International Journal of Food Science and Nutrition Engineering 2022, 12(1): 26-35
DOI: 10.5923/j.food.20221201.03

Investigation of Physicochemical and Biochemical Properties of Roasted Tiger Nut (*Cyperus esculentus*) Flour

Bou Ndiaye[1,2,*], Seyni Ndiaye[1,2], Papa Guedel Faye[1,2], Ifeoma C. Orabueze[3], Abdou Diouf[4,5], Oumar Ibn Khatab Cisse[1,2,6], Edouard Mbarick Ndiaye[1,2], Alioune Sow[1,2,7], Mama Sakho[1,2], Nicolas C. M. Asseyou[1,2]

[1]Laboratoire Eau, Energie, Environnement et Procédés Industriels (LE3PI), Ecole Supérieure Polytechnique / Université Cheikh Anta Diop, Dakar, Sénégal
[2]Center for Studies on Food Safety and Functional Molecules (CESAM-RESCIF) ESP-UCAD, Dakar, Senegal
[3]Dept. of Pharmacognosy Faculty of Pharmacy/University of Lagos, Medical campus, Idi-Araba, Nigeria
[4]Faculté des Sciences et Techniques, Université Cheikh Anta Diop de Dakar, Fann, Sénégal
[5]Institut de Technologie Alimentaire (ITA) Route des pères Maristes, Hann, Dakar, Sénégal
[6]Ecole Nationale Superieure d'Agriculture (ENSA), UIDT, Thies, Senegal
[7]UFR des Sciences Agronomiques, de l'Aquaculture et des Technologies Alimentaires (S2ATA) Université Gaston Berger de Saint Louis, Sénégal

Abstract Roasting is a thermal process that has long been used in food processing. This study evaluates the effect of roasting on tiger nuts tuber's physicochemical and biochemical parameters in order to produce high nutritional quality flour. The raw tiger nut were subjected to roasting procedure. The roasting was done using oven at a temperature of 147°C during 38 min. The nutritional properties analyses were performed on both dry raw tiger nut flour (DRTF) and roasted tiger nut flour (RTF). The data obtained for the analysis revealed that, moisture, total sugar, fat, protein contents, pH and L* index color decrease after roasting process. The contents decrease from 8.86 to 4.95% for moisture, 16.52 to 13,2% for total sugars, 6.11 to 5.04% for proteins, 24.33 for 23.83% for lipids. The pH and L index decrease respectively from 6.52 to 6.39 and 78.54 to 67.62. However, a significant increasing was constated in some parameters after roasting. Contents increase from 1.67 to 2.02% for reducing sugars, 58.29 to 63.76% for carbohydrate, 599.59 to 726.01 mg/100g for mineral elements (P, Mg, K, Ca, Na), 615.80 to 830.57 mgEAG/100g for total phenolic compounds and from 40.8 to 43.52 mgCE/100g for flavonoids. For antioxidant activity, inhibition varies from 32.94 to 60.03%, the energy value from 476.48 to 482.62 Kcal/100g, yellowing index (Y) from 31.33 to 48.20 after roasting. The browning index value were estimated from to 60.32 in roasted tiger nut flour. The infrared spectrum analysis reveals some functional groups and particular bonds in the two flours, and new bands appearing only in the roasted tiger nut flour (RTF). The roasting process reveals significant effects on color, water content, mineral elements, total sugar, polyphenols and antioxidant proprieties. It can be applied to improve the tiger nuts' nutritional value.

Keywords Tiger nut flour, Roasting, Nutritional value

1. Introduction

The last decades have been marked by a great interest in food science research and new functional foods development to fight against malnutrition and undernourishment [1], [2]. In this sense, the processing method of local products could play an important role.

Roasting is an ancient and a good processing method for preservation, inter-conversion, improving on taste and flavors used y man to conserve his food [3]. In the food industry, roasting is one of the most widely used processes to improve quality and increase stability. Roasting allows the development of desirable aroma, color, and texture and increases palatability [4]. It plays an important role in improving the nutritional value of food. It reduces antinutrient compounds such as phytates, oxalates, tannins, hydrogen cyanide, cyanogenic, and glycosides [5], [6], [7], [8]. It can also contribute to the increase of bioactive compounds such as polyphenols, flavonoids, antioxidant activity, and mineral elements [9]. It also increases the stability of food materials by the destruction of contained

* Corresponding author:
cheikbou20@yahoo.fr (Bou Ndiaye)
Received: Aug. 19, 2022; Accepted: Sep. 5, 2022; Published: Sep. 15, 2022
Published online at http://journal.sapub.org/food

microorganisms and toxins. Tiger nut (*Cyperus esculentus*) is an underutilized tuber of the family Cyperaceae, which produces tuber. Currently, the local use of tiger nuts is limited to casual snacks, similar to peanut. Tiger nut tubers constitute an important source of phytochemicals compounds such as isoflavones, flavonoids, terpenoids, alkaloids and saponins [10] [11]. It's transformation into new products precooked through roasting or any other process could boost its economic and commercial values and improve the nutritional status of consumers.

This present study focused on improving the nutritional value of tiger nuts used for infant food enrichment. Thus, this study sought to investigate the effect of roasting on the nutritional value of tiger nuts at optimal roasting process and conditions [12],[13] obtained were applied in this study.

2. Material and Methods

2.1. Material

Tiger nuts tuber was purchased from the local market of Bamako. The nuts were cleaned, washed, drained, dried at 37° during 48h in an oven (Mermmert, Germany) and packed in plastic bag until use.

2.2. Methods

2.2.1. Roasting Method

Dried nuts were roasted according to the optimal roasting process which is 147℃ for 38 minutes using an oven (Mermmert, Germany) [12], [13].

2.2.2. Analytical Methods

2.2.2.1. Proximate Composition Analysis of Tiger Nut Flour

Moisture, crude fat and crude protein and total ash contents of the samples were determined by AOAC methods [14], [15]. Mineral contents were determined by ionic chromatography and expressed as mg mineral/100 g dry weight (dw) sample. Total and reducing sugar was obtained using Luff-Schrool's method [16]. Carbohydrate was determined by difference, and energy content was determined using the Atwater factor (carbohydrate and protein values were each multiplied by 4 Kcal/g, whereas fat values were each multiplied by 9 Kcal/g).

2.2.2.2. Phenolics and Flavonoids Contents

Polyphenol content was determined using Folin-Ciocalteu reagent according to the method described by Georgé et al. [17] with some modification. Tiger nut flour (2g) sample was soaked in 10 mL of methanol-water 70% (v/v) and mixed for 30 min, and centrifuged at 4000 rpm for 10 min. An aliquot (50 µL) of supernatant and 450 µL of water were mixed and oxidized with 2.5 mL of Folin-Ciocalteu's reagent at 1/10 dilution. The mixture was re-mixed and incubated for 2 min. and neutralized by 2.5 mL of sodium carbonate (75g/L). The mixture was vortexed and placed for 30 min in a water bath at 50℃. After cooling, the absorbance was measured at 760 nm using spectrophotometer (GENESYS 10S UV-VIS, Thermo Scientific). Calibration curve was drawn using the standard drug, gallic acid. The polyphenol content was determined using the calibration curve and expressed as milligrams of gallic acid equivalent (GAE) per gram of the plant extract.

Total flavonoids content was determined using the colorimetric method described by Kim et al. [18]. Tiger nut flour (0.5 g) was treated with 10 mL of methanol, stirred and centrifuged. Distilled water (400 µL) and 5% sodium nitrate (30 µL) were added to 2 mL of supernatant. The mixture was mixed and incubated at room temperature for 5 min, after which 20 µL of 10% $AlCl_3$ and 200 µL Na_2CO_3 were added and the mixture was mixed and re-incubated for another 5 min. After the incubation 250 µL of distilled water were added to the final mixture, and absorbance was determined at 510 nm against a blank (distilled water). The flavonoids content was calculated and expressed as g of catechin equivalent (CE) per 100 g of flour. All determinations were carried out in triplicates.

2.2.2.3. DPPH-Radical Scavenging Activity Assay

The free-radical-scavenging activity of tiger nut flour extract was measured using 1,1-diphenyl-2-picrylhydrazyl (DPPH) according to Brand-Williams method [19] by soaking 2 g of flour in 20 mL methanol (95%). A measure of 0,1 ml of resultant solution was shaken in 2,9 mL of DPPH (0,6 10^{-5} mol/L). This was allowed to incubate at room temperature for 30 min in a dark place. The intensity of decolorization (absorbance) of purple free radical DPPH solution was measured at 515 nm using spectrophotometer (GENESYS 10S UV-VIS, Thermo Scientific). The same procedure was repeated without the tiger nut flour extract for control. Thus, to determine the absorbance at t = 0 min, absorbance was immediately taken after adding 0.1 mL methanol to 2.9 mL of DPPH• solution. Methanol solution was used as the blank. The antioxidant activity was calculated using the following equation:

$$\% \text{ DPPH inhibition} = [1 - \frac{\text{A extract solution at 30 min}}{\text{A control at 0 min})}] \times 100 \quad (1)$$

2.2.2.4. pH Determination

The method of Tortoe and et al. [20] was used for titratable acidity and pH determination with some modification. Tiger nut flour (10g) was mixed with 90 mL of distilled water. The mixture was shaken until particles were evenly suspended and free of lumps and digested for 30 minutes with frequent shaking. The mixture was allowed to stand for 10 mins for the particles to settle. The supernatant was decanted into the 250 mL beaker, and the pH was determined using a pH-meter (Hanna, HI 2211, Romania).

2.2.2.5. Browning Index

The color of the flour was measured with a chromameter

(Minolta CR-310 Osaka, Japan). The color index (browning index IB and yellow index) was determined by the L*a*b system.

$$IB = \frac{100(X-0,31)}{0,17} \quad (2)$$

$$X = \frac{(a-1,175L)}{5,46L+a-3,012b} \quad (3)$$

2.2.2.6. Mesure of the Absorbance of Maillard Reaction Product

Maillard reaction absorbance was analyzed by reading the absorbance at 420 nm, according to the method of Hendel et al. [21]. The measurements were made on an extract obtained by mixing 0.25 g of tiger nut flour with 10 ml of distilled water for 10 min. The suspension was stirred for 15 minutes using a mechanical stirrer (Heidolph MR Hei-Standard, Germany) and centrifuged at 5000 rpm (Universal 16A, D-78532 Tuttlingen, Germany). The supernatants were recovered, and the absorbances at 420 nm (A_{420}) were obtained with a Spectrophotometer (GENESYS 10S UV-VIS, Thermo Scientific).

2.2.2.7. Infra Red Analysis

The acquisition of infrared spectra of the flour samples is performed by using a branded infrared spectrophotometer (Perkin Elmer LAMDA TWO). The FT-IR spectra were recorded from 4000 to 400 cm^{-1}.

2.2.3. Statistical Analysis

The data obtained were analysed statistically using the STATISTICA 7.1 software. Differences were considered statistically differently at $P< 0.05$.

3. Results and Discussion

The roasted tiger nut flour (RTF) and dry raw tiger nut flour (DRTF) samples were analyzed for physicochemical properties. The proximate profiles of the samples are presented in Tables 1, 2 and 3. The water contents in dry raw tiger nut flour (DRTF) and roasted tiger nut flour (RTF) were 8.86 and 4.95% respectively. The observed low water content in the RTF resulted from the lost of water during roasting. The water may have been lost by evaporation and hydrolysis reactions during roasting. Low moisture content enhances the storage stability of flours. High moisture content encourages biochemical reactions that would lead to food spoilage and microbial growth.

The fat contents were 23.83 and 24.33%, respectively, for RTF and DRTF (Table 1). A slight decrease in the percentage of fat was noted. Analysis of variance showed that the difference was significant. This is in contrast to several other studies which have reported an increase in the fat content in several vegetable matrices after roasting [22], [23], [24]. The decrease in fat content during roasting may be due to the destruction of fat.

The protein contents were 6.11% for dry raw tiger flour (DRTF) and 5.04% for roasted tiger nut flour (RTF) (Table 1). Analysis of variance showed a significant difference ($p>0.05$) in protein content between the two samples. These results indicated that roasting negatively influences the protein content. Similar effects have been reported during the roasting of *Terminalia catappa* L nuts [25], sesame seeds [24], and millet [26]. The decrease in flour's protein content may be attributed to the protein's denaturation during roasting by the involvement of amino acids in non-enzymatic browning reactions. Volatile nitrogen-containing compounds may also be responsible for the observed decrease in protein content. The solubility profile of contained nitrogen compounds may also be a contributing factor to the decrease observed in the protein content [27]. However, contradictory results were reported by Olgunla *et al.* [28] on tiger nut tubers, Onyeike *et al.* [29] on *Plukenetia conophora* (African walnut), and Ee *et al.* [30] on seeds of *Acacia Victoriae Bentham*.

The reducing sugar content of roasted tiger nut flour (RTF) was observed to be significantly higher (2.02%) than dry raw tiger nut flour (DRTF) (1.67%). In contrast, the total sugar content decrease by 20.10% (from 16.52 g to 13.2 g / 100 g) in roasted tiger nut flour.

The increase in reducing sugar observed in RTF can be attributed to starch depolymerization reactions during roasting and sugar molecules released from phenolic molecules and other complex molecules. High temperature and long roasting time promote sucroses inversion and oligosaccharides breakdown into free monosaccharides such as glucose and fructose [31]. These results were in agreement agree with those of Rizki *et al.* [4]. They reported an increase in the free sugar content in their study of sesame seeds roasted at 150℃, within the first 120 minutes. However, the reduction in the total sugar content would be justified by the hydrolysis of complex sugars, the mobilization of sugars intervening on the one hand in the Maillard reactions [32], [26] and on the other hand in the reactions of caramelization during roasting [33]. Similar results on the variation of total sugars was recorded by Tumwine et al. [26] in their millet roasting study. The total carbohydrate evaluation showed that its content decreased from 58.29 g/100g in dry raw tiger nut flour to 63.75 g/100 in roasted tiger nut flour with a significant difference. A slight increase was seen in the roasted sample. Similar results were found by Oboh *et al.* [22] in the roasting of corn seeds and of Arinola and Adesina [27] on the nuts of *Tetracarpidium conophorum* (African walnut). This increase in the carbohydrate content of RTF is due to the loss in fat, protein, and water content of the sample during roasting [34].

The energy values for the flours made from dry raw tiger nut (DRTF) and roasted tubers (RTF) were 476,48 and 489,62 Kcal/100g, respectively. This is in line with those of Ndidi et al. [6], who documented that roasted seeds have higher energy value than raw seeds. Thus, flours from roasted tubers are good source of energy.

Ash contents were 2.43% both for the DRTF and RTF flours, respectively (Table 2). The values showed no significant difference ($p >0.05$) after the roasting and thus,

confirmed the results of Ndidi *et al.* [6]. However, some other studies recorded increase in ash content after roasting [35], [36].

The result for the mineral content is shown in table 2. The most abundant mineral was potassium. Magnesium and potassium increased by 28.39 and 47.19% respectively, in roasted nut flour. Sodium is not much affected by roasting (Table 2). The increase in mineral content may have resulted from the loss of water. Similar results were found in sesame seeds [32] and roasted cashews [37].

The calcium content is higher in unroasted tuber flour. After roasting, calcium lost of about 15.56% was observed (Table 2). Comparable results were found by Tenyang et al. [36]. In their study, Mariod *et a*l. [38] noted a decrease in all minerals' levels except sodium, which increased. The anti-nutritional factors that would have caused the observed destruction may have resulted from complexes the mineral elements formed with other food elements. The release of minerals bound to proteins and other biological molecules, could also be a contributory factor in the lowered content and bioavailability of minerals in roasted flour [25]. The disparity could also be as a result of environmental or handling factors.

The high potassium, calcium, and magnesium contents constitute an important criterion from a nutritional perspective. The Ca / P ratio of around 10.68 indicates that roasted flour is a good source of essential minerals and facilitates calcification [39]. However, the K / (Ca + Mg) ratio is 1.76. This ratio is less than 2.2, which is the recommended value for combating magnesium deficiency.

Polyphenol, flavonoids and antioxidant activities are presented in Table 3. Results showed a significant effect ($p<0.05$) of roasting on polyphenolic compounds, flavonoids, and antioxidant. The roasting increased polyphenols level by 34.84%, from 615.80 to 830.57 mg EAG / 100 g (Table 3) in roasted tuber flour (RTF). These results confirm those of Willis *et al.* [40] and Ogunlade *et al.* [28] on tiger nuts tubers and Boublenza *et al.* [41] on the fruits of *Ceratonia siliqua* L. The increase in polyphenolic content could be up to 44.03% as by Kalam Azad *et al.* [42] in roasted millet (*Panicum miliaceum* L). Fazli *et al.* [43], in his study, compared total phenolic content before and after roasting and noticed that roasting could increase the amount of phenolic compounds [44].

Table 1. Physicochemical and proximate composition of tiger nut flours (DRTF and RTF)

Samples	pH	Fat (%)	Proteins (%)	Moisture (%)	Carbohydrate (%)	Total Sugar (%)	Reducing Sugar (%)	Energy value (kcal/100g)
Roasted tiger nut flour (RTF)	6.39 ±0.00^{a}	23.83 ±2.63^{a}	5.04 ±0.00^{a}	4.95 ±0.11^{a}	63.75 ±0.66^{a}	13.89 ± 0.00^{a}	2.02 ±0.00^{a}	489.62 ±2.68^{a}
Dry raw tiger nut flour (DRTF)	6.52 ±0.00^{b}	24.33 ±0.00^{b}	6.11 ±0.00^{b}	8.86 ±0.12^{b}	58.29 ±0.54^{b}	18.13 ±0.02^{b}	1.67 ±0.00^{b}	476.48 ±2.06^{a}

Means ± standard deviations followed by a different letter in the same column indicate that the differences are significant ($p <0.05$).

Table 2. Mineral composition of tiger nut flours (DRTF and RTF)

Samples	Ash	P	Mg	K	Ca	Na
	(g/100g)	(mg/100g)				
Roasted tiger nut flour (RTF)	2.43±0.3^{a}	14.4^{a}	88.90^{a}	426.85^{a}	153.79^{a}	42.07^{a}
Dry raw tiger nut flour (DRTF)	2.43±0.52^{a}	17.2^{b}	69.24^{b}	290^{b}	182.14^{b}	41.01^{b}
Gain/loss after roasting	----	-16.28%	+28.39%	+47.19%	-15.56%	+2.58%

Means ± standard deviations followed by a different letter in the same column indicate that the differences are significant ($p <0.05$).

Figure 1. Raw tiger nut flour (left side) and roasted tiger nut flour (right side)

The phenolic compounds of certain plant species are mainly conjugated to sugars or other polyalcohols compounds via O-glucosidic or ester bonds. Thus, polyphenols content increase would result from the temperature effect, which would cause a release of phenolic compounds by the weakening of the phenol-polysaccharides and phenol-proteins bonds. It would have weakened the cell tissues, leading to easier migration of phenolic compounds in the extraction solvent. Phenolic compounds accumulated in vacuoles during heat treatment could be released due to the degradation of cellular components and membranes [45]. The reactivity of certain compounds derived from Maillard with the Folin reagent increases polyphenols content [46]. Similar results were found on cashews nut by Chandrasekara and Shahidi [47]. However, under certain conditions, roasting leads to polyphenols' losses due to their thermal sensitivity [35]. This property depends on the phenolic profile of the plant matrix and temperature used for the roasting.

Flavonoid contents were 40.80 mgEC/100g for dry raw tiger nut flour (DRTF) and 43.52 mgEC/100g for roasted tiger nut flour (RTF). The roasting impact is insignificant on the content of flavonoids. This conclusion is corroborated by Willis et al. [40] on roasted tiger nut and Ghazzawi and Al-Ismail [48], on roasted *Anacardium Occidental, Pinus sylvestris and Prunus amygdalus*.

The antioxidant properties of the flours were studied using the 2,2-diphenyl-1-pycrilhydrazyl (DPPH) radical method. The tests showed inhibition of 32.94% in the raw flour and 60.03% for the roasted tuber flour (Table 3). As shown in Table 3, the antioxidant capacity of RTF significantly increased with roasting in DPPH assay. The DRTF has the lowest antioxidant capacity. Analysis of variance showed a significant difference in the inhibition of DPPH. Several studies showed that roasting greatly influences the antioxidant activity and specific biological properties of roasted products, especially in seeds and nuts [49] or in cereals such as millet [42]. The high content of polyphenols and flavonoids may be responsible directly or indirectly for the high antioxidant effect of roasted tuber flour. The Maillard reaction products contribute strongly to these properties [46], [42]. These results can be based on the effect of denaturation and exposure of protein reactive sites and the degradation of endogenous antioxidants [50], [51]. The effect of roasting on the seeds' total antioxidant activity depends on the balance between thermal degradation of naturally antioxidant current compounds and the formation of compounds with antioxidant activities [52]. Some of the new phenolic compounds after roasting have high antioxidant properties compared to the compounds initially present. Phenolic compounds have attracted a lot of attention, because of their important biological properties that include, in particular the antioxidant, anti-inflammatory, antibacterial, antiviral, antithrombotic and vasodilator activities among other.

The pH values were 6.51 and 6.38 respectively in DRTF and RTF with a significant difference ($p<0.05$). The values were lower than those found by Emurotu [53], which were between 7.0 and 7.1. However, the values were within the range of FDA, recommended values for flour [54]. The pH decreased due to the release of new organic acid compounds (formic, acetic, glycolic, and lactic acids) from the sugar conversion and caramelization of sugars [55]. Fat reaction oxidation can contribute to a decrease in pH. According to Yousif and Alghzawi [56], acid caramelization by-products such as pyruvic acid during roasting may reduce the pH value.

The browning of processed products mainly results in a decrease in luminance (L*) [57], allows the assessment of roasting impact from a sensory point of view. After roasting, the browning degree was evaluated by determining the various colorimetric parameters (Table 4). Figure 1 illustrate the DRTF and the RTF, respectively. The findings on the color indices of a*, b*, and L* in the flour sample (Table 4) showed a significant difference at the level of 0.05. The index L* was decreased while a*, and b* increased after the roasting.

Table 3. Phenolic and flavonoids contents and antioxidant activity of tiger nut flours (DRTF and RTF)

Samples	Polyphenols (mgEAG/100g)	Flavonoids (mgEC/100g)	Antioxydant activity %
Roasted tiger nut flour (RTF)	830.57 ± 4.80^{a}	43.52 ± 8.40^{a}	60.03 ± 0.80^{b}
Dry raw tiger nut flour (DRTF)	615.80 ± 9.60^{b}	40.80 ± 1.70^{a}	32.94 ± 2.03^{a}

Means ± standard deviations followed by a different letter in the same column indicate that the differences are significant ($p < 0.05$).

Table 4. Color indices of roasted and raw tiger nut flour

Samples	L*	a*	b*	C	Y	BI	ΔE
Roasted tiger nut flour (RTF)	67.62 ± 0.04^{a}	6.05 ± 0.02^{a}	28.42 ± 0.07^{a}	$29.07 \pm 0{,}021^{a}$	48.20 ± 0.11^{a}	60.32 ± 0.01	15.38
Dry raw tiger nut flour (DRTF)	78.54 ± 0.01^{b}	0.52 ± 0.01^{b}	19.12 ± 0.01^{b}	19.13 ± 0.01^{b}	31.33 ± 0.18^{b}	ND	ND

Means ± standard deviations followed by a different letter in the same column indicate that the differences are significant ($p < 0.05$).

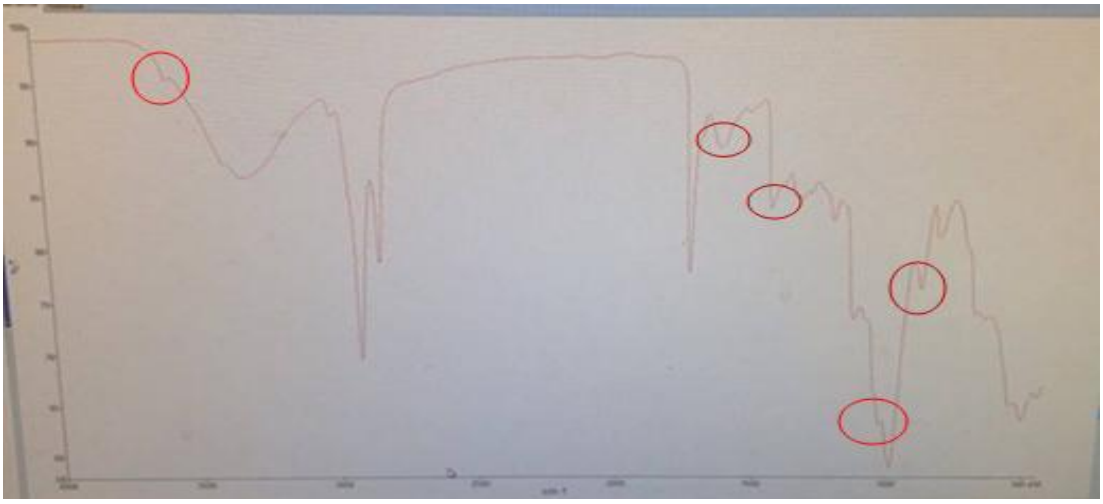

Figure 2. Infra-red spectrophotometry curve of roasted tiger nut flour (RTF)

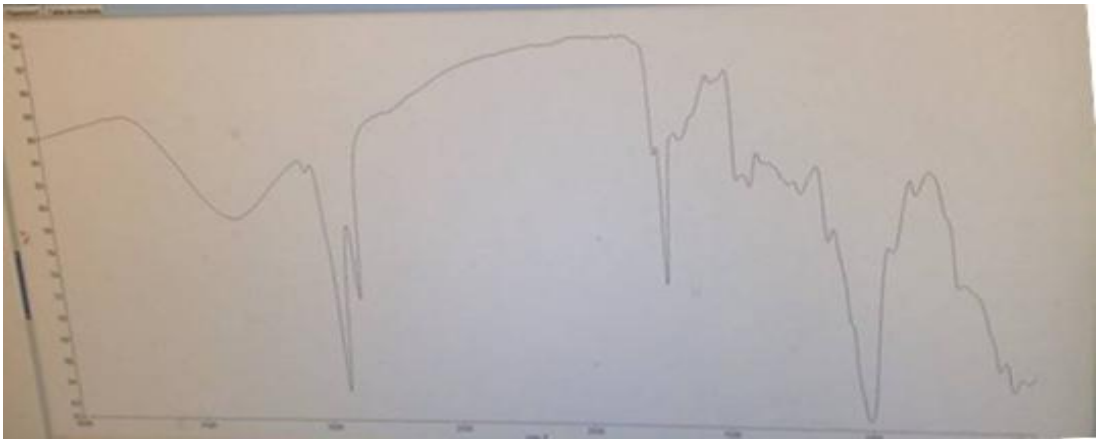

Figure 3. Infra-red spectrophotometry curve of dry raw tiger nut flour (DRTF)

Table 5. FTIR functional group composition in tiger nut flour (DRTF and RTF)

Frequency range (cm^{-1})	3650	3500-3200	2900-2850	1720	1545	1500	1200	1000
Roasted tiger nut flour (RTF)	N-H	OH	CH2, CH3	C=O	C=C	C=N	C-O	C-OC
Dry raw tiger nut flour (DRTF)	----	OH	CH2, CH3	C=O	------	-----	C-O	C-O-C

Color changes are linked to brown pigments' formation through non-enzymatic reactions such as Maillard reactions and caramelization reactions and the degradation of phospholipids during roasting [58], [55]. According to Ee *et al*. [30], colored compounds such as tetrahydrofuran, melanoidins, pyrazines, and their derivatives formed from pyrolysis reactions and caramelization and Maillard reactions; can be the source of the coloring as found in roasted seeds of *Acacia victoriae* and sesame [32].

Roasting is a thermal process that generates new molecules in the seeds. Various analysis techniques, including infrared spectroscopy, can be used to monitor the presence of newly created molecules. Flours from roasted tiger nut tubers and raw tiger nut tubers were analyzed using infrared spectroscopy method in order to identify the functional groups present in both flours. Figures 2 and 3 represent the spectra of DRTF and RTF, respectively. The different functional groups are listed in Table 5.

The above spectral studies revealed several new characteristic bands indicating the formation of new compounds. Absorption bands observed in the spectrum of dry raw tiger nut flour (DRTF) were absent and/or less intense at similar positions in roasted tiger nut flour (RTF). These observations reveal the respective presence of new functional groups and particular bonds in the two flours.

The weak band around 3550 cm^{-1} only observed in the spectrum of RTF seems to be related to N-H type bonds [59]. The band between 3500 and 3200 cm^{-1} could be attributed to O-H bonds' vibrations from polymeric groups such as alcohols and polysaccharides, carboxylic acids, and phenolic compounds [60], [61]. This band is more prominent in RTF than that obtained from DRTF. This confirms the observed increase in polyphenol content of the RTF [62], [63]. The band around 2924 cm^{-1} could be attributed to =CH bond [34].

The 2924 cm^{-1} and 2866 cm^{-1} could be corresponding respectively to the bonds of asymmetric and symmetrical aliphatic types assigned to the bonds of types CH_2, CH_3. This could be confirming the presence of hydrocarbons, triglycerides compounds and carbohydrates [55,59]. The absorbance around 1720 cm^{-1} corresponds to the band C=O bonds from organic compounds such as organic acids, triglyceride esters, or aliphatic esters and other compounds that participate in flavor development. The band seen around 1540 cm^{-1} could be attributed to C-N or C=N type bonds of amino groups and could confirm the presence of nitrogenous aromatic compounds [59], [64], [60], [65]. This band is more intense in roasted flour and may be justified by the presence of compounds such as pyrazines and pyridines. Furthermore, this absorption band could be attributed to the aromatic C=C bond, thus confirming the presence of aromatic compounds [66]. During the roasting of the seeds and nuts, compounds such as furans, pyrazines, pyrrols are formed by Maillard reactions. The bands around 1400 cm^{-1} are typical of carboxylic groups originating from amino acids [67]. It could also be attributed to the presence of phenolic compounds [62]. These bands are more prominent in roasted tuber flour, and polyphenols' high presence confirms this importance.

The presence of a C-O bond is confirmed by the appearance of a band around 1050 cm^{-1}. It can be assigned to the C-O bonds of alcohols, carboxylic acids, and esters. Roasting increased the degree of esterification reactions resulting from reactions between organic acids and alcohols [68]. However, Sharma and Neeraj [62] attributed this stretch band to the C-N type bonds of amino compounds, including primary amines. The changes observed in the spectrum of roasted tuber flour compared to raw flour could be due to acid and ester nature compounds, which increase aroma and flavor development attributed to Maillard reactions [58], [69]. The peak observed around 1220 cm^{-1} indicates the presence of ethereal aromatic compounds.

4. Conclusions

The comparative study between raw tiger nut tuber flour and flour from roasted tiger nut tubers showed that the parameters studied were affected by roasting. The contents of water, sugars, polyphenols, flavonoids, and color were significantly positively affected. The infrared spectra reveal the presence of new molecules that could be of pyrazine nature. This flour from roasted tubers could be used to produce food supplements by improving the nutritional value. The flour obtained from roasted nut tubers may well constitute an alternative to cereals, given its composition in phenolic compounds and its high antioxidant capacity. Additional analysis was carried out on the optimal product to extend the understanding.

REFERENCES

[1] N. C. Ayessou, M. Cissé, M. Gueye, C. Ndiaye, et C. M. Diop, « Nutritional Potential of Two Leafy Vegetables *Leptadenia hastata* Decne and Senna obtusifolia Link Consumed in Senegal », *Food Nutr. (Roma)*, vol. 9, p. 77‑85, 2018.

[2] N. Diop, A. Ndiaye, M. Cisse, O. Dieme, M. Dornier, et O. Sock, « Le ditax (*Detarium senegalense* JF Gmel.): principales caractéristiques et utilisations au Sénégal », *Fruits*, vol. 65, n° 5, p. 293‑306, 2010.

[3] E. Torlak, D. Sert, et P. Serin, « Fate of Salmonella during sesame seeds roasting and storage of tahini », *Int. J. Food Microbiol.*, vol. 163, n° 2‑3, p. 214‑217, 2013.

[4] H. Rizki, F. Kzaiber, et H. Ennahli, « Effects of roasting temperature and time on the physicochemical properties of sesame (*Sesamum indicum* L.) seeds », *Int. J. Innov. Appl. Stud.*, vol. 11, n° 1, p. 148‑155, 2015.

[5] E. R. Chukwuma, N. Obioma, et O. I. Christopher, « The phytochemical composition and some biochemical effects of Nigerian tigernut (*Cyperus esculentus* L.) tuber », *Pak. J. Nutr.*, vol. 9, n° 7, p. 709‑715, 2010.

[6] U. S. Ndidi, C. U. Ndidi, A. Olagunju, A. Muhammad, F. G. Billy, et O. Okpe, « Proximate, Antinutrients and Mineral Composition of Raw and Processed (Boiled and Roasted) *Sphenostylis stenocarpa* Seeds from Southern Kaduna, Northwest Nigeria », *ISRN Nutr.*, vol. 2014, n° 1‑9, 2014, doi: http://dx.doi.org/10.1155/2014/280837.

[7] A. Kanu, J. Kalu, et A. Okorie, « Nutritional and health values of African walnut (*Tetracarpidium conophorum*) », *Int. J. Sci. Technol. Res.*, vol. 4, p. 215‑220, 2015.

[8] U. E. Inyang, E. O. Akpan, et F. A. Bello, « EFFECT OF BOILING AND ROASTING ON THE NUTRIENT AND ANTI-NUTRIENT CONTENTS IN CONOPHOR NUT FLOUR », vol. 2, n° 6, p. 769‑772, 2015.

[9] M. van Boekel *et al.*, « A review on the beneficial aspects of food processing », *Mol. Nutr. Food Res.*, vol. 54, n° 9, p. 1215-1247, 2010.

[10] T. Imam, F. Aliyu, et H. Umar, « Preliminary phytochemical screening, elemental and proximate composition of two varieties of *Cyperus esculentus* (tiger nut) », *Niger. J. Basic Appl. Sci.*, vol. 21, n° 4, p. 247‑251, 2013.

[11] J. A. Ayo, O. E. Adedeji, et G. Ishaya, « PHYTOCHEMICAL COMPOSITION AND FUNCTIONAL PROPERTIES OF FLOUR PRODUCED FROM TWO VARIETIES OF TIGERNUT (*Cyperus esculentus*) », *FUW Trends Sci. Technol. J.*, vol. 1, n° 1, p. 261‑266, 2016.

[12] N. NDIAYE, A. SOW, P. G. FAYE, S. NDIAYE, F. DIEYE, A. DIOUF, M. SAKHO and N. C. AYESSOU «Optimization of tiger nut (*Cyperus esculentus*) roasting process using response surface methodology, Food and Nutrition Sciences, ID: 2703093-20210512-104113-5393 FNS, 2022, accepted for publication.

[13] B. NDIAYE, « CONTRIBUTION A LA VALORISATION DES TUBERCULES DE SOUCHET (*Cyperus esculentus*): APPORT NUTRITIONNEL, ITINERAIRES TECHNOLOGIQUES ET PROPRIETES GALACTOGENES » thèse de doctorat Université Cheikh Anta Diop, p. 168, 2021.

[14] AOAC, « Officiel Méthode of Analysis. Association of Agricultural Chemist », *Wash. DC*, p. 34, 1995.

[15] AOAC (Association of Official Analytical, « Official methods of analysis ». Aoac Washington, DC, 1990.

[16] Association Française de Normalisation (AFNOR)., *Produits dérivés des fruits et légumes jus de fruits*. Paris. France., 1982.

[17] S. Georgé, P. Brat, P. Alter, et M. J. Amiot, « Rapid Determination of Polyphenols and Vitamin C in Plant-Derived Products. », *J. Agric. Food Chemestry*, vol. 53, p. 1370‑1373, 2005.

[18] J. H. Kim *et al.*, « Comparative Assessment of Compositional Components, Antioxidant Effect, and Lignan Extractions From Korean White and Black Sesame (*Sesamum Indica* L.) Seeds for Different Crop Years.Comparative Assessment of Compositional Components, Antioxidant Effect, and Lignan Extractions From Korean White and Black Sesame (*Sesamum Indica* L.) Seeds for Different Crop Years. », *J. Funct. Foods*, vol. 7, p. 495‑505, 2014.

[19] W. Brand-Williams, M. E. Cuvelier, et C. Berset, « Use of a free radical method to evaluate antioxidant activity », *LWT - Food Sci. Technol.*, vol. 28, n° 1, p. 25‑30, janv. 1995, doi: 10.1016/S0023-6438(95)80008-5.

[20] C. Tortoe, P. Akonor, K. Koch, C. Menzel, et K. Adofo, « Physicochemical and functional properties of flour from twelve varieties of Ghanaian sweet potatoes. », *Int. Food Res. J.*, vol. 24, n° 6, 2017.

[21] C. E. Hendel, G. Bailey, et D. Taylor, « Measurement of nonenzymatic browning of dehydrated vegetables during storage », *Food Technol.*, vol. 4, n° 9, p. 344‑347, 1950.

[22] G. Oboh, A. O. Ademiluyi, et A. A. Akindahunsi, « The effect of roasting on the nutritional and antioxidant properties of yellow and white maize varieties », *Int. J. Food Sci. Technol.*, vol. 45, n° 6, p. 1236‑1242, 2010.

[23] W. Liaotrakoon, T. Namhong, C. Yu, et H. Chen, « Impact of roasting on the changes in composition and quality of cashew nut (*Anacardium occidentale*) oil », *Int. Food Res. J.*, vol. 23, n° 3, p. 986, 2016.

[24] F. Makinde, A. Adetutu, et G. Olorunyomi, « Influence of Roasting Techniques on Chemical Composition and Physico-chemical Properties of Sesame (*Sesamum indicum*) Seed Flour and Oil ».

[25] F. Makinde et R. Akinoso, « Nutrient composition and effect of processing treatments on antinutritional factors of Nigerian sesame (*Sesamum indicum* Linn) cultivars », *Int. Food Res. J.*, vol. 20, n° 5, p. 2293, 2013.

[26] G. Tumwine, A. Atukwase, G. A. Tumuhimbise, F. Tucungwirwe, et A. Linnemann, « Production of nutrient-enhanced millet-based composite flour using skimmed milk powder and vegetables », *Food Sci. Nutr.*, vol. 7, n° 1, p. 22‑34, 2019.

[27] S. O. Arinola et K. Adesina, « Effect of thermal processing on the nutritional, antinutritional, and antioxidant properties of *Tetracarpidium conophorum* (African walnut) », *J. Food Process.*, vol. 2014, 2014.

[28] I. Ogunlade, B. A. Adeyemi, et O. Aluko, « Chemical compositions, antioxidant capacity of tigernut (*Cyperus esculentus*) and potential health benefits », *Eur. Sci. J.*, 2015.

[29] E. N. Onyeike, E. A. Anyalogbu, et M. O. Monanu, « Effect of heat processing on the proximate composition and energy values of African walnut (*Plukenetia conophora*) and African Elemi (*Canarium schweinfurthii*) consumed as masticatories in Nigeria », *IJSTR*, vol. 4, n° 8, p. 295‑301, 2015.

[30] K. Y. Ee, J. Zhao, A.-U. Rehman, et S. Agboola, « Effects of roasting on the characteristics of Australian wattle (*Acacia Victoriae Bentham*) seed and extracts », *Int. J. Food Prop.*, vol. 16, n° 5, p. 1135‑1147, 2013.

[31] K. A. McDaniel, B. L. White, L. L. Dean, T. H. Sanders, et J. P. Davis, « Compositional and mechanical properties of peanuts roasted to equivalent colors using different time/temperature combinations », *J. Food Sci.*, vol. 77, n° 12, p. C1293‑C1299, 2012.

[32] F. Makinde, A. Adetutu, et G. Olorunyomi, « Influence of Roasting Techniques on Chemical Composition and Physico-chemical Properties of Sesame (*Sesamum indicum*) Seed Flour and Oil ».

[33] G. Baker, J. Cornell, D. Gorbet, S. O'keefe, C. Sims, et S. Talcott, « Determination of pyrazine and flavor variations in peanut genotypes during roasting », *J. Food Sci.*, vol. 68, n° 1, p. 394-400, 2003.

[34] Y. Kumar, V. S. Sharanagat, L. Singh, et S. Mani, « Effect of germination and roasting on the proximate composition, total phenolics, and functional properties of black chickpea (*Cicer arietinum*) », *Legume Sci.*, vol. 2, n° 1, p. e20, 2020, doi: 10.1002/leg3.20.

[35] N. Singh, J. David, D. Thompkinson, B. S. Seelam, H. Rajput, et S. Morya, « Effect of roasting on functional and phytochemical constituents of finger millet (*Eleusine coracana* L.) », *Pharma Innov. J.*, vol. 7, n° 4, p. 414‑418, 2018.

[36] N. Tenyang *et al.*, « Effects of boiling and roasting on proximate composition, lipid oxidation, fatty acid profile and mineral content of two sesame varieties commercialized and consumed in Far-North Region of Cameroon », *Food Chem.*, vol. 221, p. 1308‑1316, 2017.

[37] B. Orhevba et I. Yusuf, « Effect of roasting temperature on nutritional quality of cashew nut (*Anacardium Occidentale*) », *Int. J. Sci. Technol. Res.*, vol. 5, n° 6, p. 182‑184, 2016.

[38] A. A. Mariod *et al.*, « Effects of roasting and boiling on the chemical composition, amino acids and oil stability of safflower seeds », *Int. J. Food Sci. Technol.*, vol. 47, n° 8, p. 1737‑1743, 2012.

[39] Nieman D. C.; Butterworth D. E. and Niewman C. N., « Nutrition », *Winc Brown Publ. Dubuque USA*, p. 237-312., 1992.

[40] S. Willis, C. Jackson, et M. Verghese, « Effects of Processing on Antioxidant Capacity and Metabolizing Enzyme Inhibition of Tiger Nut Tubers », *Food Nutr. Sci.*, vol. 10, n° 09, p. 1132, 2019.

[41] I. Boublenza, H. A. Lazouni, L. Ghaffari, K. Ruiz, A.-S. Fabiano-Tixier, et F. Chemat, « Influence of roasting on sensory, antioxidant, aromas, and physicochemical properties of carob pod powder (*Ceratonia siliqua* L.) », *J. Food Qual.*,

vol. 2017, 2017.

[42] M. O. Kalam Azad *et al.*, « Effect of different processing methods on the accumulation of the phenolic compounds and antioxidant profile of broomcorn millet (*Panicum miliaceum* L.) flour », *Foods*, vol. 8, n° 7, p. 230, 2019.

[43] M. Fazli Aghdaei, S. A. H. Goli, J. Keramat, et A. Ansarian, « The effect of roasting process on total phenolic compounds and antioxidant activity of two domestic and wild varieties pistachio oil. », *J. Food Sci. Technol. 2008-8787*, vol. 13, n° 51, 2016.

[44] Z. Sheng, J. Zhao, I. Muhammad, et Y. Zhang, « Optimization of total phenolic content from T*erminalia chebula* Retz. fruits using response surface methodology and evaluation of their antioxidant activities », *PloS One*, vol. 13, n° 8, p. e0202368, 2018.

[45] S. Chethan et N. Malleshi, « Finger millet polyphenols: Optimization of extraction and the effect of pH on their stability », *Food Chem.*, vol. 105, n° 2, p. 862‑870, 2007.

[46] M. M. Win, A. Abdul-Hamid, B. S. Baharin, F. Anwar, M. C. Sabu, et M. S. Pak-Dek, « Phenolic compounds and antioxidant activity of peanut's skin, hull, raw kernel and roasted kernel flour », *Pak J Bot*, vol. 43, n° 3, p. 1635‑1642, 2011.

[47] N. Chandrasekara et F. Shahidi, « Effect of roasting on phenolic content and antioxidant activities of whole cashew nuts, kernels, and testa », *J. Agric. Food Chem.*, vol. 59, n° 9, p. 5006-5014, 2011.

[48] H. A. Ghazzawi et K. Al-Ismail, « A comprehensive study on the effect of roasting and frying on fatty acids profiles and antioxidant capacity of almonds, pine, cashew, and pistachio », *J. Food Qual.*, vol. 2017, 2017.

[49] A.-J. Kim, « Optimization of roasting conditions through antioxidant and anti-inflammatory activities of Yak-kong (*Rhynchosia nulubilis*) », *Food Sci. Biotechnol.*, vol. 25, n° 4, p. 1175‑1182, 2016.

[50] G. Šarić, K. Marković, D. Vukičević, E. Lež, M. Hruškar, et N. Vahčić, « Changes of antioxidant activity in honey after heat treatment », *Czech J. Food Sci.*, vol. 31, n° 6, p. 601‑606, 2013.

[51] Y. Choi, S. Lee, J. Chun, H. Lee, et J. Lee, « Influence of heat treatment on the antioxidant activities and polyphenolic compounds of Shiitake (*Lentinus edodes*) mushroom », *Food Chem.*, vol. 99, n° 2, p. 381‑387, 2006.

[52] I. Irina et G. Mohamed, « Biological activities and effects of food processing on flavonoids as phenolic antioxidants », *Adv. Appl. Biotechnol.*, p. 101‑124, 2012.

[53] J. E. Emurotu, « Comparison of the Nutritive Value of the Yellow and Brown Varieties of Tiger Nut », *IOSR J. Appl. Chem. IOSR-JAC*, vol. 10, n° 9, p. 29‑32, 2017.

[54] S. M. Bala, « Effect of forced convection roasting on physicochemical and antioxidant properties of whole grain maize (*Zea mays* L.) and optimisation of roasting conditions », 2016.

[55] M. Mosayebi, M. Kashaninejad, et L. Najafian, « Optimizing Physiochemical and Sensory Properties of Infrared-Hot Air Roasted Sunflower Kernels Using Response Surface Methodology », *J. Food Qual.*, vol. 2018, 2018.

[56] A. K. Yousif et H. Alghzawi, « Processing and characterization of carob powder », *Food Chem.*, vol. 69, n° 3, p. 283‑287, 2000.

[57] K. B. Hicks *et al.*, « Inhibition of enzymatic browning in fresh fruit and vegetable juices by soluble and insoluble forms of β-cyclodextrin alone or in combination with phosphates », *J. Agric. Food Chem.*, vol. 44, n° 9, p. 2591‑2594, 1996.

[58] I. A. Wani, A. Gani, A. Tariq, P. Sharma, F. A. Masoodi, et H. M. Wani, « Effect of roasting on physicochemical, functional and antioxidant properties of arrowhead (*Sagittaria sagittifolia* L.) flour », *Food Chem.*, vol. 197, p. 345-352, 2016.

[59] A. Dogan, G. Siyakus, et F. Severcan, « FTIR spectroscopic characterization of irradiated hazelnut (C*orylus avellana* L.) », *Food Chem.*, vol. 100, n° 3, p. 1106‑1114, janv. 2007, doi: 10.1016/j.foodchem.2005.11.017.

[60] C. Christou, A. Agapiou, et R. Kokkinofta, « Use of FTIR spectroscopy and chemometrics for the classification of carobs origin », *J. Adv. Res.*, vol. 10, p. 1‑8, 2018.

[61] M. C. Ayo, J. D. Madufor, G. A. Onyeagoro, et O. Ogbobe, « Effect of filler characterization on the properties of chemically treated groundnut shell », *Macromol. Indian J.*, vol. 11, n° 2, p. 043‑050, 2015.

[62] S. Sharma et Neeraj, « FTIR Spectroscopic Characterization of Almond Varieties (*Prunus dulcis*) from Himachal Pradesh (India) », *Int. J. Curr. Microbiol. Appl. Sci.*, vol. 7, n° 5, p. 887-898, 2018, doi: https://doi.org/10.20546/ijcmas.2018.705.108.

[63] A. A. Wani, I. A. Wani, P. R. Hussain, A. Gani, T. A. Wani, et F. A. Masoodi, « Physicochemical properties of native and γ-irradiated wild arrowhead (*Sagittaria sagittifolia* L.) tuber starch », *Int. J. Biol. Macromol.*, vol. 77, p. 360‑368, juin 2015, doi: 10.1016/j.ijbiomac.2015.03.012.

[64] N. Wang et L.-T. Lim, « Fourier Transform Infrared and Physicochemical Analyses of Roasted Coffee », *J. Agric. Food Chem.*, vol. 60, n° 21, p. 5446‑5453, mai 2012, doi: 10.1021/jf300348e.

[65] A. Subramanian, W. Harper, et L. Rodriguez-Saona, « Cheddar cheese classification based on flavor quality using a novel extraction method and Fourier transform infrared spectroscopy », *J. Dairy Sci.*, vol. 92, n° 1, p. 87‑94, 2009.

[66] S. Azeez, O. Lasekan, S. Jinap, et R. Sulaiman, « Effect of roasting conditions on the browning intensity and structural changes in jackfruit (*Artocarpus hetrophyllus*) seeds », *J. Food Sci. Technol.*, vol. 52, n° 12, p. 8050-8058, 2015.

[67] M. D. Argirova, I. D. Stefanova, A. D. Krustev, et V. I. Turiiski, « Testing biological activity of model Maillard reaction products: studies on gastric smooth muscle tissues », *Amino Acids*, vol. 38, n° 3, p. 797‑803, 2010.

[68] V. Ntukidem, P. Ukwo, I. Udoh, et E. Umoinyang, « Influence of Different Pre-treatments on the Nutritional and Organoleptic Properties of Vegetable Milk produced locally from Tiger-Nut (*Cyperus esculentus*) Tubers »Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), Vol. 13, n° 6, PP 55-61. 2019.

[69] S. Ng, O. Lasekan, K. Muhammad, R. Sulaiman, et N. Hussain, « Effect of roasting conditions on color development and Fourier transform infrared spectroscopy (FTIR-ATR)

analysis of Malaysian-grown tropical almond nuts (*Terminalia catappa* L.) », *Chem. Cent. J.*, vol. 8, n° 1, p. 1-11, 2014.

Copyright © 2022 The Author(s). Published by Scientific & Academic Publishing
This work is licensed under the Creative Commons Attribution International License (CC BY). http://creativecommons.org/licenses/by/4.0/