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Effect of different roasting systems and cotton (*Gossypium hirsutum* L.) varieties on chemical and bioactive properties, and fatty acids of cottonseed and oils

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Abstract

In the present work, the effect of two different roasting methods on the total oil, carotenoid, chlorophyll, total phenolic, total flavonoid, antioxidant activity, phenolic compounds, and fatty acid profiles of three different cottonseed varieties was investigated. The oil contents of control (raw / unroasted) groups were between 11.35% (Beyaz Altın 119) and 19.55% (Carisma). The oil contents of cottonseeds roasted by microwave were between 18.0% (Beyaz Altın 119) and 20.70% (Carisma). The bioactive properties of Beyaz Altın 119 cottonseed roasted in both microwave and oven were found higher than the other varieties. Gallic acid, 3,4-dihydroxybenzoic acid, (+)-catechin, 1,2-dihydroxybenzene, and syringic acid were the major phenolic compounds found in control (raw / unroasted) and roasted cottonseeds. The major fatty acids found in cottonseed oils were palmitic, oleic, linoleic, and linolenic acids. Linoleic acid contents of oils obtained from cottonseeds roasted by microwave were between 54.70% (Beyaz Altın 119) and 55.60% (Gloria), while those of oils obtained from cottonseeds roasted by oven were between 54.90% (Beyaz Altın 119) and 56.42% (Carisma).

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Introduction

Cotton (*Gossypium hirsutum* L.; family Malvaceae) is a herbaceous or woody, grown in tropical and subtropical regions of more than eighty countries, and planted to obtain fibre and oil (Danışman, 2008). Cotton plays a dominant role in the agricultural and textile industry which consumes 90% of cotton production worldwide and is one of the most important commercial crops of Türkiye (Mert *et al.,* 2015; Bozdoğan-Konuşkan *et al.,* 2017). Cotton production in Türkiye is performed widely in Mediterranean, Aegean, and Southeast Anatolia regions. Approximately, 80% of the 65% of the exported textile products consist of cotton production (Mert *et al.,* 2015; Bozdoğan-Konuşkan *et al.,* 2017). China, US, India, Pakistan, Brazil, and Türkiye are the countries that produce the most cotton. Altogether, these countries produce 75% of world cotton (Pinar *et al.,* 1998).

Cotton is primarily cultivated for its lint or fibre, and its seeds are used as a source of oil for human consumption. At the same time, cotton oil, which has a mild taste and is usually light golden in colour, is often used as the standard for measuring flavour and odour qualities of other oils (Agarwal *et al.,* 2003). Cottonseed oil is one of the most used cooking oils today, along with sunflower oil (Karaosmanoğlu *et al.,* 1999; Metin *et al.,* 2003; Sekhar and Rao, 2011; Kolsarıcı *et al.,* 2015).

The ratio of polyunsaturated fatty acid to saturated fatty acid in cottonseed oil is 2:1 (Sekhar and Rao, 2011). Since roasting has an effect on the texture, colour, flavour, and appearance of plant materials, the unique crispness and taste characteristics of the final product are more

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appreciated than unroasted (Nicoli *et al*., 1999). It has been stated that the phenolic compound composition changes as a result of roasting edible seeds, and in some cases, it increases their antioxidant capacity (Dewanto *et al.,* 2002b; Kim *et al.,* 2011).

In microwave drying, since the electromagnetic field affects the material as a whole, a different drying is achieved than traditional drying methods since selective heating is directly targeted to the water molecules in the material (Drouzas *et al*., 1999). In this method, since the heat is directly formed inside the product, the moisture in the product is heated and evaporated in a very short time, and due to the vapour pressure difference between the inside and outside environments, the moisture transfer is from the inside to the outside. Thus, the heat transfer problem that occurs in traditional drying methods is eliminated in the microwave drying method (Soysal *et al*., 2009).

The characteristic properties of cotton oil depend on the type of cotton, the geographical region where it grows, soil conditions, climate, fertiliser, and conditions such as harvesting and storage after harvest. Cotton fibre oil and pulp are raw materials of the textile and cellulose industry, edible oil industry, and feed industry. The purpose of the present work was to investigate the effect of two different roasting methods on the total oil, carotenoid, chlorophyll, total phenolic, total flavonoid, antioxidant activity, phenolic compounds, and fatty acid profiles of three different cottonseed varieties.

Materials and methods

Materials

"Beyaz Altın 119", "Carisma", and "Gloria" varieties were cottonseeds used in the present work. Beyaz Altın 119 variety was provided by the Dippers and Gin and Prese Factory in Kahramanmaraş Province, while Carisma and Gloria varieties were provided by the Eastern Mediterranean Agricultural Research Institute Directorate in Adana. Then, the dried seeds were cleaned of foreign materials such as stems and leaves with an air filter cleaner.

Methods

The three different cottonseed varieties that were harvested were first subjected to roasting. Roasting was performed in a microwave and an oven. The samples were roasted in the microwave at 720 W for 45 min, and in the oven at 120°C for 5 h. In both heating systems, seeds classified as being of the same size were laid out in a single row on a Teflon tray and roasted at the specified wattage and temperature. This process was repeated three times. During roasting, the seeds were subjected to uniform heat treatment. No heat treatment was applied to the control group cottonseeds. Roasted cottonseeds were kept in the desiccator and cooled to room temperature. Then, the samples were then ground using a grinder.

Moisture content

The KERN & SOHN GmbH infrared moisture analyser was used to analysis the moisture of cottonseed samples.

Oil content

After the cottonseeds were ground, they were weighed into a 10-g Soxhlet cartridge and placed in the extractor. After the ground seeds were extracted with petroleum ether at 50°C for 5 h, the solvent was removed by evaporator, and the amount of crude oil was calculated gravimetrically.

Carotenoid content

Extraction of carotenoids was performed according to Silva da Rocha *et al*. (2013). After some analytical pretreatments, the volume of the extracts was completed to 25 mL by petroleum ether, and the absorbance of the samples was measured at 450 nm using a spectrophotometer.

Chlorophyll content

The chlorophyll contents of cottonseed oils were determined at 670 nm using a spectrophotometer (Minguez-Mosquera *et al.*, 1991) and Eq. 1:

$$\text{Chlorophyll (mg/kg)} = A670 \times 106/613 \times 100 \times d \quad \text{(Eq. 1)}$$

where, A = absorbance; and d : cuvette thickness.

Total phenolic content

The total phenolic contents of the cottonseed extracts were determined by the Folin-Ciocalteu method (Yoo *et al.*, 2004). The absorbance was then determined at 750 nm using a spectrophotometer. Results were expressed as mg gallic acid equivalent (GAE) 100 g (dw).

Total flavonoid content

The total flavonoid contents of the cottonseed extracts were determined according to Hogan *et al.* (2009). After 0.3 mL of $NaNO_2$, 0.3 mL of $AlCl_3$ and 2 mL of NaOH were added to the cottonseed extract (1 mL), and it was vigorously vortexed. After pretreatments, the absorbance was determined at 510 nm using a spectrophotometer. Results were expressed as mg QE/100 g (dw).

Antioxidant activity

The antioxidant activities of the cottonseed extracts were determined using 2,2-diphenyl-1-picrylhydrazyl (DPPH) according to Lee *et al.* (1998). Briefly, 0.1 mL extract was mixed with 2 mL of DPPH solution, and the absorbance values of the samples stored in the dark for 30 min were determined at 517 nm using a spectrophotometer. This process was run in parallel for each variety.

Phenolic compounds

Chromatographic determination of phenolic compounds found in roasted and unroasted cottonseed extracts were carried out by HPLC (Shimadzu) assembled with a PDA detector and an Inertsil ODS-3 (5 µm; 4.6 × 250 mm) column. The mobile phase was a mixture of 0.05% acetic acid in water (A) and acetonitrile (B) at a flow rate of 1 mL/min at 30°C. The injection volume was 20 µL. The peaks were detected at 280 nm using a PDA detector. The elution programme employed was 0 - 0.10 min 8% B; 0.10 - 2 min 10% B; 2 - 27 min 30% B; 27 - 37 min 56% B; 37 - 37.10 min 8% B; and 37.10 - 45 min 8% B. The total running time per sample was 60 min.

Fatty acid composition

The analysis of fatty acid methyl esters of cottonseed oils was performed according to ISO-5509 (ISO, 1978) method using gas chromatography (Shimadzu GC-2010) assembled with flame-ionisation detector (FID) and capillary column (Tecnocroma TR-CN100; 60 m × 0.25 mm; film thickness: 0.20 µm). The temperature of injection block and detector was 260°C. The mobile phase was nitrogen with 1.51 mL/min flow rate. The total flow and split rates were 80 mL/min and 1/40, respectively. The column temperature was programmed at 120°C for 5 min, increased to 240°C at 4°C/min, and held 25 min at 240°C. A standard fatty acid methyl ester mixture (Sigma Chemical Co.) was used to determine the sample peaks.

Statistical analyses

JMP version 9.0 (SAS Inst. Inc., Cary, N.C.U.S.A) was used for the analysis of variance (ANOVA) of the study results. Means of the main sources of variation showing statistically significant differences were examined using the Tukey's Multiple Comparison Test, and the level of statistical significance was set at $p < 0.05$. All analyses were carried out in three replicates, and the results were expressed as the mean ± standard deviation (MSTAT C) of independent cotton roasting types and varieties.

Results and discussion

Physicochemical and bioactive properties of raw and roasted cottonseeds

Physicochemical and bioactive properties of cottonseeds roasted in microwave and oven systems are illustrated in Table 1. The moisture contents of unroasted cottonseeds (control) were between 6.45% (Carisma) and 6.81% (Gloria). The moisture contents of cottonseeds roasted by microwave were between 3.47% (Carisma) and 4.05% (Beyaz Altın 119), and those roasted by oven were between 3.85% (Gloria) and 4.34% (Beyaz Altın 119).

The oil contents of control groups were between 11.35% (Beyaz Altın 119) and 19.55% (Carisma). The oil contents of cottonseeds roasted by microwave were between 18.0% (Beyaz Altın 119) and 20.70% (Carisma), and those roasted by oven were between 18.70% (Gloria) and 24.25% (Carisma). The air temperature likely affects the content of the seed as well as the growth and development of the plant, and the oil content and quality of the seed decreased at low temperature. The oil contents of desi and American cottonseeds were reported to be between 14.4 and 18.7%, and 15.8 to 20.2%, respectively (Sharma *et al.,* 2009). Gotmare *et al.* (2004) determined 17.61 - 19.54% oil in six cotton races (*G. arboreum*) seed. Roy *et al*. (2012) reported that the cottonseed (*G. herbaceum*) contained 15.0% oil. While vegetable oils generally contain 6 - 15% saturated fatty acids, cottonseed oil consists of 29.40% saturated fatty acids (Norton, 1989). Salam *et al.* (2018) determined 17.74 - 18.46% oil in seeds of five cotton genotypes. In previous studies, cottonseeds contained oil between 12.40 - 25.20%

Table 1. Physicochemical and bioactive properties of cottonseeds roasted in microwave and oven systems.

Treatment	Variety	Moisture (%)	Oil (%)	Carotenoid (mg/kg)	Chlorophyll (mg/100 g)	Total phenolic (mg GAE/100 g)	Total flavonoid (mg QE/100 g)	Antioxidant activity (%)
Control	Beyaz Altın 119	6.61 ± 0.08^{b}	11.35 ± 0.40^{c}	15.83 ± 0.00^{b}	24.47 ± 0.00^{a}	57.78 ± 0.03^{a}	53.83 ± 0.02^{a}	5.31 ± 0.00^{a}
	Carisma	6.45 ± 0.27^{c}	19.55 ± 0.85^{a}	15.83 ± 0.00^{b}	5.15 ± 0.00^{c}	0.55 ± 0.00^{b}	7.83 ± 0.00^{c}	0.78 ± 0.00^{c}
	Gloria	6.81 ± 0.13^{a}	14.15 ± 0.15^{b}	16.71 ± 0.00^{a}	9.46 ± 0.00^{b}	1.45 ± 0.00^{b}	13.05 ± 0.00^{b}	2.15 ± 0.00^{b}
Microwave	Beyaz Altın 119	4.05 ± 0.09^{a}	18.00 ± 1.20^{c}	17.33 ± 0.00^{a}	33.12 ± 0.00^{a}	2.29 ± 0.00^{b}	22.84 ± 0.00^{a}	0.84 ± 0.01^{c}
	Carisma	3.47 ± 0.10^{b}	20.70 ± 0.10^{a}	17.33 ± 0.00^{a}	28.37 ± 0.00^{b}	3.33 ± 0.00^{a}	21.86 ± 0.00^{b}	4.12 ± 0.00^{a}
	Gloria	3.48 ± 0.31^{b}	20.05 ± 0.35^{b}	16.71 ± 0.00^{b}	24.49 ± 0.00^{c}	1.60 ± 0.00^{c}	20.88 ± 0.00^{c}	2.51 ± 0.00^{b}
Oven	Beyaz Altın 11	4.34 ± 0.18^{a}	19.50 ± 0.50^{b}	16.71 ± 0.00^{b}	29.15 ± 0.00^{a}	1.29 ± 0.00^{a}	22.18 ± 0.00^{a}	1.55 ± 0.01^{a}
	Carisma	4.02 ± 0.11^{b}	24.25 ± 2.35^{a}	17.33 ± 0.00^{a}	17.70 ± 0.00^{b}	0.51 ± 0.00^{b}	11.09 ± 0.00^{b}	0.54 ± 0.00^{b}
	Gloria	3.85 ± 0.10^{c}	18.70 ± 1.10^{c}	16.22 ± 0.00^{c}	8.99 ± 0.00^{c}	0.51 ± 0.00^{b}	8.81 ± 0.00^{c}	0.18 ± 0.00^{c}

Values are mean ± standard deviation. Means within similar column followed by different lowercase superscripts are significantly different at $p < 0.05$.

(Agarwal *et al.,* 2003; Mert *et al.,* 2015). Our results regarding moisture and oil contents of seeds were similar to those of Agarwal *et al*. (2003), Gotmare *et al*. (2004), Sharma *et al*. (2009), and Mert *et al*. (2015), but higher than the results of Roy *et al*. (2012). Factors such as variety, growing conditions, and extraction methods are the main reasons for this difference.

The total carotenoid contents of control cottonseeds were between 15.83 mg/100 g (Beyaz Altın 119 and Carisma) and 16.71 mg/100 g (Gloria). The total carotenoid contents of cottonseeds roasted by microwave were between 16.71 mg/100 g (Gloria) and 17.33 mg/100 g (Beyaz Altın 119 and Carisma), while the total carotenoid contents of cottonseeds roasted by oven were between 16.22 mg/100 g (Gloria) and 17.33 mg/100 g (Carisma).

The total chlorophyll contents of control cottonseeds were between 5.15 mg/100 g (Carisma) and 24.47 mg/100 g (Beyaz Altın 119). The total chlorophyll contents of cottonseeds roasted by microwave were between 24.49 mg/100 g (Gloria) and 33.12 mg/100 g (Beyaz Altın 119), and those roasted by oven were between 8.99 mg/100 g (Gloria) and 29.15 mg/100 g (Beyaz Altın 119).

The total phenolic contents of control cottonseeds were between 0.55 mg GAE/100 g (Carisma) and 57.78 mg GAE/100 g (Beyaz Altın 119). The total phenolic contents of cottonseeds roasted by microwave were between 1.60 mg GAE/100 g (Gloria) and 3.33 mg GAE/100 g (Carisma), and those roasted by oven were between 0.51 mg GAE/100 g (Carisma and Gloria) and 1.29 mg GAE/100 g (Beyaz Altın 119).

The total flavonoid contents of control cottonseeds were between 7.83 mg/100 g (Carisma) and 53.83 mg/100 g (Beyaz Altın 119). The total flavonoid contents of cottonseeds roasted by microwave were between 20.88 mg/100 g (Gloria) and 22.84 mg/100 g (Beyaz Altın 119), and those roasted by oven were between 8.81 mg/100 g (Gloria) and 22.18 mg/100 g (Beyaz Altın 119).

The antioxidant activities of control cottonseeds were between 0.78% (Carisma) and 5.31% (Beyaz Altın 119). The antioxidant activities of the cottonseeds roasted by microwave were between 0.84% (Beyaz Altın 119) and 4.12% (Carisma), and those roasted by oven were between 0.18% (Gloria) and 1.55% (Beyaz Altın 119) (Figure 1).

In general, a significant increase was observed in the oil, chlorophyll, and flavonoid (except Beyaz Altın 119) contents of cottonseeds roasted in microwave and oven compared to the control groups. The bioactive properties of Beyaz Altın 119 cottonseed roasted in both microwave and oven were found higher than the other varieties. It was observed that the roasting process was effective on the bioactive properties of cottonseeds ($p < 0.05$). In general, a linear relationship was observed between total phenolic and antioxidant activity values of raw and roasted cottonseeds (Figure 1). As heat treatment disrupts the cell membranes and structure of cell walls in the material, they release soluble phenolic contents from insoluble ester bonds (Dewanto *et al*., 2002a). Additionally, it has been reported that the roasting and heating process may lead to the formation of phenolic compounds during the Maillard reaction and the degradation of insoluble phenolic compounds, resulting in better extraction and increased antioxidant capacity (Dewanto *et al*., 2002a; Vadivel *et al*., 2011; Liu *et al*., 2020). In addition to the antioxidant activity of the Maillard reaction products formed by roasting, it is estimated that these products may react with the Folin-Ciocalteu reagent and cause the formation of many compounds (Manzocco *et al*., 1998). Therefore, it is thought that the Maillard reaction products may also cause the increase in total phenolics measured by the Folin-Ciocalteu method (Siddhuraju and Becker, 2007). Cottonseed contained 11.90 ± 0.4% total flavonoid, 1.62 ± 0.00 mg/100 g total phenolic, 15.04 ± 0.01% moisture, and 6.57 ± 0.04% oil (Ayeni *et al.,* 2015). Bozdoğan-Konuşkan *et al*. (2017) determined 119 - 140 mg/kg total carotenoid in the cottonseed oils. In general, the lowest bioactive compounds values were observed in "Gloria" cotton variety. The cottonseeds contained 11 mg GAE/g total phenolic (Rifat-uz-Zaman *et al.,* 2011). Patel and Mishra (2018) reported that cottonseeds contained 0.284 ± 0.00120 total flavonoids (mg QE/g) and 0.145 ± 0.00066 total phenolic (mg GAE/g). Total flavonoid and total phenolic contents of cottonseed were 410 ± 0.74 mg quercetin equivalents/g (dw) and 5.86 ± 0.75 mg gallic acid equivalents/g (dw), respectively (Kumar *et al.,* 2011). The IC_{50} values for DPPH assay of cottonseed and ascorbic acid were 44.69 and 13.80 µg/mL, respectively (Kumar *et al.,* 2011). Our findings regarding moisture, oil content, and bioactive properties of cottonseed showed differences

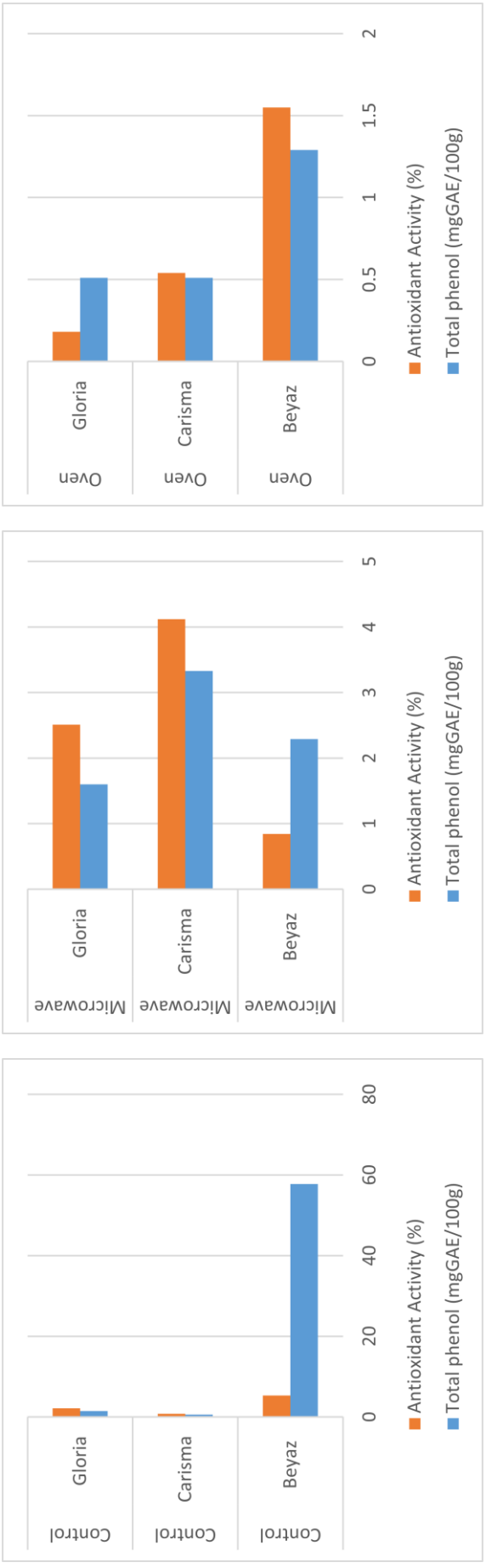

Figure 1. Total phenolic contents and antioxidant activities of cottonseeds roasted by microwave and oven systems.

with the results of previous studies (Kumar *et al.,* 2011; Rifat-uz-Zaman *et al.,* 2011; Patel and Mishra, 2018). Total phenolic, flavonoid, and antioxidant activity values of raw (control) and roasted cottonseeds differed significantly from literature data. These differences observed in our results compared with literature data may be due to genetic makeup, variety, cultural activities, climatic conditions, solvent solubilization capacity, location, harvest time, milling method, and other analytical procedures.

Phenolic compounds of raw and roasted cottonseeds

The phenolic compositions of cottonseeds roasted by oven and microwave systems are shown in Table 2. Gallic acid and 3,4-dihydroxybenzoic acid contents of cottonseeds were between 0.66 mg/100 g (Gloria) and 3.22 mg/100 g (Beyaz Altın 119); 1.19 mg/100 g (Gloria) and 2.75 mg/100 g (Carisma), respectively. (+)-Catechin contents of control group were between 1.07 mg/100 g (Gloria) and 6.09 mg/100 g (Carisma), while 1,2-dihydroxybenzene contents of cottonseeds (control groups) were between 1.03 mg/100 g (Gloria) and 3.89 mg/100 g (Beyaz Altın 119). The syringic acid contents of control cottonseeds were between 0.43 mg/100 g (Gloria) and 1.36 mg/100 g (Carisma). The caffeic acid contents of control cottonseeds were between 0.24 mg/100 g (Gloria) and 1.03 mg/100 g (Beyaz Altın 119 and Carisma). The highest naringenin (1.27 mg/100 g) and isorhamnetin (2.92 mg/100 g) in control groups were found in "Beyaz Altın 119" cotton variety. The contents of other phenolic compounds in control groups were under 0.95%. In addition, among cotton varieties belonged to control groups, "Gloria" seed yielded the lowest phenolic contents (except apigenin-7-glucoside). While the gallic acid contents of cottonseeds roasted by oven were between 1.59 mg/100 g (Gloria) and 3.83 mg/100 g (Beyaz Altın 119), the gallic acid contents of cottonseeds roasted by microwave were between 1.17 mg/100 g (Carisma) and 2.16 mg/100 g (Beyaz Altın 119). 3,4-Dihydroxybenzoic acid contents of cottonseeds roasted by oven and microwave systems were specified to be between 1.19 mg/100 g (Gloria) and 3.86 mg/100 g (Carisma), to 1.35 mg/100 g (Beyaz Altın 119) and 3.71 mg/100 g (Gloria), respectively. In addition, (+)-catechin contents of cottonseeds roasted by oven and microwave were between 2.02 mg/100 g (Gloria) and 5.03 mg/100 g (Carisma) and 2.58 mg/100 g (Beyaz Altın 119) and 2.87 mg/100 g (Carisma), respectively. 1,2-dihydroxybenzene contents of oven-roasted seeds were between 1.55 mg/100 g (Gloria) and 5.67 mg/100 g (Carisma), and those roasted by microwave were between 2.27 mg/100 g (Beyaz Altın 119) and 2.82 mg/100 g (Gloria). Syringic acid contents of cottonseeds roasted by oven and microwave systems were between 0.45 mg/100 g (Gloria) and 1.49 mg/100 g (Carisma) and 0.62 mg/100 g (Carisma) and 1.35 mg/100 g (Gloria), respectively.

In general, while the contents of phenolic constituents of Beyaz Altın 119 cottonseeds roasted by oven decreased, the contents of phenolic constituents of "Carisma" cottonseeds roasted by oven increased compared to the control groups. The contents of some phenolic compounds of "Gloria" cottonseeds roasted by oven also increased, while the contents of phenolic compounds of "Beyaz Altın 119" and "Carisma" cottonseeds roasted by microwave decreased (except rutin-trihydrate, apigenin-7-glucoside, resveratrol, and quercetin for "Carisma") compared to the control. The phenolic contents of "Gloria" cottonseeds increased (except *trans*-ferulic acid, and apigenin-7-glucoside) compared to the control. The major phenolic compounds of "Beyaz Altın 119" and "Carisma" cottonseeds roasted by oven were higher than those of "Beyaz Altın 119" and "Carisma" cottonseeds roasted by microwave. Also, the amounts of all phenolic compounds (except naringenin) of "Gloria" cottonseeds roasted by oven were low compared to "Gloria" cottonseeds roasted by microwave system. In previous study, the ethanol extract of cotton flowers contained kaempferol, quercetin, and hyperoxide flavonoids (Wu *et al.,* 2008). Results showed fluctuations depending on cotton varieties and roasting types compared to the control. The variations in the amount of phenolic components could possibly have been caused by the genetic structure of the seeds, variety, the applied heat power and temperature intensity, the enzymatic activity at the beginning of roasting, the molecular structure of the seeds, and the processing during roasting.

Fatty acid compositions of oils obtained from raw and roasted cottonseeds

The fatty acid composition of cottonseed oils roasted by microwave and oven systems are illustrated in Table 3. The major fatty acids found in cottonseed oils were palmitic, oleic, linoleic, and linolenic acids. Results exhibited some changes based on cotton varieties and roasting types compared to the

Table 2. Phenolic compounds of cottonseeds roasted in microwave and oven systems (mg/100 g).

Phenolic constituent	Control Beyaz Altın	Control Carisma	Control Gloria	Oven Beyaz Altın	Oven Carisma	Oven Gloria	Microwave Beyaz Altın	Microwave Carisma	Microwave Gloria
Gallic acid	3.22 ± 1.52^{a}	2.23 ± 0.32^{b}	0.66 ± 0.42^{c}	3.83 ± 1.80^{a}	3.72 ± 0.51^{a}	1.59 ± 1.46^{b}	2.16 ± 0.89^{a}	1.17 ± 0.17^{c}	1.83 ± 1.40^{b}
3.4-Dihydroxybenzoic	2.40 ± 0.25^{b}	2.75 ± 1.09^{a}	1.19 ± 0.81^{c}	2.15 ± 0.77^{b}	3.86 ± 0.66^{a}	1.19 ± 0.68^{c}	1.35 ± 1.59^{c}	1.75 ± 0.42^{b}	3.71 ± 2.61^{a}
(+)-Catechin	4.44 ± 0.11^{b}	6.09 ± 3.82^{a}	1.07 ± 0.09^{c}	3.66 ± 1.90^{b}	5.03 ± 1.26^{a}	2.02 ± 0.36^{c}	2.58 ± 0.92^{c}	2.87 ± 0.49^{a}	2.84 ± 1.66^{b}
1.2-Dihydroxybenzene	3.89 ± 1.37^{a}	3.32 ± 1.85^{b}	1.03 ± 0.37^{c}	3.24 ± 1.47^{b}	5.67 ± 2.78^{a}	1.55 ± 0.74^{c}	2.27 ± 1.47^{c}	2.55 ± 0.38^{b}	2.82 ± 1.87^{a}
Syringic acid	1.10 ± 0.20^{b}	1.36 ± 0.74^{a}	0.43 ± 0.11^{c}	0.88 ± 0.40^{b}	1.49 ± 0.56^{a}	0.45 ± 0.14^{c}	0.90 ± 0.54^{b}	0.62 ± 0.20^{c}	1.35 ± 0.92^{a}
Caffeic acid	1.03 ± 0.25^{a}	1.03 ± 0.71^{a}	0.24 ± 0.03^{b}	0.51 ± 0.22^{b}	1.09 ± 0.45^{a}	0.27 ± 0.18^{c}	0.73 ± 0.39^{a}	0.63 ± 0.18^{c}	0.67 ± 0.36^{b}
Rutin trihydrate	0.95 ± 0.24^{a}	0.71 ± 0.47^{b}	0.41 ± 0.10^{c}	0.51 ± 0.26^{b}	0.97 ± 0.79^{a}	0.37 ± 0.20^{c}	0.58 ± 0.18^{b}	0.74 ± 0.10^{a}	0.59 ± 0.40^{b}
p-Coumaric acid	0.10 ± 0.01^{b}	0.14 ± 0.09^{a}	0.05 ± 0.00^{c}	0.04 ± 0.02^{b}	0.16 ± 0.10^{a}	0.04 ± 0.02^{b}	0.05 ± 0.02^{b}	0.07 ± 0.02^{a}	0.07 ± 0.05^{a}
trans-Ferulic acid	0.32 ± 0.13^{b}	0.50 ± 0.16^{a}	0.27 ± 0.11^{c}	0.17 ± 0.07^{c}	0.44 ± 0.23^{a}	0.19 ± 0.07^{b}	0.18 ± 0.07^{c}	0.39 ± 0.18^{a}	0.22 ± 0.20^{b}
Apigenin-7-glucoside	0.15 ± 0.08^{c}	0.37 ± 0.11^{a}	0.33 ± 0.08^{b}	0.13 ± 0.08^{c}	0.68 ± 0.39^{a}	0.16 ± 0.03^{b}	0.14 ± 0.10^{c}	0.44 ± 0.28^{a}	0.16 ± 0.11^{b}
Resveratrol	0.16 ± 0.10^{a}	0.07 ± 0.06^{b}	0.04 ± 0.01^{c}	0.05 ± 0.00^{c}	0.12 ± 0.13^{a}	0.08 ± 0.04^{b}	0.07 ± 0.01^{b}	0.15 ± 0.09^{a}	0.07 ± 0.07^{b}
Quercetin	0.94 ± 0.56^{a}	0.65 ± 0.48^{b}	0.44 ± 0.07^{c}	0.35 ± 0.15^{c}	0.88 ± 0.41^{a}	0.42 ± 0.21^{b}	0.45 ± 0.19^{c}	0.73 ± 0.36^{a}	0.58 ± 0.24^{b}
trans-Cinnamic acid	0.42 ± 0.14^{a}	0.16 ± 0.12^{b}	0.07 ± 0.05^{c}	0.07 ± 0.04^{b}	0.20 ± 0.11^{a}	0.04 ± 0.03^{c}	0.04 ± 0.02^{c}	0.10 ± 0.05^{b}	0.14 ± 0.11^{a}
Naringenin	1.27 ± 0.72^{a}	0.12 ± 0.09^{b}	0.06 ± 0.01^{c}	0.08 ± 0.02^{c}	0.28 ± 0.13^{a}	0.12 ± 0.05^{b}	0.08 ± 0.02^{b}	0.08 ± 0.03^{b}	0.10 ± 0.03^{a}
Kaempferol	-	-	-	0.09 ± 0.00^{b}	0.31 ± 0.00^{a}	-	-	0.11 ± 0.03^{a}	0.63 ± 0.55^{b}
Isorhamnetin	2.92 ± 1.37^{a}	0.35 ± 0.27^{b}	0.23 ± 0.08^{c}	0.50 ± 0.09^{a}	0.45 ± 0.02^{b}	0.30 ± 0.13^{c}	0.13 ± 0.07^{c}	0.15 ± 0.05^{b}	0.42 ± 0.13^{a}

Values are mean ± standard deviation. Means within similar row followed by different lowercase superscripts are significantly different at $p < 0.05$. (-): not identified.

Table 3. Fatty acid compositions of oils extracted from cottonseeds roasted in microwave and oven systems (%).

Fatty acid	Control Beyaz Altın	Control Carisma	Control Gloria	Microwave Beyaz Altın	Microwave Carisma	Microwave Gloria	Oven Beyaz Altın	Oven Carisma	Oven Gloria
Myristic	0.62 ± 0.01^{a}	0.45 ± 0.01^{c}	0.59 ± 0.02^{b}	0.62 ± 0.01^{a}	0.46 ± 0.00^{c}	0.52 ± 0.00^{b}	0.63 ± 0.03^{a}	0.46 ± 0.01^{c}	0.57 ± 0.05^{b}
Palmitic	24.40 ± 0.05^{a}	21.51 ± 0.09^{c}	23.60 ± 0.23^{b}	24.50 ± 0.22^{a}	21.89 ± 0.06^{c}	24.04 ± 0.35^{b}	24.27 ± 0.26^{a}	21.75 ± 0.17^{c}	23.24 ± 0.13^{b}
Stearic	2.14 ± 0.00^{c}	2.37 ± 0.01^{a}	2.18 ± 0.02^{b}	2.27 ± 0.01^{c}	2.51 ± 0.01^{a}	2.32 ± 0.00^{b}	2.21 ± 0.02^{b}	2.36 ± 0.01^{a}	2.21 ± 0.00^{b}
Elaidic	0.09 ± 0.00^{b}	0.32 ± 0.00^{a}	0.32 ± 0.00^{a}	0.61 ± 0.01^{a}	0.58 ± 0.00^{c}	0.59 ± 0.01^{b}	0.33 ± 0.01^{b}	8.88 ± 8.49^{a}	0.59 ± 0.00^{b}
Oleic	15.63 ± 0.03^{b}	17.53 ± 0.07^{a}	15.03 ± 0.07^{c}	16.32 ± 0.06^{c}	18.32 ± 0.03^{a}	17.17 ± 0.26^{b}	16.17 ± 0.16^{b}	18.99 ± 8.39^{a}	15.81 ± 0.06^{c}
Linolelaidic	0.08 ± 0.00^{c}	0.23 ± 0.00^{a}	0.22 ± 0.00^{b}	0.37 ± 0.00^{a}	0.25 ± 0.09^{b}	0.13 ± 0.00^{c}	0.22 ± 0.00^{c}	0.27 ± 0.00^{b}	0.31 ± 0.03^{a}
Linoleic	55.49 ± 0.03^{c}	56.09 ± 0.01^{b}	56.77 ± 0.26^{a}	54.70 ± 0.13^{a}	55.08 ± 0.13^{c}	55.60 ± 0.60^{b}	54.90 ± 0.12^{c}	56.42 ± 0.05^{a}	55.99 ± 0.20^{b}
Arachidic	0.23 ± 0.00^{b}	0.24 ± 0.00^{a}	0.23 ± 0.00^{b}	0.30 ± 0.04^{a}	0.29 ± 0.01^{b}	0.29 ± 0.00^{b}	0.26 ± 0.01^{a}	0.24 ± 0.00^{c}	0.25 ± 0.00^{b}
Linolenic	0.54 ± 0.00^{a}	0.48 ± 0.00^{b}	0.13 ± 0.00^{c}	0.05 ± 0.05^{c}	0.32 ± 0.00^{a}	0.21 ± 0.00^{b}	0.13 ± 0.03^{c}	0.14 ± 0.00^{b}	0.23 ± 0.00^{a}
Behenic	0.11 ± 0.00^{b}	0.12 ± 0.00^{a}	0.12 ± 0.00^{a}	0.18 ± 0.00^{b}	0.17 ± 0.00^{c}	0.21 ± 0.00^{a}	0.15 ± 0.01^{b}	0.12 ± 0.00^{c}	0.16 ± 0.01^{a}
Erucic	-	-	-	0.03 ± 0.00	-	-	-	-	-
Arachidonic	0.09 ± 0.00^{a}	0.09 ± 0.00^{a}	-	0.06 ± 0.01^{c}	0.13 ± 0.00^{b}	0.14 ± 0.00^{a}	0.10 ± 0.00^{a}	0.08 ± 0.01^{b}	0.10 ± 0.00^{a}

Values are mean ± standard deviation. Means within similar row followed by different lowercase superscripts are significantly different at $p < 0.05$. (-): not identified.

control groups. While palmitic acid contents of cottonseed oils (control groups) were between 21.51% (Carisma) and 24.40% (Beyaz Altın 119), stearic acid contents of cottonseed oils for control groups were between 2.14% (Beyaz Altın 119) and 2.37% (Carisma). Oleic acid contents of cottonseed oils for control groups were between 15.03% (Gloria) and 15.63% (Beyaz Altın 119), while linoleic acid contents of cottonseed oils were between 55.49% (Beyaz Altın 119) and 56.77% (Gloria). While palmitic acid contents of cottonseed oils roasted by microwave were between 21.89% (Carisma) and 24.50% (Beyaz Altın 119), palmitic acid contents of cottonseed oils roasted by oven were between 21.75% (Carisma) and 24.27% (Beyaz Altın 119). In addition, stearic acid contents of cottonseed oils roasted by microwave and oven systems were between 2.27% (Beyaz Altın 119) and 2.51% (Carisma) and 2.21% (Beyaz Altın 119 and Gloria) and 2.36% (Carisma). Also, while oleic acid contents of the cottonseed oils were between 16.32% (Beyaz Altın 119) and 18.32% (Carisma), oleic acid contents of cottonseed oils roasted by oven were between 15.81% (Gloria) and 18.99% (Carisma). Linoleic acid contents of cottonseed oils roasted by microwave were between 54.70% (Beyaz Altın 119) and 55.60% (Gloria), while linoleic acid contents of cottonseed oils roasted by oven were between 54.90% (Beyaz Altın 119) and 56.42% (Carisma).

As seen in Table 3, other fatty acids found in cottonseed oils were found at low levels (0.63%). The high unsaturated fatty acid content of cottonseed oil, particularly palmitic acid, indicated that the oil was more stable. Furthermore, the high linoleic fatty acid content indicated that cottonseed oil was rich in essential fatty acids. A previous study analysed the oil extracts of the seeds of seven cotton varieties in terms of their fatty acid composition, and found that there were myristic, palmitic, stearic, oleic, linoleic, and linolenic acids. Sikorski and Kolaskowska (2003) determined 36 - 43% linoleic acid, 21 - 26% palmitic acid, 15 - 22% oleic acid, 2 - 3% stearic acid, and 1% linolenic acid in cottonseed oils. Bozdoğan-Konuşkan *et al*. (2017) determined 52.00 - 55.82% linoleic, 24.85 - 25.63% palmitic, 14.06 - 17.00% oleic, and 3.01 - 3.13% stearic acids in the cottonseed oils. Roy *et al.* (2012) reported that cottonseed oil in Bangladesh contained 6.30% myristic, 11.73% palmitic, 9.90% stearic, 29.40% oleic, 13.11% linoleic, 0.10% arachidic, and 27.56% eicosenoic acids. While oleic acid contents of cottonseed oils roasted by microwave and oven increased compared to control, linoleic acid contents of cottonseed oils roasted by both roasting methods decreased. Also, while palmitic acid contents of cottonseed oils roasted by microwave increased compared to control and oven roasting, these results were different compared to the results of studies carried out by Sikorski and Kolaskowska (2003), Roy *et al.* (2012), and Bozdoğan-Konuşkan *et al*. (2017). The changes monitored in fatty acid composition of cottonseed oils could have been due to variety, climatic factors in growing periods, cultural factors, and oxidation reaction during roasting.

Conclusion

In “Gloria”, the amount of carotenoid did not change following microwave roasting, but decreased following oven roasting. In “Carisma”, while the amount of antioxidant increased following microwave roasting, cottonseeds exhibited distinctive phenolic profiles and fatty acids. While oleic acid contents of cottonseed oils roasted by microwave and oven increased compared to control, linoleic acid contents of cottonseed oils decreased. In general, roasting slightly increased the fatty acid content of cottonseed oils compared to unroasted. The high unsaturated fatty acid content of cottonseed oil, particularly palmitic acid, indicated that the oil was more stable. Furthermore, the high linoleic fatty acid content indicated that cottonseed oil was rich in essential fatty acids. The present work showed that these cottonseed oils could be a good source of edible oil (after refining), and the extracted oil can be treated as edible oil. Future studies will examine the stabilisation of cottonseed at different temperatures and changes in phytochemical compounds.

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