^{d}	1.46 ± 0.05^{f}	2.68 ± 0.07^{a}
	OPA#8	8.14 ± 1.27^{c}	32.84 ± 0.03^{b}	22.59 ± 0.13^{c}	36.43 ± 1.43^{c}	59.02 ± 1.30^{bc}	1.80 ± 0.04^{d}	1.61 ± 0.07^{e}

Means not followed by the same superscript letters in each column of the pods and seeds are significantly different (P<0.05) from each other. Data are expressed as mean ± standard error of replicate determinations (n=2). Where: FA, fatty acid; SFA, saturated fatty acid; MUFA, Monounsaturated fatty acid; PUFA, polyunsaturated fatty acid and UFA, unsaturated fatty acid.

Total UFA content of the pods of okra accessions was significantly (P<0.05) high in OPA#1 (36.96%) and was low in OPA#7 (21.41%). In the seeds of okra accessions, OPA#3 was high (63.54%) but did not differ significantly (P>0.05) from accession OPA#1 (61.71%) and OPA#5 (61.70%) and OPA#7 was the lowest (51.09%). The mean total UFA concentrations of the pods and seeds were 27.53% and 58.68%, respectively (Figure 2).



Fifure 2 Mean proportion of fatty acids (%) of the pods and seeds of eight okra accessions

This also indicate that the mean total UFA in the seed accession is two times higher than the pods of okra accessions.

The ratios of unsaturated fatty acid to saturated fatty acid (UFA: SFA) of the pods and seeds of okra accessions are shown in Table 2.

The ratio of UFA: SFA of the pods of okra accessions was significantly (P<0.05) high in OPA#1 (1.10), OPA#2 (1.07) and OPA#3 (1.11) and it was low in OPA#4 (0.66). In the seeds of okra accessions, UFA: SFA was significantly (P<0.05) high in OPA#1 (2.84) and was low in OPA#7 (1.46). The mean UFA: SFA ratios of the pods and seeds of okra accessions were 0.88 and 1.98, respectively (Figure 2).

Oil yields

The percentage of crude oil yields of eight accessions of okra seed oils are shown in Figure 3. It can be noted that the studied yield of okra seed oils varied from 19.25% (OPA#3) to 38.19% (OPA#2). The accession, OPA#2 was significantly (P<0.05) high in crude oil content (38.19%) and was followed by OPA#7 (34.01%), OPA#4 (33.18%), OPA#5 (32.31%) in that order. However, the accession, OPA#3 was low (19.25%) in oil yield. The mean percentage of oil yield (29.64%) of the seeds obtained in this study was higher than the value reported by Ndangui *et al*. (2010) (24.90%) for okra seeds. The variation in oil yield with other reports may be due to the differences in variety

of plant, cultivation climate, ripening stage, the harvesting time of the seeds and the extraction method used (Mohamed *et al*., 2005).

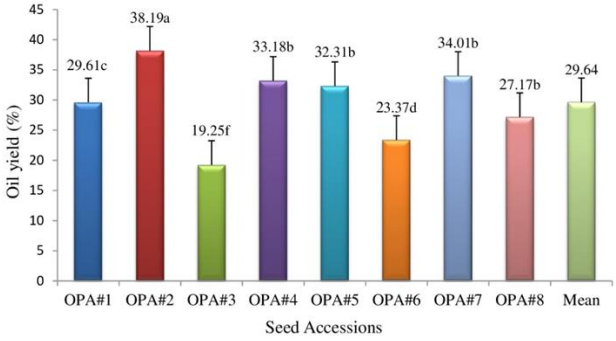


Figure 3 Percentage oil yields of the seeds of eight okra accessions

The range of oil yield (19.25-38.19%) of okra seeds in the present study was relatively found in the ranges of some conventional oil seed crops: cotton (15.0-24.0%), soybean (17.0-21.0 %), safflower (25.0-40.0%) and mustard (24.0-40.0%) (Knothe & Steidley, 2005) and lower than some unconventional oilseeds such as *canarium schwenfurthii* fruits (36.1%) and B*alanites aegyptiaca* almonds (48.3%) (Nzikou *et al*., 2006). The oil content of okra seeds (19.25-38.19%) in the present study was also found to exceed, or fell in the ranges of some common edible oils reported by Nichols & Sanderson (2003) for cottonseed (22-24%), safflower (30-35%), soybean (18-22%), rapeseed (40-48%), and olive (12-50%). Therefore, okra seeds could be considered as a potential source of vegetable oil for domestic and industrial purposes that would be of economic importance.

4. CONCLUSION

This study showed that okra seed oil is a good source of essential fatty acids with an important nutritional potential. The oil can be classified in the oleic-linoleic acid group. Linoleic acid, which is an essential polyunsaturated fatty acid, dominated the fatty acid profile in all the accessions. Okra seeds, especially OPA#3 accessions, could be a good source of essential fatty acids such as oleic and linoleic acid. The crude oil yield of seeds of eight okra accessions were significantly ($P<0.05$) varied and ranged from 19.25-38.19%. Compared with other vegetable oils, the present study revealed that okra seeds could be considered as potential sources of edible oil. In general, this study could be used as baseline data to develop okra seed oil for both domestic and industrial purposes and also for promotion and cultivation of this vegetable in a sustainable manner. Further investigation on tocopherol and phytosterol amount of the seed oils is recommended.

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