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Comparison of the bioactive properties, tocopherol and phenolic components of germinated, roasted, and boiled chufa (*Cyperus esculentus*) tubers

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Abstract

Background: Chufa flour can be used as a supplement to cereal flour to increase its calcium content. Many studies have shown that chufa tubers have high nutritional value.

Results: The carotenoid contents of the tubers ranged from 0.270 (roasting) to 1.897 μg/g (germination). The total flavonoid contents of chufa tuber were recorded between 4.60 and 17.93 mg CE/100 g. According to the results obtained, oil yield was determined between 12.55% (germination) and 18.05% (roasting). The protein content of the chufa tuber was found to be 16.60% in the germinated sample with the highest value. Potassium (3792.67–8384.85), sulfur (975.74–1804.01), phosphorus (944.08–1256.78), and magnesium (504.45–672.82 ppm) are the main inorganic components of ash in the samples examined. The highest carotenoid content in the oil was observed in the germinated sample with 7084.10 μg/g, total phenol content 9.44 mgGAE/100 g, total flavonoid content 561.10 mg CE/100 g, and antioxidant activity value 32.39%. It was determined that oleic acid (70.95%–73.47%) was the dominant fatty acid. The results of tocopherol content of chufa tuber oil belong to the highest α-tocopherol by boiling (8.91 mg/kg), roasting (9.07 mg/kg), and germinating (9.64 mg/kg).

Conclusion: According to the results of the study, the germination process applied to the chufa tuber increased the protein and macro mineral content. The germination process applied to the chufa tuber increased the content of unsaturated fatty acids and tocopherol. Chufa tuber oil contains highly unsaturated fatty acids, vitamin E and phenolic compounds. Due to its nutritional quality, chufa oil is recommended for consumption and industrial use.

KEYWORDS
boiling, chufa (*Cyperus esculentus*), germination, oil, phytochemicals, roasting

INTRODUCTION

Chufa (*Cyperus esculentus*) is a member of the Cyperaceae family.[1] The tubers of this plant are known by various names such as tiger nut, ground nut, ground almond, sedge nut, tigernut, hanti, and chufa.[2–4] Chufa have been accepted as a food item since ancient times and were consumed as an important food in Ancient Egypt.[5,6] These tubers are mainly used to make a milk-like beverage called "horchata de chufa" in Spain. It is a refreshing nonalcoholic beverage in the form of milk and is usually consumed during the summer months.[6] This

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beverage has been considered the ancestor of the modern "horchata".[5,6] It can be consumed raw, cooked, roasted, or processed.[4] While roasted chufa flour is sometimes added to biscuits and other baked goods, oil, soap, and starch extracts are also produced from this tuber. It is also used as a flavoring agent in the preparation of nougat, jam, brewing, ice cream, and kunnu (a local beverage in Nigeria).[6,7] Similarly, it has been reported that chufa flour can be incorporated into wheat flour as a good alternative to cocoa or for the production of bread, cakes, and biscuits in the bakery industry.[8,9] Its oil can be used in salads or stir-fries.[6] Chufa growing season is between April and November.[10] Chufa grown with continuous irrigation should be properly dried before storage. The drying process is completely natural and drying can take up to a month. Drying provides a longer shelf life to the product, prevents rotting or other bacterial contamination, and preserves its quality and nutritional value. The drying process limits the acceptability of chufa tuber and makes the shell of the chufa wrinkled.[7,10] Arafat et al.[11] revealed that chufa tubers have high calcium, sodium, and copper and low magnesium, manganese, phosphorus, iron, and zinc mineral contents. The high amounts of calcium in chufa are sufficient for bone and tooth development in babies. The presence of other minerals such as iron is very important due to the requirement for blood formation. Therefore, chufa flour can be used as a supplement to cereal flour to increase its calcium content.[11,12] Many studies have shown that chufa tubers have high nutritional value.[2–4,13] Due to its the high fat (25%) and carbohydrate (50%) contents, chufa tubers provide approximately 400–450 kcal/100 g of energy. It also contains a significant amount of protein (8%), dietary fibers (6%), mineral substances (4%), namely calcium, sodium, potassium, magnesium and phosphorus, and especially catalase, lipase, and amylase enzymes.[2,4] The fatty acid profile of chufa tuber oil is comparable with olive oil and is mostly dominated by oleic acid in its composition.[1,14] Chufa oil is considered a superior cooking oil due to its stability and nutritional properties. Chufa oil contains highly unsaturated fatty acids, vitamin E, and phenolic compounds. The phytosterol content of chufa oil, especially stigmasterol and campesterol, is higher than in olive oil, which distinguishes chufa and olive oil from each other.[1,4,14] The aim of this study is to determine the effects of germination, roasting and boiling processes on protein, ash, mineral, moisture, carotenoid, total phenol, total flavonoid, antioxidant activity, phenolic component, and oil yield of chufa tubers. Also, it was aimed to determine the effect of germination, roasting, and boiling on free acidity, peroxide number, carotenoid, total phenol, total flavonoid, antioxidant activity, phenolic component, fatty acid composition, and tocopherol content of the chufa tuber oil.

MATERIALS AND METHODS

Material

Chufa tubers of "Sarışeker" variety used in this study were grown in Sarayönü district of Konya province (Figure 1). Tubers brought to the laboratory were washed and foreign, damaged, broken tubers, and foreign materials were removed. After the germination, roasting, and boiling processes were applied, analyzes were carried out on chufa tuber and their oils.



FIGURE 1 Chufa plant and its tubers.

Method

Sample preparation

Germination, roasting, and boiling processes were applied to chufa tubers (Figure 2). The germination process was kept at room temperature with a 1:2 ratio (w/v) tuber:water mixture under normal conditions and was carried out on 10 days until the day when the leaflets started to emerge from the tuber. The roasting process was carried out in an oven at 160°C for 30 min under controlled conditions after the dried tubers were cut into several pieces. In the boiling process, the tubers were boiled in 1:3 (w/v) water at 100°C for 2 h and 50 min. Chufa tubers were ground in an electric laboratory mill through a 0.5 mesh sieve, and the ground samples were placed in colored glass jars, tightly capped, and stored at +4°C until analysis.[12]

Preparation of tuber extracts

Extracts from the control sample, germinated, roasted, and boiled chufa tubers were obtained according to method described by Jakopic et al.[15] Control, germinated, roasted, and boiled chufa tubers were weighed into 5 g centrifuge tubes. A volume of 15 mL of methanol/water (MeOH/H_2O, 80:20, v/v) solution was added. It was kept in a shaking water bath (WiseBath) at room temperature for 1 h. Then it was centrifuged at 6000 rpm for 10 min (Hermle Z-200A). The supernatant part of the samples taken from the centrifuge was separated. Then, 10 mL of hexane was added to the supernatant and shaken in an ultrasonic water bath (Bandelin Sonorex) for 5 min, and then the supernatant was removed. After the procedures were repeated twice, the lower phase was taken into the balloon and evaporated at 45°C in a rotary evaporator. The volume was made up to 10 mL with methanol/water (MeOH/H_2O, 80:20, v/v) solution. The extracts were kept frozen at −18°C until used in analysis.



FIGURE 2 Chufa tubers that are germinated and roasted.

Preparation of tuber oil extracts

After 2 mL of chufa tuber oil into a centrifuge tube were weighed, a mixture of 1 mL of Hexane and 2 mL of methanol:water (MeOH/H_2O, 60:40, v/v) was added. The mixture was agitated in an ultrasonic water bath (Bandelin Sonorex) for 5 min and then centrifuged at 4000 rpm for 5 min (Hermle Z-200A). The methanol:water phase was separated and the procedures were repeated two times. The collected extracts were analyzed by passing them through 0.45-µm syringe filters.[16,17]

Moisture content

The % moisture content of control, germinated, roasted, and boiled chufa tubers was determined by Kern Dbs 60–3 moisture analyzer.

Oil extraction from chufa tubers

After 10 grams of ground chufa tubers were put into the Soxhlet cartridge, 2/3 of petroleum ether was poured into the balloon and placed in the Soxhlet apparatus. The % oil yield was calculated by extracting the sample at 50 oC for 4 h.[18]

Protein and ash content

Protein and ash amounts in chufa tubers were determined according to the AOAC method.[19]

Mineral content

Here, 0.2 g of ground chufa tubers was placed in incinerators containing 15 mL of pure HNO_3 and 2 mL of H_2O_2 (30%; w/vc). Chufa samples were burned in a microwave oven (Cem-MARS Xpress, at 210°C). After the burned samples were filtered/filtered (#42), the filtrates were collected in 50 mL bottles for elemental analysis in ICP-AES (Varian-Vista).[20]

Carotenoid content of chufa tubers

The extraction process for the determination of carotenoids was also performed according to the method stated by da Rocha et al.,[21] with some modifications. After 2 g of sample was weighed, 25 mL of acetone was added on it. The mixture was shaken in an ultrasonic water bath (Bandelin Sonorex) for 10 min, and filtered using filter paper (Whatman No.1) and then taken into separatory funnels. The filtrate was then fractionated with 20 mL of petroleum ether and washed with 100 mL of distilled water to remove the acetone. These processes were repeated twice. Filter paper using anhydrous sodium sulfate (5 g) to filter the petroleum ether portion and remove the residual water. The volume of the extracts obtained was made up to 25 mL with petroleum ether. After these processes, the absorbance values of samples were measured at 450 nm in a Spectrophotometer.

The total phenolic content of chufa tuber and oils

The total phenol content of samples was determined with the Folin–Ciocalteu reagent according to the method described by Yoo et al.[22] 0.5 mL of extract was mixed with 2.5 mL of Folin Ciocalteu reagent and 2 mL of Na_2CO_3 (sodium carbonate) solution. After being kept at room temperature and in the dark for 2 h, the total phenolic contents of the samples were measured in a spectrophotometer (Shimadzu UV mini 1240, Japan) at a wavelength of 725 nm. Results are given in mg gallic acid equivalent (GAE)/100 g weight.

Total flavonoid contents of chufa tuber and oils

Total flavonoid content of samples was determined according to Dewanto et al.[23] After the extracts were diluted with distilled water, 5% $NaNO_2$ (sodium nitrite) solution was added to each test tube. After 5 min, 10% $AlCl_3$ (aluminum chloride) solution was added and after 6 min 1.0 M NaOH (sodium hydroxide) solution was added sequentially. At the end of these processes, after making up with distilled water until the total volume of the sample was 5 mL, the

mixture was thoroughly mixed in vortex. The absorbance values of the samples were measured at 510 nm. The calibration curve was prepared using Catechol as a standard. Flavonoid content is expressed as mg Catechol equivalents (CE) per dry weight (mg CE/g DW).

Antioxidant activity values of chufa tuber and oils

Antioxidant activity values of tuber samples were determined using 2,2-diphenyl-1-picrylhydrazil (DPPH) according to the methods described by Lee et al.[24] After 0.1 mL of extract was mixed with 2 mL of DPPH solution, the mixture was incubated for 30 min at room temperature and in the dark. At the end of this period, the absorbance values of the samples were measured at 517 nm.

Determination of phenolic compounds of chufa tuber and oils

The extracts obtained for the phenolic component profile of the chufa tubers, which were subjected to control, germination, roasting, and boiling processes, were taken into 0.5-mL vials. After adding 0.5 mL of methanol, the samples were made to be injected into HPLC. The phenolic component profile of the samples was determined at 280 nm with the help of a Shimadzu-HPLC device. Phenolic component contents of the samples were determined with the help of a Shimadzu-HPLC device equipped with an Inertsil ODS-3 (5 µm; 4.6 × 250 mm) column and PDA detector. A mixture of water (A) and acetonitrile (B) containing 0.05% acetic acid was used as the mobile phase. The flow rate of the mobile phase is 1 mL/min at 30°C and the injection volume is 20 µL. It was recorded at 280 and 330 nm. The operating time of the device for each sample is 60 min.[25]

Free fatty acidity

After weighing the sample in the range of 2 g from the oil sample to the Erlenmeyer with a volume of 250 mL, 50–100 mL of the ethanol-diethyl ether mixture was added to the sample. It was shaken for 1 min to dissolve the oil by mixing. Then, 3–4 drops of phenolphthalein were instilled. Titration was carried out with 0.1 N ethanolic KOH in the burette until a permanent pink color was obtained. Consumption was recorded, and the results were given as % oleic acid.[26]

Peroxide value

Peroxide number is the amount of active oxygen in oils and peroxide in 1 kg of oil is the amount of oxygen in milliequivalent grams. Acetic acid/chloroform (3:2, v/v) mixture was added to 1.0 g of oil samples. After adding 0.5 mL of KI solution, it was left to react in the dark. Then it was titrated with 0.1 N $Na_2S_2O_3$ (sodium thiosulfate) solution. The peroxide number was calculated by determining the spent consumption.[26]

Total carotenoid content of chufa tuber oils

A volume of 50 µL of oil was taken from the obtained samples and dissolved in 10 mL of hexane. Then, by vortexing for 20 s, 3 mL of the sample was taken into the quartz cuvette, and the absorbance value was recorded at 450 nm wavelength in the UV-Spectrophotometer device.[21,27]

Fatty acid composition

The fatty acid compositions of the chufa oil samples were determined by modifying the method described by Hışıl.[28] Oil samples (50–100 mg) were converted to fatty acid methyl esters (FAME). For the esterification process, 0.1 g oil sample was first dissolved by adding 10 mL of n-hexane (C_6H1_4) and centrifuged at 4500 rpm for 30 min (Hermle Z-200A). Then, 2 N methanolic KOH was added and the solution was stirred for a short time by vortexing, and then left for 30 min at room temperature and in the dark. After phase separation, 1 mL of the supernatant was taken, transferred to vials, and made ready for analysis. Methyl esters of fatty acids were analyzed in a gas chromatography instrument (Shimadzu GC-2010) equipped with flame-ionization detector (FID) and capillary column (Teknokroma TR CN100, P/N TR 882162 fused silica column, 60 m × 0.25 mm × 0.20 µm). The temperature of injection block and detector was 260°C. Mobile phase was nitrogen with 1.51 mL/min flow rate. Injection block total flow rate was 80 mL/min and split rate was also 1/40. Column temperature was programmed 120°C for 5 min and increased 240°C at 4°C/min and held 25 min at 240°C.

Tocopherol content

Tocopherol analysis was performed using the Shimadzu-HPLC device according to the method specified in AOAC.[29] All solvents and all other reagents used are HPLC analytical grade. Then, 25-µL extracts were chromatographed on a 5-µm silica column (250 × 4.6 mm) using ethyl acetate/acetic acid/hexane (1:1:198 v/v/v) mobile phase. The flow rate was set to 1.5 mL/min, and a fluorescent detector was used with excitation and emission wavelengths at 290–330 nm, respectively. The calibration curve was constructed using the standard α-tocopherol (SigmaAldrick; 0 to 10 µg/mL; $R2 = 0.999$), and the identification was made by comparing the retention time with the standard.

Statistically analysis

Minitab 16 statistical program was used to interpret the data obtained as a result of the research. The data were subjected to analysis of variance. The averages of the main sources of variation whose differences were found to be statistically significant were compared with the

Tukey multiple comparison test, and the statistical significance level was accepted as $p < 0.05$. The results are given with mean values and standard deviations.[30]

RESULTS AND DISCUSSION

Oil, protein, and ash contents of chufa tubers

Oil, protein, and ash amounts of the control group, germinated, roasted, and boiled chufa tubers are given in Table 1. The oil yield results of the chufa tuber samples, which were processed raw, roasted, germinated, and boiled, were determined as 14.85%, 18.05%, 12.55%, and 16.95%, respectively. According to the results, the germination process applied to the chufa tuber samples decreased the oil yield, while the roasting and boiling processes increased the oil yield. Okoye and Ene[31] determined the oil content of raw chufa tubers as 24.45%, and the oil content of germinated tubers. They determined that it was 22.53%. Adejuyitan et al.[13] reported that the oil yield of chufa tubers flour fermented at different times varied between 11.24% (72 h) and 14.41% (0 h). Wayah and Shehu (2015)[32] found that chufa tubers oil was 24.8%. Özcan et al.[33] determined the oil yield between 16.20% (raw Beeswax) and 18.20% (sprouted Yellow Sugar). Our results regarding the fat content of tubers were similar to some literature data and differed from others. These differences may have resulted from the agronomic activities, climatic factors, and the treatments applied to the tuber during the development phase of the plant.

The protein amounts in the chufa tuber samples varied between 12.21% (raw) and 16.60% (germination). Germination and boiling processes applied to chufa tubers showed an increasing effect on protein content. Adebayo and Arinola[34] reported that the protein amount of the raw tuber was 10.50%, while the protein amount of the germinated tuber was 13.24%. Okoye and Ene[31] determined the protein content of raw samples to be 8.09% and germinated samples to be 8.49%. Chinma et al.[35] found the protein content of tubers germinated at different times between 8.23% and 12.40%. Adejuyitan et al.[2] determined the protein content of chufa tubers flour fermented at different times between 6.67% and 9.23%. Ogunlade et al.[36] determined the protein content of dry, raw, and roasted samples as 1.56%, 1.32%, and 2.24%, respectively. Okorie and Nwanekezi[37] reported that while the protein content of raw ground almonds was 4.13%, it decreased to 1.52% after boiling.

The ash content of the raw, roasted, germinated, and boiled chufa tubers samples varied between 1.97% (roasted) and 3.12% (raw). Roasting, germination, and boiling processes applied to the chufa tubers reduced the ash amount of the tuber. Adebayo and Arinola[34] determined the ash content of the chufa tubers between 5.64% (raw) and 6.32%. Adel et al.[38] reported that the ash amount of the dry ground almond tuber was 2.85%. Okoye and Ene[31] determined that the ash content of the raw sample was 1.82%, and the germinated sample was 2.11%. Chinma et al.[35] determined the ash content of tubers germinated at different times between 3.28% and 4.26%. Adejuyitan et al.[2] found the ash content of chufa tubers flours fermented at different times between 2.37% (72 h) and 2.72% (0 h). Okorie and Nwanekezi[37] reported that the ash content of the raw chufa tubers sample (1.8%) was higher than the boiled sample (0.142%).

Mineral contents of chufa tubers

Mineral amounts of the control group, germinated, roasted, and boiled chufa tubers are given in Table 2. Phosphorus, potassium, calcium, magnesium, sulfur, sodium, iron, copper, manganese, nickel, and zinc minerals were determined in chufa tuber samples. Potassium was the most abundant mineral substance in ground almond tubers. The potassium content of the chufa tuber samples was found to be between 3792.67 ppm (scalding) and 8384.85 ppm (germination). The sulfur content of the samples was determined between 975.74 ppm (scalding) and 1804.01 ppm (germination). The amount of phosphorus in the chufa tubers samples varied between 944.08 ppm (scalding) and 1256.78 ppm (germination). The magnesium content of the raw, roasted, germinated, and boiled chufa tuber samples was determined to be between 504.45 ppm (scalding) and 793.87 ppm (germination). The calcium content of the chufa samples was determined to be between 325.18 ppm (roasting) and 529.57 ppm (germination). In addition, the sodium content of the chufa tuber samples was determined to be between 84.85 ppm (boiling) and 220.83 ppm (germination). The highest iron content (15.75 ppm) was determined in the raw chufa tuber sample. The highest zinc content was determined as 9.68 ppm (germination) in raw and roasted, germinated, and boiled chufa samples. The highest copper content of the chufa tuber samples was determined in 5.78-ppm germinated samples. While it was observed that there were fluctuations in the mineral amounts of the chufa tubers that were subjected to the roasting process, the mineral amounts of the tubers that were subjected to the germination process

TABLE 1 Oil, protein, and ash contents of chufa tuber samples (%).*

Processes	*n*	Oil content	*n*	Crude protein	Ash
Control	2	14.85 ± 0.07^{c}	3	12.21 ± 0.22^{b}	3.12 ± 0.14^{a}
Roasting	2	18.05 ± 0.21^{a}	3	12.25 ± 0.50^{b}	1.97 ± 0.10^{C}
Germination	2	12.55 ± 0.21^{d}	3	16.60 ± 0.75^{a}	2.57 ± 0.26^{b}
Boiling	2	16.95 ± 0.07^{b}	3	15.94 ± 0.78^{a}	2.43 ± 0.27^{bc}

*The values indicated with different letters between a and d in the same column were found to be statistically significant ($p < 0.05$).

TABLE 2 Mineral contents of ground almond tuber samples (mg/kg).

Processes	*n*	P	K	Ca	Mg	S	Na	Fe	Cu	Mn	Ni	Zn
Control	3	1076.63 ± 55.03^{b}	6909.58 ± 342.30^{b}	411.72 ± 59.20^{bc}	672.82 ± 6.64^{b}	1630.75 ± 13.93^{b}	117.44 ± 6.37^{b}	15.75 ± 1.18^{a}	4.91 ± 0.06^{b}	2.34 ± 0.16^{a}	0.99 ± 0.03^{b}	8.54 ± 0.55^{b}
Roasting	3	965.51 ± 21.06^{c}	7482.43 ± 718.68^{ab}	325.18 ± 19.89^{c}	640.92 ± 5.11^{c}	1503.73 ± 38.89^{c}	120.16 ± 6.16^{b}	11.96 ± 1.78^{bc}	5.27 ± 0.47^{ab}	1.75 ± 0.11^{b}	1.07 ± 0.01^{b}	7.48 ± 0.17^{c}
Germination	3	1256.78 ± 30.37^{a}	8384.85 ± 169.82^{a}	529.57 ± 30.38^{a}	793.87 ± 14.89^{a}	1804.01 ± 26.37^{a}	220.83 ± 5.08^{a}	14.60 ± 0.73^{ab}	5.78 ± 0.08^{a}	2.29 ± 0.18^{a}	1.18 ± 0.06^{a}	9.86 ± 0.19^{a}
Boiling	3	944.08 ± 9.80^{c}	3792.67 ± 42.66^{c}	460.06 ± 55.63^{ab}	504.45 ± 16.90^{d}	975.74 ± 25.04^{d}	84.85 ± 0.98^{c}	10.47 ± 1.04^{c}	2.14 ± 0.32^{c}	1.47 ± 0.09^{b}	0.25 ± 0.01^{c}	7.84 ± 0.29^{bc}

Note: Values indicated with different letters between a and d in the same column were found to be statistically significant ($p < 0.05$).

increased in general. Since potassium, calcium, magnesium and sodium are water-soluble elements, they reduced the mineral substance content of boiled chufa tubers since they were transferred to water during boiling. Phosphorus, potassium, calcium, magnesium, sulfur, sodium, iron, copper, manganese, nickel, and zinc minerals were determined in chufa tuber samples. Potassium was the most abundant mineral substance in chufa tubers. The potassium content of the chufa tuber samples was found to be between 3792.67 ppm (scalding) and 8384.85 ppm (germination). The sulfur content of the samples was determined to be between 975.74 ppm (scalding) and 1804.01 ppm (germination). The amount of phosphorus in the chufa samples varied between 944.08 ppm (scalding) and 1256.78 ppm (germination). The magnesium content of the raw, roasted, germinated, and boiled chufa tuber samples was determined between 504.45 ppm (scalding) and 793.87 ppm (germination). The calcium content of the chufa samples was determined between 325.18 ppm (roasting) and 529.57 ppm (germination). In addition, the sodium content of the chufa tuber samples was determined between 84.85 ppm (boiling) and 220.83 ppm (germination). The highest iron content (15.75 ppm) was determined in the raw chufa tubers sample. The highest zinc content was determined as 9.68 ppm (germination) in raw and roasted, germinated, and boiled chufa samples. The highest copper content of the chufa tuber samples was determined in 5.78 ppm germinated samples. While it was observed that there were fluctuations in the mineral amounts of the chufa tubers that were subjected to the roasting process, the mineral amounts of the tubers that were subjected to the germination process increased in general. Since potassium, calcium, magnesium, and sodium are water-soluble elements, they reduced the mineral substance content of boiled chufa tubers since they were transferred to water during boiling. Arafat et al.[11] reported that K, Na, and Ca in chufa tubers were the most abundant inorganic components. Among the trace minerals (excluding zinc, copper, and iron), the values in chufa tubers are low and within the recommended limits for nutrition.[11] Özcan et al.[39] determined the mineral content of chufa tubers with ICP-AES. Chufa tubers were found to be rich in some minerals. These are Al (709.1 mg/kg), Ca (739.1 mg/kg), Fe (412.5 mg/kg), K (9821.7 mg/kg), Mg (1190.5 mg/kg), Na (2407.4 mg/kg), and P (3012.6 mg /kg). In a few studies on the effect of germination in legumes, it has been reported that germination can increase protein content, dietary fiber, decrease tannin, and vegetable content and increase mineral substance bioavailability.[40] Germination has also been reported to be associated with increased vitamin concentration and bioavailability of trace elements and minerals.[41] Germination improved calcium, copper, manganese, zinc, riboflavin, niacin, and ascorbic acid content.[42]

Properties of chufa tuber and oils

Moisture, total carotenoid, total phenolic substance, total flavonoid contents, and antioxidant activities determined in control (raw/raw), germinated, roasted, and boiled chufa tuber and oils are given in Table 3. The moisture content of chufa tubers was determined

TABLE 3 Moisture, carotenoid, total phenol, flavonoid contents, and antioxidant activity characteristics of chufa tuber and oils.*

Process	*n*	Nem (%)	*n*	Tuber				Oil			
				Carotenoid (μg/g)	Total phenolic content (mg GAE/100 g)	Total flavonoid (mg CE/100 g)	Antioxidant activity (%)	Carotenoid (μg/g)	Total phenolic content (mg GAE/100 g)	Total flavonoid (mg CE/100 g)	Antioxidant activity (%)
Control (non-processed)	2	46.17 ± 0.11^{b}	3	0.85 ± 0.12^{b}	6.03 ± 0.32^{b}	13.60 ± 2.18^{a}	33.20 ± 1.03^{a}	7024.10 ± 0.00^{a}	1.64 ± 0.82^{b}	4.60 ± 1.00^{c}	24.29 ± 1.79^{a}
Roasting	2	14.49 ± 0.21^{c}	3	0.27 ± 0.14^{c}	6.03 ± 0.43^{b}	17.93 ± 2.52^{a}	39.63 ± 4.63^{a}	4826.90 ± 10.0^{c}	3.56 ± 0,35^{b}	373.10 ± 41.60^{b}	28.05 ± 0.23^{b}
Germination	2	65.70 ± 0.79^{a}	3	1.90 ± 0.10^{a}	6.54 ± 0.13^{b}	4.60 ± 0.50^{b}	39.62 ± 1.05^{a}	7084.10 ± 84.7^{a}	9.44 ± 1.75^{a}	561.10 ± 102.70^{ab}	32.39 ± 1.08^{c}
Boiling	2	45.26 ± 0.21^{b}	3	0.65 ± 0.06^{b}	11.28 ± 0.81^{a}	15.93 ± 2.02^{a}	40.25 ± 2.58^{a}	6090.00 ± 31.6^{b}	2.89 ± 0.42^{b}	755.70 ± 188.60^{a}	31.64 ± 0.28^{c}

*The values indicated with different letters between a and c in the same column were found to be statistically significant ($p < 0.05$).

between 14.49% (roasted) and 65.70% (germinated). According to these values, the moisture content increased with germination and decreased with roasting. Ukpabi and Ukenye[43] determined the moisture content of the tuber as 20.90%. In addition, the same researchers determined the moisture content of the rehydrated chufa tuber as 52.96%. Ogunlade et al.[36] moisture contents of dry, raw, and roasted samples of chufa tubers, respectively; They found 12.27%, 43.84%, and 24.96%. Okorie and Nwanekezi[37] determined the moisture content of raw chufa tubers to be 50.66%, while they determined the moisture content of boiled chufa tubers to be 51.41%. The carotenoid contents of Chufa tubers were determined between 0.27 μg/g (roasting) and 1.90 μg/g (germination). While the carotenoid content was 0.85 μg/g in the control samples, it was found 0.65 μg/g in the boiled chufa tubers. It was observed that the germination process slightly increased the carotenoid dissolution of the chufa, while the roasting process decreased it. Ukpabi and Ukenye[43] reported that the β-carotenoid content of chufa tubers was 9.17 and 2.20 μg/g in rewetted samples. Bado et al.[44] reported that the total phenolic content of boiled samples was determined as 11.28 mg GAE/100 g. The total phenolic content of the germinated samples was determined as 6.54 mg GAE/100 g. It was observed that the roasting process did not cause a difference in the total phenolic content of the chufa tubers. It was observed that the boiling process caused an increase in the total phenolic content of the tuber. Adebayo and Arinola[34] determined the phenol content as 4.01 mg/100 g in raw chufa tubers and 3.98 mg/100 g in germinated tubers. Özcan et al.[33] determined the effect of germination on the bioactive properties, phytochemicals, and mineral contents of chufa tubers and oils. They reported that the total phenol content of chufa tubers varied between 21.54-mg GAE/100 g (raw Yellow Sugar) and 28.79-mg GAE/100 g (Sprouted Yellow Sugar). The total flavonoid content of the control (raw), roasted, germinated, and boiled samples were, respectively, was determined as 13.60, 17.93, 4.60, and 15.93 mg CE/100 g. While roasting and boiling processes did not significantly affect the total flavonoid content in the chufa tuber samples, germination process decreased it significantly. Ijarotimi et al.[9] determined the total flavonoid content of raw and fermented chufa flour between 0.19 (fermented chufa tuber flour for 72 h)-0.35 (raw chufa tuber flour) mg/g.

Antioxidant activity values of chufa tuber samples that have been subjected to control, roasting, germination, and boiling processes are given in Table 4. The difference between the results was found to be statistically significant ($p < 0.05$). The antioxidant activity of the chufa tuber sample in the control group was 33.20%. It was determined that it was 40.25% in boiled chufa tuber samples. While the lowest antioxidant activity was detected in the control sample, the highest value was determined in the boiled sample. Roasting, germinating, and boiling processes increased the antioxidant activity partly compared with the control group. Özcan et al.[33] determined the antioxidant activity as 16.36% in raw chufa tubers, and 15.79% in sprouted chufa tubers. Ijarotimi et al.[9] determined the antioxidant activity in raw and fermented chufa tuber flour between 24.5% (chufa tuber flour fermented for 72 h) and 54.9% (raw chufa tuber flour). Our findings showed partial differences with the results of previous studies. The possible reasons

TABLE 4 Phenolic components of chufa tuber and oil samples treated with different treatments (mg/100 g).*

		Tuber				Oil			
Phenolic compounds	***n***	**Control**	**Roasting**	**Boiling**	**Germination**	**Control**	**Roasting**	**Boiling**	**Germination**
Gallic acid	3	0.42 ± 0.23^{b}	0.25 ± 0.11^{b}	0.36 ± 0.05^{b}	1.09 ± 0.23^{a}	2.07 ± 0.53	2.91 ± 1.25	2.09 ± 1.82	1.69 ± 1.32
3,4-Dihydroxybenzoic acid	3	0.33 ± 0.12	0.30 ± 0.11	0.29 ± 0.04	0.45 ± 0.10	0.74 ± 0.66	2.92 ± 4.24	1.05 ± 1.53	1.07 ± 0.91
(+)-Catechin	3	0.51 ± 0.15	0.40 ± 0.17	0.39 ± 0.09	0.32 ± 0.20	0.58 ± 0.07	0.55 ± 0.17	0.52 ± 0.28	0.62 ± 0.34
Caffeic acid	3	0.04 ± 0.01	0.03 ± 0.03	0.03 ± 0.02	0.02 ± 0.02	0.02 ± 0.01	0.18 ± 0.25	0.08 ± 0.12	0.04 ± 0.03
Syringic acid	3	0.03 ± 0.01	0.03 ± 0.02	0.04 ± 0.02	0.03 ± 0.02	0.04 ± 0.02	0.07 ± 0.03	0.09 ± 0.03	0.06 ± 0.00
Rutin	3	0.82 ± 0.16^{ab}	0.27 ± 0.15^{bc}	1.00 ± 0.40^{a}	0.09 ± 0.02^{c}	0.07 ± 0.15^{c}	0.25 ± 0.14^{a}	0.14 ± 0.05^{bc}	0.21 ± 0.04^{ab}
p-Coumaric acid	3	0.04 ± 0.01	0.02 ± 0.01	0.59 ± 0.97	0.02 ± 0.00	0.02 ± 0.01^{b}	0.26 ± 0.06^{a}	0.19 ± 0.02^{a}	0.02 ± 0.00^{b}
Ferulic acid	3	0.02 ± 0.01^{ab}	0.02 ± 0.00^{ab}	0.04 ± 0.02^{a}	0.02 ± 0.01^{b}	0.04 ± 0.00	0.33 ± 0.49	0.03 ± 0.02	0.05 ± 0.01
Resveratrol	3	0.01 ± 0.01	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.03 ± 0.02	0.03 ± 0.02
Quercetin	3	0.05 ± 0.01	0.06 ± 0.03	0.12 ± 0.11	0.08 ± 0.05	0.14 ± 0.09	0.07 ± 0.04	0.07 ± 0.02	0.06 ± 0.03
Cinnamic acid	3	0.09 ± 0.07	0.01 ± 0.01	0.04 ± 0.03	0.02 ± 0.02	0.02 ± 0.03	0.04 ± 0.02	0.05 ± 0.03	0.04 ± 0.03
Kampferol	3	0.06 ± 0.03	0.06 ± 0.05	0.04 ± 0.04	0.06 ± 0.03	0.80 ± 0.07^{a}	0.35 ± 0.17^{b}	0.39 ± 0.14^{b}	0.45 ± 0.15^{ab}

*The values indicated with different letters between a and c on the same line were found to be statistically significant ($p < 0.05$).

for these differences may be due to the treatments applied to the tubers, the type and amount of solvent used, tuber maturity, harvest time, and some/different analytical conditions. It has been determined that the chufa tuber oils obtained by solvent extraction method with chufa tubers that have undergone control and germination, roasting, and boiling processes; total carotenoid, total phenolic substance, total flavonoid contents, and antioxidant activity data are given in Table 3. The carotenoid contents of the chufa oil samples were determined as 4826.90 μg/g(roasting), 6090.00 μg/g (boiling), 7024.10 μg/g (crude), and 7084.10 μg/g (germination). While boiling and roasting decreased the carotenoid content of the oil samples, germination increased it, although not significantly. Hu et al.[45] determined the β-carotenoid amounts of the samples obtained as a result of the extraction of chufa tuber oil by microwave and Soxhlet method, between 17.15 and 25.43 mg/kg. The total phenol contents of the oils obtained from the chufa tuber with control, germination, roasting, and boiling processes were found to range from 1.64 mg GAE/100 g (crude) to 9.44 mg GAE/100 g (germination). The treatments applied to the chufa tuber increased the total phenol content of the oil. Ezeh et al.[1] reported that chufa tuber oil has a total phenol content of 17.9 mg GAE/kg. Hu et al.[45] determined the total phenol content of the samples obtained as a result of the extraction of chufa tuber oil by microwave and Soxhlet method between 58.37 and 92.53 mg GAE/kg. The flavonoid contents of the chufa tuber oil samples are given in Table 3. The flavonoid contents of the chufa tuber oil samples ranged from 4.60-mg CE/100 g (raw) to 755.70-mg CE/100 g (boiled). Roasting, boiling, and germination processes significantly increased the total flavonoid amounts of chufa tuber oils. Antioxidant activity analysis results were determined between 24.29% (raw) and 32.39% (germination). The treatments applied to the chufa tuber increased the antioxidant activity of the oil. The highest increase was observed in the germinated chufa tuber sample. When the bioactive components and properties of chufa tubers were compared with the literature data, it was observed that there were significant differences. These differences may be due to how the oil is obtained from the tuber, the agricultural characteristics and growth-development conditions of the tuber, the solvents used in the extraction, and the parameters applied to the tuber.

Phenolic component results of chufa tuber

The phenolic component results of control group, germinated, roasted, and boiled chufa tuber and oils are given in Table 4. Rutin, gallic acid, and catechin were the most abundant phenolic compounds in chufa tuber samples. Rutin contents of chufa tubers ranged from 0.27 mg/100 g (roasted) to 1.00 mg/100 g (boiled) in raw, roasted, germinated, and boiled chufa tuber samples. Gallic acid amounts of the samples were determined between 0.25 mg/100 g (roasting) and 1.09 mg/100 g (germination). The catechin content of the chufa tuber samples was determined between 0.32 mg/100 g (germination) and 0.51 mg/100 g (crude). According to the phenolic component determination results, the amount of 3,4-dihydroxybenzoic acid in the

chufa tuber samples was determined between 0.29 mg/100 g (boiling) and 0.45 mg/100 g (germination). The highest amount of *p*-coumaric acid was determined as 0.59 mg/100 g (boiled) in the ground almond tuber samples. The highest amount of cinnamic acid was determined in the raw sample (0.09 mg/100 g) in the chufa tuber samples that were subjected to raw, roasting, germinating, and boiling processes. The highest amount of resveratrol in the chufa tuber samples was determined as 0.02 mg/100 g (roasting and germination). Roasting, germination, and boiling processes applied to the chufa tuber did not have a significant effect on the phenolic component contents. Özcan et al.[33] reported that the most abundant phenolic component in chufa tubers is gallic acid. The phenolic component amounts of tubers showed some differences with the results of previous studies. In addition, there are those that contain values close to each other.

According to the phenolic component analysis results of chufa oil, gallic acid, and 3,4-dihydroxybenzoic acid were the most abundant phenolic components. The gallic acid content of the tubers was determined as 1.69 mg/100 g (germination), 2.07 mg/100 g (raw), 2.09 mg/100 g (boiled), and 2.91 mg/100 g (roasted). The lowest 3,4-dihydroxybenzoic acid contents of the chufa tuber oils were 0.74 mg/100 g (crude) and the highest 2.92 mg/100 g (roasted). In addition, kampferol contents in chufa tuber oils were determined between 0.35 mg/100 g (roasted) and 0.80 mg/100 g. According to the results of the phenolic component content of chufa tuber oil, the lowest catechin content was determined in the boiled samples with 0.52 mg/100 g and the highest in the germinated samples with 0.62 mg/100 g. Caffeic, syringic, *p*-coumaric, ferulic, cinnamic acid, rutin, resveratrol, and quercetin were found to be minor phenolic components. Phenolic components of chufa tuber oils were found to be partially higher than tuber oils. Differences in phenolic component results could possibly be due to tuber treatments, climatic factors, harvest time, solvent used, type and duration of extraction, and the treatments applied to the tuber.

Free fatty acidity and peroxide value and tocopherol profiles of ground almond oil

The results of free fatty acidity and peroxide numbers of chufa oils obtained by solvent extraction method are given in Table 5. While the free acidity value in the oil obtained from the raw chufa tuber was 1.40%, the amount of free acidity in the oil was determined as 1.34% as a result of the germination process applied to the chufa tuber. It was found to be 0.39% in the sample with the boiling process and 0.56% in the sample with the roasting process. Roasting and boiling processes increased the free acidity of chufa tuber oil. Germination process did not significantly ($p < 0.05$) affect the amount of free acidity in chufa tuber oil. Adel et al.[38] found the amount of free acidity in the oil of chufa tuber, which were subjected to soaking, boiling, and roasting, between 3.64% oleic acid and 5.42% oleic acid. Warra[46] determined the free acid content of chufa tuber to be between 72.67% (yellow) and 77.00% (brown) oleic acid. Muhammad et al.[47] reported that the oil acidity of chufa tuber was 0.45 mg/g. Arafat et al.[11] determined that the amount of free acid in chufa tuber oil was 0.80% oleic acid.

The peroxide numbers of chufa tuber oils obtained by solvent extraction method from the control and germination, roasting, and boiling processes were found between 3.00 meq O_2/kg (germination) and 4.50 meq O_2/kg (raw). While the peroxide number was determined as 3.50 meq O_2/kg in the boiled sample, it was determined as 4.00 meq O_2/kg in the roasted sample. Statistically significant differences were observed between the peroxide numbers of the samples ($p < 0.05$). Adel et al.[38] found the peroxide number of chufa tuber oils to be between 0.79 (raw) and 1.52 (wetted) meqO_2/kg, in which they applied different treatments. Warra[46] found the peroxide number of chufa tubers between 3.80 (brown) and 4.10 (yellow) meq H_2O_2 has detected. Muhammad et al.[47] reported that the peroxide number of chufa tuber oil was 3.69 mEq/kg. Arafat et al.[11] determined that the peroxide number of chufa tuber oil is 0.30 Meq.O_2/kg. Considering the results, the amount of free acidity was found to be quite low compared with the literature findings, and the peroxide number was found to be similar. This difference in free fatty acid amounts, probably due to the fact that the tubers were excessively moist in obtaining the oil, causing hydrolyzation of the oil.

According to the tocopherol results of chufa oil given in Table 5, α-tocopherol, β-tocopherol, and γ-tocopherol were detected in chufa oil samples. The α-Tocopherol content of the oil samples was between 8.91 mg/kg (boiled), 9.07 mg/kg (roasted), and 9.64 mg/kg (germination), while the β-tocopherol contents were 2.27 mg/kg (crude) and 2.30 mg/kg (roasted) were determined between γ-tocopherol contents of ground almond tuber oils in roasted, raw, boiled, and germinated samples, respectively. It was determined as 2.03, 2.04, 2.37,

TABLE 5 Free acidity*, peroxide numbers*, and tocopherol contents of chufa oil (mg/kg)**.

Process	*n*	Free fatty acidity (%)	Peroxide value (meq O_2/kg yağ)	*n*	α-Tocopherol	β-Tocopherol	γ-Tocopherol	δ-Tocopherol
Control	2	1.40 ± 0.08[a]	4.50 ± 0.71	3	-***	2.27 ± 0.01	2.04 ± 0.00	-
Roasting	2	0.56 ± 0.00[b]	4.00 ± 0.00	3	9.07 ± 0.16	2.30 ± 0.00	2.03 ± 0.09	-
Germination	2	1.34 ± 0.00[a]	3.00 ± 0.00	3	9.64 ± 0.18	-	2.38 ± 0.00	-
Boiling	2	0.39 ± 0.08[b]	3.50 ± 0.71	3	8.91 ± 0.04	-	2.37 ± 0.01	-

*The values indicated with different letters between a and b in the same column were found to be statistically significant ($p < 0.05$).
**Values stated in the same column were not found to be statistically significant ($p > 0.05$).

and 2.38 mg/kg. According to the results obtained, δ-tocopherol could not be detected in the chufa tuber oil samples. Wayah and Shehu[32] determined the vitamin E content of chufa tuber to be 5.39 mg/L. Ezeh et al.[1] determined the α-tocopherol content of chufa tuber oils as 145.7 μg/g. Yeboah et al.[48] determined α-tocopherol as 86.73 μg/g and β-tocopherol as 33.37 μg/g in chufa tuber oils, but γ-tocopherol and δ-tocopherol could not be detected. Roselló-Soto et al.[49] determined the α-tocopherol contents of chufa tubers from different countries between 4.6 and 86.73 μg/g. While El-Naggar[50] determined the tocopherol contents of chufa tuber oils as α-tocopherol 16.1 mg/100 g, γ-tocopherol 50 mg/100 g, and δ-tocopherol 31.3 mg/100 g, β-tocopherol could not be detected. The result obtained showed similarities on the basis of components and showed differences with the literature in terms of qualitative values. These differences may possibly be due to the variety, growing conditions, climatic factors, harvest time, amount of unsaponifiable matter, treatments applied, and solvents used.

Fatty acid composition of chufa tuber oil

Fatty acid compositions of chufa tuber oils obtained by solvent extraction method from chufa tubers in the control group, germination, roasting, and boiling processes are given in Table 6. Saturated fatty acids (palmitic, stearic, and arachidic), mono and poly unsaturated fatty acids were determined in chufa tuber oils. Chufa oil has a high level of unsaturated fatty acids. Oleic acid is the most abundant fatty acid in chufa tuber oils with 70.95% (germination), 73.00% (boiling), 73.05% (crude), and 73.47% (roasting). Palmitic acid, the most abundant fatty acid after oleic acid in chufa tuber oils, was determined as 12.64% (scalding), 12.87% (roasting), 12.93% (crude), and 13.39% (germination). Linoleic acid was found to be 10.53% (roasting), 10.69% (crude), 11.20% (boiling), and 12.03% (germination) in chufa tuber oils. According to the results of the analysis, it was determined that the stearic acid content was between 2.64% (roasting) and 2.70% (germination). According to the results of the analysis of chufa tuber oil, arachidic acid contents of chufa oil varied between 0.49% (roasting, boiling) and 0.54% (germination). While the linolenic acid contents of oil samples were determined in the oil of 0.12% raw tubers and 0.39% germinated tubers, it could not be determined in roasted and boiled chufa tuber oil. Adel et al.[38] carried out a study on the physicochemical, compositional, and structural properties of seed oils obtained from chufa tubers grown in Egypt. The same researchers determined 15.19% palmitic, 5.07% stearic, 69.25% oleic, 8.37% linoleic, 0.19% linolenic acids in crude chufa tuber oil. Oderinde and Tairu[51] found the presence of palmitic acid 10.21%, linoleic acid 11.64%, stearic acid 1.47%, linolenic acid 0.64%, and arachidic acid 0.32% in chufa tuber oils. Linssen et al.[14] found palmitic acid 13.4%–14.1%, linoleic acid 8.7%–9.1%, stearic acid 3.0%–3.3%, linolenic acid 0.4%, and arachidic acid 0.2%–0.5% in chufa tuber oils. Muhammad et al.[47] found that linoleic acid 11.8%, palmitic acid 10.4%, arachidic acid 6.1% linolenic acid 0.6% and stearic acid 0.3% in chufa tuber oils. Arafat et al.[11] reported that chufa tuber oil contains 14.5% palmitic, 1.5% palmitoleic, 3.40% stearic, 69.50% oleic, 8.80% linoleic, and 0.40% linolenic acids. In another study, it was reported that chufa tuber oil contains 10.21%–14.1% palmitic, 1.47%–3.3% stearic, 74.70%–75.72% oleic, 8.7%–11.64% linoleic, and 0.4%–0.64% linolenic acid.[51,52] Oleic acid is the main fatty acid in chufa tuber oil.[11] Yoon[53] reported that the oleic acid contents of chufa tuber oils varied between 64.4% and 66.1%. In a study conducted in Egypt, it was reported that chufa tuber oil contains 1.7% myristic, 15.4% palmitic, 5.3% stearic, 6.1% behenic, 65.8% oleic, 5.5% linoleic, and 0.2% linolenic acid.[50] Özcan et al.[33] have determined 71.36% (crude Beeswax)-73.58% (sprouted Beeswax) oleic acid, 11.42% (raw Beeswax)-12.26% (sprouted Yellow Sugar) palmitic acid, and 10.24% (crude Yellow Sugar)-11.75% (sprouted Honey tuber) linoleic acid in chufa tuber oils. When our results were compared with the literature findings, some differences were observed. However, it was observed that the dominant fatty acids were the same, and their amounts were partially different. This difference may be due to the variety, genetic structure, temperature demand during the growing period, and harvest time.

CONCLUSION

In this study, the effects of germination, boiling, and roasting processes applied to chufa tubers on their bioactive properties, tocopherol, and phenolic compounds were determined. Compared with the raw/control group sample of roasted chufa tuber, moisture, total carotenoid contents decreased, while total flavonoid and antioxidant activities increased. Germination process, determined moisture, total carotenoid, total phenolic content, and antioxidant activities increased compared with control samples, while total flavonoid content decreased. While the total phenolic substance, total flavonoid

TABLE 6 Fatty acid composition of ground almond oils (%).

Process	*n*	Palmitic	Stearic	Oleic	Linoleic	Arachidic	Linolenic
Control	2	12.93 ± 0.26^{ab}	2.68 ± 0.04	73.05 ± 0.32^{a}	10.69 ± 0.07^{c}	0.53 ± 0.01^{a}	0.12 ± 0.17^{ab}
Roasting	2	12.87 ± 0.02^{ab}	2.64 ± 0.00	73.47 ± 0.02^{a}	10.53 ± 0.00^{d}	0.49 ± 0.00^{b}	-**
Germination	2	13.39 ± 0.21^{a}	2.70 ± 0.02	70.95 ± 0.21^{b}	12.03 ± 0.02^{a}	0.54 ± 0.01^{a}	0.39 ± 0.00^{a}
Boiling	2	12.64 ± 0.03^{b}	2.67 ± 0.00	73.00 ± 0.05^{a}	11.20 ± 0.01^{b}	0.49 ± 0.00^{b}	-

Note: *The values indicated with different letters between a and d in the same column were found to be statistically significant ($p < 0.05$). **-: Not detected. *** TE: Not detected.

content, and antioxidant activities of the boiled samples increased compared with the data of the raw sample, the total carotenoid content decreased. Roasting applied to the chufa tuber reduced free acidity, peroxide number, and carotenoid content in tuber oil. Total phenol increased flavonoid content and antioxidant activity. When the fatty acid composition is examined, fatty acid contents showed a partial decrease compared with raw chufa tubers. It did not cause a significant difference in phenolic component and tocopherol content. The germination process did not show any change in free acidity and carotenoid content in chufa oil. While the number of peroxides decreased, total phenol, flavonoid, and antioxidant activities increased. The results of phenolic component content, fatty acid profile, and tocopherol content increased, although not at a significant level. Free acidity, peroxide number, and carotenoid content decreased according to the results obtained from chufa tuber oil which was boiled. Total phenol, flavonoid content, and antioxidant activity increased. Phenolic component content, fatty acid composition, and tocopherol content results showed fluctuations. As a result, bioactive properties, tocopherol, fatty acids, and phenolic components of germinated, boiled, and roasted chufa tuber samples showed statistically significant differences compared with raw chufa tuber. During germination, some components in the tuber are released and improve the taste and aroma of the food. It is also thought to cause a relative increase in some nutritional components in the tuber. The health benefits of chufa tubers have been known for a long time as they are rich in protein and minerals such as phosphorus, potassium, calcium, and magnesium. According to the results of the study, the germination process applied to the chufa tuber increased the protein and macro mineral content. Chufa tuber oil contains highly unsaturated fatty acids, vitamin E, and phenolic compounds. The germination process applied to the chufa tuber increased the content of unsaturated fatty acids and tocopherol. Due to its nutritional quality, chufa oil is recommended for consumption and industrial use.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing financial interests.

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Research data are not shared.

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