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Assessment of *Balanites aegyptiaca* and *Sesamum indicum* Artisanal Oils Quality and Vitamin Contents

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Abstract: In Senegal, artisanal vegetable oils trade is developing and *Balanites aegyptiaca* (desert date) as well as *Sesamum indicum* (sesame) are popular vegetal species. Present study focused on oils obtained from these two plants seeds. These oils have various applications such as for dietary and cosmetic purposes. Sampling carried out in Dakar region allowed collection of five oil samples for each specie, mainly in different districts shops or craft fairs. Their peroxide, acid, iodine and saponification values as well as volatile matter, tocopherols and vitamin A contents have been determined through reference methods described by International Organization for Standardization (ISO) or French Standardization Association (AFNOR). Obtained experimental data were compared with *Codex Alimentarius* standard and/or literature, since some parameters are not subject to specific regulation. *Balanites aegyptiaca* and *Sesamum indicum* oil samples showed an orange-yellow or pale yellow coloration. Only one desert date oil sample had an adequate peroxide value while two from sesame were not compliant. Iodine values for *B. aegyptiaca* samples were closed to a result previously described by peer researchers for an oil produced from seeds harvested in Senegal but out of *Codex* specification range for sesame oils. All ten samples had a suitable acidity, widely below maximum value of 4.0 mg KOH/g. Two sesame oil samples had correct saponification value. Among ten oil samples collected, eight showed a volatile matter content exceeding standard. Vitamin A had not been detected in any sample. Desert date oils tocopherols content were comprised between 975.38 and 1141.36 mg/kg and *S. indicum* samples met the standard indicating a tocopherols level in the range [330 - 1010 mg/kg]. Present study results are not all conclusive and reinforce reservations about commercially available artisanal oils quality. However, literature review allows to state that oils physico-chemical properties and nutrient content vary greatly.

Keywords: *Balanites aegyptiaca*, *Sesamum indicum*, Oil, Quality, Physico-chemical Parameters, Vitamins

1. Introduction

Oils and fats represent valuable products which are highly promoted for their nutrient content and contribution to human diet as well as in numerous industrial and pharmaceutical applications, therapeutic and cosmetic products [1]. Oils are products obtained from vegetal species consisting of approximately 95% triacylglycerols and 2-5% non-glyceride compounds (phospholipids, carbohydrate traces, methyl ketones, free fatty acids and their degradation products) [2]. In Senegalese culinary practices, edible oils are very used and, at least, thirty brands locally made or imported can be found on national market [3]. Furthermore, new types of Senegalese artisanal vegetal oils are currently experiencing a boom thanks to other operator types, namely Economic Interest Groups (EIGs) and rural processors. These oils are also attracting a great deal of interest in terms of their quality. This research area is interesting due to high level of oil

consumption in Senegal, combined with absence of mandatory technical specifications and control which encouraged diverse frauds variety: oils mixture or substitution, false claims of nutritional and/or curative values. These irregularities involve consumers' safety who are unable to check products quality. Key interest parameters determine shelf-life as well as quality and hence economic value of oils: iodine value (degree of unsaturation), peroxide value (formation of primary oxidation products), moisture content, acid value (free fatty acids coming from rancidity)… [3]. We were interested in *Balanites aegyptiaca* and *Sesamum indicum* oils. *Balanites aegyptiaca* Del. (Zygophyllaceae) is an evergreen dicotyledonous multibranched savannah tree specie native to arid and semi-arid areas of Africa, the Arabian Peninsula and South Asia. It is one of most common trees in Senegal [4, 5]. *B. aegyptiaca* English name is desert date [6]. *B. aegyptiaca* seeds are 1.5 to 3 cm long, light brown, fibrous, extremely hard and make up 50 to 60% of fruits (Figure 1a) [4, 6]. Their kernels contain 30 to 60% oil [7]. *B. aegyptiaca* oil presents interesting characteristics making it applicable in many areas including food, cosmetics and biodiesel. It also possesses medicinal properties and insecticidal activity [8-10]. Seed oil major fatty acids are linoleic (47.84%), oleic (22.80%), palmitic (16.68%) and stearic (11.67%) [11]. Sesame (*Sesamum indicum* L.) is an oilseed crop of great economic importance which contains 42 to 54% oil and belongs to Pedaliaceae family. It is an annual herb native to the tropics and cultivated widely in many parts of the world: Asia, Africa and Latin America [12-14]. Sesame oil is obtained from *S. indicum* seeds (Figure 1b) [15]. It contains many bioactive compounds such as phytosterols, tocopherols and lignans including sesamin, sesamolin and sesamol which have antioxidant properties. Sesame oil contains high oleic and linoleic fatty acids levels [16]. It is consumed as a healthy cooking or seasoning oil [17]. In chemical industry, this oil is used for manufacture of various products such as margarine, cosmetics and perfumes [18]. It also exhibits pharmacological activities and medical uses [19, 20]. Present study aimed at determining quality and vitamins contents of *B. aegyptiaca* and *S. indicum* oil samples commercially available in Dakar city.

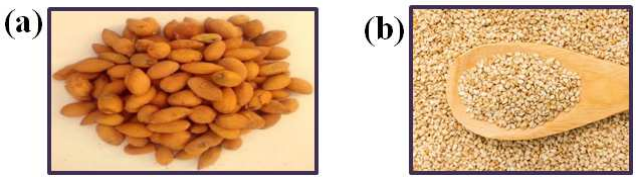

Figure 1. *B. aegyptiaca fruits (a) and S. indicum seeds (b).*

2. Materials and Methods

Solvents and chemicals of analytical or HPLC grade, double distilled or ultrapure water as well as class A glassware were used during our investigations.

2.1. Oil Samples

Sampling was carried out in May 2016. Samples relative information are mentioned in Table 1. *B. aegyptiaca* oils had an orange-yellow coloration excepted sample n°4 which was pale yellow like *S. indicum* oils.

Table 1. *Information on collected oil samples.*

Specie	Sample	Code	Production information	Collection place
B. aegyptiaca	1	*BA*1	Slightly steaming then extraction by cold pressing with a press machine	Shop in *Liberté 5* district
	2	*BA*2	Slightly heating then extraction by cold pressing with a vice press in Ziguinchor area (Senegal)	Shop in *Amitié* district
	3	*BA*3	Cold pressing in Diourbel area (Senegal)	Shop in *Jet d'eau* district
	4	*BA*4	Cold pressing	In a private home, *Cité Keur Gorgui*
	5	*BA*5	Steaming then extraction by cold pressing with a press machine Fruits harvested in *Lomène* village (Diourbel area - Senegal)	*Patte d'oie* district craft fair
S. indicum	1	*SI*1	Cold pressing with a press machine and without heating	Shop in *Liberté 5* district
	2	*SI*2	Slightly heating then extraction by cold pressing with a vice press in Ziguinchor area (Senegal)	Shop in *Amitié* district
	3	*SI*3	Cold pressing in Diourbel area (Senegal)	Shop in *Jet d'eau* district
	4	*SI*4	-	*Patte d'oie* district craft fair
	5	*SI*5	Cold pressing	*Sacré-coeur* district craft fair

2.2. Determination of Peroxide Value

Oil sample (2 g) was dissolved in an acetic acid/isooctane (15 mL/10 mL) mixture before addition of 0.5 mL potassium iodide solution (3 g KI in 2 mL H_2O). After 5 minutes in obscurity, starch indicator solution (10 mL) and distilled water (75 mL) were added. Titration was realised with 0.01 N sodium thiosulfate until yellow colour disappeared. A fat-free blank was carried out under same conditions. Peroxide value was calculated using following formula [21]:

$$PV = \frac{1000 \times (V_1 - V_0) \times c}{w}$$

PV: peroxide value expressed in meq O_2/kg; V_1 = sodium thiosulfate consumption in main test (mL); V_0 = sodium thiosulfate consumption in blank test (mL); c = sodium thiosulfate normality; w = oil weighed portion (g).

2.3. Determination of Iodine Value

Oil sample (0.2 g) was dissolved in an acetic acid/cyclohexane (10 mL/10 mL) mixture before addition of

Wijs solution (25 mL). Mixture was kept in dark for 1 h then 10% (m/m) KI solution (20 mL) and H_2O (150 mL) were introduced. Titration was realised with 0.1 N sodium thiosulfate in presence of starch indicator solution (0.1 g in 10 mL) until disappearance of blue colour. A fat-free blank was carried out under same conditions. Iodine value was calculated using following formula [22]:

$$IV = \frac{12.69 \times c \times (V_0 - V_1)}{w}$$

IV: iodine value expressed in g/100 g; c = sodium thiosulfate normality; V_0 = sodium thiosulfate consumption in blank test (mL); V_1 = sodium thiosulfate consumption in main test (mL); w = oil weighed portion (g).

2.4. Determination of Acid Value

Oil sample (10 g) was dissolved in an ethyl alcohol/diethyl ether (70 mL/30 mL) mixture which was previously neutralised with 0.1 N potassium hydroxide (KOH) ethanolic solution. Titration was carried out with same KOH solution until reaching pink-violet colour. Phenolphthalein was used as an indicator. Acid value was calculated using following formula [23]:

$$AV = \frac{V \times c \times 56.1}{w}$$

AV: acid value expressed in mg/g; V = potassium hydroxide consumption (mL); c = potassium hydroxide normality; w = oil weighed portion (g).

2.5. Determination of Saponification Value

Oil sample (2 g) dissolved in 0.5 N KOH ethanolic solution (25 mL) was gently boiled under reflux during one hour. Cooled mixture was titrated with 0.5 N hydrochloric acid in presence of phenolphthalein until discolouration. A fat-free blank was carried out under same conditions. Saponification value was calculated using following formula [24]:

$$SV = \frac{(V_0 - V_1) \times c \times 56.1}{w}$$

SV: saponification value expressed in mg/g; c = hydrochloric acid normality; V_0 = hydrochloric acid consumption in blank test (mL); V_1 = hydrochloric acid consumption in main test (mL); w = oil weighed portion (g).

2.6. Determination of Volatile Matter Content

Oil sample (10 g) was placed in a weighed crucible then dried during 4 hours at 103°C. After cooling in desiccator, volatile matter was calculated using following formula [25]:

$$VM = \frac{w_2 \times 100}{w_1}$$

VM: moisture content expressed in%; w_2 = weight loss upon drying (g); w_1 = oil sample weighed portion (g).

2.7. Determination of Vitamin A Content

Oil sample (2 g), methanol (50 mL), ascorbic acid (0.25 g) and 50% (w/w) KOH solution (5 mL) were introduced in a ground-neck flask. Mixture was homogenised then placed in the dark overnight. Saponified oil was introduced in a separating funnel containing water (50 mL) and diethyl ether (50 mL). After decantation, organic layer was recovered and aqueous phase was washed twice with diethyl ether (50 mL). Combined organic phases was rinsed two times with water before drying using anhydrous sodium sulfate, filtration and evaporation under reduce pressure below 50°C. Dry extract was dissolved in methanol (5 mL), filtered through a 0.45 µm diameter Acrodisc® then analysed on an Agilent 1100 Series liquid chromatograph equipped with reverse-phase column and UV-Visible detector (λ = 325 nm). Eluent system consisted of methanol: ethyl acetate (90:10) at 1 mL/min flow rate. Retinol was used as external standard [26]. This compound is a hydrophobic vitamin A form [27].

2.8. Determination of Tocopherols Content (TC)

Oil sample (4 g) was dissolved in hexane (50 mL) then analysed on an Agilent 1100 Series liquid chromatograph equipped with reverse-phase column and fluorescence detector (λ_{ex} = 290 nm; λ_{em} = 330 nm). Eluent system consisted of hexane: isopropanol (99.5:0.5) at 1 mL/min flow rate. Tocopherol isomers were used for external calibration [28].

3. Results and Discussion

Artisanal oils consumed in Senegal do not always meet international quality requirements. Sampling focused on two vegetal species oils that are very popular nationally: *S. indicum* and *B. aegyptiaca*. Five samples of each oil type were collected from Dakar market and their quality parameters were assessed. Difficulties were encountered during sampling. Traders were reluctant to share information about oils provenance and age as well as extraction processes. We were also confronted with a marketing problem. Indeed, for *SI*4 oil, seller initially told us that the product originated from Burkina Faso (sign of quality for traders) but then retracted her statement after long exchange.

It should also be noted that all samples, excepted *BA*3 and *SI*3, were either sun exposed in markets or stored to daylight on shops shelves.

In addition to orange-yellow and pale yellow colours mentioned above, green-yellow is also described as *B. aegyptiaca* oil samples characteristic [9, 29]. A reddish yellow coloration has been reported for *S. indicum* oil [30].

Unsaturated oils and fats become rancid by oxidation, forming peroxides. Peroxide value is a parameter specifying oxygen content as peroxide, especially hydroperoxides [31, 32]. Iodine value is a measure of total unsaturation of oils and fats [33, 34]. It reflects oxidation ability. Acid value determines amount of free fatty acids in lipid materials [35]. A degraded oil contains more free acids which increase its AV. This is linked to transformation of triglycerides ester bonds into glycerol by hydrolysis or enzymatic activity. Saponification value pertains to all fatty acids present in sample [36, 37]. “Moisture and volatile matter content” is

another term used for volatile matter [3].

Excepted *BA*2, all *B. aegyptiaca* samples showed PVs above *Codex* standard (15 milliequivalents of active oxygen/kg oil) [38]. Nevertheless, excess is very slight for *BA*1 (16,71 méq O_2/kg). However, only two *S. indicum* samples were non-compliant (Table 2). These non-standard results reflect an advanced state of oxidation and low resistance to peroxidation. It may also be effects of carotenoids, vitamins A and E or squalene oxidation leading to PV increase. These phenomena generally occur under action of oxygen, light, catalysts (metals, pigments, enzymes) or a rise in temperature. Precautions can be taken to slow down this oxidation during oils manufacture as well as storage, in particular by choosing appropriate packaging and/or through nitrogen inerting. Oils stability could also be enhanced if endogenous antioxidants naturally present in raw materials were preserved during manufacture and distribution processes [39].

B. aegyptiaca samples IVs are comparable to Diedhiou *et al*. findings which obtained 66.7 g/100 g for an oil sample extracted from desert date seeds harvested in Senegal central and northern regions. These values are related to unsaturated nature of *B. aegyptiaca* oils [7]. *Codex* standard specifies an IV in the interval [104 - 120 g/100 g] for sesame-seed oil [38]. All values determined were out of range. However, it should be noted that *SI*2 sample IV (101.7 g/100 g) was relatively close to the lower limit (Table 2).

A good quality oil should have no or low acidity (AV ≤ 4.0 mg KOH/g) [38]. All *B. aegyptiaca* and *S. indicum* samples were compliant, indicating that oils had been fairly well preserved from humidity or any other parameter that favours hydrolysis. In general, determined AV for oils are in line with regulation [15, 29]. There are exceptions such as a Colombian sesame oil sample (2.97 mg KOH/g) or Nigerian desert date one (12.1 mg KOH/g) [9, 14].

Concerning *B. aegyptiaca* oil, any official standard known to date does not give an indication for SV; while for *S. indicum*, it must be between 186 and 195 mg KOH/g. Results showed that *SI*1 and *SI*4 samples exceeded upper limit (246.11 and 210.98 mg KOH/g). On the other hand, *SI*5 oil SV did not meet minimum requirement (178.71 mg KOH/g) (Table 2).

Only two of the ten samples were compliant with a moisture content lower than 0.2% (m/m) that represents maximum allowed value [38]. This parameter varies widely. For an oil sample extracted from Nigerian desert date seeds, authors reported 7.16% [9]. We determined a maximum level of 4.85% (Table 2).

Physico-chemical properties of oils vary greatly. Ogala *et al.* analysed *B. aegyptiaca* oil sample having specific parameters: SV = 136 mg KOH/g; IV = 43,1 g/100g; PV = 37 méq O_2/kg) [9]. IVs close to 100 g/100 g have been obtained by Okia *et al.* for oil samples extracted from Ugandan desert date seeds [29]. Purnamayati *et al.* also reported non-compliant IV and SV for an Indonesian sesame oil sample (133.53 g/100 g and 176.68 mg KOH/g) [30]. In Sudan, Ali *et al.* produced a *B. aegyptiaca* oil in accordance with Codex standard for AV (0.53 mg KOH/g) and PV (3.08 méq O_2/kg) but not compliant for VM (3.27%). SV was relatively close to our results (194.33 mg KOH/g) while IV was higher (98.09 g/100g) [40]. Diedhiou *et al.* got same magnitude order for SV (182.2 mg KOH/g) [7].

Vitamin A is an important micro-essential nutrient that is required for normal vision, cell growth, reproductive action, and preventing infection. It is critical for maintaining a plethora of mammalian biological functions [41, 42]. Vitamin A was not detected in any sample, limit of detection being of 0.25 ppm. This may be explained by molecule denaturation during manufacture as well as sunlight and elevated temperature exposition.

Table 2. *Oils physico-chemical characteristics.*

Specie	Sample code	PV (meq O_2/kg)	IV (g/100g)	AV (mg KOH/g)	SV (mg KOH/g)	VM * (%)
	*BA*1	16.71 ± 2.78	84.00 ± 2.71	0.42 ± 0.12	259.37 ± 3.08	0.09
	*BA*2	9.02 ± 4.02	68.61 ± 23.49	0.09 ± 0.02	202.91 ± 9.74	1.65
B. aegyptiaca	*BA*3	24.57 ± 2.04	71.96 ± 20.91	0.43 ± 0.01	176.31 ± 39.30	3.09
	*BA*4	46.87 ± 2.94	74.00 ± 16.52	0.16 ± 0.00	214.12 ± 17.00	4.85
	*BA*5	62.92 ± 5.77	50.57 ± 3.03	0.46 ± 0.02	201.25 ± 4.07	1.03
	*SI*1	37.67 ± 1.00	81.43 ± 19.10	0.15 ± 0.10	246.11 ± 12.40	0.31
	*SI*2	7.53 ± 1.22	101.70 ± 6.95	0.16 ± 0.07	191.73 ± 0.73	1.11
S. indicum	*SI*3	35.10 ± 7.00	77.23 ± 20.34	0.21± 0.01	194.69 ± 0.72	1.31
	*SI*4	1.53 ± 0.17	83.37± 11.53	0.30 ± 0.03	210.98± 17.6	0.98
	*SI*5	4.67 ± 0.35	80.95 ± 18.77	1.37 ± 0.01	178.71 ± 21.5	0.17

Values are means of two replicates ± standard deviation; * n = 1.

Table 3. *Oil samples tocopherols contents.*

Sample	***B. aegyptiaca*** **oil TC (mg/kg)**	***S. indicum*** **oil TC (mg/kg)**
1	975.38	894.15
2	1123.34	973.03
3	1038.85	968.05
4	1383.46	947.37
5	1141.36	972.66

Tocopherols represent four vitamin E saturated analogues (α, β, γ and δ forms) which differ in methyl group position on chromanol ring. They are biological antioxidants thanks to their ability to inhibit lipid peroxidation by blocking oxygen reactive forms [43, 44]. Analysis results for *B. aegyptiaca* oils tocopherols content showed concentrations comprised between 975.38 and 1141.36 mg/kg (Table 3). Diedhiou *et al.* obtained approximately half value compared to our samples (512.4 mg/kg) [7]. With regard to *S. indicum*, all five samples met the standard indicating a level in the range [330 - 1010 mg/kg]

(Table 3) [38]. Thus, *S. indicum* and *B. aegyptiaca* are excellent food oils and vitamin E sources for preventing oxidative stress as well as tissue ageing. Tocopherols are also generally responsible of oils stability during storage. Pang *et al.* reported compliant tocopherols contents over six sesame oil Chinese commercial samples (maximum 546.4 mg/kg) as well as Melo *et al.* for an oil from Spanish seeds (483.95 mg/kg) [19, 45]. Crews *et al.* also mentioned up to 717 mg/kg for tocopherols in sesame oils from various origins (Burkina Faso, China, Egypt, India, Japan, Mexico, Myanmar and Thailand) [12]. All these values were lower to ours comprised between 894.15 and 973.03 mg/kg. In contrast, Hajimahmoodi *et al.* described γ-tochopherol contents for Iranian sesame oils up to 1095.31 mg/kg [46]. Recent study highlighted extensive variability in tocopherols contents among diverse origins (China, Lao People's Democratic Republic, Guatemala and Thailand) sesame seeds [47].

4. Conclusion

Present study aimed to assess quality of *B. aegyptiaca* and *S. indicum* artisanal oil samples commercially available in Dakar city. Their physico-chemical parameters and vitamin contents were determined through official methods. Results on collected samples are not all conclusive and reinforce reservations about commercially available artisanal oils quality. Indeed, some parameters were not in conformity with standard. These oils may have been subject to a lack of control in good practices, particularly during production or conservation stages. We will tend to believe that they are unfit for consumption and present a real risk to human health. To confirm these hypotheses, it would be relevant to extend sampling but also to collect directly from producers as well as improving study by monitoring parameters evolution along production and distribution chains, notably at packaging stages in order to highlight oils stability.

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References

[1] Hafer, E., Holzgrabe, U., Wiedemann, S., Adams, K. M., & Diehl, B. (2020). NMR spectroscopy: determination of peroxide value in vegetable and krill oil by using triphenylphosphine as tagging reagent. *European Journal of Lipid Science and Technology*, 122 (5), 1900442. DOI: 10.1002/ejlt.201900442.

[2] Clara, M. P. F., Veronezi, C. M., & Jorge, N. (2020). Evaluation of quality of chia (*Salvia hispanica*), Sesame (*Sesamum indicum*), and quinoa (*Chenopodium quinoa*) oils ». *Brazilian Archives of Biology and Technology*, 63, e20190351. DOI: 10.1590/1678-4324-2020190351.

[3] Diop, A., Sarr, S. O., Ndao, S., Cissé, M., Baldé, M., Ndiaye, B., & Diop, Y. M. (2014). Effect of deep-fat frying on chemical properties of edible vegetable oils used by senegalese households. *African Journal of Food, Agriculture, Nutrition and Development*, 14 (66), 9418-9438. DOI: 10.18697/ajfand.66.13315.

[4] Chothani, D., & Vaghasiya, H. (2011). A review on *Balanites aegyptiaca* Del (desert date): phytochemical constituents, traditional uses, and pharmacological activity. *Pharmacognosy Reviews*, 5 (9), 55-62. DOI: 10.4103/0973-7847.79100.

[5] Abdelaziz, S. M., Lemine, F. M. M., Tfeil, H. O., Filali-Maltouf, A., & Boukhary, A. O. M. S. (2020). Phytochemicals, antioxidant activity and ethnobotanical uses of *Balanites aegyptiaca* (L.) Del. fruits from the arid zone of Mauritania, northwest Africa. *Plants*, 9 (3), 401. DOI: 10.3390/plants9030401.

[6] Aremu, M. O., Andrew, C., Oko, O. J., Odoh, R., Ambo, I. A., & Hikon, B. N. (2021). Nutrient, antinutrient and sugar contents in desert date (*Balanites aegyptiaca* (L.) Del) seed and pulp ». *International Journal of Sciences*, 10 (7), 12-21. DOI: 10.18483/ijSci.2484.

[7] Diedhiou, D., Faye, M., Candy, L., Vandenbossche, V., Vilarem, V., Sock, O., & Rigal, L. (2021). Composition and balance of the analytical fractionation of desert date (*Balanites aegyptiaca* L.) seeds harvested in Senegal. *African Journal of Biotechnology*, 20 (4), 150-158. DOI: 10.5897/AJB2021.17327.

[8] Elbadawi, S. M. A., Ahmad, E. E. M., Mariod, A. A., & Mathäus, B. (2017). Effects of thermal processing on physicochemical properties and oxidative stability of *Balanites aegyptiaca* kernels and extracted oil. *Grasas y Aceites*, 68 (1), e184. DOI: 10.3989/gya.1048162.

[9] Ogala, H., Elinge, C. M., Wawata, I. G., Adegoke, A. I., Muhammad, A. B., & Ige, A. R. (2018). Extraction and physicochemical analysis of desert date (*Balanites Aegyptiaca*) seed oil. *International Journal of Advanced Academic Research*, 4 (4), 1-12.

[10] Mokhtar, M. M., Li, J., Du, Z., & Cheng, F. (2021). Insecticidal efficacy and chemical composition of *Balanites aegyptiaca* (L.) Delile seed oils against *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) ». *Chilean Journal of Agricultural Research*, 81 (1), 102-108. DOI: 10.4067/S0718-58392021000100102.

[11] Murthy, H. N., Yadav, G. G., Dewir, Y. H., & Ibrahim, A. (2020). Phytochemicals and biological activity of desert date (*Balanites aegyptiaca* (L.) Delile). *Plants*, 10 (1), 32. DOI: 10.3390/plants10010032.

[12] Crews, C., Hough, P., Brereton, P., Godward, J., Lees, M., Guiet, S. & Winkelmann, W. (2006). Quantitation of the main constituents of some authentic sesame seed oils of different origin. *Journal of Agricultural and Food Chemistry*, 54 (17), 6266-6270. DOI: 10.1021/jf0603578.

[13] Shin, B. R., Song, H.-W., Lee, J.-G., Yoon, H.-J., Chung, M.-S., & Kim, Y.-S. (2016). Comparison of the contents of benzo (a)pyrene, sesamol and sesamolin, and volatiles in sesame oils according to origins of sesame seeds. *Applied Biological Chemistry*, 59 (1), 129-141. DOI: 10.1007/s13765-015-0138-3.

[14] Espitia Cubillos, A. A., Delgado-Tobón, A. E., & Chaparro, W. A. A. (2019). Comparative study of the thermal properties of sesame oil and two mineral oils of different viscosity. *INGE CUC*, 15 (2), 99-109. DOI: 10.17981/ingecuc.15.2.2019.10.

[15] De Almeida Vittori Gouveia, L., Zago, L., & Moreira, A. S. B. (2017). Physical-chemical characterization and nutritional quality of sesame oil (*Sesamum indicum* L.). *Journal of Nutritional Health & Food Science*, 5 (3), 1-7. DOI: 10.15226/jnhfs.2017.00100.

[16] Hadeel, S. Y., Khalida, S. A., & Walsh, M. (2020). Antioxidant activity of sesame seed lignans in sunflower and flaxseed oils. *Food Research*, 4 (3), 612-622. DOI: 10.26656/fr.2017.4 (3). 331.

[17] Yi, J. Y., Kim, H. J., & Chung, M.-S. (2017). Manufacture of low-benzo (a)pyrene sesame seed (*Sesamum indicum* L.) oil using a self-designed apparatus. *PLOS ONE*, 12 (3), e0173585. DOI: 10.1371/journal.pone.0173585.

[18] Carvalho, R. H. R., Galvão, E. L., Barros, J. Â. C., Conceição, M. M., & Sousa, E. M. B. D. (2012). Extraction, fatty acid profile and antioxidant activity of sesame extract (*Sesamum indicum* L.). *Brazilian Journal of Chemical Engineering*, 29 (2), 409-420. DOI: 10.1590/S0104-66322012000200020.

[19] Pang, M., Cao, L., Zheng, D., Lei, Z., Ge, Y., Cheng, J., Jiang, S. & Cao, L. (2020). Simultaneous detection of lignans and tocopherols in sesame oil by reversed-phase high-performance liquid chromatography. *Preprints*. DOI: 10.22541/au.159242090.06956031.

[20] Morris, J. B., Wang, M. L. & Tonnis, B. D. (2021). Variability for oil, protein, lignan, tocopherol, and fatty acid concentrations in eight sesame (*Sesamum indicum* L.) genotypes. *Industrial Crops and Products*. 164, 113355. DOI: 10.1016/j.indcrop.2021.113355.

[21] International Organization for Standardization (ISO). (2007). ISO 3960:2007. Animal and vegetable fats and oils - Determination of peroxide value - Iodometric (visual) endpoint determination.

[22] International Organization for Standardization (ISO). (2013). ISO 3961: 2013. Animal and vegetable fats and oils - Determination of iodine value.

[23] International Organization for Standardization (ISO). (2009). ISO 660: 2009. Animal and vegetable fats and oils - Determination of acid value and acidity.

[24] International Organization for Standardization (ISO). (2013). ISO 3657: 2013. Animal and vegetable fats and oils - Determination of saponification value.

[25] International Organization for Standardization (ISO). (2016). ISO 662: 2016. Animal and vegetable fats and oils - Determination of moisture and volatile matter content.

[26] French Standardization Association (AFNOR). (2014). NF EN 12823-1: 2014. Foodstuffs - Determination of vitamin A by high performance liquid chromatography.

[27] Park, H., Mun, S., & Kim, Y.-R. (2019). UV and storage stability of retinol contained in oil-in-water nanoemulsions. *Food Chemistry*, 272, 404-410. DOI: 10.1016/j.foodchem.2018.08.076.

[28] International Organization for Standardization (ISO). (2006). ISO 9936:2006. Animal and vegetable fats and oils - Determination of tocopherol and tocotrienol contents by high-performance liquid chromatography.

[29] Okia, C. A., Kwetegyeka, J., Okiror, P., Kimondo, J. M., Teklehaimanot, Z. & Obua, J. (2013). Physico-chemical characteristics and fatty acid profile of desert date kernel oil. *African Crop Science Journal*, 21 (s3). 723-734.

[30] Purnamayati, L., Sumardianto, Romadhon, & Dewi, E. N. (2019). Physical blending characteristic of fish oil and sesame oil. *IOP Conference Series: Earth and Environmental Science*, 246, 012054. DOI: 10.1088/1755-1315/246/1/012054.

[31] Talbot, G. (2016). The stability and shelf life of fats and oils. In *The Stability and Shelf Life of Food*, Elsevier, 461-503. DOI: 10.1016/B978-0-08-100435-7.00016-2.

[32] Mariod, A. A., Mirghani, M. E. S., & Hussein, I. (2017). Chapter 28 - *Vangueria madagascariensis* (Rubiaceae) as new oil source. In *Unconventional Oilseeds and Oil Sources*, Academic Press, 167-180. DOI: 10.1016/B978-0-12-809435-8.00028-7.

[33] Barrera-Arellano, D., Badan-Ribeiro, A. P., & Serna-Saldivar, S. O. (2019). Corn oil: composition, processing, and utilization. In *Corn*, Elsevier, 593-613. DOI: 10.1016/B978-0-12-811971-6.00021-8.

[34] Da Silva Oliveira, W., Neves, D. A., & Ballus, C. A. (2019). Mature chemical analysis methods for food chemical properties evaluation. In *Evaluation Technologies for Food Quality*, Elsevier, 63-90. DOI: 10.1016/B978-0-12-814217-2.00005-6.

[35] Onu, P., & Mbohwa, C. (2021). New approach and prospects of agrowaste resources conversion for energy systems performance and development. In *Agricultural Waste Diversity and Sustainability Issues*, Elsevier, 97-118. DOI: 10.1016/B978-0-323-85402-3.00007-3.

[36] Barret, R. (2018). Importance and evaluation of lipophilicity. In *Therapeutical Chemistry*, Elsevier, 53-78. DOI: 10.1016/B978-1-78548-288-5.50003-2.

[37] Thangarasu, V., & Anand, R. (2019). Comparative evaluation of corrosion behavior of Aegle Marmelos Correa diesel, biodiesel, and their blends on aluminum and mild steel metals. In *Advanced Biofuels*, Elsevier, 443-471. DOI: 10.1016/B978-0-08-102791-2.00017-9.

[38] CODEX. (1999). CODEX STAN 210-1999. Standard for named vegetable oils.

[39] Cuvelier, M.-E., & Maillard, M.-N. (2012). Stabilité des huiles alimentaires au cours de leur stockage. *Oilseeds and fats, Crops and Lipids*, 19 (2), 125-132. DOI: 10.1051/ocl.2012.0440.

[40] Ali, A. E., Mohammed, B., Ali, H. A. A. M., Malik, I. O. M., Ali, M. A. e. M., & Hamadnalla, H. M. (2021). Biochemical properties and nutritional value of *Balanites aegyptiaca* (Laloub) seed oil. *Insights in Chemistry and Biochemistry*, 2 (1), 1-4. DOI: 10.33552/ICBC.2021.02.000527.

[41] Takahashi, N., Saito, D., Hasegawa, S., Yamasaki, M., & Imai, M. (2021). Vitamin A in health care: Suppression of growth and induction of differentiation in cancer cells by vitamin A and its derivatives and their mechanisms of action. *Pharmacology & Therapeutics*, In Press, 107942. DOI: 10.1016/j.pharmthera.2021.107942.

[42] Honarbakhsh, M., Ericsson, A., Zhong, G., Isoherranen, N., Zhu, C., Bromberg, Y., Van Buiten, C., Malta, K., Joseph, L., Sampath, H., Lackey, A. I., Storch, J., Vetriani, C., Chikindas, M. L., Breslin, P., & Quadro, L. (2021). Impact of vitamin A transport and storage on intestinal retinoid homeostasis and functions. *Journal of Lipid Research*, 62, 100046. DOI: 10.1016/j.jlr.2021.100046.

[43] Malloy, M. J., & Kane, J. P. (2015). Lipoprotein disorders. In *Rosenberg's Molecular and Genetic Basis of Neurological and Psychiatric Disease*, Elsevier, 577-588. DOI: 10.1016/B978-0-12-410529-4.00051-6.

[44] Chew, S. C., & Nyam, K. L. (2020). Refining of edible oils. In *Lipids and Edible Oils*, Elsevier, 213-241. DOI: 10.1016/B978-0-12-817105-9.00006-9.

[45] Melo, D., Álvarez-Ortí, M., Nunes, M. A., Costa, A. S. G., Machado, S., Alves, R. C., Pardo, J. E., & Oliveira, M. B. P. P. (2021). Whole or defatted sesame seeds (*Sesamum indicum* L.)? The effect of cold pressing on oil and cake quality. *Foods*, 10 (9), 2-15. DOI: 10.3390/foods10092108.

[46] Hajimahmoodi, M., Oveisi, M. R., Sadeghi, N., Jannat, B., Bahaeddin, Z., & Mansoori, S. (2008). Gamma tocopherol content of Iranian sesame seeds. *Iranian Journal of Pharmaceutical Research*, 7 (2), 135-139.

[47] Rangkadilok, N., Pholphana, N., Mahidol, C., Wongyai, W., Saengsooksree, K., Nookabkaew, S., & Satayavivad J. (2010). Variation of sesamin, sesamolin and tocopherols in sesame (*Sesamum indicum* L.) seeds and oil products in Thailand ». *Food Chemistry*, 122 (3), 724-730. DOI: 10.1016/j.foodchem.2010.03.044.