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Oil and Fatty Acid Contents of White Sorghum Varieties under Soaking, Cooking, Germination and Fermentation Processing for Improving Cereal Quality

Abd El-Moneim M.R. AFIFY[1], Hossam S. EL-BELTAGI[1,2*], Samiha M. ABD EL-SALAM[3], Azza A. OMRAN[3]

[1]*Department of Biochemistry, Faculty of Agriculture, Cairo University, P. Box 12613, Gamma St, Giza, Cairo, Egypt*

[2]*Vice-Rectorate for Graduate Studies and Research, SUDLS, King Saudi University, Riyadh 11451, Kingdom of Saudi Arabia; lbltg@yahoo.com (* corresponding author)*

[3]*Department of Crops Technology, Food Technology Research Institute, Agricultural Research Center, Egypt*

Abstract

The changes in lipid and fatty acid contents after soaking, cooking, germination and fermentation of three white sorghum varieties were studied to improve cereal quality. The results revealed that oil in raw sorghum varieties ranged from 3.58 to 3.91%, respectively and 'Dorado' represents the highest variety in oil content. As general trend after germination, oil content was decreased. Fatty acid contents of raw sorghum contains palmitic (12.10 to 13.41%), palmitoleic (0.47 to 1.31%), stearic (1.13 to 1.36%), oleic (33.64 to 40.35%), linoleic (42.33 to 49.94%), linolenic (1.53 to 1.72%), arachidic (0.10 to 0.18%) and eicosenoic acid (0.24 to 0.39% of total lipid). 'Dorado' was the highest variety in oleic acid while 'Shandaweel-6' was the highest variety in palmitic, stearic, linolenic, arachidic, eicosenoic acid and total saturated fatty acids. 'Giza-15' was the highest variety in palmitoleic, linoleic, total unsaturated fatty acids and ratio of unsaturated to saturated fatty acids. Fatty acids relative percentage changed after soaking, cooking, germination and fermentation.

Keywords: cooking, fatty acid, fermentation, germination, oils, soaking, sorghum

Introduction

One of the important facts of cereal crops is their diverse pool of fatty acids. The oil seeds contains particular fatty acids with industrially important because of their characteristic properties. The main constituent of all the oils is the fatty acids which may include saturated fatty acids (SFA), monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) that contribute in human physiology in different ways. PUFAs are present as component of membrane phospholipids in specific tissue or a precursor of hormone like prostaglandins (Patil and Gislerod, 2006).

Sorghum (*Sorghum bicolor* [L.] Moench) one of the most important weaning foods in low-income and high-income countries (Abdel-Rahim and El-Beltagi, 2010; Lonnerdal, 2000; Shallan *et al.,* 2010a; Shallan *et al.,* 2010b; Shehab *et al.,* 2010). It ranks fifth among the world cereals, following wheat, maize, rice and barley in production area and total production. Sorghum is an extremely important crop in Asia, Africa and other semi-arid regions of the world (Dillon *et al.,* 20007).

The nutrient composition of sorghum indicates that it is a good source of energy, proteins, carbohydrates, vitamins and minerals (Afify *et al.,* 2011a, 2012a, 2012b; Dicko *et al.,* 2006). Sorghum contains good quality proteins are those that are readily digestible and contain the essential amino acids in quantities that correspond to human requirements (Afify *et al.,* 2011b; El-Beltagi and Mohamed, 2010; El-Beltagi, 2011; El-Beltagi *et al.,* 2011a; 2011b; Zhao *et al.,* 2008).

Sorghum contains rather low levels of total oils (3.20-3.90%), with most occurring in the germ fraction (Morrison, 1978). Oleic and linoleic acids are 84% of the total fatty acids, making the lipids highly unsaturated (Hoseney *et al.,* 1981).

Sorghum, which is characterized by a relatively high concentration of fatty acids, which exceeds that of other competing cereals like barley, wheat and millet (Osagie, 1987; Matz, 1991; Palmer *et al.,* 1987; Shallenbcrger, 1971).

Most of the sorghum varieties polyunsaturated fatty acids were higher than monounsaturated fatty acids (Mehmood *et al.,* 2008). *Sorghum bicolor* varieties could be additional sources of edible oil due to presence of clinically important saturated and high concentration of unsaturated fatty acids.

The objective of this study was to investigate the changes in oils and fatty acids after soaking, cooking, germina-

tion and fermentation of three white sorghum varieties and make attention of sorghum as a source of edible oil.

Materials and methods

Samples and chemicals

Three white sorghum varieties (*Sorghum bicolor* L. Moench), were obtained from the Crops Research Institute, Agricultural Research Center for 'Shandaweel-6', and from Central Administration for Seed Certification (CASC), Ministry of Agriculture and Land Reclamation, Giza, Egypt for 'Dorado' and 'Giza-15'. The grains were carefully cleaned and freed from broken grains and extraneous matter.

Fatty acids were obtained from Sigma-Aldrich Chemical Co., St. Louis, USA. All other chemicals used were of analytical reagent grade.

Treatments

For soaking, sorghum grains were soaked in distilled water for 20 h with a ratio 1:5 w/v and the soaked water changed twice. At the end of soaking period, the soaked water was discarded. The grins were rinsed twice with distilled water and the grains were dried in oven at 45±5°C.

For germination, soaked grains were germinated, placed in plastic boxes, covered with cotton cloth and left at room temperature for 72h, and then the grains were dried. The root and shoot portions were manually removed. The grains were milled into fine flour and kept until analysis (Fig. 1).

For fermentation, sorghum flour which obtained from dried soaked grains was cooked by boiling with sufficient amount of distilled water for 10 min. Then the obtained slurry were dried, milled and kept until analysis as shown in (Fig. 1).

Determination of total oils

Oils content of raw sorghum and treatments were determined according to the methods of AOAC (2000).

Fatty acid determination

Sorghum oil was extracted by hexane and fatty acids were analyzed by Agilent HP 6890 capillary gas chromatography and reported in relative area percentages. The methyl esters of fatty acids were prepared according to the method of Glass (1971). A solution of oil (ca. 0.1 g) in hexane (2 ml) was mixed with methanolic potassium hydroxide (0.2 ml, 2N) by shaking vigorously for 30sec. Upper layer was decanted which contains the methylester. The hexane layer was suitable for injection into the gas chromatograph. The fatty acid methyl esters were identified using a gas chromatograph equipped with dual flame ionization detector was used. The fractions of fatty acid methyl esters were conducted using a DB-23 capillary-coiled glass column (60 m x 0.32 mm x 0.25 μm). The initially oven temperature was 150°C, nitrogen gas was used as a carrier 3 ml/min, the flow rates for hydrogen and air were 40 ml/min and 450 ml/min, respectively and the temperature of injector and detector were 230°C and 250°C, respectively. The fatty acid methyl esters were identified by comparison their retention times with known fatty acid standard mixture. Peak areas were automatically computed by an integrator. The fatty acid composition was expressed as percentage of total fatty acids.

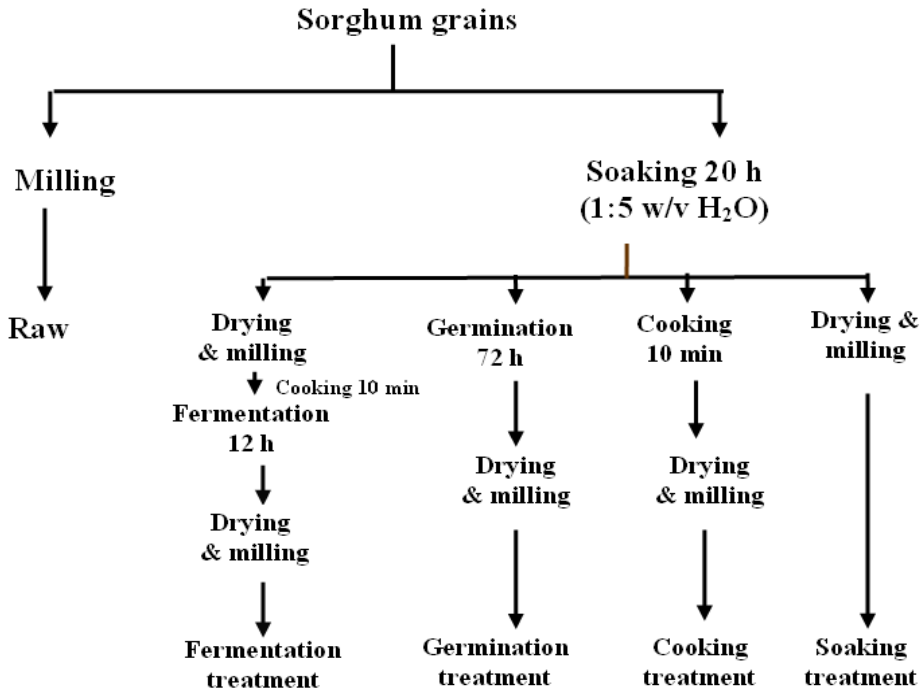

Fig. 1. Flow chart for the different treatments of sorghum grains

Statistical analysis

For the analytical data, mean values and standard deviation are reported. The data obtained were subjected to one-way analysis of variance (ANOVA) and least significant difference (LSD) at $p<0.05$.

Results and discussion

Oils content of sorghum at different treatments

Tab. 1 presents oils content of sorghum after soaking, cooking, germination and fermentation. Oil content ranged from 3.58 to 3.91% in raw sorghum and 'Dorado' variety represents the highest value. Sorghum contains 3.39-3.62% and 3.23-3.78%, oil in Sudan and Korea respectively while in Nigeria sorghum had 3.90% oil (Adeyeye and Ajewole, 1992; Chung *et al.,* 2011; Hamad, 2007).

Oil contents were significantly decreased after different treatments except for soaking treatment which non-significantly increased. Results are in agreement with Okrah (2008), who found that oil content of germinated sorghum varied from 1.44-2.57%, while in other study; soaking and fermentation reduce oil content (El Maki *et al.,* 2007). The reduction may be due to the fact that biochemical and physiological changes occurred during germination; such changes require energy to proceed, and therefore part of the seed oil was utilized for the production of this energy. Germination and cooking processes caused significant decreases in oil content (Mubarak, 2005). Sorghum oil was significantly decreased after fermentation which improves the bioavailability of iron and zinc during soaking and germination of three white sorghum varieties (Afify *et al.,* 2011a; Alemu, 2009). On the same time fennel were germinated on Murashige and Skoog medium (MS) without plant growth regulators reduce the amount of estragole (not favorite for Human consumption) and increase the amount of trans-anethole (Afify *et al.,* 2011c).

Sorghum saturated fatty acid

Tab. 2 shows sorghum saturated fatty acid at after soaking, cooking, germination and fermentation. The results indicted that raw sorghum contains palmitic (12.10-13.41%), stearic (1.13 to 1.36%) and arachidic acid (0.10-0.18%). 'Shandaweel-6' was the highest variety in palmitic and arachidic acid.

The results are in agreements with Mehmood *et al.* (2008), who found that sorghum contains palmitic acid (11.73-20.18%) and stearic acid (1.09-2.59%). While palmitic acid (11.88-14.18%), stearic acid (1.09-1.64%) and arachidic acid (0.12-0.33%) were present in the grain oil of different sorghum varieties (Pontieri, 2011). In addition, sorghum oil contains 10.90% palmitic and 2.70% stearic acid (Adeyeye and Ajewole, 1992). While Asiedu *et al.* (1993), found that sorghum oil contains palmitic acid (13.2%), stearic acid (1.30%) and arachidic acid (0.20%).

Tab. 1. Oil contents of sorghum at different treatments (% on DW)*

Treatment	Oil
Raw	
'Dorado'	3.91±0.25^{ab}
'Shandaweel-6'	3.66±0.15^{bc}
'Giza-15'	3.58±0.22^{c}
Soaking	
'Dorado'	4.10±0.27^{a}
'Shandaweel-6'	3.78±0.01^{bc}
'Giza-15'	3.53±0.22^{c}
Cooking	
'Dorado'	2.13±0.05^{e}
'Shandaweel-6'	2.46±0.05^{d}
'Giza-15'	2.31±0.21^{de}
Germination	
'Dorado'	1.70±0.09^{f}
'Shandaweel-6'	2.28±0.11^{de}
'Giza-15'	1.66±0.04^{f}
Fermentation	
'Dorado'	1.39±0.04^{g}
'Shandaweel-6'	1.36±0.03^{g}
'Giza-15'	1.25^{g} ±0.03
LSD	0.2555

* DW basis= dry weight basis.. Values are mean of three replicates ±SD, number in the same column followed by the same letter are not significantly different at $p<0.05$ level. LDS = Least Significant Difference

Tab. 2. Sorghum saturated fatty acid at different treatments (% of total oils)

Treatments	C16:0	C18:0	C20:0
Raw			
'Dorado'	13.14±0.10^{g}	1.31±0.01^{h}	0.15±0.01^{ef}
'Shandaweel-6'	13.41±0.01^{f}	1.36±0.02^{g}	0.18±0.01^{cd}
'Giza-15'	12.10±0.10^{jk}	1.13±0.01^{i}	0.10±0.01^{g}
Soaking			
'Dorado'	12.96±0.04^{h}	1.35±0.01^{g}	0.17±0.02^{de}
'Shandaweel-6'	13.13±0.03^{g}	1.35±0.01^{g}	0.17±0.01^{de}
'Giza-15'	13.06±0.06^{g}	1.16±0.02^{i}	0.15±0.01^{ef}
Cooking			
'Dorado'	12.74±0.04^{i}	1.28±0.02^{h}	0.19±0.01^{cd}
'Shandaweel-6'	13.57±0.03^{e}	1.53±0.02^{c}	0.18±0.02^{cd}
'Giza-15'	19.19±0.01^{a}	1.89±0.01^{b}	0.19±0.01^{cd}
Germination			
'Dorado'	14.86±0.04^{d}	2.09±0.01^{a}	0.20±0.02^{bc}
'Shandaweel-6'	12.17±0.02^{j}	1.74±0.04^{c}	0.27±0.02^{a}
'Giza-15'	12.07±0.05^{k}	1.62±0.02^{d}	0.26±0.02^{a}
Fermentation			
'Dorado'	11.22±0.02^{l}	1.47±0.03^{f}	0.22±0.02^{b}
'Shandaweel-6'	15.70±0.02^{b}	1.65±0.05^{d}	0.19±0.02^{cd}
'Giza-15'	15.12±0.02^{c}	1.91±0.01^{b}	0.13±0.01^{f}
LSD	0.0780	0.0378	0.0258

Palmitic acid =C16:0, stearic acid= C18:0 and arachidic acid= C20:0. Values are mean of three replicates ±SD, number in the same column followed by the same letter are not significantly different at $p<0.05$ level

Tab. 3. Sorghum unsaturated fatty acid at different treatments (% of total oils)

Treatments	C16:1	C18:1	C18:2	C18:3	C20:0
			Raw		
'Dorado'	0.48±0.02^{e}	40.34±0.15^{bcd}	42.58±0.10^{g}	1.62±0.02^{f}	0.38±0.02^{cde}
'Shandaweel-6'	0.47±0.01^{e}	40.15±0.11^{d}	42.33±0.10^{h}	1.72±0.01^{de}	0.39±0.02^{cd}
'Giza-15'	1.31±0.01^{a}	33.64±0.10^{g}	49.94±0.04^{c}	1.53±0.02^{g}	0.24±0.02^{f}
			Soaking		
'Dorado'	0.50±0.02^{de}	38.68±0.20^{e}	44.28±0.10^{e}	1.68±0.02^{e}	0.38±0.01^{cde}
'Shandaweel-6'	0.49±0.01^{e}	40.64±0.12^{ab}	42.13±0.03^{hi}	1.70±0.01^{e}	0.38±0.02^{cde}
'Giza-15'	0.47±0.03^{e}	30.75±0.20^{i}	52.15±0.15^{b}	1.75±0.05^{d}	0.50±0.02^{b}
			Cooking		
'Dorado'	0.53±0.01^{cd}	40.49±0.30^{bc}	42.71±0.20^{g}	1.69±0.01^{e}	0.37±0.01^{de}
'Shandaweel-6'	0.47±0.01^{e}	40.18±0.13^{cd}	41.96±0.04^{i}	1.69±0.02^{e}	0.41±0.01^{c}
'Giza-15'	0.47±0.01^{e}	33.30±0.10^{h}	43.15±0.05^{f}	1.56±0.04^{g}	0.35±0.01^{e}
			Germination		
'Dorado'	0.54±0.02^{c}	37.26±0.11^{f}	42.69±0.10^{g}	1.99±0.01^{a}	0.36±0.01^{de}
'Shandaweel-6'	0.47±0.01^{e}	40.88±0.10^{a}	42.14±0.11^{hi}	1.84±0.02^{c}	0.51±0.02^{b}
'Giza-15'	0.32±0.02^{g}	40.37±0.30^{bcd}	42.95±0.05^{f}	1.91±0.01^{b}	0.49±0.02^{b}
			Fermentation		
'Dorado'	0.60±0.01^{b}	29.76±0.11^{j}	54.37±0.35^{a}	1.99±0.01^{a}	0.37±0.01^{de}
'Shandaweel-6'	0.38±0.02^{f}	40.40±0.22^{bcd}	39.40±0.30^{j}	1.61±0.01^{f}	0.67±0.02^{a}
'Giza-15'	0.55±0.03^{c}	30.76±0.20^{i}	49.17±0.10^{d}	1.87±0.02^{c}	0.48±0.02^{b}
LSD	0.0301	0.2823	0.2355	0.0373	0.0279

Palmitoleic acid= C16:1, oleic acid= C18:1, linoleic acid= C18:2, linolenic acid= C18:3 and eicosenoic acid=C20:1. Values are mean of three replicates ±SD, number in the same column followed by the same letter are not significantly different at $p<0.05$ level

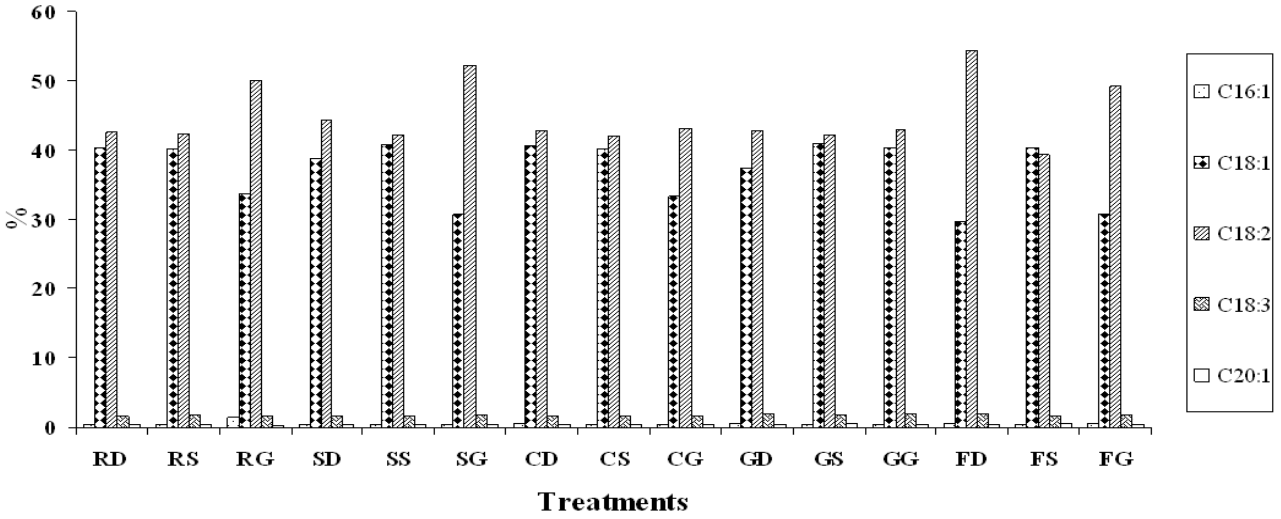

Fig. 2. Unsaturated fatty acids after soaking, cooking, germination and fermentation of sorghum varieties

Treatments: (RD: Raw 'Dorado'; SD: Soaked 'Dorado'; CD: Cooked 'Dorado'; GD: Germinated 'Dorado'; FD: Fermented 'Dorado'; RS: Raw 'Shandaweel-6'; SS: Soaked 'Shandaweel-6'; CS: Cooked 'Shandaweel-6': GS; Germinated 'Shandaweel-6'; FS: Fermented 'Shandaweel-6'; RG: Raw 'Giza-15'; SG: Soaked 'Giza-15'; CG: Cooked 'Giza-15'; GG: Germinated 'Giza-15'; FG: fermented 'Giza-15')

Sorghum unsaturated fatty acid

Tab. 3 and Fig. 2 present sorghum saturated fatty acid after soaking, cooking, germination and fermentation. The results indicted that raw sorghum contains palmitoleic (0.47-1.31), oleic (33.64-40.35%), linoleic (42.33-49.94%), linolenic (1.53-1.72%) and eicosenoic acid (0.24-0.39%). 'Dorado' was the highest variety in oleic acid. While 'Shandaweel-6' was the highest variety in linolenic and eicosenoic acid and 'Giza-15' was the highest variety in palmitoleic and linoleic. The results are in agreement with previous study, who found that sorghum fatty acid contains palmitoleic acid (0.43-0.56%), oleic acid (31.12-48.99%), linoleic acids (27.59-50.73%) and linolenic acid (1.71-3.89%) (Mehmood *et al.*, 2008). While

palmitoleic acid (0.42-0.71%), oleic acid (33.26-43.81%), linoleic acids (35.51-49.37%), linolenic acid (1.35-2.14%) and eicosenoic acid (0.14-0.52%) were present in the grain oil of different sorghum varieties (Pontieri *et al.*, 2011).

Percentage of saturated fatty acids (SFA), unsaturated fatty acids (Un SFA) and Un SFA/SFA ratio

Tab. 4 shows percentage of saturated fatty acids (SFA), unsaturated fatty acids (Un SFA) and Un SFA/SFA ratio after soaking, cooking, germination and fermentation. The results indicted that raw sorghum oil contains 13.33 to 14.94% and 85.06 to 86.67% of SFA and Un SFA, respectively. 'Shandaweel-6' was the highest variety in SFA. While 'Giza-15' was the highest variety in Un SFA and Un SFA/SFA ratio. Most of sorghum varieties polyunsaturated fatty acids were higher than monounsaturated fatty acids (Mehmood *et al.,* 2008). The white sorghum oil contains 12.40% total saturated fatty acid and 87.60% total unsaturated fatty acid, respectively (Hadbaoui *et al.,* 2010). Also, sorghum grains had high degrees of unsaturation (86.4%) and high quantities of essential fatty acids (58.0%) compared with the other cereals (Adeyeye and Ajewole, 1992). As the saturated fatty acids increases the risks of cardiovascular diseases, cancer and autoimmune disorders (Iso *et al.,* 2002). Oils being source of lipids, are of more nutritional value if they have more unsaturated to saturated fatty acid ratio (Aronson *et al.,* 2001).

Tab. 4. Percentage of saturated fatty acids (SFA), unsaturated fatty acids (Un SFA) and Un SFA/SFA ratio of sorghum at different treatments

Treatments	SFA*	Un SFA**	Un SFA/ SFA ratio
Raw			
'Dorado'	14.60	85.40	5.26
'Shandaweel-6'	14.94	85.06	5.69
'Giza-15'	13.33	86.67	6.50
Soaking			
'Dorado'	14.48	85.52	5.91
'Shandaweel-6'	14.66	85.34	5.82
'Giza-15'	14.37	85.63	5.96
Cooking			
'Dorado'	14.22	85.78	6.03
'Shandaweel-6'	15.28	84.72	5.54
'Giza-15'	21.28	78.72	3.70
Germination			
'Dorado'	17.15	82.85	4.83
'Shandaweel-6'	14.18	85.82	6.05
'Giza-15'	13.95	86.05	6.17
Fermentation			
'Dorado'	12.92	87.08	6.74
'Shandaweel-6'	17.55	82.45	4.70
'Giza-15'	17.16	82.84	4.83

*SFA= Saturated fatty acids. **Un SFA= Unsaturated fatty acids

The fat in sorghum grain (mainly present in the germ) is rich in polyunsaturated fatty acids (Glew *et al.,* 1997). The fatty acid composition of sorghum fat (linoleic acid 49%, oleic 31%, palmitic 14%, linolenic 2.7%, stearic 2.1%, *etc.*) is similar in content to that of corn oil, but it is more unsaturated (Adeyeye and Ajewole, 1992; FAO, 1995; Knudsen *et al.,* 1988). Sorghum is a good source of carotene, vitamins, notably the B vitamins (thiamin, riboflavin, pyridoxine, *etc.*), and the lipid soluble vitamins A, D, E and K (Anglani, 1998; Afify *et al.,* 2012a).

In addition, sorghum oil contains 28.40% oleic acid, 50.90% linoleic acid and 7.11% linolenic acid (Adeyeye and Ajewole, 1992). While Asiedu *et al.* (1993), found that sorghum oil contains palmitoleic acid (0.50%), oleic acid (41.20%), linoleic acids (40.10%), linolenic acid (3.0 %) and eicosenoic acid (0.20%).

The oil levels of sorghum varieties decreased on germination, cooking and fermentation. The observed decrease might be due to the increased activities of the lipolytic enzymes during germination and fermentation, which hydrolyse oils to fatty acids and glycerol (Raham and Aal, 1986). The simpler products can be used for synthesis of carbohydrate and protein or as a source of energy for developing embryo. Similar observation was made by other researchers (Obizoba and Atti, 1994; Nnam, 2000). In addition, reduced oil contents in malted millet for "Ogi) production and low lipid levels are known to increase shelf-life (Inyang and Idoko, 2006). Fermentation has also been strongly suggested to have inhibitory effects on the groups of micro-organisms that can cause spoilage or food poisoning (Odumodu and Inyang, 2006).

Germination induces the synthesis of hydrolytic enzymes, *e.g.* starch degrading enzymes, and proteases and phytases. Phytate content was significantly reduced from 23.59 to 32.40% for soaking treatment and 24.92 to 35.27% for germination treatments, respectively (Afify *et al.,* 2011a).

The reduction of phytic acid, flavonoids, tannine and phenolic acid and proanthocyanidins has been observed during germination and soaking (Afify *et al.,* 2012a; FAO, 1995; Traoré *et al.,* 2004). Germination of sorghum is important for the preparation of weaning foods with low paste viscosity and high energy density (Malleshi and Desikachar, 1988). Lipids mainly present in the germ and more unsaturated than in corn fatty acid composition and considered similar to corn, with linoleic (49%), oleic (31%), and palmitic acid (14%) (Glew *et al.,* 1997).

Conclusions

Vegetable oil not only provides high quality food, containing essential nutrients for the life, but also bioactive compounds that have particular clinical significance. Sorghum is worth attention as a source of health promoting component for foods. Fatty acids with some pharmacological significance have caught the attention of both

consumer and industries. Raw sorghum oil contains 13.33 to 14.94% and 85.06 to 86.67% of SFA and Un SFA, respectively. 'Dorado' was the highest variety in oil content. After germination, oil content was decreased. 'Dorado' was the highest variety in oleic acid. While 'Shandaweel-6' was the highest variety in palmitic, stearic, linolenic, arachidic, eicosenoic acid and total saturated fatty acids. 'Giza-15' was the highest variety in palmitoleic, linoleic, total unsaturated fatty acids and unsaturated to saturated fatty acids ratio. Most of fatty acids percentage changed after different treatments. *Sorghum bicolor* varieties could be additional sources of edible oil due to presence of clinically important saturated and high concentration of unsaturated fatty acids.

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