Optimization of the Refining Process and Oxidative Stability of Chufa (*Cyperus esculentus* L.) Oil for Edible Purposes

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Abstract Process conditions of alkali refining, bleaching, and deodorization of crude chufa oil extracted from chufa (*Cyperus esculentus* L.) tubers grown in Korea were optimized to obtain an edible grade vegetable oil. The overall scope of refining conditions was similar to other vegetable oils. The degumming process, however, could be omitted since phospholipids were removed during alkali-refining and bleaching processes. RBD (alkali-refined, bleached, and deodorized) chufa oil fully satisfied Korean quality standards for edible vegetable oil. Chufa oil contained a high level of oleic acid, along with palmitic acid and linoleic acid. Physicochemical properties of chufa oil were similar to olive oil. The order of oxidative stability of chufa oil was crude > deodorized > degummed > refined > bleached oil. RBD chufa oil was virtually colorless and bland tasting, and was considered suitable for edible purposes.

Keywords: chufa oil, refining process, fatty acid composition, tocopherol, oxidative stability

Introduction

Chufa (*Cyperus esculentus* L.) is a sedge-like edible perennial grass-like plant also known as tiger nut, earth almond, earth nut, nut grass, rush nut, edible galingale, and yellow nut sedge (1). Chufa was originally a weed plant growing in tropical and Mediterranean regions; and people in several countries in those regions have traditionally taken chufa roots as food stuffs for edible oil and carbohydrate sources (2,3). It is well known that dried chufa tuber contains 17–25% (w/w) total lipids, and major fatty acid was oleic acid (4,5). Chufa oil contains palmitic acid as the main saturated acid, and oleic acid as the dominant unsaturated acid. The major fatty acid of non-polar and polar lipids of chufa oil is oleic acid (6).

Crude oil extracted from chufa tubers must be refined to obtain edible grade refined, bleached, and deodorized (RBD) chufa oil, and RBD chufa oil should meet specifications for ordinary edible vegetable oils to be used as commercial products (7). The physical and chemical characteristics of agricultural products varied with the changes of the growing conditions such as cultivation place and environments even in a same species, and crude lipids obtained from different sources are subject to different refining process to produce edible grade fats and oil due to the differences in physical and chemical properties (7). The self-sufficiency rate of edible fats and oils in Korea was less than 3% recently, since the cultivation area of oil crops have been continuously limited (8). There have been many trials to find out novel resources for edible purpose to replace the imported fats and

oils in part. In this study, the refining conditions of crude chufa oil were optimized to obtain an edible grade refined, bleached, and deodorized (RBD) chufa oil.

Materials and Methods

Materials Chufa tubers were washed with running tap water several times to remove soil and impurities, and dried at 65°C for 24 h in an forced air-dried drying oven (Model No. 51028141; Heratherm general protocol oven, Thermo Scientific, Waltham, MA, USA) to a moisture content of 20% measured by oven drying gravimetry. A large quantity of crude chufa oil was extracted using the immersion shaking method with hexane as an extraction solvent (9). Dried chufa tubers were ground using a hammer mill (Hammer Mill 5.5 KW; Hanil Machinery, Seoul, Korea) to pass through a No. 30 sieve (Tyler sieve 28 mesh) with a 0.595 mm opening. Hexane was added to 2 kg of ground chufa powder (4:1, v:w) in a flask with continuous vigorous stirring at 60°C under reflux for 1 h. After filtration of micelle using duck cloth and filter paper (No. 42; ashless, Whatman International Co., Ltd., Kent, UK), crude chufa oil was obtained after removal of the solvent using a rotary evaporator (Rotavapor R-215; BÜCHI Labortechnik AG, Flawil, Switzerland). Crude chufa oil was subject to a refining process, including degumming, alkali refining, bleaching, and deodorization as described below. Chufa oil obtained after each refining step were

transferred to opaque polyethylene bottles with nitrogen flushing, and stored in the dark at 4°C. All reagents used were of analytical grade unless otherwise specified.

Oil refining process Crude chufa oil was refined following refining methods for soybean, rice bran, and camellia oils after modification of refining conditions (7,10,11).

Degumming process: For degumming, 1.5 kg of crude chufa oil was poured into a four necked, round-bottomed flask equipped with a thermometer and an impeller type stirrer. Nitrogen was purged into the oil continuously through sintered glass sparger during the degumming process. Water and 85% phosphoric acid were added as degumming agents to oil at a level of 0-3%. Degumming of crude oil was carried out at 70°C with continuous slow agitation using impeller type stirrer. After 15 min of agitation, gums were separated from oils using centrifugation (CL 10; Thermo Scientific) at 10,000×*g* for 10 min. Degummed oil was then water-washed at 80°C with slow agitation, and centrifuged at 10,000×*g* for 10 min to obtain degummed and water-washed camellia oil.

Alkaline refining process: For alkali refining, 1 kg of degummed oil was poured into a 4 necked, round-bottomed flask fitted with a thermometer and a magnetic stirrer (PC 353; Corning, Corning, NY, USA). Oil was heated to 75°C using heating mantle (0414; Glas-Col LLC, Terre Haute, IN, USA) under a nitrogen atmosphere, then 0.1% alkali solutions (10-18° Baume NaOH solutions) were added to 0.5% of the excess level. This is a unique and widely used expression in alkali refining process with continuous heating and stirring for 20 min using a magnetic stirrer (PC 353; Corning). The mixture was cooled to ambient room temperature without agitation, then centrifuged at 10,000×*g* for 10 min to remove soap stocks. Alkali-refined oil was washed with hot distilled water at 70°C 3 times to remove residual soap. Water-washed oil was dried at 90°C under a vacuum for 30 min, then allowed to cooled to 30°C in the ambient room temperature. Cooled oil was stored with nitrogen flushing for further processing and analysis.

Bleaching process: Bleaching of alkali-refined oil was conducted using 0.4-2% activated clay (Waco Chemical, Tokyo, Japan). A slurry was heated to 90°C under a vacuum of 75±25 mmHg with vigorous agitation using impeller type stirrer for 40 min. Bleached oil was cooled to 30°C with nitrogen flushing, followed by centrifugation to remove bleaching clay using centrifuge at 10,000×*g* for 10 min. Supernatant oil was then filtered through Whatman No. 42 filter paper using a tap-water aspirator.

Deodorization process: Bleached oil was deodorized in a laboratory scale deodorizer at 140-200°C for 60 min in a 3-necked, round-bottomed flask equipped with a thermometer, a microburet, and condensing traps connected to a vacuum pump. The thermometer and microburet were extended to the bottom of the flask. One L of bleached oil was placed in the flask and heated to desired temperatures under a reduced pressure of 0.3 mmHg. One % (w/w) of steam to oil was supplied directly through a sintered glass sparger.

After deodorization, oil was cooled to 100°C with nitrogen flushing to break the vacuum, and stored at 4°C in a refrigerator for further analysis.

Analytical methods The extraction yield of crude lipids was determined using the Soxhlet method with hexane as an extraction solvent (10). The phosphorus content, acid value, refractive index, iodine value, saponification value, and peroxide value were determined using the American Oil Chemists' Society (AOCS) methods Ca 12-55, Cd 3a-63, Tp 1a-64, Cd 1-25, Cd 3-25, and Cd 8-53, respectively (12). The oil color was measured using a Lovibond Tintometer (Model E; Lovibond Tintometer, Sarasota, FL, USA) with a 5 1/4 inch cell (11). GC (Model 5890; Hewlett-Packard, Anaheim, CA, USA) was used to determine fatty acid compositions of chufa oils following AOCS method Ce 2-66 (12). The GC column used for fatty acid analysis was a Supelcowax-10 capillary column (300.2 mm i.d., 0.2 μm film thickness) (Supelco, St. Louis, MO, USA) under conditions of an initial temperature of 175°C, a temperature increase rate of 3°C/min to a final temperature of 240°C, and a final holding time of 15 min. The temperatures of the injector and FID were 260°C and 270°C, respectively. The flow rate of the helium carrier gas was 25 mL/min, and samples were injected in split mode with a split ratio of 50:1.

Tocopherol contents in chufa oils were determined using HPLC (13). Oils were dissolved in 5 mL of n-hexane and filtered through a 0.2 μm PTFE membrane (Millipore, Molsheim, France). The filtrate (20 μL) was injected into an Alliance HPLC system (Waters, Milford, MA, USA). A μ-porasil column (330×3.9 mm, 10 μm size) (Waters) and a fluorescence detector with an excitation wavelength of 290 nm and emission wavelength of 330 nm were used. The mobile phase was 0.2% (v/v) isopropanol in n-hexane at a flow rate of 2 mL/min. Each tocopherol was identified based on comparison of retention times with standard tocopherols, and was quantified using respective calibration curves which were obtained from experiments. All analytical data reported were average values of triplicates.

Induction periods of chufa oils were measured using the Rancimat method at 95°C (14). A Metrohm Rancimat Model 743 (Metrohm, Herisau, Switzerland) was used with a stream of air (20 L/h) bubbled into 3 g of oil samples in a reaction vessel placed in an electric heating block. Effluent air containing volatile organic acids from oils was collected in a measuring vessel containing 60 mL of distilled water and the conductivity of the water as oxidation proceeded was measured automatically.

Statistical analysis All experimental values were expressed as average values of triplicate determinations and standard deviation (SD) values were less than ±3% unless otherwise specified (*n*=3). SD values were not provided when the SD was less than ±3%. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA) to ascertain significant differences between treatments. Significance was defined as *p*<0.05.

Results and Discussion

General characteristics of chufa oil The extraction yield of crude lipids from chufa tubers using a Soxhlet apparatus with hexane was $19.96 \pm 0.58\%$. The extraction yield in a large quantity using the immersion-shaking method with hexane was $17.56 \pm 0.53\%$, which was approximately 88% of the extraction yield using the analytical Soxhlet method. Physicochemical properties and fatty acid compositions of chufa oils are given in Table 1. The iodine value of chufa oil of 82.48 ± 2.37 g of $I_2/100$ g was higher than typical values for olive oil of 75.1 ± 0.5 g of $I_2/100$ g, whereas the saponification value of chufa oil of 191.83 ± 3.57 mg of KOH/g was similar to olive oil 190.3 ± 10.0 mg KOH/g. The refractive index and Lovibond color were similar to soybean and camellia vegetable oils (7,11). The phosphorus content of crude chufa oil was 20.0 ± 0.5 ppm, which was lower than for soybean and camellia oils (7,11). The tocopherol content was 970 ± 19.8 ppm, which was lower than for soybean oil (11). The fatty acid composition of chufa oil was similar to olive oil (2). Total lipids consisted of oleic acid ($65.8 \pm 1.79\%$), palmitic acid ($15.4 \pm 0.46\%$), and linoleic acid ($15.0 \pm 0.44\%$) as major fatty acids, and palmitoleic, stearic, linolenic, arachidic, eicosenoic, and behenic acids as minor fatty acids (0.1 – 0.6%).

Degumming process Crude chufa oil was degummed by water and 85% phosphoric acid. The initial phosphorus content of crude chufa oil was 20ppm, and decreased to less than 1ppm after degumming (Table 2). As the addition amount of water and phosphoric acid increased, the residual phosphorus contents decreased gradually ($p < 0.05$) (Table 2). No significant ($p > 0.05$) difference; however, was found when the amount of added water was higher than 1%, compared with controls. As a result of degumming process, addition of 1.5% water or 0.5% phosphoric acid significantly reduced the residual phosphorus contents below 0.1 ppm ($p < 0.05$).

Phospholipids in oils are hydrated by water or acid. The swollen phospholipids by water and acid were removed by centrifugation (15,16). In degumming of chufa oil, addition of 1.5% water or 0.5% of 85% phosphoric acid were considered as optimum level for suitable degumming. A water level of 1 or 85% phosphoric acid at 0.2% could be used for degumming. It was reported; however, that besides the degumming process, alkali refining, bleaching, and deodorization processes also decreased residual phospholipid contents of degummed oils. The original phospholipid content of crude chufa oil of 20.0 ± 0.6 ppm was lower than for other vegetable oils (11). Therefore, a separate degumming process was not necessary for chufa oil. The residual phosphorus content of chufa oil after the refining process was lower than 1 ppm, which was considered suitable for edible grade oil.

Alkali refining process The purpose of alkali refining is removal of free fatty acids from oils. Key factors in alkali refining are the concentration of a Baume (Bé) caustic, the amount of caustic added,

Table 1. Physicochemical properties of crude chufa oil¹⁾

Item	Value
Acid value (mg KOH/g)	4.11
Peroxide value (meq/Kg)	1.33
Iodine value (g $I_2/100$ g)	82.48
Saponification value (mg KOH/g)	191.83
Refractive index (20)	1.4643
Lovibond color Red	1.5
Yellow	24.4
Blue	0.1
Phosphorus (ppm)	20
Tocopherols (ppm)	970
Fatty acid composition (% area)	
C16:0	15.4
C16:1	0.1
C18:0	2.2
C18:1	65.8
C18:2	15.0
C18:3	0.4
C20:0	0.6
C20:1	0.3
C22:0	0.2

¹⁾Values are an average of triplicate determinations, and SD values were less than $\pm 3\%$ unless otherwise specified ($n=3$).

Table 2. Effects of added amounts of water and 85% phosphoric acid on residual phosphorus contents of degummed chufa oil¹⁾

Amount added (%, w/w)	Residual phosphorus (ppm) ²⁾	
	Water	85% Phosphoric acid
Crude chufa oil	20 ^e	20 ^c
0.1	5 ^d	2 ^b
0.2	3 ^c	1 ^a
0.5	2 ^b	< 1 ^a
1	1 ^a	< 1 ^a
1.5	< 1 ^a	< 1 ^a
2	< 1 ^a	< 1 ^a

¹⁾Values are an average of triplicate determinations, and SD values were less than $\pm 3\%$ unless otherwise specified ($n=3$).

²⁾Values with the same superscripts in same column are not significantly different at $p < 0.05$.

effective contact between the caustic and the oil for a controllable time, and heating of mixtures prior to centrifugation (17). The free fatty acid content of chufa oil was $2.05 \pm 0.06\%$ because the acid value of the chufa oil was 4.11 ± 0.12 mg of KOH/g (Table 1). Therefore, 10–20° Bé NaOH solutions with an excess of 0.1–0.5% were used to determine the optimal NaOH concentration.

Effects of the NaOH concentration and the excess level on the refining process at 75°C for 20 min are shown in Table 3. The concentration of NaOH used for alkali refining reached an optimum at 12° Bé NaOH with an excess level of 0.5% based on the acid value of refined oil, which increased again at a concentration higher than 12° Bé NaOH solution. To determine the optimum temperature, the refining process was performed using treatment with 12° Bé NaOH solutions for 20 min (Fig. 1A). The acid value decreased with an

Table 3. Effects of the NaOH concentration and excess level on degummed chufa oil¹⁾

NaOH		Acid value (mg KOH/g)	Lovibond color ²⁾		
Concentration (%)	Excess level (%)		R	Y	B
0		4.11	1.5	24.4	0.1
10	0.1	1.88	1.3	20.1	0
	0.3	0.17	1.0	15.4	0
	0.5	0.15	1.0	15.2	0
12	0.1	1.11	1.2	17.2	0
	0.3	0.18	1.1	14.4	0
	0.5	0.15	1.0	14.2	0
14	0.1	1.67	1.2	18.2	0
	0.3	0.19	1.1	15.3	0
	0.5	0.16	1.0	15.2	0
16	0.1	1.47	1.2	20.5	0
	0.3	0.18	1.0	14.3	0
	0.5	0.18	1.0	14.6	0
18	0.1	0.93	1.2	20.5	0
	0.3	0.18	1.0	14.4	0
	0.5	0.18	1.0	14.3	0

¹⁾Values are reported as an average of triplicate determinations, and SD values were less than $\pm 3\%$ unless otherwise specified ($n=3$).

²⁾R, Red; Y, Yellow; B, Blue

increasing temperature up to 75°C, and increased again at temperatures higher than 75°C. To determine the optimum time, the refining process was performed using treatment with 12° Bé NaOH solutions at 75°C (Fig. 1B). The acid value decreased with an increasing time up to 20 min, and increased again after more than 20 min of treatment. Optimum conditions for the alkali refining process of degummed chufa oil were a 12° Bé NaOH solution with a 0.5% excess level at 75°C for 20 min.

Bleaching process Activated clay showed a substantial effects on decolorization of degummed chufa oil (Table 4). The Lovibond red color unit of degummed chufa oil decreased from 1.0 to 0.1 with addition of 0.8% acid clay, and yellow color unit decreased from 14.2 to 1.3 with same amount of acid clay ($p<0.05$). Acid value decreased from 0.15 to 0.13 ($p<0.05$), while peroxide value increased from 3.57 to 4.35 ($p<0.05$). With 1.2% of acid clay, acid value decreased from 1.3 to 1.1. Effects of bleaching temperature on decolorization was shown in Table 5. The red and yellow unit did not decrease further at higher than 90°C, and acid value were constant at higher than 85°C. Even though peroxide value decreased more at 95°C, color and acid value were not changed. Optimum bleaching temperature was, therefore, determined at 90°C. Bleaching time affected the decolorization of degummed chufa oil (Table 6). The red and yellow color unit of chufa oil decreased to 0.1 and 1.3, respectively, and remained constant thereafter, as well as acid value remained at 0.11. The optimum conditions of degumming of chufa oil were as determined as 1.2% acid clay, 90°C bleaching temperature, and 30 min bleaching time.

Fig. 1. Effect of alkali-refining temperature on acid value of degummed chufa oil for 20 min (A), and of alkali-refining time on acid value of degummed chufa oil at 75 (B). Values are reported as an average of triplicate determinations, and SD values are less than $\pm 3\%$ unless otherwise specified ($n=3$).

Deodorization process During deodorization process of fats and oils, off-flavor materials are stripped off by steam injection as well as free fatty acids, tocopherols, and sterols (18,19). The efficiency of deodorization is affected by deodorization temperature, time, strength of vacuum, and amount of steam injected (7). For deodorization of common vegetable oils, deodorization conditions of the vacuum strength of 1 mmHg or below, 1% steam injection, and 1 h deodorization time were widely used (7,19). The colors were not changed with the increase of deodorization temperature (Table 7). Acid value decreased from 0.11 to 0.01 at 180°C ($p<0.05$), whereas peroxide value decreased from 4.34 to 0.09 ($p<0.05$) (Table 6 and 7). Peroxide values at 180 and 200°C were not significantly different ($p>0.05$). The optimum temperature for chufa oil deodorization was, therefore, determined as 180°C.

Characterization of crude and refined chufa oils The physico-chemical properties of chufat oils at different refining steps are summarized in Table 8. After the whole refining process, the characterization of final deodorized oil was suited within the specification of other edible RBD vegetable oils with respect to acid value, peroxide value, phosphorus content, and Lovibond color (10,11). Fatty acid composition of oils at different refining steps were not significantly different ($p>0.05$).

The total tocopherol content in crude chufa oil was 970 ± 25 ppm, and the refining process removed approximately 9.8% of tocopherols from crude chufa oil (Table 8). The tocopherol content in chufa oil

Table 4. Effects of activated clay amounts on chufa oil for 30 min under nitrogen at 90°C¹⁾

Amount (%,w/w)	Acid value (mg KOH/g) ²⁾	Peroxide value (meq/Kg) ²⁾	Lovibond color ³⁾		
			R	Y	B
0	0.15 ^d	3.57 ^a	1.0	14.2	0
0.4	0.14 ^{cd}	4.51 ^e	0.5	10.3	0
0.8	0.13 ^c	4.35 ^{de}	0.1	1.3	0
1.2	0.11 ^b	4.34 ^{de}	0.1	1.3	0
1.6	0.11 ^b	4.25 ^d	0.1	1.2	0
2.0	0.07 ^a	4.12 ^c	0.1	1.2	0
2.4	0.07 ^a	4.02 ^b	0.1	1.3	0

¹⁾Values are reported as an average of triplicate determinations, and SD values were less than ±3% unless otherwise specified (n=3).

²⁾Values with the same superscripts in the same column are not significantly different at $p<0.05$.

³⁾R, Red; Y, Yellow; B, Blue

Table 5. Effects of bleaching temperature on chufa oil with 1.2% activated clay for 30 min under nitrogen¹⁾

Temperature (°C)	Acid value (mg KOH/g) ²⁾	Peroxide value (meq/Kg) ²⁾	Lovibond color ³⁾		
			R	Y	B
80	0.14 ^b	4.32 ^b	0.3	1.5	0
85	0.11 ^a	4.33 ^b	0.2	1.4	0
90	0.11 ^a	4.34 ^b	0.1	1.3	0
95	0.11 ^a	4.08 ^a	0.1	1.3	0

¹⁾Values are an average of triplicate determinations, and SD values were less than ±3% unless otherwise specified (n=3).

²⁾Values with the same superscripts in the same column are not significantly different at $p<0.05$.

³⁾R, Red; Y, Yellow; B, Blue

was lower than for soybean oil (1,670 ppm) and rice bran oil (6,500 ppm), and it has been reported that substantial amounts of tocopherols in crude soybean oil and crude rice bran oil were removed during oil processing (10,11). Deodorization was mainly responsible for decreasing the tocopherol content in oil during processing (Table 8).

Compositions of tocopherols in chufa oil at different processing steps are shown in Table 8. Even though the total tocopherol content decreased as the refining process proceeded, compositions of tocopherols in chufa oils were not significantly ($p>0.05$) changed during processing, compared with controls. Alpha-, γ -, and δ -tocopherols were major components, whereas α -tocopherol was not found. Compositions of α -, γ -, and δ -tocopherols in deodorized chufa oil were 42.4±1.27, 28.6±0.85, and 29.0±0.86%, respectively. Free fatty acid compositions of oils at different refining steps were not significantly different ($p>0.05$).

Oxidative stability of chufa oil The oxidative stability of chufa oils at different refining steps is shown in Table 8. The oxidative stability was expressed as the induction period (IP). The IP value was directly related to oxidation of chufa oil because oxygen reacts with oils to

Table 6. Effect of bleaching time on chufa oil with 1.2% activated clay at 90°C under nitrogen¹⁾

Time (min)	Acid value (mg KOH/g) ²⁾	Peroxide value (meq/Kg) ²⁾	Lovibond color ³⁾		
			R	Y	B
10	0.15 ^b	4.66 ^c	0.3	3.4	0
15	0.15 ^b	4.51 ^b	0.2	2.1	0
20	0.15 ^b	4.19 ^a	0.1	1.7	0
25	0.15 ^b	4.27 ^{ab}	0.1	1.5	0
30	0.11 ^a	4.34 ^b	0.1	1.3	0
35	0.11 ^a	4.34 ^b	0.1	1.3	0
40	0.11 ^a	4.12 ^a	0.1	1.3	0

¹⁾Values are an average of triplicate determinations, and SD values were less than ±3% unless otherwise specified (n=3).

²⁾Values with the same superscripts in the same column are not significantly different at $p<0.05$.

³⁾R, Red; Y, Yellow; B, Blue

Table 7. Effect of the deodorizing temperature on chufa oil under a 0.3 mmHg vacuum and a 1% steam for 1 h¹⁾

Temperature (°C)	Acid value (mg KOH/g) ²⁾	Peroxide value (meq/Kg) ²⁾	Lovibond color ³⁾		
			R	Y	B
140	0.05 ^c	1.98 ^c	0.1	1.3	0
160	0.03 ^b	0.45 ^b	0.1	1.3	0
180	0.01 ^a	0.09 ^a	0.1	1.3	0
200	0.01 ^a	0.07 ^a	0.1	1.3	0

¹⁾Values are average of triplicate determinations, and SD values were less than ±3% unless otherwise specified (n=3).

²⁾Values with the same superscripts in the same column are not significantly different at $p<0.05$.

³⁾R, Red; Y, Yellow; B, Blue

produce peroxy radicals and hydroperoxides that form volatile polar compounds (20). IP values, starting with crude oil, decreased from 60.5±1.5 to 9.5±0.5 h throughout the refining process. The IP value of deodorized oil; however, increased to 50.0±1.2 h. The order of oxidative stability of oils was crude>deodorized>degummed>alkali-refined>bleached oil. It was reported that the IP value of olive oil was 6-11 h at 120°C (21), and the IP value of soybean oil at 60°C was 4 days (20). The excellent oxidative stability of chufa oil was due to high contents of oleic acid and intrinsic tocopherols, which have been also reported for olive oil (22). It was reported that vegetable oils subjected to refining process were less stable than crude oils (10,11). Crude chufa oil was the most resistant oil to oxidation while degummed, alkali-refined, bleached, and/or deodorized chufa oils were less resistant due to low degrees of oxidative stability.

The appearance of RBD chufa oil was shown to be very similar to that other commercial RBD vegetable oils, and to have no off-flavor. The physicochemical properties of RBD chufa oil meets the specification of common vegetable salad and cooking oils in Food Codex of Korea. Therefore, RBD chufa oil can be used for edible purposes with a high degree of oxidative stability.

Table 8. Characteristics of chufa oils at different refining steps^{1,2)}

Item	Crude oil	Degummed oil	Alkali-refined oil	Bleached oil	Deodorized oil
Acid value (mg of KOH/g)	4.11 ^e	3.21 ^d	0.15 ^c	0.11 ^b	0.02 ^a
Peroxide value (meq/Kg)	1.33 ^b	1.54 ^c	3.57 ^d	4.34 ^e	0.09 ^a
Phosphorus (ppm)	20 ^b	1 ^a	< 1 ^a	< 1 ^a	< 1 ^a
Tocopherols (ppm)	970 ^d	962 ^{cd}	946 ^{bc}	920 ^b	875 ^a
α -Tocopherol (%)	38.8	37.5	41.0	39.7	42.4
γ -Tocopherol (%)	26.9	28.4	25.2	31.0	28.6
δ -Tocopherol (%)	34.3	34.1	33.8	29.3	29.0
Lovibond color					
Red	1.5	1.1	1.0	0.1	0.1
Yellow	24.4	18.6	14.2	1.3	1.3
Blue	0.1	0	0	0	0
Fatty acid composition (% area)					
C16:0	15.4	14.5	14.4	14.7	15.4
C18:0	2.2	2.4	2.3	2.3	2.2
C18:1	65.8	66.9	67.0	66.7	65.9
C18:2	15.0	14.7	14.8	14.7	14.9
Others	1.6	1.5	1.5	1.6	1.6
Induction Period (h)	60.5 ^e	39.5 ^c	20.0 ^b	9.5 ^a	50.0 ^d

¹⁾ Values are an average of triplicate determinations, and SD values were less than $\pm 3\%$ unless otherwise specified ($n=3$).

²⁾ Values with no or the same superscripts in the same row are not significantly different at $p<0.05$.

Disclosure The authors declare no conflict of interest.

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