The Effect of Solvent Type and Roasting Processes on Physico-Chemical Properties of Tigernut (Cyperus esculentus L.) Tuber Oil

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Abstract: In this study, physico-chemical properties of raw and roasted tigernut oils extracted by two different solvents were determined. Peroxide values of raw and roasted tigernut oils extracted by petroleum ether and n-hexane solvents changed between 0.83 and 0.91 meqO₂/100g to 1.57 and 1.63 meqO₂/100g, respectively. While oleic acid contents of raw tigernut oils extracted by petroleum ether and n-hexane are determined as 66.83 and 67.47%, oleic acid contents of roasted tigernut oils extracted by petroleum ether and n-hexane were determined as 67.08 and 68.16%, respectively. The highest δ-tocopherol content was found in raw tigernut oil extracted by petroleum ether (54.91 mg/100g), while the lowest level is determined in roasted tigernut oil by n-hexane (50.77 mg/100g). As a result, the fatty acid profiles of roasted tigernut oil extracted by n-hexane were higher compared to results of raw tigernut oils extracted by petroleum ether (p < 0.05).

Key words: tigernut, Cyperus esculentus L., oil, solvent types, roasting, physico-chemical properties, fatty acid, tocopherol

1 INTRODUCTION

Tigernut (Cyperus esculentus L.) grows widely in tropical and semi-tropical regions such as Greece, Italy, Turkey, Israel countries. Tigernut called as chufa, earth almond, nut grass earth nut and yellow nut sedge is an edible perennial plant. Tigernut is rich in oil content (17-25%), and it is a potential new source of stable edible cooking and salad oil. Also, tigernut oil can be used for industrial purposes, too. Tigernut consumed as raw, roasted, dried, baker and refreshing beverage called as tigernut milk is rich in energy content, minerals and vitamins E and C. The main saturated acid and the dominant unsaturated acids of tigernut oils were palmitic and oleic acids, respectively. Several studies were conducted on fatty acid composition of untreated tigernut oil. Solvent extraction is the most widely used procedure on an industrial scale. Conventional heating process is being used for several food processing operations. The roasting conditions have significant influences on color, flavor, fatty acid profile and bioactive compounds of kernel and seeds. But, limited study was conducted on fatty acid compositions of tigernut oil obtained by different preparation methods. However, the aim of current work was to investigate the effect on fatty acid composition of tiger nut oil of solvent types and roasting process.

2 MATERIAL AND METHODS

2.1 Material

Tigernut (Cyperus esculentus L.) was cultivated in experiment field in Mersin distinct in Turkey.

2.2 Methods

2.2.1 Heating processing

Each sample was heated as without the shell in oven. Tigernut tubers were heated in commercial electrical ovens at 130°C for 20 min. The heated samples were ground into powder using a grinder before analysis.

2.2.2 Oil content

After tigernut tubers were cleaned from impurities such as muld, leaf and root parts, tubers were extracted by

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Soxhlet Apparatus by using two solvents (petroleum ether and n-hexane) for 5 h, and the solvent. After solvent was removed with a rotary vacuum evaporator at 50°C, crude oil was kept at +4°C till analysis. 2.2.3 Physico-chemical properties

Standard AOAC methods were used to determine the acid value, peroxide value, density, iodine value, refractive index, saponification and unsaponification values for tigernut tuber oil samples.

2.2.4 Fatty acid composition

After tigernut oil was esterified according to ISO-5509 method, and Fatty acid methyl esters of samples were analysed gas chromatography (Shimadzu GC-2010) equipped with flame-ionization detector (FID) and capillary column (Tecnocroma TR-CN100, 60 m x 0.25 mm, film thickness: 0.20 μm). The temperature of injection block and detector was 240°C. Mobile phase was nitrogen with 1.51 mL/min flow rate. Total flow rate was 80 mL/min and split rate was also 1/40. Column temperature was programmed 120°C for 5 minutes and increased 240°C at 4°C/min and held 25 minutes at 240°C.

2.2.5 Tocopherol analyses

Tocopherol contents of tigernut tuber oils were performed according to Spika et al. 0.1 g of oil was dissolved in 10 mL of n-hexane and filtered through a 0.45 μm nylon filter. HPLC analyses of tocophers were determined using Shimadzu-HPLC equipped with PDA detector and Li-ChroCART Silica 60 (4.6 x 250 mm, 5 μ; Merck, Darmstadt, Germany) column. Tocopherols were separated by isocratic chromatography using a mobile phase of 0.7% propan-2-ol in n-hexane. The flow rate of the mobile phase was 0.9 mL/min and the injection volume was 20 μL. The peaks were recorded at 295 and 330 nm with PDA detector. The total running time per sample was 30 min. Standard solutions of tocopherols (α, β, γ, and δ-tocopherol) were constructed in the concentrations of 0-100 mg/L. All analyses were made in triplicate.

2.3 Statistical analysis

A complete randomized split plot block design was used analysis of variance (ANOVA) was performed by using JMP version 9.0 (SAS Inst. Inc., Cary, N.C.U.S.A). All analyses were carried out three times and the results are mean ± standard deviation (MSTAT C) of 25 of independent tigernut oils.

3 RESULTS AND DISCUSSION

Physico-chemical properties of of raw and roasted tigernut oils extracted by the two different solvents are given in Table 1. As seen in Table 1, acid values for all studied oils were found between 0.11 and 0.17% for raw tigernut oil and 0.34 and 0.68% for roasted tigernut oil. The low acid value determined for tigernut oils is an indication that the triacylglycerols present have not been hydrolysed. This can be attributed to the low action of lipolytic enzymes. Acid value is a measure of the free fatty acid in the oil sample and it can also be used as an indicator for the age of the oil and as one of important quality attributes measurements. Peroxides are the primary reaction products formed in the initial stages of oxidation of oil and therefore give an indication of the process of lipid peroxidation. While peroxide values of raw tigernut oils extracted by petroleum ether and n-hexane change between 0.83 and 0.91 meqO2/100 g, peroxide values of roasted tigernut oils were determined 1.57 and 1.63 meqO2/100 g respectively. Consequently, the peroxide value cleared that significant differences between raw and roasted tigernut oil samples (p<0.05). El-Naggar reported 0.369 meqO2/kg peroxide value for tigernut oil, 2.5 meqO2/kg peroxide value for olive oil, 0.5 meqO2/kg peroxide value for maize oil, 0.5 meqO2/kg peroxide value for sunflower oil and 0.7 meqO2/kg peroxide value for soybean oil samples. Increasing of peroxide values of tigernut oils obtained by soxhlet system from raw and roasted tigernut tubers can be probably due to solvent used, heat application and oxygen contact during extraction process.

Table 1 Physical and chemical properties of raw and roasted tigernut oils extracted by two different solvents.

| Parameters                  | Raw tigernut oil | Roasted tigernut oil |
|-----------------------------|------------------|----------------------|
|                            | Petroleum ether  | n-Hexane             | Petroleum ether  | n-Hexane             |
| Acid value (%)              | 0.11±0.01*a      | 0.17±0.03*s          | 0.34±0.05*b     | 0.68±0.03*a          |
| Peroxide value (meqO2/kg)   | 0.83±0.09, **    | 0.91±0.07*s          | 1.57±0.03*b     | 1.63±0.11*s          |
| Saponification value (mgKOH/g) | 199.13±1.34     | 199.57±1.07*s        | 200.43±0.11*s   | 202.57±1.37*s        |
| Unsaponification value (%)  | 1.83±0.13*       | 1.79±0.09*s          | 1.54±0.07*b     | 1.61±0.15*s          |
| Iodine value (gl/100g)      | 71.17±1.56*      | 72.84±0.78*s         | 70.76±0.61*s    | 71.58±0.93*s         |
| Refractive index (nD)       | 1.4653±0.0021*a  | 1.4650±0.0017*a      | 1.4658±0.0013*b | 1.4661±0.0009*a      |
| Density (g/cm³; 25°C)       | 0.9160±0.0009    | 0.9113±0.0013        | 0.9207±0.0013*s | 0.9231±0.0007*s      |

*a mean Standard deviation; **Values within each row followed by different letters are significantly different (p<0.05)
Saponification of oil samples changed between 199.13 mgKOH/g and 199.57 mgKOH/g for raw tigernut oil and 200.43 and 202.57 mgKOH/g for roasted tigernut oil. According to Muhammad et al.\(^{21}\) report, oil with higher saponification values contain high proportion of lower fatty acid. Therefore, the saponification value obtained for tigernut oil in this study show that it contains high amounts of long chain fatty acids. The highest unsaponification matter content was observed in untreated (raw tigernut) sample (1.83 and 1.79%), while the lowest level is found in roasted tigernut sample (1.54 and 1.61%). Significant differences were observed between raw and roasted tigernut oils for parameters of all studied oils \((p<0.05)\). Iodine values of raw and roasted tigernut oils changed between 71.17 and 72.84 to 70.76 and 71.58 gI\(_2/100\) g, respectively. Also, density values of tigernut oils determined between 0.9160 and 0.9113 for roasted tigernut oil samples. Significant differences were observed in iodine values of tigernut oils \((p<0.05)\). Tigernut oil could be classified as non-drying oil, higher resistance to oxidation and high quality\(^{20}\). Adel et al.\(^{4}\) reported that untreated and roasted tigernut oils had 1.4646 and 1.4651 refractive index, 3.64 and 4.51% acidity, 200.71 and 201.24 mgKOH/g saponification value, 72.53 and 72.94 gI\(_2/100\) g iodine value, 0.79 and 0.80 meqO\(_2/kg\) peroxide value and 1.71 and 0.46% unsaponification values. El-Naggar\(^{23}\) determined 0.9200 specific gravity, 1.465 refractive index, 0.22% acid value, 192.88 saponification number, 87.08 iodine value, 0.70% unsaponification matter in tigernut oil. The results confirmed a previous report that roasting was found to cause an increase in the passage of acid, peroxide, saponification values, and density\(^{4,24}\). Results were found close to those reported by Olagunju\(^{25}\), El-Naggar\(^{26}\), Belewu and Abodunrin\(^{27}\), and Muhammad et al.\(^{21}\).

Fatty acid composition of raw and roasted tigernut oils obtained by two different solvents are given in Table 2. While oleic acid contents of raw tigernut tuber oils extracted by petroleum ether and \(n\)-hexane solvents are determined as 66.83 and 67.47%, oleic acid contents of roasted tigernut tuber oils extracted by petroleum ether and \(n\)-hexane solvents were established as 67.08 and 68.16%, respectively. Palmitic acid contents of raw tigernut tuber oil extracted by solvents were found lower (14.89-15.67%) than those of roasted tigernut tuber oil (16.71-17.86%). In addition, linoleic acid contents of roasted tigernut tuber oil extracted by solvents were found higher (10.43-11.56%) than those of raw tigernut tuber oil (9.74-11.03%). Generally, the fatty acid composition of tiger nut oil closely similar to the fatty acid composition of olive oil. While it is observed statistically differences among fatty acid compositions of raw tigernut oils and roasted tigernut oils treated with oven heating compared to fatty acid compositions of tigernut oils extracted by different solvents \((p<0.05)\). Although tigernut oil has low polyunsaturated fatty acid (linoleic and linolenic acids), the oleic acid contents of tigernut oils (66.47-69.71%) were found higher than those of literature values (sunflower oil (23.6%), soybean oil (24.9%), and corn oil (23.8%)), but it was found partly similar with olive oil\(^{38-39}\). Oderinde and Tairu\(^{21}\) reported that tigernut oil is rich in oleic acid and relatively stable and resistant to oxidation. It was observed that the process of solvent extractions and roasting had affected on fatty acid composition of tigernut oils. These results showed partly differences with results of Jung et al.\(^{21}\), Kim et al.\(^{10}\), Adel et al.\(^{4}\) and Yoon\(^{5}\). Adel et al.\(^{4}\) determined 15.05-15.21% palmitic, 5.07-5.31% stearic, 68.97-69.33% oleic

| Table 2 | Fatty acid composition of raw and roasted tigernut oils extracted by two different solvents (%) |
| --- | --- |
| **Raw tigernut oil** | **Roasted tigernut oil** |
| **Fatty acids** | Petroleum ether | \(n\)-Hexane | Petroleum ether | \(n\)-Hexane |
| Myristic | 0.17 ± 0.03*, 0.21 ± 0.01 | 0.23 ± 0.07, 0.27 ± 0.03 | 0.17 ± 0.03*, 0.21 ± 0.01 | 0.23 ± 0.07, 0.27 ± 0.03 |
| Palmitic | 14.89 ± 0.56**, 15.67 ± 0.73 | 16.71 ± 1.05, 17.86 ± 1.17 | 16.71 ± 1.05, 17.86 ± 1.17 | 16.71 ± 1.05, 17.86 ± 1.17 |
| Palmitoleic | 0.32 ± 0.09, 0.35 ± 0.07 | 0.43 ± 0.01, 0.51 ± 0.03 | 0.43 ± 0.01, 0.51 ± 0.03 | 0.43 ± 0.01, 0.51 ± 0.03 |
| Stearic | 4.76 ± 0.11, 5.38 ± 0.23 | 5.17 ± 0.17, 5.93 ± 0.28 | 5.17 ± 0.17, 5.93 ± 0.28 | 5.17 ± 0.17, 5.93 ± 0.28 |
| Oleic | 66.83 ± 1.38, 67.47 ± 1.27 | 67.08 ± 1.52, 68.16 ± 1.19 | 67.08 ± 1.52, 68.16 ± 1.19 | 67.08 ± 1.52, 68.16 ± 1.19 |
| Linoleic | 9.74 ± 0.69, 11.03 ± 0.54 | 10.43 ± 0.71, 11.56 ± 0.47 | 10.43 ± 0.71, 11.56 ± 0.47 | 10.43 ± 0.71, 11.56 ± 0.47 |
| Linoleic | 0.37 ± 0.05, 0.42 ± 0.03 | 0.41 ± 0.09, 0.49 ± 0.07 | 0.41 ± 0.09, 0.49 ± 0.07 | 0.41 ± 0.09, 0.49 ± 0.07 |
| Arachidic | 0.53 ± 0.03, 0.58 ± 0.09 | 0.61 ± 0.07, 0.67 ± 0.05 | 0.61 ± 0.07, 0.67 ± 0.05 | 0.61 ± 0.07, 0.67 ± 0.05 |
| Gondoic | 0.33 ± 0.01, 0.28 ± 0.01 | 0.39 ± 0.07, 0.34 ± 0.09 | 0.39 ± 0.07, 0.34 ± 0.09 | 0.39 ± 0.07, 0.34 ± 0.09 |
| Behenic | 0.26 ± 0.03, 0.23 ± 0.01 | 0.31 ± 0.07, 0.25 ± 0.05 | 0.31 ± 0.07, 0.25 ± 0.05 | 0.31 ± 0.07, 0.25 ± 0.05 |

*mean Standard deviation; **Values within each row followed by different letters are significantly different \((p < 0.05)\)
and 8.28-8.42% linoleic acids in tigernut treated by different preparation methods such as untreated, soaking, blanching and roasting. The variations of fatty acid compositions of tigernut oil affected during roasting were found statistically significant (p<0.05). Generally, all fatty acids dominated in the roasted tigernut oil samples was higher compared to fatty acid results of raw tigernut oils. Palmitic, stearic and oleic acids results showed similarity with those palmitic, stearic and oleic acids (except linoleic) of seed oils treated by higher microwave heating\cite{22,23}. Yoon\cite{55} investigated the effect of two different solvents on fatty acid composition of tigernut oils, and determined 15.2-16.0% palmitic, 2.0-2.2% stearic, 64.4-66.1% oleic, 14.8-15.9% linoleic and 0.4-0.5% linolenic acids. According to study of Yoon\cite{54}, oleic acid content (66.1%) of tigernut oil extracted diethyl ether was found compared to n-hexane (65.8%) and chloroform/methanol (64.4%). In addition roasting, solvent types caused variations in fatty acid compositions of tigernut oils. The fatty acid composition of tigernut oils obtained with n-hexane was higher compared to results of tigernut oils extracted petroleum ether. The variation in the percentage of fatty acid compositions in tigernut oil was found statistically significant (p<0.05).

Tocopherol contents of raw and roasted tigernut oils extracted by two different solvents are shown in Table 3. While α-tocopherol contents of raw tigernut oils change between 17.83 mg/100 g (petroleum ether) and 16.74 mg/100 g (n-hexane), α-tocopherol contents of roasted tigernut oils varied between 15.64 mg/100 g (petroleum ether) and 15.07 mg/100 g (n-hexane). β-tocopherol contents of tigernut oils were found at the low levels. The highest δ-tocopherol content was found in raw tigernut oil extracted by petroleum ether (54.91 mg/100 g), while the lowest level is determined in roasted tigernut oil by n-hexane (50.77 mg/100 g). While γ-tocopherol contents of raw tigernut oils extracted by petroleum ether and n-hexane change between 36.44 mg/100 g and 35.53 mg/100 g, γ-tocopherol contents of roasted tigernut oils changed between 50.77 and 34.27 mg/100 g, respectively. As seen in Table 3, it could be concluded that the tigernut tuber oils had the highest antioxidants substances due to high tocopherol contents. Tigernut oil had a significantly higher in total tocopherol compounds compared with the most of other edible oils such as sunflower, maize and soybean\cite{23,34}. Thus, it would be expected to contribute to excellent oxidative stability and protection to tigernut oil during storage and processing. El-Naggar\cite{23} determined 16.1 mg/100 g α-tocopherol, 50 mg/100 g δ-tocopherol and 31.3 mg/100 g γ-tocopherol in tigernut oil.

4 CONCLUSION

Both solvent types and roasting had affected on fatty acids of tigernut oils. A partial increase in the fatty acids of the tigernut oil with roasting has been observed. This increase was also observed in tigernut oil extracted with n-hexane depending on the solvent type too. The fatty acid compositions of tigernut oils obtained with n-hexane treated by roasting process were higher compared to results of raw tigernut oils extracted by petroleum ether. α-Tocopherol, γ-tocopherol and δ-tocopherol contents of tigernut oils extracted with petroleum ether were found higher than those of tigernut oils obtained by n-hexane. Tocopherol contents changed not only from one oil extract source to another but also among cultivation factors. As a result, n-hexane can be recommended as the best solvent at the extraction of tigernut oil. At the same time, it may be advisable to roast the raw tiger nut tuber due to the increase in fatty acids. But, refining process should be made after extraction using n-hexane.

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Table 3 Tocopherol contents of raw and roasted tigernut oils extracted by two different solvents (mg/100 g).

| Tocopherols   | Petroleum ether   | n-Hexane     | Petroleum ether | n-Hexane     |
|---------------|--------------------|--------------|-----------------|--------------|
| α-tocopherol  | 17.83 ± 0.78\*     | 16.74 ± 0.81\* | 15.64 ± 0.75\*  | 15.07 ± 0.43\* |
| β-tocopherol  | 0.13 ± 0.01\**,    | 0.21 ± 0.03   | 0.09 ± 0.01     | 0.14 ± 0.03   |
| δ-tocopherol  | 54.91 ± 1.13\*     | 53.67 ± 1.27\*| 51.63 ± 0.98\*  | 50.77 ± 0.75\*|
| γ-tocopherol  | 36.44 ± 0.27\*     | 35.53 ± 0.31\*| 35.81 ± 0.56\*  | 34.27 ± 0.75\*|

\* mean Standard deviation; **Values within each row followed by different letters are significantly different (p < 0.05)
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References

1. Etsheshola, E.; Oraedu, A.C. Fatty acid compositions of tigernut tubers (Cyperus esculentus L.) and their mixture. J. Am. Oil Chem. Soc. 63, 255-257 (1996).
2. Ozcan, M.M.; Gumuscu, A.; Er, F.; Arslan, D.; Ozkalp, B. Chemical and fatty acid composition of Cyperus esculentus. Chem. Nat. Comp. 46, 276-277 (2010).
3. Yeboah, S.O.; Mitei, Y.C.; Ngila, J.C.; Wessjohann, L.; Schimidt, J. Compositional and structural studies of the oils from two edible seeds: Tigernut, Cyperus esculentum, and asianto, Pachira insignis, from Ghana. Food Res. Int. 47, 259-266 (2012).
4. Adel, A.A.M.; Awad A.M.; Mohamed, H.H.; Iryna, S. Chemical composition, physicochemical properties and fatty acid profile of tigernut (Cyperus esculentum L.) seed oil as affected by different preparation methods. Int. Food Res. J. 22, 1931-1938 (2015).
5. Yoon, S.H. Physical and chemical characteristics of chufa (Cyperus esculentus L.) oils extracted from chufa tubers grown in the midportion of Korea. Food Sci. Biotechnol. 24, 2027-2029 (2015).
6. Sanchez-Zapata, E.; Fernandez-Lopez, J.; Perez-Alvarez, J.A. Tigernut (Cyperus esculentus) commercialization: Health aspects, composition, properties, and food applications. Comp. Rev. Food Sci. F 11, 365-377 (2012).
7. Zhang, H.; Hanna, M.A.; Ali, Y.; Nan, L. Yellow nutshell (Cyperus esculentus L.) tuber oil as fuel. Ind. Crops Prod. 5, 177-181 (1996).
8. Barninas, J.T.; Maina, H.M.; Tahir, S.; Kuhmarwa, D.; Tsware, K. A preliminary investigation into the biofuel characteristics of tigernut (Cyperus esculentus L.) oil. Biores. Technol. 97, 87-89 (2001).
9. Belewu, M.A.; Belewu, K.Y. Comparative physicochemical evaluation of tigernut, Soy bean and coconut milk sources. Int. J. Agric. Biol. 5, 785-787 (2003).
10. Oladele, A.K.; Aina, J.O. Chemical composition and functional properties of flour produced from two varieties of tiger nut. African J. Biotechnol. 6, 2473-2476 (2007).
11. Bamishaiye, E.B.; Muhammad, N.O.; Bamishaiye, O.M. Assessment of biological value of tigernut (C. esculentus) tuber oil meal based diet in rats. Annals Biol. Res. 1, 274-280 (2010).
12. Rosenberg, U.; Bogl, W. Microwave thawing, drying and baking in the food industry. Food Technol. 41, 85-91 (1987).
13. Megahed, M.G. Microwave roasting of peanuts: Effects on oil characteristics and composition. Nahrung-Food 4, 255-257 (2001).
14. Yoshida, H.; Kajimoto, G. Microwave heating affects composition and oxidation stability of sesame (Sesamum indicum) oil. J. Food Sci. 59, 613-625 (1994).
15. Kim, I.H.; Kim, C.J.; You, J.M.; Lee, K.W.; Kim, C.T.; Chung, S.H.; Tae, B.S. Effect of roasting temperature and time on the chemical composition of rice germ oil. J. Am. Oil Chem. Soc. 79, 413-418 (2002).
16. AOAC. Official Methods of Analysis, 15th ed. Association of Official Analytical Chemists, Washington, DC (1990).
17. ISO-International Organization for Standardization, Animal and vegetable fats and oils preperation of methyl esters of fatty acids, ISO. Geneve, Method ISO 5509, 1-6 (1978).
18. Spica, M.J.; Kraljic, K.; Koprivnjak, O.; Skevan, D.; Zanetic, M.; Katalinic, M. Effect of agronomical factors and storage conditions on the tocopherol content of Oblica and Leccino virgin olive oil. J. Am. Oil Chem. Soc. 92, 1293-1301 (2015).
19. Puskulcu, H.; Ikiz, F. Introduction to Statistic. Bilgehan Press, Bornova, Izmir, Turkey p. 333 (1989). (in Turkish).
20. Sengupta, A.; Gupta, M.P. Studies on seed fat composition of Moringa family. Fette Seifen Anstrich. 72, 6-10 (1970).
21. Mohammad, N.O.; Banishaiye, E.B.; Usman, L.A.; Salawu, M.O.; Nafiu, M.O.; Oloyede, O.B. Physicochemical properties and fatty acid composition of C. esculentus (Tigernut) tuber oil. Biore. Bull. 5, 51-54 (2011).
22. Shaker, M.A.; Ahmed, M.G.; Amany, M.B.; Shereen, L.N. Chufa tubers (C. esculentus L.): As a new source of food. World Appl. Sci. J. 7, 151-156 (2009).
23. El-Naggar, E.A. Physicochemical characteristics of Tiger nut tuber (Cyperus esculentus Lam) oil. Middle East J. Appl. Sci. 6, 1003-1011 (2016).
24. Durnaz, G.; Gokmen, V. Changes in oxidative stability, antioxidant capacity and phytochemical composition of Pistacia terebinthus oil with roasting. Food Chem. 128, 410-414 (2011).
25. Olagunju, A.O. Extraction and characterization of oil from tiger nut seed (Cyperus esculentus) using 23 full factorial design. M. Sc. Thesis, Dep. of Chemical Engineering, Federal Univ. of Technology, Minna, Niger State, Nigeria (2006).
26. El-Naggar, E.A. Effect of different heat treatments on the physical, chemical and biological characteristics of some edible oils. Ph. D. Thesis, Faculty of Agriculture, Al-Azhar University, Egypt (2007).
27. Belewu, M.A.; Abodunrin, O.A. Preparation of Kunnu from unexploited rich food source: Tigernut (Cyperus esculentus). World J. Diary Food Sci. 1, 19-21 (2006).
28. Warner, K.; Knowlton, S. Frying quality and oxidative stability of high-oleic corn oils. J. Am. Oil Chem. Soc. 74, 1317-1322 (1997).
29. Romero, A.; Cuesta, C.; Sanchez-Muniz, F.J. Effect of oil replenishment during deep-fat frying of frozen

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J. Oleo Sci. 67, (7) 823-828 (2018)
foods in sunflower oil and high-oleic acid sunflower oil. J. Am. Oil Chem. Soc. 75, 161-167 (1988).

30) Chung, J.; Choe, E. Effect of sesame oil in thermooxidative stability of soybean oil. Food Sci. Biotechnol. 10, 446-450 (2001).

31) Oderinde, R.A.; Tairu, O.A. Evaluation of the properties of yellow nutsedge (Cyperus esculentus) tuber oil. Food Chem. 28, 233-237 (1988).

32) Jung, M.Y.; Bock, J.Y., Baik, S.O., Lee, J.H., Lee, T.K. Effects of roasting on pyrazine contents and oxidative stability of red pepper seed oil prior to its extraction. J. Agric. Food Chem. 47, 1700-1704 (1999).

33) Yoshida, H.; Tomiyama, Y.; Hirakawa, Y.; Mizushina, Y. Microwave roasting effects on the oxidative stability of oils and molecular species of triacylglycerols in the kernels of pumpkin (Cucurbita spp.) seeds. J. Food Comp. Anal. 19, 330-339 (2006).

34) AlJuhaimi, F.; Şimşek, Ş.; Özcan, M.M. Comparison of chemical properties of taro (Colocasia esculenta L.) and tigernut (Cyperus esculentus) tuber and oils. J. Food Process. Preserv. 42, e13534 (2018).