International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(5): 1855-1863

Received: 21-07-2018
Accepted: 24-08-2018

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Improvement of nutritional quality of sesame (*Sesamum indicum* L.) oil by applying technological treatment

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Abstract
Present study was conducted to investigate the influence of germination time on physicochemical and biochemical characteristics of oil extracted sesame (*Sesamum indicum*) seeds. Sesame seeds were soaked and germinated in laboratory under room conditions (humidity 85%, temperature 25 °C) during 4 days. Oils were extracted using a screw press and analyzed by conventional methods. The results have shown that germination significantly decreased oils moisture, triglycerides (98.31 to 90.32%) and oils viscosity (71.09 to 66.29 mPa.s). It increased iodine value (104.64 to 105.98 g I_2/100 g) saponification index (191.11 to 193.82 mg KOH/g). There was no detectable peroxide value during germination and the color of extracted oils was significantly affected. Antioxidant power of oils has been improved by increasing vitamin E (0 to 597.65 µg/g) and vitamin A (0.80 to 4.80 µg/g) contents. Nutrient information reported illustrates the benefits to public health for consumers of these plant seeds.

Keywords: cold pressure, Côte d'Ivoire, germination, oil, *Sesamum indicum* L

Introduction
The importance of utilizing oilseeds as complementary nutrient sources for human consumption has received considerable attention in recent years. There is a wide variety of oil crops ranging from largely known and highly utilized ones like soya bean, palm kernel, groundnut, extra, to underutilized one [1]. In fact, African ecosystems abound with many multi-purposes plant species that remain in the wild and underutilized. Among them, *Sesamum indicum*, grow in Côte d'Ivoire and its seeds were rich in fat. Indeed, sesame (*S. indicum*) is a plant native to Tropical Africa and widely cultivated in Asia since along time. Belonging to the *Pedalaceae* Family, it has approximately 36 species [2]. Sesame is highly tolerant to drought like conditions, and grows where other crops may fail [3]. Asian countries are the largest producers in the world [4]. It's an annual oleaginous plant which is grown for its edible seeds. Indeed, sesame seeds contain 57-63% oil, 23-25% protein, 13.5% carbohydrate and 5% ash [5]. It is used at 65% for oil extraction and 35% for food [6]. Sesame have health benefits such as antioxidative, hypocholesteremic, antihypertensive, immunoregulation and anticancer which are mainly accredited to lignans and their glycosides [7]. In addition, studies have shown that sesame oil consumption has too many benefits to health like minimizing the occurrence of cancer. It contributes also to the avoidance of degenerative processes; therefore decreases the death rate through cerebro and cardio-vascular diseases [8]. The oil is very stable due to some antioxidants such as sesamin, sesamolin and sesamol [9, 10]. Therefore, it has along shelf life and can be blended with less stable vegetable oils to improve their stability and longevity [9, 11]. With the increasing knowledge on the dietary and health benefits of sesame the market demand for its seed and oil is likely to increase. Continued use of sesame oil for the known applications might depend on maintaining a consistent chemical composition [12].
Although, Sesame seeds are a potential source of oil, it is important to emphasize that the value of its oil lies in its intrinsic characteristics including the physicochemical, biochemical and nutritive properties. These parameters can be improved by applying various technologies to the raw seeds prior extraction. Nowadays, there is a growing interest in Western countries in natural, minimally processed foods, and additive-free, nutritional and healthy foods. Germinated and fermented oilseeds can be offered as natural nutritive products, which can be

beneficial to health [13]. As far as it concerned germination which is the focus of this research, it is simple and inexpensive process that has been used for a long time to improve the nutritional quality of foods. Germination process leads to structural modification and synthesis of new compounds in seeds [14]. It is a complex metabolic process during which the lipids, carbohydrates and storage protein within the seeds are broken down in simpler form that are much easily assimilated [15]. Germination leads to a reduction in phytic acid and increases of the minerals solubility in foods and could thus improve bioavailability of minerals in seeds [16, 17].

In addition, all a several scientific studies have reported that the physicochemical, biochemical and nutritive composition of sesame depends as much on the variety, geographical location and pedoclimatic conditions of the area, cultivation as well as on the treatment undergone by the seeds [3, 6, 12, 18-20]. Indeed, there is no information on the characteristics of the Ivorian sesame seeds. To the best of our knowledge, the advantages and disadvantages of germinating seeds used for human consumption have not been established. Hence the need to characterize sesame produced in Cote d'Ivoire. To retain the desirable contents of sesame seeds for commercial applications, it is crucial to profile their compositional changes during and after germination. This information is essential for determining potential uses of this product in food formulation. Therefore, to contribute to non-conventional oils promotion, we have focused our attention on oil extracted from sesame (*S. indicum*) seeds. So, the aim of this study was to investigate the effects of the germination time on the physicochemical, biochemical and nutritive characteristics of the extracted oil in order to contribute to the valorization of sesame grown in Côte d'Ivoire.

Material and Methods

Plant materiel

The plant material used in this study is Sesame seeds (*S. indicum*) purchased from producers in Méagui, a Bakwe locality in the south-west of Côte d'Ivoire and belonging to the department of Soubré (55° 24' 43" North, 6° 33' 37" west).

Preparation of germinated sesame seeds

A germination experiment was undertaken according to [21]. Two (2) Kilograms of sorted sesame seeds was carefully washed with tap water to remove the worn and immature seeds and soaked during 24 hours in 10 liters of water (ratio 1/5: w / v) contained in a plastic seal of 15 liters. After soaking, the seeds were rinsed and then spread on a 100% cotton fabric, in a room whose humidity and temperature were respectively 85 ± 5% and 28 ± 3 °C. Each day, the germinating seeds are watered once and samples are taken. Starting from the second day of germination, and every day thereafter, dishes of germinated seeds were removed, oven-dried, weighed, packed in plastic container and stored at room temperature prior to oil extraction. Germination lasted four (4) days.

Oil extraction

The oil extraction was carried out using a screw press type Komet Ca59G (IBG Monfort Oekotek, Germany). This press has the particularity of ensuring a "cold" extraction of oil from oilseeds and has a flow rate of 5 to 8 kg/h [24]. A mass of 250 g of seeds was introduced through a hopper in the previously heated press. The seeds are transported through a rotational movement of the screw. The compression and the simultaneous entrainment of the seeds causes the extraction of the oil which reflux towards the perforated cylinder (Length 9 cm x Diameter 3.4 cm), provided with 6 perforations on 20 rows. The oil is collected through the perforations in a 500 mL beaker. As for the cake, it comes out at the end of the axis by a calibrated orifice (6 mm for the study) interchangeable, which acts as a brake on the flow of the cake. The recovered crude oil is freed from suspended particles (press feet) by centrifugation at 4200 rpm for 20 min. It was finally stored in glass bottles with a capacity of 100 mL, previously washed, oven dried and covered with aluminum foil.

Oil samples were obtained: ORS (Oil extracted from Raw Sesame seeds), OGS_0 (Oil extracted from Sesame seeds soaked for 24 hrs.) and OGS_1, OGS_2, OGS_3, OGS_4 (respectively Oil extracted from Germinated Sesame seeds for 1, 2, 3 and 4 days).

The following diagram gives essentials steps of the process (Figure 1):

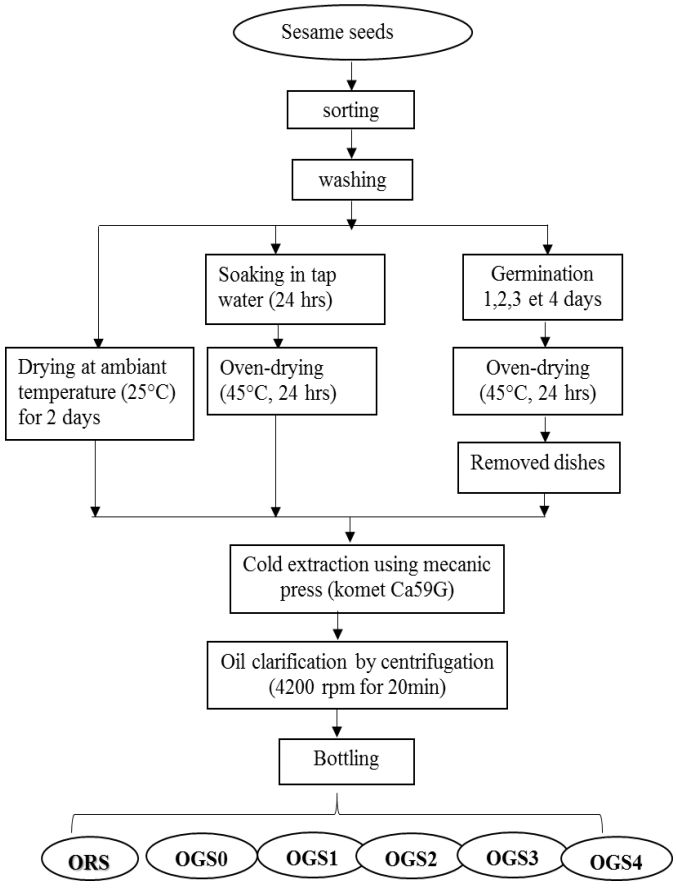

Fig 1: Diagram of germination and oil extraction process

ORS: Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds;

OGS_1; OGS_2; OGS_3 and OGS_4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Physical and chemical parameters

Acid, peroxide, iodine and saponification index were determined by using the [23] methods. Refractive index at 20 °C was carried out following the [24] methods by using a Refractometer (Mettler Toledo, Japan). Density and viscosity were determined at 20 °C by using a Viscosimeter (Anton Paar Gmbh, Austria). pH values of oil samples were was

determined at 25 °C according to [25]. Color, and cloud point were determined by the [26] methods.

Biochemical characteristics

Moisture and impurities contents were determined according to the [26] test methods. Unsaponifiables matter content of oil samples was determined following the [24] method. The triglycerides percentage was calculated with the mathematique relation of [27, 28].

Triglyceride (%) = 100 – [(free fatty acid, %) + (unsaponifiable matter, %)]

Vitamins A and E contents were determined according the method [29] using an ultra-performance liquid chromatography (UPLC) analysis. Separation by UPLC was carried out using a liquid chromatography system (Acquity Waters, USA) equipped with an optical detector TUV system and a BEH C_{18} column (150m x 0.25 mm x 1.7 µm). The injection volume was 10µl. The mobile phase was methanol-water (98:2, v/v) and the elution was performed at a flow rate of 2 mL/min. The analytical column was kept at 45 °C. Vitamin A and E of oil sample were detected at 325 nm and 292 nm respectively and identified by comparing its retention time with this of authentic standard. All the data obtained were stored and processed by Empower software (Waters, USA).

Fatty acid composition was determined by conversion of oil to fatty acid methyl esters (FAME) through methylation according to [30] methods. FAME were analyzed using gas chromatography on (Clarus 580 GC, USA), equipped with a flame ionization detector (FID) and a polar capillary column RT-2560 (Restec GC Columns, USA) (100 m x 0.25 mm x 0.2 µm; cross-linked biscyanopropyl polysiloxane). Column temperatures were programmed from 100 °C for 4 min, with a rise of 3 °C/min to 240 °C for 15 min. The injector and detector were maintained at 240 °C and 250 °C, respectively. The sample volume injected on to the capillary column was 1 µL using splitless injection mode. Hydrogen gas at a flow rate of 1.2 mL/min was used as the mobile phase. The FAME were identified by comparing their retention time with those of the standards. Quantification of the identified fatty acids was performed by reference to established calibration lines for different concentrations of the standards used. The areas obtained was initially corrected by the internal calibration method using erucic acid as internal standard. The acquired data was processed by Total chrom navigator software (Clarus 580 GC, USA). The yield of each fatty acid was calculated as follow: (area of fatty acid/ areas of total fatty acids in the oil sample) x100.

Evaluation of oils oxydability

Oxydability of oil was determined by calculed oxydability (Cox). The Cox value of the oils was calculated based on the percentage of unsaturated C18 fatty acids, applying the formula proposed by [31]: Cox value = [1 (18: 1%) + 10.3 (18: 2%) + 21.6 (18: 3%)] / 100

1: oxidation rate of oleic acid; 10.3: oxidation rate of linoléic acid and 21.6: oxidation rate of linolenic acid.

Statistical analysis

Results are expressed as mean ± standard deviation. The data were analyzed using STATISTICA version 7.1 Statistical Software. Statistical parameters were estimated with analysis of variance (ANOVA). Differences between means were evaluated by the Duncan multiple range test and significance was accepted at $p<0.05$. Pearson correlation coefficients (r) for relationships between various oil properties were calculated. The variations observed in the physico-chemical and biochemical composition of extracted sesame oil were examined by Principal Component Analysis (PCA) with the Statistical Software version 7.1.

Results and Discussion

Physical and Chemical Properties

In this study, it was found that the crude fat content significantly decreased during germination ($p<0.05$). The oil contents of ungerminated sesame seed (45.6%) increased after the soaking (45.85%) but it decreased as function of germination time to 37.09% (Table 1). This reduction may be due to the fact that biochemical and physiological changes occur during germination. In fact, storage oil breakdown play an important role in the life cycle of many plants as carbon source [15]. This metabolic process is initiated by lipases which catalyze the hydrolysis of triacylglycerols to release glycerols and free fatty acids [14, 32]. Some of fatty acid liberated are oxidized into acetyl-CoA then transformed into simple carbohydrates and transferred to the embryo as saccharose [33] to serve as energy source.

Refractive index

The refractive index is a criterion of oil purity in relation to the fatty acid composition [34, 35]. Figure 2 show that germination decreased refractive index from 1.4724% to 1.4714% for ORS and OGS_4 respectively. These results are not in consistent with the theory that states the refractive index varies proportionally with the iodine index [36]. Therefore, the results obtained in this study cannot be attributed to the degree of unsaturation but rather to other factors. Indeed, the refractive index also provides information on the state of degradation of the oil. According to [37], the presence of free fatty acid decreases the refractive index. Otherwise, Pearson correlation (Table 4) revealed a negative correlation of refractive index with free fatty acid (r = -0.93, $p<0.05$). The result also showed that increasing of FFA during germination alters oil quality. This is reflected herein by the decrease of the refractive index.

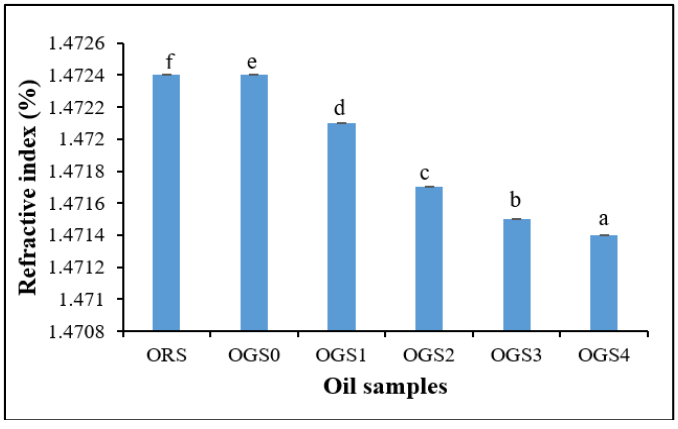

Fig 2: Evolution of refractive index in raw and germinated sesame oil

ORS: Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds;

OGS_1; OGS_2; OGS_3 and OGS_4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Density and Viscosity

The data in Table 1 allow us to observe a significant decrease (p<0.05) in density and viscosity of various oil samples. The results have shown that the viscosity of the raw and germination oils were 71.09 and 66.29 mPa.s oil respectively. The significant variations in viscosities between the samples could be attributed to the fact that viscosity depends on the fatty acid composition. In fact, during germination, we assist to the increasing of unsaturation of the fatty which results in an increase in the iodine value (Figure 4). This pattern is in close conformity with the studies which have shown that density and viscosity decrease as the molecular weight of fatty acids decreases and the degree of unsaturation increases [37, 38]. In summary, sesame seed germination increases the fluidity of the oil and decreases its density by increasing of unsaturated fatty acids.

Color

Color is one of the most important quality attributes evaluated by consumers, producers and distributors. The pigments are responsible for the color of the oil, but their concentrations are influenced by a number of factors [39]. Those pigments are widely affected by germination process which occur degradation and a change of color. The intensity of the color is higher for the oil from the germinated seeds (72.90Y, 5.70R) followed by the oil from the raw ones (8.17Y, 2.73R) (Table 2). The change in the color of the oil extracted from the germinated seeds could be due to the increase in the content of chlorophylls and carotenoids which are synthesized during the early stages of germination [40]. This finding is consistent with Pearson correlation (Table 4) and PCA analysis (Figure 5) which revealed a positive correlation of color with vitamins A and E (r = 0.85; 0.94 p<0.05) contents. Indeed, vitamin A provide to carotenoids which are pigments highly appreciated as functional components for its coloring properties and its health benefits for the human consumption. Carotenoids, besides their participation in coloring of fruit, vegetables and oils, are bioactive compounds which have antioxidant activity [39].

Cloud point

Cloud point (CP) of the oil indicates the temperature at which a beginning of crystallization appears, resulting in an alteration of the limpidity of the oil [41] (Lambert, 2005). Germination results in a significant decrease in cloud point from -7.57 °C to -5.48 °C for ungerminated and germinated (4 days) sesame oil respectively (Table 2). Sesame oils also have a low temperature stability compared to their cloud point which is lower than that of palm oil [42] (4 °C). An increase of unsaturation results in a decrease in the melting temperature. So at ordinary temperature, all unsaturated fatty acids are liquid [43].

Peroxide value (PV)

The PV indicates the presence of primary oxidation products [44]. It is an index of rancidity, thus the high peroxide value of oil indicates a poor resistance of the oil to peroxidation during storage. The PV of sesame seed oil was determined less than 0.1 meq O_2/kg (Table 1). These results suggested that sesame seed oil stability to oxidation is relatively good, which is due to the presence of antioxidants (Sesamol, sesamolin and sesamin) together with tocopherols [8, 45]. The PV of Sesame seeds are very little below the maximum acceptable value of 15 meq O_2/kg set by the Codex [46].

Table 1: Physicochemical composition of raw and germinated sesame oil

Oil samples	Yield of press (%)	Peroxide value (meqO_2/kg)	Density at 20 °C (g/cm3)	Viscosity at 20°C (mPa,s)	pH (25°C)	Color Red	Color Yellow	Cloud point (°C)
ORS	45.50±0.10^{d}	< 0.1	0.9190±0.0001^{e}	71.09±0.02^{f}	5.58±0.01^{a}	2.73±0.06^{a}	8.17±0.15^{a}	-7.57±0.06^{a}
OGS_0	45.85±0.15^{f}	< 0.1	0.9192±0.0000^{f}	70.78±0.00^{e}	5.76±0.01^{c}	3.30±0.10^{b}	28.37±0.06^{b}	-7.30±0.10^{b}
OGS_1	45.10±0.13^{e}	< 0.1	0.9173±0.0000^{d}	69.01±0.00^{d}	6,39±0.01^{e}	4.13±0.06^{c}	70.00±0.00^{e}	-6.23±0.15^{c}
OGS_2	43.82±0.18^{c}	< 0.1	0.9168±0.0000^{c}	68.20±0.00^{c}	5.71±0.01^{b}	5.10±0.00^{d}	72.90±0.00^{d}	-5.83±0.15^{d}
OGS_3	39.70±0.12^{b}	< 0.1	0.9155±0.0000^{a}	66.29±0.00^{a}	8.11±0.02^{f}	5.40±0.00^{e}	70.00±0.00^{e}	-5.57±0.12^{e}
OGS_4	37.09±0.11^{a}	< 0.1	0.9161±0.0000^{b}	67.14±0.01^{b}	6.24±0.01^{d}	5.70±0.00^{f}	58.00±0.00^{c}	-5.48±0.10^{e}

The different letter averages on the same line are significantly different at p<0.05 ORS: Oil extracted from raw sesame seeds; OGS_0: Oil extracted from soaking (24 h) sesame seeds; OGS_1; OGS_2; OGS_3 and OGS_4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Free fatty acid

Taking into account the acidity, the quantity of free-fatty acids (FFAs), usually referred as the acid value, is an important quality factor and has extensively been used as a traditional criterion for classifying oil into various commercial grades [45]. FFA determination is particularly important for industrial purposes since FFA can modify the organoleptic or physicochemical properties of oil. The results indicated that germination has drastically increased the free fatty acids from 0.22% for the raw sample to 9.05% for OGS_3 (Figure 3). The ORS, OGS_0 and OGS_1 samples were found to be very low, below the minimum acceptable value of 4.0% for sesame recommended by [46] for edible oil. Beyond two days of germination, oil acidity is higher than the standard. Therefore, it will be used in the field of soap factory. The higher percentage of FFA and acid value for the oil extracted from germinated seeds could be due to the initial hydrolysis (lipolysis) of triacylglycerols by lipases to glycerol and free fatty acids (FFA) [40]. The FFA formation are responsible for increasing of oil acidity [47] This high value is frequently an indication for a strong enzymatic hydrolysis of sesame seeds during harvesting, handling or oil processing [48].

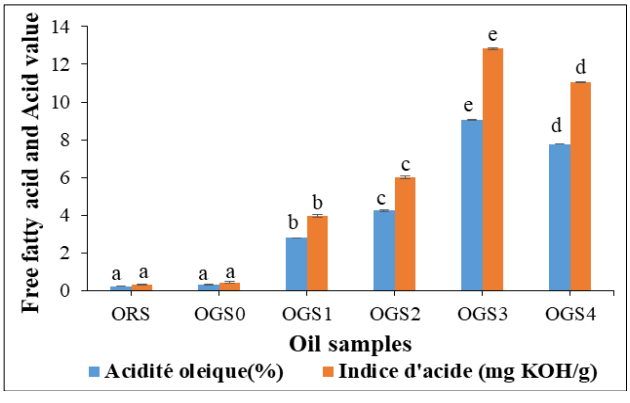

Fig 3: Evolution of free fatty acid (FFA) and acid value in raw and germinated sesame oil

ORS: Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds;
OGS_1; OGS_2; OGS_3 and OGS_4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Iodine value

As regards the iodine value (IV) which is a measure of the total number of double bonds present in fats and oils [44], values of ORS and OGS_0, OGS_1 and OGS_2 are not significantly different. However, there is a significant difference between the IV of ORS and OGS3 and OGS_4 with values of 104.64, 105.33 and 105.98 respectively (Figure 4). Therefore, germination significantly influences the IV. This increase in IV could be explained by the fact that during germination, there is production of polyunsaturated fatty acids [49]. The high iodine index in OGS3 and OGS4 is probably due to its high level of linolenic acid. However high iodine-value oil contains a greater number of double bonds than low iodine-value oil and has usually a reduced oxidative stability [50], this is why the oxidative stability of the different oil samples has been studied through the determination of the peroxide value (PV).

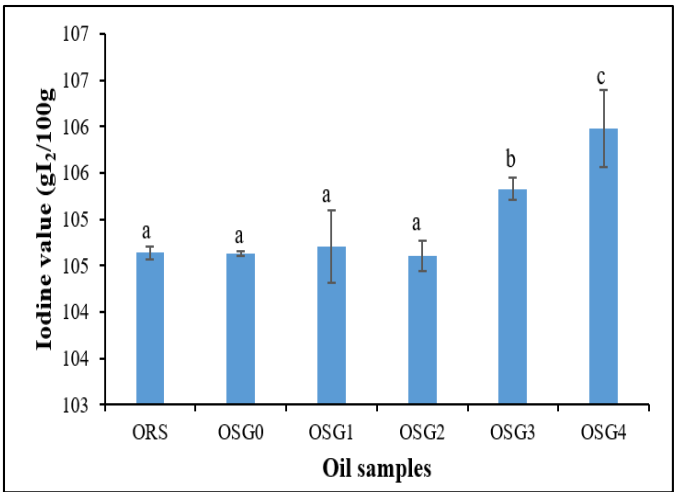

Fig 4: Evolution of iodine value in raw and germinated sesame oil

ORS: Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds;
OGS_1; OGS_2; OGS_3 and OGS_4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Saponification index

The saponification index is an indicator of the molecular weight of fatty acids and triglycerides as well as the length of carbon chain that contains the oil. It is inversely proportional to the molecular weight of the oil [43]. The values obtained from the saponification index of the oils studied vary from 191.11 to 193.25 mg KOH/g for raw and germinated sesame oil (4 days) respectively (Figure 5). These results are in consistent with those obtained by [51] who suggested that these values indicate the absence of lauric acid in the investigated oils, and this range is indicative of oils characterized by medium chain-length FAs. Pearson correlation (Table 4) and PCA analysis (Fig. 6) revealed a strong negative correlation saponification index with unsaponifiable matter (r =-0.90, p<0.05). This could explain the increase of the saponification index.

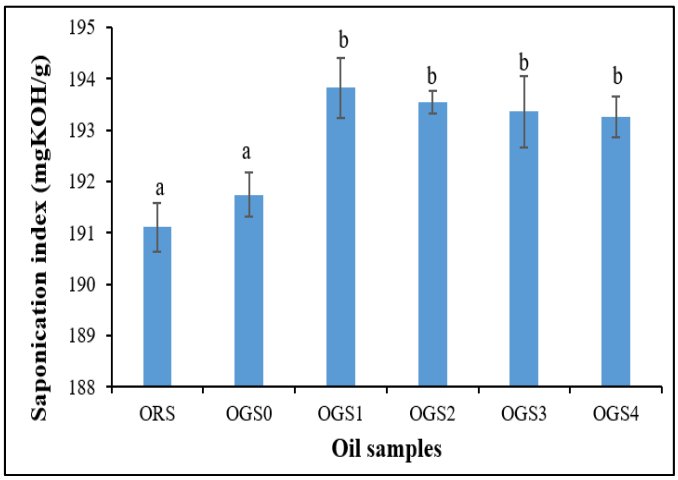

Fig 5: Evolution saponification index in raw and germinated sesame oil

ORS: Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds;
OGS_1; OGS_2; OGS_3 and OGS_4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Biochemical and nutritive parameters

Impurities

The biochemical and nutritive parameters of oil extracted from raw and germinated sesame seeds are shown in table 2. Impurities are organic or non-organic foreign bodies, other than glycerides, fatty acids and unsaponifiables [52]. Thus, the increase in the impurity level of the oils during germination would probably be due to the released fatty acids. This therefore makes it possible to further explain the decrease in the refractive index despite the increase in the iodine value. However, although not refined, these cold pressed oils did not show quite high impurity levels 0.078 (HSF) and 0.096% (HSG_3). These levels were slightly above the 0.05% threshold for refined oils [46]. Refining would help remove these impurities and increase the nutritional quality and shelf life of these oils [52].

Unsaponifiables

The unsaponifiable matter of fatty substance corresponds to all of its constituents which, after basic hydrolysis (saponification), are very sparingly soluble in water and soluble in organic solvents [53]. The decrease of the unsaponifiable content observed during the germination period may probably be due to the decreasing of lipid content observed and other major reserves of the seed [51]. A parallel decrease in the content of triglycerides was also observed. Indeed, the Pearson correlation (Table 4) shows a strong negative correlation between triglyceride and FFA levels in oils (r=-1.00, p<0.05), yellow color (r=-0.94, p<0.05) and vitamin E content (r=-0.78, p<0.05). This is explained by the fact that, during germination, triglycerides are broken down and free fatty acids are formed in the sesame seeds. In addition, the color and vitamin content of the oils increase during germination, which contribute to reduce unsaponifiable matter. In fact, the compounds of unsaponifiable consist of triterpenes, liposoluble vitamins (A, D, E and K), fatty alcohols, carotene hydrocarbons (yellow pigments) and carotenoids, sterols and tocopherols [43].

Vitamins A and E

The chromatographic profile of the unsaponifiable fraction of ungerminated and germinated sesame oils reveals the presence of vitamin A and vitamin E. In vegetable oil, vitamin A is obtained from β-carotene which plays an important role in human health by acting as a biological antioxidant [54]. It is an essential nutrient needing in small amounts by humans for the normal functioning of visual system, growth and development, maintenance of epithelial cell integrity, immune function and reproduction [55]. The data shown that there is an increase in vitamin A in the oil as a function of the germination time of seeds. The lowest value is attributed to non-sprouted sesame oil (0.08 mg/kg) and the high value to oil extracted from sesame seeds sprouted 4 days (4.80 mg/kg). However, this observed content remains lower than that reported (1 g/kg) of palm oil [42]. Nevertheless, the consumption of its oils could cover the daily vitamin A requirements of the child from 0 to 6 months estimated at 0.375 mg [56]. With regard to vitamin E, owing to their role in the protection against oxidative deterioration of polyunsaturated fatty acids in plant material, tocopherols in seed oil are extremely important. They are natural lipophilic antioxidants mainly found in vegetable oils [45]. The results obtained show a significant variation in the vitamin E content of the oils which goes from 0 mg/100g for ungerminated sesame to 57.77 mg/100g after 4 days of germination (Table 3). Germinated seeds presents an excellent α-tocopherol content, the most active form of vitamin E. The increase of α-tocopherol after germination indicates this process provide abundant vitamin E that could be readily absorbed by human body [8]. Monitoring composition changes of sesame is crucial to capturing the best timing for seed processing such that the desired contents could be retained for commercial applications. In fact, vitamin E deficiency could lead to neurological and muscular disorders. It can also cause haemolytic anemia and increase the risk of retinal damage in premature infants [38]. Thus, consumption of germinated sesame oil would help to reduce diseases related to vitamin E deficiency.

Table 2: Biochemical composition of raw and germinated sesame oil

Oil samples	Humidity (%)	Impurity (%)	Unsaponi-fiables (%)	Triglyceride (%)[a]	Vitamin E (µg/g)	Vitamin A (µg/g)
ORS	0.73±0.06^{b}	0.078±0.001^{a}	1.47±0.01^{c}	98.31±0.01^{f}	0.00±0.00^{a}	0.80±0.10^{a}
OGS_0	0.61±0.02^{a}	0.079±0.001^{a}	1.45±0.01^{b,c}	98.24±0.01^{e}	28.84±0.29^{b}	0.90±0.10^{a}
OGS_1	0.54±0.05^{a}	0.080±0.001^{a}	1.40±0.03^{a,b}	95.81±0.05^{d}	89.14±1.35^{c}	1.73±0.12^{c}
OGS_2	0.74±0.06^{b}	0.091±0.001^{b}	1.35±0.01^{a}	94.41±0.03^{c}	433.64±3.99^{d}	2.20±0.10^{d}
OGS_3	0.63±0.06^{a}	0.096±0.001^{c}	1.38±0.03^{a}	89.57±0.05^{a}	552.46±5.72^{e}	4.23±0.21^{e}
OGS_4	0.55±0.05^{a}	0.094±0.001^{c}	1.39±0.03^{a}	90.82±0.03^{b}	597.65±6.24^{f}	4.80±0.35^{f}

The different letter averages on the same line are significantly different at $p<0.05$ **ORS:** Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds; **OGS_1; OGS_2; OGS_3** and **OGS_4:** Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Fatty acid

The analysis of sesame oils by GC/FID permitted to obtain seven fatty acids were determined in both sesame oils. The relative fatty acid content for both oils was listed in Table 3. The PUFAs contents was affected by germination, linoleic acid content was unchanged while α-linolenic acid increased from 0.11% to 0.79% for ungerminated and germinated respectively. This suggests that the biosynthetic pathway of fatty acids is efficient in the formation of linolenic acid, justifying therefore the higher amount of the latter fatty acid. It could be concluded that sesame sprouted is rich in unsaturated fatty acids with oleic acid and linoleic acid being the major fatty acids. Today, polyunsaturated fatty acids are well known for their nutritional importance. Their consumption promotes the synthesis of HDL cholesterol and reduces LDL cholesterol and hypertension in humans [57, 58]. The observed effects have been attributed to the chemical composition of the oil, characterized by a low level of saturated fatty acids. Indeed, extracted oil content nearly 84% unsatured fatty acid. The results are in consistent in [58, 59]. The increase in polyunsaturated fatty acid content in sesame oil during germination highlights the importance of this technology in human and animal nutrition. In addition to these beneficial effects in diet, they could also have several advantageous properties in cosmetics and body care. The AGPI / AGS ratio, lower in 2 days of germination, reaches its maximum between the 3rd and 4th day. As for the oxidability of the oils, it increases from 3 days of germination. The higher values of the AGPI/AGS and Cox ratio observed in the OGS_3 and OGS_4 oils indicate that their stability is lower than that of the others. Because of this low stability, the applications of these oils will be limited, although they have a good nutritional value. These oils will therefore require more care for their conservation. They must be kept away from light and moisture in a package that is totally impermeable to oxygen, preferably tinted glass.

Table 3: Fatty acid composition of raw and germinated sesame oil

	Oils samples					
Fatty acid (%)	**ORS**	**OGS_0**	**OGS_1**	**OGS_2**	**OGS_3**	**OGS_4**
Myristic acid	0.07±0.01^{b}	0.07±0.01^{a,b}	0.07±0.01^{a,b}	0.06±0.00^{a}	0.09±0.01^{c}	0.09±0.00^{c}
Palmitic acid	9.43±0.01^{b}	9.40±0.07^{b}	9.43±0.08^{b}	9.65±0.05^{c}	9.32±0.00^{b}	9.13±0.03^{a}
Stearic acid	7.14±0.02^{a}	7.16±0.06^{a}	7.16±0.03^{a}	7.11±0.05^{a}	7.15±0.03^{a}	7.16±0.02^{a}
Oleic acid	45.59±0.13^{b}	45.62±0.16^{b}	45.61±0.06^{b}	45.40±0.04^{a}	45.33±0.03^{a}	45.28±0.02^{a}
Linoleic acid	37.62±0.10^{a}	37.52±0.11^{a}	37.45±0.13^{a}	37.48±0.09^{a}	37.56±0.05^{a}	37.51±0.13^{a}
Linolenic acid	0.11±0.02^{a}	0.16±0.01^{a,b}	0.24±0.05^{b}	0.25±0.05^{b}	0.50±0.06^{c}	0.79±0.10^{d}
Arachidic acid	0.05±0.01^{a}	0.07±0.01^{a}	0.05±0.00^{a}	0.07±0.03^{a}	0.06±0.01^{a}	0.05±0.01^{a}
SFA	16.69±0.02^{c}	16.70±0.01^{c}	16.70±0.06^{c}	16.88±0.07^{d}	16.62±0.03^{b}	16.42±0.02^{a}
UFA	83.31±0.05^{a}	83.31±0.03^{a}	83.29±0.23^{a}	83.12±0.11^{a}	83.38±0.05^{b}	83.58±0.21^{b}
MUFA	45.59±0.13^{b}	45.63±0.11^{b}	45.60±0.06^{b}	45.40±0.04^{a}	45.33±0.03^{a}	45.28±0.02^{a}

PUFA	37.73±0.09[a]	37.38±0.08[a]	37.69±0.18[a]	37.73±0.07[a]	38.05±0.05[b]	38.30±0.20[c]
PUFA/SFA	2.26±0.00[b]	2.26±0.00[b]	2.26±0.01[b]	2.23±0.01[a]	2.29±0.00[c]	2.33±0.01[d]
Cox value	4.35±0.01[a]	4.35±0.01[a]	4.36±0.02[a]	4.37±0.01[a]	4.43±0.01[b]	4.49±0.03[c]

The different letter averages on the same line are significantly different at $p<0.05$ **ORS:** Oil extracted from raw sesame seeds; **OGS_0:** Oil extracted from soaking (24 hrs) sesame seeds; **OGS_1; OGS_2; OGS_3** and **OGS_4:** Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.; **SFA**: satured fatty acid; **UFA**: unsatured fatty acid; **MUFA**: monounsatured fatty acid; **PUFA**: polyunsatured fatty acid; **PUFA/SFA**: polyunsatured fatty acid and satured fatty acid ratio

Principal component analysis

Principal Component Analysis (PCA) was used to visualize the variation in properties of sesame oil as a function of germination time (Figure 6). The first and the second axes described 82.67% and 13.24% of the variance, respectively. Together, they represented 95.91% of the total variability. Three (3) homogeneous groups of individuals were identified. Group I, positively correlated to Axis 1, is consisted essentially of the individuals ORS and OGS_0. Group II, above Axis 1 (negatively correlated to Axis 2), is consisted of the individuals OGS_1 and OGS_2. Group III, to the left of Axis 2 more precisely in the negative part of Axis 1, is composed of the individuals OGS_3 and OGS_4. Overall, the results show that germination influences the parameters studied. Correlations between the properties of oil were also supported by Pearson's correlation coefficients (Table 4).

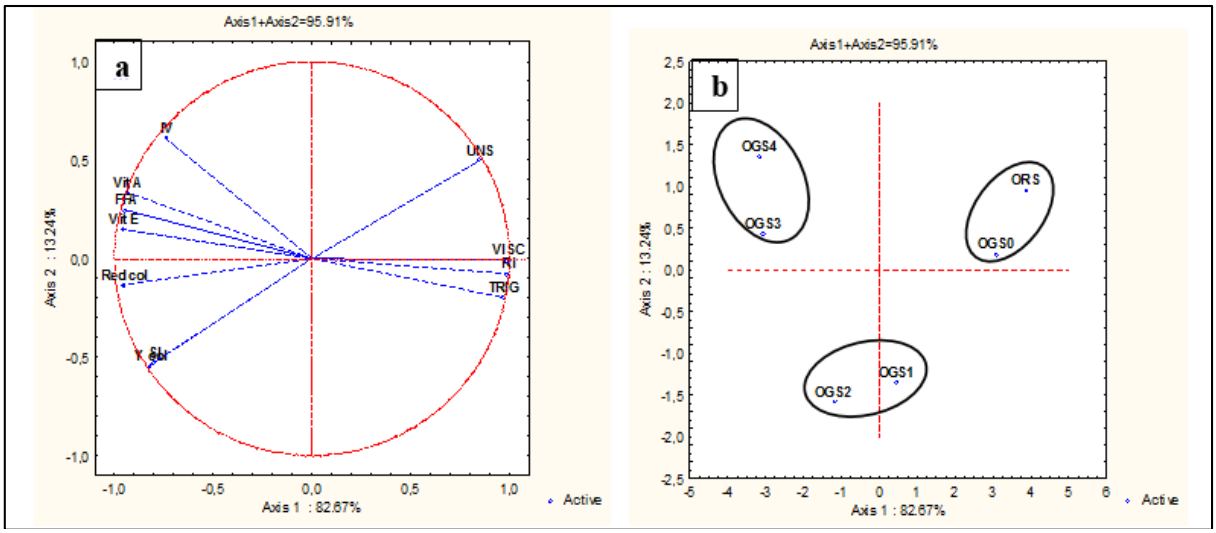

Fig 6: Principal Component Analysis (PCA) of properties of oil extracted from raw and germinated sesame (*Sesamum Indicum*) seeds.

a: Circle of correlation of variables; b: projection of individuals in the factorial plane. FFA: Free Fatty Acid; IV: Iodine Value; SI: Saponification Index; RI: Refractive Index; Visc: Viscosity; Uns: Unsaponifiable matter; TRIG: Triglyceride; R col: Red color; Y col: Yellow color; Vit A: Vitamin A; Vit E: Vitamin E. ORS: Oil extracted from Raw Sesame Seeds; OGS_0: Oil extracted from Sesame Seeds soaked for 24hrs; and OGS1; OGS2; OGS3, OGS4: Oils extracted from germinated sesame seeds respectively during 1, 2, 3 and 4 days.

Table 4: Pearson correlation coefficients between various physicochemical and biochemical properties of extracted oil from raw and germinated sesame (*Sesamum Indicum*) seeds

	significative correlations at $p<.05$										
	FFA	IV	SI	RI	VISC	UNS	TRIG	Red col	Y col	Vit A	Vit E
FFA	1,00										
IV	0,83	1,00									
SI	0,64	0,33	1,00								
RI	-0,93	-0,78	-0,73	1,00							
VISC	-0,97	-0,71	-0,78	0,96	1,00						
UNS	-0,66	-0,30	-0,90	0,82	0,82	1,00					
TRIG	-1,00	-0,80	-0,66	0,95	0,98	0,71	1,00				
Red col	0,83	0,65	0,82	-0,97	-0,91	-0,91	-0,86	1,00			
Y col	0,66	0,30	0,99	-0,75	-0,82	-0,94	-0,70	0,84	1,00		
Vit A	0,98	0,92	0,59	-0,95	-0,93	-0,62	-0,97	0,85	0,60	1,00	
Vit E	0,92	0,76	0,63	-0,98	-0,94	-0,78	-0,94	0,94	0,67	0,94	1,00

FFA: Free Fatty Acid; **IV**: Iodine Value; **SI**: Saponification Index; **RI**: Refractive Index; **Visc**: Viscosity; **Uns**: Unsaponifiable matter; **R col**: Red color; **Y col**: Yellow color; **Vit A**: Vitamin A; **Vit E**: Vitamin E. **TRIG**: Triglyceride

Conclusion

It can be concluded that germination have significantly affected the physicochemical and biochemical properties of the extracted oils from sesame (*Sesamum indicum*) seeds. Germination increased vitamins A and E contents and oil unsaturation in particularly α-linolenic acid. The physical characteristics of the extracted oils have shown significant changes in the colors as well as the viscosities and densities of the processed oils. On the other hand, the chemical properties have revealed an increasing, while only the peroxide values have not changed due to processing. Oils presented good stability due to novo synthesis of antioxydants. This oil, therefore, has a potential for its use in human nutrition or industrial applications. Nutrient information reported herein illustrates the benefits to public health for consumers of these plant seeds.

Acknowledgements

This study was supported by Ph D. grant to the first author. Our thanks to Mr. KAPONGO Kahoyaumaud Bertin (Head of quality control department of SANIA $_{cie}$) who allowed the realization of this research work in the Laboratory.

The authors thank Prof. KOFFI Kouamé Kévin from the Phytotechnical and Genetic Improvement Laboratory (Nangui Abrogoua University, Côte d'Ivoire) for his technical assistance in oil extraction.

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