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The effect of roasting process on tiger nut oil properties and enhancing the oxidative stability of sunflower oil by blending with it

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Abstract

Many efforts are made to develop new resources of edible oils, specially non- traditional oils, due to the lack of recent resources. Tiger nut is a popular Egyptian snack with high non- traditional oil content. The present investigation aimed to study the effect of roasting process on the TNO properties and study the effect of adding roasted tiger nut oil (RTNO) to sunflower oil (SFO) in order to enhance SFO stability. Proximate analysis, fatty acid composition, total phenolic content (TPC), carotenoids content, antioxidant capacity and oxidative stability of roasted and unroasted TNO were measured. 10, 20, and 30 % of RTNO were added to SFO and thechange of fatty acid composition and oxidative stability were studied. The oil blends were heated for four weeks in the oven at 60 °C and the lipid oxidation of the oil samples were studied using FTIR spectrophotometer. Fatty acid profile of TNO showed high amount of oleic acid about 70%, followed by palmitic acid (13.05%), linoleic acid (9.23%) and stearic acid (5.77%). The results showed a decrease in the moisture content, free fatty acid % and iodine value. Peroxide value was increased by heating in roasting process while fatty acid composition almost didn't change by roasting. TPC, antioxidant activity and oxidative stability were also increased by roasting process. Also, the addition of RTNO to SFO increased the mono-unsaturated fatty acids and decreased the poly-unsaturated fatty acid by increasing the concentration of RTNO which make it more nutritionally valuable. Moreover, the addition of RTNO to SFO increased its oxidative stability. The results showed that tiger nut tubers are promising source for non-traditional edible oil with high stability, shelf life and nutritional value.

***Key words*:** Tiger nut oil, roasting process, fatty acid composition, poly-phenols, antioxidant activity, oxidative stability, cooking oil, FTIR analysis.

1. Introduction

Worldwide interest is oriented for non- traditional oils with unique constituents and chemical properties. Non- traditional oils are of great important for the human health due to their high content of minor lipid components such as phenolic compounds, carotenoids, phytosterols, and tocopherols [1]. Non-conventional oils could be blended with other oils to increase their stability [2]. Tiger nut is the most known folklore snacks in Egypt [3]. It was cultivated in the region between Egypt and Sudan on the Nile River borders. It was cultivated in ancient Egypt many thousands of years ago [4]. Archeologists found tiger nut in the earthen jars in Pharaohs graves. The nutritive, disinfective, and digestive values of tiger nut were mentioned in some Arab documents. Tiger nut (Cyperus Esculenuts), which known as earth almonds, belongs to the family Cyperaceae [5]. In 18th century The Arabs introduced the tiger nut crop in the Mediterranean area especially Valencia in Spain [4, 6]. It has been recognized for its health benefits as it contains high amounts of oleic acid, and minerals soluble glucose, and high energy content [7, 8]. As reported before, tiger nut helps in preventing some diseases as heart attacks, colon cancer, diabetis, thrombosis, and activates the blood circulation [5, 9]. Tiger nut can be consumed as food. It can be eaten as snack. It can be eaten also row, roasted, dried and baked [10]. Its pleasant nutty flavor makes it suitable to be used in production of Jam nougat and ice cream. It's also used as flavoring agent in cakes and biscuits [4, 9]. It can be also used in production of a

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non-alcoholic refreshing beverage or tiger nut milk [3, 11]. Tiger nut is under-utilization and consumed by a lot of consumers without knowing its nutritional potential [7, 10]. Tiger nut is regarded for development as non-conventional edible oil resources due to its high oil content and ease of cultivation [3,5]. The high stability of tiger nut oil (TNO) made it competitor with other stable vegetable oils as olive, soybean, corn and cotton seed oils [7]. It has been described to have similar fatty acid of olive oil. TNO was used 4000 years ago by the Egyptians as nutritional and healthier alternative to olive oil. [4]

TNO can reduce the risk of coronary heart diseases, cholesterol and atherosclerosis [5]. TNO has exceptional resistant to chemical changes at high temperature and low absorption so it can be used in deep frying. The uniform liquid form of TNO at temperature of refrigeration makes it more suitable to be used in Salad preparation [7]. TNO is recommended to be used in cosmetics and health care production [12]. The high content of unsaturated oleic acid and low acidity make it excellent for production of body cream [13]. It has also many applications as industrial anticorrosive instrumental, lubricants [14], and waterproof textile fibers [7] and in the production of biodiesel fuel [15]. Tiger nut is usually roasted to increase the acceptability and desired quality which depend on the test, flavor and color of the product [16]. However, roasting was observed to decrease the anti-nutritive factors [4]. The major goal of this work was studying the chemical and biological properties of TNO and the effect of roasting process on it. Another aim was to study the effect of blending RTNO in different concentrations with cooking oil [sunflower oil (SFO)] on the fatty acid composition and oxidative stability of this cooking oil.

2. Materials and methods

Tiger nut tubers were purchased from local market in Tanta city, Egypt. Sunflower oil was kindly supplied from oil technology for edible oils and detergents S.A.E company, Sadat city, Egypt. The used solvents are analytical grade. They were purchased from Elnasr Pharmaceutical Chemicals Co. (ADWIC), Egypt. Folin-Ciocalteu reagent was purchased from Sisco Research Laboratories Chemicals, India. The free radical was purchased DPPH· from Sigma-Aldrich (St Louis, MO, USA).

2.1. Roasting, preparation, and extraction of TNOs:

The dried tiger nut tubers were roasted in the electrical ovens for 15 min at 170℃. The roasted and unroasted tiger nut tubers were ground into powder using the lab mill. The oil was extracted from roasted and unroasted tiger nut tubers using both stirring and sonication for 1 h. Hexane was used as extraction solvent. The hexane was evaporated under vacuum using rotary evaporator (Heidolph) and the oil samples were kept at 4°C in until the analysis.

2.2. Proximate analysis:

The oil content was determined using soxhlet apparatus and hexane as described previously [17]. Standard AOCS official methods were used to determine the moisture content, [18] free fatty acid (FFA) [19], peroxide value (PV) [20] and iodine value (IV) [21]. *p*-Anisidin value (*p*-AV) was determined according to the method described in detail by El-Mallah et al, 2018 [22]. The total oxidation value (TOTOX value) was calculated to estimate the oil total oxidation.

$$\text{TOTOX value} = p\ \text{AV} + 2\ \text{PV}$$

2.3. Determination of Fatty acid Composition:

Fatty acid composition was determined using a Hewlett Packard HP 6890 gas chromatograph as described previously [23]. The peak identification was mad by comparing with standard fatty acid methyl ester chromatograms (Sigma, USA).

The oxidizability of TNOs, (Cox value) was calculated by the formula proposed by Fatemi et al. 1980 [24].

Cox value = {[C18:1(%)] 10.3+[C18:2(%)] 21.6+[C18:3(%)]}/100.

2.4. Determination of bioactive components in UTNO and RTNO:

2.4.1. Determination of chlorophyll and carotenoids content:

Chlorophyll and carotenoids contents of UTNO and RTNO were evaluated spectrophotometrically using Shimadzu, UV-spectrophotometer UV-240 as described before [25]. 1 g of oil was dissolved in 10 mL acetone and the absorbance was measured at 662 nm, 645 nm and 470 nm. The total content of chlorophyll (a & b) and carotenoids were calculated from the equations mentioned below:

Cx+c = (1000 A470 - 2.27 Ca - 81.4 Cb)/227
Ca = 11.75 A662- 2.35 A645
Cb = 18.61 A645 - 3.96 A662
Cx+c: content of carotenoids, Ca: content of chlorophyll a, and Cb: content of chlorophyll b.

2.4.2. Determination of total phenolic content:

Total phenolic content of UTNO and RTNO was determined spectrophotometrically using Shimadzu,

UV-spectrophotometer UV-240 according to Folin-Ciocalteu colorimetric method described before [26]

2.5. *Measurement of antioxidant activity of UTNO and RTNO:*

2.5.1. DPPH• radical scavenging activity:

The antioxidant activity of UTNO and RTNO was determined by DPPH• assay using Toluene to dissolve both oil samples and DPPH• according to Ramadan, 2013 [27]. EC_{50} is amount of oil that can scavenge 50 % of DPPH• radicals. EC_{50} was determined using excel program by plotting the R.S.A. % against sample concentration. The relation line was drown and the EC_{50} was calculated using the resulted equations as described in our previous work [22].

2.5.2. β- Carotene-Linoleic Acid Oxidation Method (Coupled Autoxidation):

The antioxidant activity of UTNO and RTNO was also evaluated spectrophotometricaly by the β-carotene-linoleic acid bleaching method (coupled autoxidation). The method is based on the ability of sample to decrease the losses of β-carotene in a β-carotene/linoleic acid emulsion during the oxidation process [28].

2.6. Oxidative Stability Index :

The induction period (IP) measured by rancimat is the oxidative stability index of the oil. The IP of UTNO and RTNO was measured on an automated Metrohm Professional Rancimat model 892 at 110 ±0.1°C and an air flow of 20 L/h according to AOCS Official Method Cd 12b–92 [29].

2.7. Preparation and evaluation of oil blended:

Three different concentrations were prepared by adding 10, 20, and 30 % of RTNO to SFO. The oil samples were mixed thoroughly using the vortex apparatus to form uniform blends. Fatty acid composition and IP were determined for individual SFO and the blended samples. The protective factor (PF), percentage extension of the IP, of the RTNO is was calculated :

$$PF = (IP\ s - IPc / IPc) \times 100$$

Where, IPs and IPc represented the IP of blended oil samples and control (SFO) respectively [30].

2.8. Thermal oxidative stability evaluation of oil blends (oven test, FTIR)

The oil samples were kept in an oven at 60 °C for 4 weeks [22]. After four weeks the lipid oxidation was studied by FTIR spectroscopy. The infrared spectra were obtained from KBr-disks using a Nicolt IS-10 FT-IR Spectrophotometer and reported in cm^{-1}.

Statistical analysis

Results are presented as the mean ± standard deviation from three replicates of each experiment. A P-value < 0.05 was used to denote significant differences between mean values determined by the Microsoft Excel 2010. One-way analysis of variance (ANOVA) was used

3. Results and discussion

Roasting process is the major step in seeds and nuts processing as it improve its antioxidant activity. As well as it enhances the test, flavor, and color of the nuts. It's also destroys the cell barriers and facilitates the extraction of oil. This thermal treatment leads to some chemical changes [16].

3.1. Effect of roasting process on the physic-chemical properties of TNO:

Results in Table 1 showed the changes in the proximate analysis (oil content, moisture, FFA, PV, p-AV, and IV) before and after roasting process. The oil content of UTNO and RTNO nearly kept constant but the moisture content % decreased from 6.4 % (UTNO) 4.75 % (RTNO). It was noticed that the FFA also nearly kept constant after roasting (4.2 % and 3.98 % for UTNO and RTNO respectively). Roasting heat increased the primary oxidation products, so the PV of UTNO of 3.9meq/Kg was increased by roasting process to 9.2 meq/ Kg for RTNO. It also increased the secondary oxidation products and hence increased the p-AV from 4.13 to 5.95 for UTNO and RTNO respectively. The total oxidation occurred during the roasting process was calculating using the values of PV and p-AV. TOTOX value was found to be increased from 11.96 to 24.35 for UTNO and RTNO respectively. IV of UTNO was found to be 52.12 g I_2/100 g oil this value decreased to 46.63 g I_2/100 g by roasting process **(**Table 1) The same results were obtained by Abd-Elhafeez etal ,2020 [31]

3.1. Fatty acid Composition of UTNO and RTNO:

The fatty acid composition recorded in Table 2. The results showed that both UTNO and RTNO have the same amount of saturated fatty acids (SFA) about (20%). The same observation was found for mono and polyunsaturated fatty acids (MUFA and PUFA), which mean that roasting process had no effect on the fatty acid composition. SFA represented in palmitic acid (13.05 and 13.21 %) and stearic acid (5.77 and 5.40 %) for UTNO and RTNO respectively. Oleic acid was the major MUFA with the highest value among all other fatty acids (70.20 and 70.53 % for UTNO and RTNO respectively). Concerning PUFA, linoleic acid (ω6) is the main PUFA (9.23 and 8.92

for UTNO and RTNO respectively) with traces of linolenic acid (ω3) (Table 2).

Table 1: Proximate analysis of unroasted and roasted tiger nut oil:

Proximate analysis	UTNO	RTNO
Oil content %	30.22 ±0.16	29.20 ±0.14
Moisture content %	6.40 ± 0.05	4.75 ± 0.18
FFA %	4.2 ± 0.002	3.98 ± 0.01
PV (meq/Kg)	3.9 ± 0.11	9.2± 0.52
***p*-AV**	4.13 ± 0.08	5.95 ± 0.05
TOTOX value	11.96	24.35
***I*V (g I_2/100g)**	52.12 ± 0.63	46.63 ± 1.32

AV : acid value, PV: Peroxide value, *P*-AV: *P* anisidine value, TOTOX value: total oxidation value

The fatty acid composition of TNO was found to be similar to the olive oil that considers one of the healthier vegetable oils. These results are in agreement with those obtained previously [5]. The high content of oleic acid indicates the importance of TNO in human diet as a good source of essential fatty acid comparing with other vegetable oils like sunflower, cotton seed, and maze oils [32]. It's excellent for the skin productions. Oleic acid is linked with reduction of the coronary heart disease risk. It's also help in building of the cellular membranes, transformation of energy into nerve impulses, and cellular communication [6]. UFA/SFA is important ratio, higher ratio means more nutritional potential of the oil. It is also indicates the tendency of oil toward oxidative stability [33]. UFA/SFA of UTNO and RTNO were 4.028 and 4.069. These ratios were found to be lower than that of olive oil in previous works (4.54 and from 4.6 to 4.88) [33,34]. The lowest value of the sum of linoleic and linolenic acids over oleic acid (L+Ln)/O indicates its highest stability [35]. (L+Ln)/O of UTNO and RTNO were 0.133 and 0.129. These values were slightly lower than that of olive oils (0.139). Higher values were recorded previously for corn and soybean oils (1.59 and 1.56) which indicating the higher stability of tiger nut oil [35]. The low content of PUFA makes TNO more stable in cooking and during frying [36]. The fatty acid composition results are in agree with [3,6]

The Cox value was calculated based on the percentage of UFA. It's an indicator of the oil's tendency to oxidation and oil stability stable oils have lower cox values[17]. The Cox values dcreased slightly by roasting process and hence the stability increased. The cox vlaues are 1.68 and 1.62 for UTNO and RTNO respectively. These Cox values of URTN and RTNO are better than some other edible oils such as sunflower oil (6.42), soybean oil (6.89), black cumin seed oil (6.6), tomato seed oil (6.5), grape seed oil (7.3), and wheat germ oil (7.8) [17]. These results indicate the high stability of roasted and unroasted TNO compared to some other edible oils.

3.2. Effect of roasting on bioactive compounds of RTNO and UTNO:

The content of bioactive compounds represented in total phenolic content (TPC), chlorophyll, and carotenoids as well as the changes in their content during roasting process was studied. Chlorophyll a and Chlorophyll b contents were 2.51 and 3.73 mg/kg respectively in UTNO. The chlorophyll contents were decreased by roasting to 1.83 and 2.88 mg/kg. Meanwhile, carotenoids (vitamin A) decreased from 0.41 to 0.14 mg/kg due to vitamin degradation occurred by roasting temperature (Table 3) [16,17].
Concerning TPC, it was increased from 532.16 for UTNO to 551.25 mg gallic acid equivalent/ 100 g oil for RTNO. This increase may be due to the releases of bound phenols during the destruction of cell structure by roasting (Table 3) [37]

Table 2: Fatty acid composition of unroasted and roasted tiger nut oil:

Fatty acid	UTNO	RTNO
Saturated fatty acids %		
C16:0 (palmitic acid)	13.05 ± 0.002	13.21 ±0.12
C18:0 (stearic acid)	5.77 ±0.002	5.40 ± 0.001
C20:0 (arachidic acid)	0.64 ±0.02	0.63 ± 0.01
C22:0 (Behenic acid)	0.16 ± 0.00	0.13 ± 0.002
C24:0 (tetracosanoic acid)	0.17 ± 0.001	0.26 ± 0.003
Total SFA	19.79	19.63
monounsaturated fatty acid %		

C18:1 (oleic acid) ω9	70.20 ± 0.007	70.53± 0.002
C20:1 (eicosenoic acid)	0.15 ± 0.001	0.22 ±0.001
Total MUFA	70.35	70.75
Polyunsaturated fatty acids %		
C18:2n6 (linoleic acid) ω6	9.23 ± 0.003	8.92 ±0.001
C18:3 (linolenic acid) ω3	0.14 ±0.002	0.14 ±0.001
Total PUFA	9.37	9.06
Total UFA	79.72	79.81
Relations		
SFA/ UFA	19.79	19.63
UFA/SFA	4.03	4.07
(L + Ln)/O	0.13	0.12
L/Ln (w6/w3)	52.89	33.64
Cox value	1.68	1.62

SFA = saturated fatty acids, MUFA= monounsaturated fatty acids, PUFA = polyunsaturated fatty acids ,UFA = unsaturated fatty acids, O= oleic acid, L= lenoliec acid, Ln = lenolienic acid

3.3. Effect of roasting on antioxidant activity and of stability of the of RTNO and UTNO:

The antioxidant activity (R.S.A %) is the ability of oil to scavenging the free radicals of DPPH and hence its ability to delay the lipid oxidation process and oil deterioration. R.S.A % of oils was measured using DPPH˙ scavenging assay (Fig 1). The results indicated that the R.S.A % increased by roasting process. The decrease of EC_{50}, from 117 to 101, and increase of antiradical power ($1/EC_{50}$), from 8.54 to 9.9, during roasting process confirm the increase of oil antioxidant activity during the roasting process (Table 3). Although the oxidation and degradation of some bioactive compounds such as phenolic compounds can take place during roasting process, some of the phenolic compounds can be incorporated into new compounds (melanoidins), that have metal chelating and antioxidant proprieties due to the presence of their phenolic moieties [17]

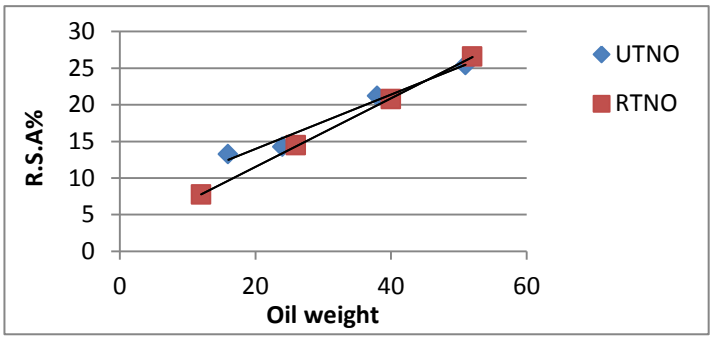


Figure 1: Radical scavenging activity (R.S.A.%) of UTNO and RTNO in DPPH˙ assay.

3.4. Oxidation and thermal stability of RTNO and UTNO:

The ability of oil to resist high temperature and oxygen is one of the most quality factors for vegetable oils. It was found that the induction period (IP) was measured by rancimat method. The IP of UTNO and RTNO were 28.6 and 39.46 h at 110 °C respectively. It was noticed that roasting process had a great effect on the stability of TNO. The IP of RTNO was higher than that reported previously for olive oil at 110 °C (11.60 and 33.97 h) [38].

The improvement of oil antioxidant activity and oxidation stability by roasting may be attributed to several factors: a: Inactivation of enzymes that start oil deterioration by roasting causes the better oxidative stability. B: Maillard reaction products that have antioxidant capacity provide higher protection and oxidative deterioration. C: Moreover, more natural antioxidants can be extracted with oil as a result of extraction improvement by roasting [16].

Table 3: Bioactive compounds and antioxidant activity of unroasted and roasted tiger nut oil:

	UTNO	**RTNO**
Chlorophyll a	2.51 ± 0.15	1.83 ± 0.05
Chlorophyll b	3.73 ± 0.17	2.88 ± 0.15
Carotenoids	0.41± 0.01	0.14 ± 0.02
TPC (mg gallic acid equivalent / 100g oil)	532.16 ± 13.82	551.25±36.81
AOA %	84.57 ± 0.38	95.06 ± 1.31

EC_{50} (mg oil)	117	101`
$1/EC_{50}$x1000	8.54	9.9
IP	28.6	39.46

TPC= total phenolic content (µg gallic acid/ 1g oil), AOA%= antioxidant activity (value represent the percent inhibition of oxidation of the linoleic acid/β-carotene emulation) EC_{50}= concentration of extract that causes a 50% decrease in DPPH absorbance, $1/EC_{50}$ =antiradical power.

3.6. Blending of RTNO with SFO:

From the above results, it was found that the characteristics of RTNO as TPC, IP, antioxidant activity, and fatty acid composition make it suitable to be used as value added natural antioxidant to improve stability of some cooking oils. In the present investigation, enhancing the stability and shelf life of SFO with adding different concentrations from RTNO (10, 20, and 30%) was studied

3.6.1. Fatty acid composition of SFO and oil blends:

Results in Table 4 showed the fatty acid composition changes in SFO after adding 10, 20, and 30 % from RTNO. Increase in SFA was observed by blending with RTNO especially when adding 30% from RTNO, it increased from 11.76 to 15.14%. Oleic acid increased from 27.49 % for individual SFO to 30.7, 35.27, and 38.4 for TSO1, TSO2, and TSO3 respectively. Meanwhile, linoleic acid decreased by adding RTNO from 60.74 for SFO to 56.31, 52.44, and 46.04 for TSO1, TSO2, and TSO3 respectively. This increase in MUFA and decrease in PUFA have appositive effect on the stability and shelf life of blends as it can decreases the susceptibility of the oil samples to deterioration. These results were emphasized by the Cox value which used as indicator in oil stability. As the Cox value decreased the oil stability increased. TSO3 was found to has the lowest Cox value and hence the best stability. The Cox values were 6.53, 6.11, 5.55, and 5.13 for SFO, TSO1, TSO2, and TSO3 respectively (Table 4). So the oils with higher stability can be arranged as TSO3 > TSO2 > TSO1 > SFO

SFA/USFA ratio was used as oils quality indicator. The increase in SFA/UFA and (L + Ln)/O values by increasing the amount of RTNO indicating the improvement of the oil Stability [35]. The decrease in UFA/SFA also indicates the increase of oil stability [33]. PUFA/SFA ratio is usually taken as a measure of the tendency of oils to oxidation [2]. Increasing the amount of RTNO also decreased the PUFA/SFA ratio and increased the oil stability.

Table 4: Fatty acid composition of sunflower oil and its blends with roasted tiger nut oil:

Fatty acid	SFO	TSO1	TSO2	TSO3
Saturated fatty acids				
C16:0 (palmitic acid)	8.80 ± 0.01	9.06 ± 0.03	8.50 ± 0.01	11.74 ±0.01
C18:0 (stearic acid)	2.96 ±0.02	3.74 ± 0.03	3.58 ±0.01	3.40 ±0.06
Total SFA	11.76	12.8	12.08	15.14
monounsaturated fatty acid				
C16:1	---	0.17 ±0.02	0.19 ± 0.01	0.27 ±0.001
C18:1 (oleic acid) ω9	27.49 ±0.01	30.70 ±0.21	35.27 ±0.19	38.40 ±0.03
Total MUFA	27.49	30.87	35.46	38.67
Polyunsaturated fatty acids				
C18:2n6 (linoleic acid) ω6	60.74 ±0.02	56.31±0.1	52.44±0.30	46.04 ±0.03
Total PUFA	60.74	56.31	52.44	46.04
Total UFA	88.23	87.18	87.90	84.74

Relations				
SFA/ UFA	0.133	0.146	0.137	0.178
UFA/SFA	7.48	6.81	7.27	5.60
PUFA/SFA	5.16	4.40	4.34	3.04
Cox value	6.53	6.11	5.75	5.13

SFA = saturated fatty acids, MUFA= monounsaturated fatty acids, PUFA = polyunsaturated fatty acids , UFA = unsaturated fatty acids

3.6.2. Oxidative stability of oil blends:

The susceptibility of individual SFO and oil blends to oxidation was measured by the Rancimat and expressed by the induction period (IP). Fig 2 showed that the increase of IP by increasing the amounts of RTNO to SFO. The addition of RTNO extended the IP of SFO from 5.48 h to 8.94, 9.68, and 11.67 h for TSO1, TSO2 and TSO3 respectively.

By calculating the protective factor (PF) it was found that the addition of 10, 20 and 30 % from RTNO to SFO extended the IP by 63.13, 76.64 and 113.16 % respectively. The increase of the amount of non-traditional oils to SFO led to the increase in its oxidative stability and PF.

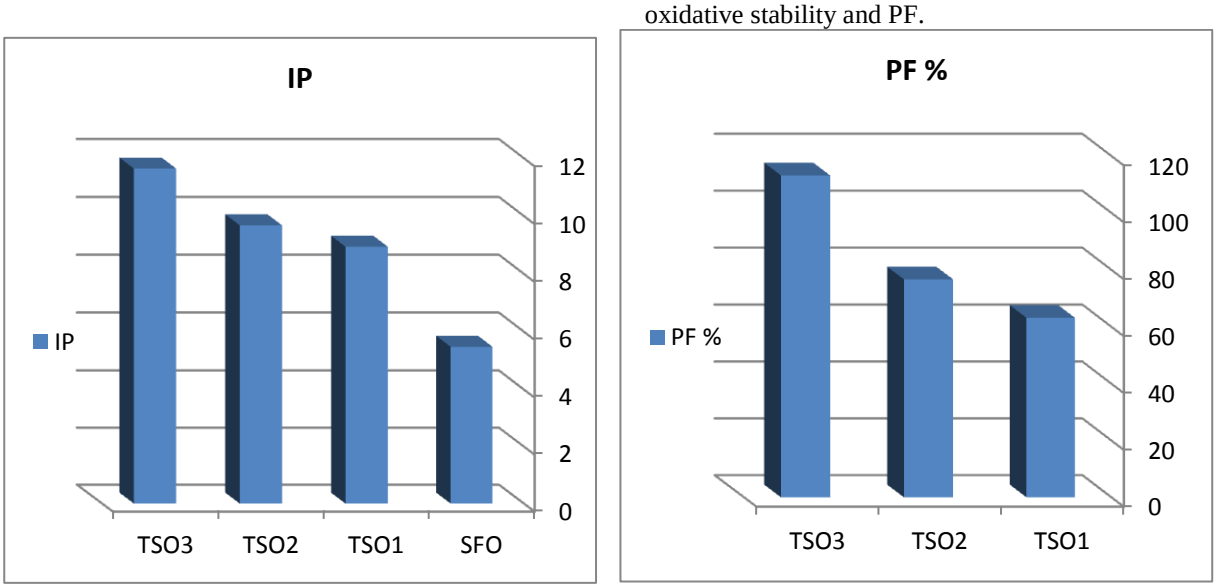


Figure 2: Induction period IP and protective factor PF% of SFO, and blended oils of 10, 20, 30 % RTNO with SFO (TSO1, TSO2, and TSO3 respectively).

3.6.3. FT-IR confirmation of the stability of SFO blended with RTNO:

FT-IR a powerful analytical tool used in the study of oils oxidation because it is non-destructive, rapid method that reduce the usage toxic solvents. FT-IR provides information about oil status and the changes in the oil different functional groups during the oxidation progress [39, 40]. The changes in the peaks intensity during oil thermal oxidation may be attributed to the fact that the intensities of the bands are proportional to the concentration of the functional groups [41]. The changes in bands frequency and intensity in FT-IR spectra can provide meaningful information about the enhancement of the oxidative stability of SFO and their blends with RTNO after thermal oven heating at 60 °C for four weeks.

FT-IR spectra of SFO and oxidized oil samples (SFO, TSO1, TSO2, and TSO3). Fig 3 showed that the band around 3611 cm^{-1} was assigned to (–O-O-H) stretching vibration of hydroperoxides[42, 43]. Non-oxidized SFO showed a weak band at 3611 cm^{-1} assigned in usual to the overtone of the absorption of the glyceride ester groups [44, 45]. After the oxidation, the band becomes wider and more intense.[46] and the frequency shifted to lower wavenumber. This shifting was attributed to the overlaping of the original band with the new band absorption of produced hydroperoxides groups during oil oxidation [45] (Fig. 3). The band shifted to the lowest wavenumber in oxidized SFO which mean more oxidation and formation of peroxides than other oxidized blends (3484.7, 3555.38, 3522.16, and 3616.27 cm^{-1} for

SFO, TSO1, TSO2, and TSO3 respectively.).These results are in agreement with some previous work [45, 47]. The increase in the band width and absorption was found to be greater in case of oxidized SFO than in the oxidized blended oils.

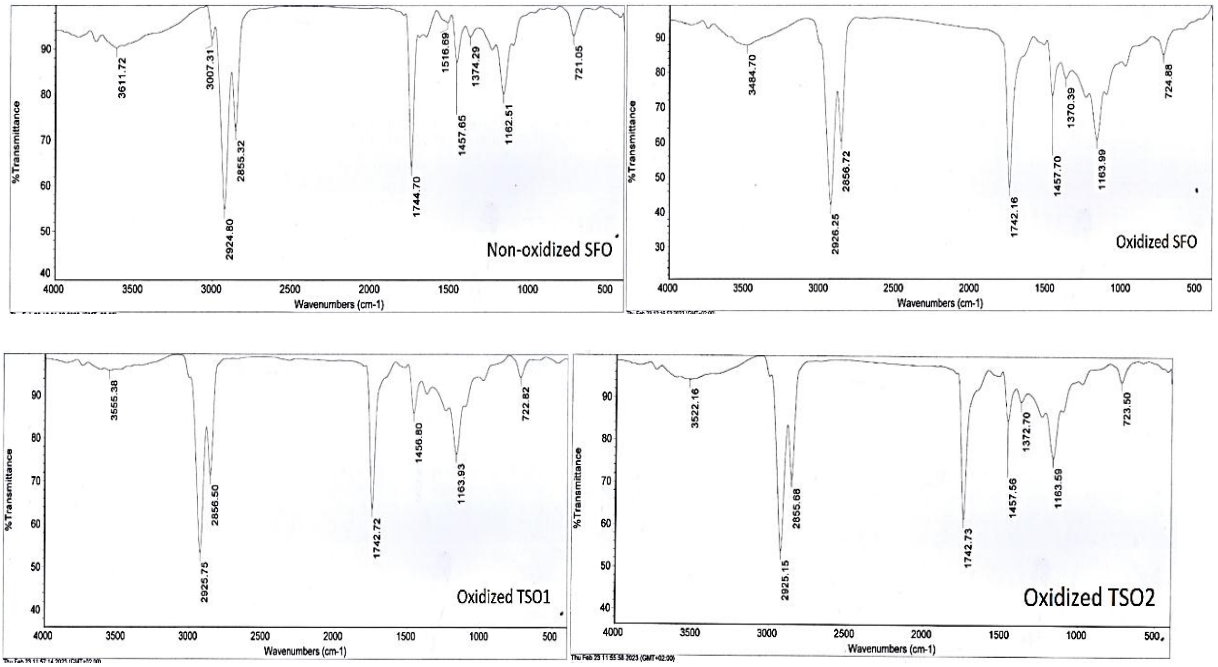
The band found around 2926 and 2855 cm^{-1} were characteristic of methyl and methylene symmetric and asymmetric C-H stretching vibration. The increase in the absorbance and width of these bands in oxidized oils refers to the surrounding chemical changes occurred after oxidation. Figs 3 showed that the increase in the bands absorbance and width was greater in oxidized SFO than in oxidized blends of SFO and TNO [48, 49].

The FT-IR spectra showed major absorbance around 1745 cm^{-1} due to the carbonyl of the triglycerides ester (C=O stretching vibrations). Saturated ketones, aldehydes, and other secondary oxidation products cause the absorbance band at 1728 cm^{1} [46, 48]. This band overlaps with the band at 1745 cm^{-1} of triglycerides ester carbonyl resulting in increasing the absorbance and broadening of the original band of the 1745 cm^{-1} to lower wave number [49].

Figs 3 showed that the change in intensity of the band at 1744.7 cm^{-1} was lower in oxidized blended oil samples than in oxidized SFO which means lower formation of the secondary oxidation products by adding RTNO to SFO with different concentrations. Two other bands appeared near 1236 and 1162 cm^{-1} are related to the proportion of saturated acyl group in the sample [50]. The increase in the band intensity was also greater in oxidized SFO than in the blended oil samples. This proves that the amounts of saturated acyl group were greater in SFO control samples [47, 50]. The band at 988 cm^{-1} associated with bending vibration of CH *cis-trans* and *trans-trans* conjugated diene of hydroperoxides which formed due to the isomerization that occurs as the lipid oxidation takes place [45, 47].

The changes of the bands 987 and 967 cm^{-1} occurred during oxidation and the formation of trans conjugated diene of hydroperoxides and trans non-conjugated bonds assigned to isolated trans double bond in ketones or aldehydes that produced during secondary oxidation process [51]. The bands intensity highly increased in oxidized SFO than the oxidized blended oil samples.

Generally, the changes occur due to oxidation process in oil samples of SFO blended with 10, 20, and 30 % RTNO were lower than that occurred in oxidized SFO. By increasing the amount of non-traditional oils the stability increased so, the addition of 30 % RTNO to SFO give the higher stability than the other blends. This means that the addition of high stable RTNO, with low polyunsaturated fatty acids, high antioxidant content, and high oxidative stability can retard the oil oxidation of SFO during heating at 60°C and improved its oxidative stability, shelf life, quality and nutritional value. FT-IR results confer a proof upon the results obtained from rancimat method (IP).



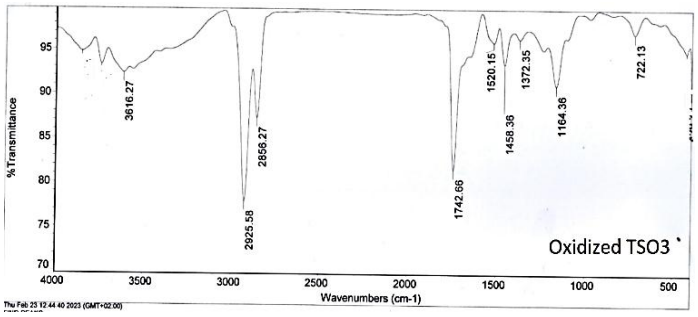


Figure 3: FTIR spectrum of SFO and oxidized blended oils of 10, 20, 30 % RTNO with SFO (TSO1, TSO2, and TSO3 respectively).

Conclusion

Tiger nut tubers are promising source for non-traditional edible oil with high stability and shelf life. It has been recognized for its health benefits as it contains high amounts of oleic acid. The high stability of tiger nut oil (TNO) made it competitor with other stable vegetable oils as olive, soybean, corn and cotton seed oils. It has been described to have similar fatty acid of olive oil. The roasting process enhanced the physicochemical properties, oxidative stability and antioxidant activity of TNO while fatty acid composition didn't affect by roasting. It was found that roasted and unroasted TNO contained highly phytonutrients components such as TPC, chlorophyll, and carotenoids. Addition of RTNO to cooking oils (SFO) was found to improve the cooking oil stability. The SFO can be blended with RTNO to protect it against oxidation and to increase its shelf life. Admixing of SFO with non-traditional RTNO at a level of 30 % RTNO was found to be more satisfactory and stable. Blending oils (SFO and RTNO) increased the oxidative stability which is a major parameter determining the oil quality and shelf life.

Conflicts of Interest: The authors declare that they have no conflict of interest in this article.

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