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Antioxidant Properties of Roasted Whole-Grain, Oilseed and Nut Snacks and Effect of Roasting Process on These Properties

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ABSTRACT

In this research, the antioxidant properties of unroasted and roasted snacks such as hazelnut, pistachio, peanut, sunflower seed, pumpkin seed, chickpea, corn and wheat were determined using Trolox® (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) equivalent antioxidant capacity (TEAC), ferric-reducing antioxidant power (FRAP) and Folin-Ciocalteu total phenolic methods, besides their acrylamide contents. Variations were detected in the total antioxidant capacity (TAC) and total phenolic (TP) contents of roasted snacks, which were obtained from at least four different processing plants. Although antioxidant capacity tests produced different values for snacks, a significant and positive correlation (r^2=0.91, P<0.01) was found between TEAC and FRAP results. Similarly, significant and positive correlations were obtained between TP contents and TEAC (r^2=0.91, P<0.01) and FRAP (r^2=0.94, P<0.01) values. Among snack foods, roasted sunflower seed had the highest mean TAC and TP content (TEAC 46.6 μmol TE/g, FRAP 63.9 μmol TE/g and TP 1021.5 mg GAE/100 g), followed by roasted pistachio (TEAC 28.9 μmol TE/g, FRAP 22.3 μmol TE/g and TP 530.5 mg GAE/100 g) and roasted corn (TEAC 5.6 μmol TE/g, FRAP 10.6 μmol TE/g and TP 178.0 mg GAE/100 g). The TAC of remaining snacks (TEAC 2.4-3.3 μmol TE/g, FRAP 2.9-5.7 μmol TE/g) and their TP contents (37.2-265.1 mg GAE/100 g) were lower and somewhat comparable. The TAC and TP contents of hazelnuts and peanuts decreased significantly (P<0.05) upon roasting, while those of sunflower seed, pumpkin seed, corn and wheat were influenced to a lesser extent. Acrylamide contents of roasted snacks were low (<290.9 μg/kg).

Keywords: Antioxidant, Grain, Nut, Roasting, Snack food

Kavrulmuş Tüm Tane Çerez Gıdaların Antioksidan Özellikleri ve Kavurma İşleminin Etkileri

ÖZ

Bu çalışmada, kavrulmamış (ham) ve kavrulmuş fındık, Antep fıstığı, yer fıstığı, ayçiçeği çekirdeği, kabak çekirdeği, nohut, mısır ve buğday çerezlerinin antioksidan özellikleri, Trolox® (6-hidroksi-2,5,7,8-tetrametilkroman-2-karboksilik asit) eşdeğeri antioksidan kapasite (TEAC), demir indirgeme antioksidan gücü (FRAP) ve Folin-Ciocalteu toplam fenolik madde yöntemleri kullanılarak araştırılmıştır. Ayrıca, tahıl ve baklagil esaslı çerezlerin akrilamid içerikleri de belirlenmiştir. Her biri en az dört farklı işletmeden temin edilen kavrulmuş çerezlerin toplam antioksidan kapasite (TAC) ve toplam fenolik madde (TP) içeriklerinde kaynaklarına göre farklılıklar saptanmıştır. Antioksidan kapasite testleri (TEAC ve FRAP) farklı rakamsal değerler vermekle birlikte, TEAC ve FRAP değerleri arasında önemli bir korelasyon (r^2=0.91, P<0.01) bulunmuştur. Çerezlerin toplam fenolik madde (TP) içerikleri ile TEAC (r^2=0.91, P<0.01) ve FRAP (r^2=0.94, P<0.01) değerleri arasında da önemli korelasyonlar tespit edilmiştir. Çerez gıdalardan kavrulmuş ayçiçeği çekirdeği en yüksek TAC ve TP değerleri sağlamış (TEAC 46.6 μmol TE/g, FRAP 63.9 μmol TE/g, TP 1021.5 mg GAE/100 g), bunu kavrulmuş Antep fıstığı (TEAC 28.9 μmol TE/g, FRAP 22.3 μmol TE/g, TP 530.5 mg GAE/100 g) ve kavrulmuş mısır (TEAC 5.6 μmol TE/g, FRAP 10.6 μmol TE/g, TP 178.0 mg GAE/100 g) takip etmiştir. Diğer çerezlerin TAC (TEAC 2.4-3.3 µmol TE/g, FRAP 2.9-5.7 µmol TE/g) ve TP içerikleri (37.2-265.1 mg GAE/100 g) daha düşük ve birbirleriyle benzer bulunmuştur. Fındık ve yer fıstığının TAC ve TP içerikleri kavurma işlemiyle önemli oranda (P<0.05) düşerken, ayçiçeği çekirdeği, kabak çekirdeği, mısır ve buğdayın TAC ve TP içerikleri daha az etkilenmiştir. Çerez gıdaların akrilamid içerikleri ise oldukça düşük (<290.9 µg/kg) düzeyde bulunmuştur.

Anahtar Kelimeler: Antioksidan, Hububat, Kuru yemiş, Kavurma, Çerez gıda

INTRODUCTION

Most foods contain health-promoting antioxidant phytochemicals, namely tocopherols, ascorbic acid, carotenoids, phenolics, flavonoids and sterols, all of which, along with human self-defense enzymes, protect consumers against harmful effects of oxidative stress [1, 2]. It has been well documented that oxidative stress plays a key role in the etiology of many degenerative chronic diseases, including certain cancers, coronary heart diseases and even diabetes [3, 4]. It is, therefore, important to consume plant foods that are rich in dietary antioxidants, such as fruits and vegetables [1, 5], whole-grain cereals and legumes [5, 6] and certain nuts and oilseeds [7-10]. Additionally, Maillard reaction products that occur during heat-processing of foods, i.e. roasting of snack foods, were shown to possess antioxidant activities [11], although a probable human carcinogen, acrylamide, was also formed [12, 13]. Since food processing technologies significantly alter contents and compositions of phytochemicals in foods [14], minimally processed foods, specifically roasted whole-grain cereals, legumes, oilseeds and nuts, are of nutritional advantages over fully processed cereal-based extruded or otherwise expanded snack foods [15].

Roasted whole-grain snack foods of corn, wheat and chickpea, roasted nuts (hazelnut, pistachio etc.) and oilseeds (peanut, sunflower seed, pumpkin seed etc.) constitute a major share of snack foods in Turkey and neighboring countries [9, 10, 15-17]. Hazelnut, pistachio, peanut and sunflower seeds are rich sources of tocopherols and phenolics [8, 9, 18-20]. Among legumes, chickpea is plentiful in isoflavonoid antioxidants [21]. Cereal grains of corn and wheat, however, are abundant sources of phenolics, carotenoids and tocopherols [22].

Although there is a vast amount of literature on antioxidants of raw or unroasted nuts, oilseeds, cereals and legumes [19, 23, 24], limited research is available on their roasted snack foods. Arcan and Yemenicioğlu [25] determined that roasted hazelnut had reduced antioxidant capacity and total phenolics, due mainly to skin removal of hazelnut during roasting process. Jogihalli and coworkers [26] found that microwave roasting of chickpea resulted in significant increases in total phenolics (8.0-27.9 mg GAE/g) and antioxidant activities (22.9-46.7%). Krings and Berger [27] verified that ethanol extracts of wheat and hazelnut contained respectively 22.2 and 45.5 µg/mL of total phenolics. Oboh and colleagues [28] determined that roasting of yellow and white corns resulted in a marked reduction in phenolic contents and antioxidant capacities.

Roasting is a dry-heat process, in which moisture contents of roasted materials range from 15 to 20% and roasting temperatures from 100 to 200°C [29]. Due to elevated temperatures in roasting, such physicochemical reactions as Maillard, caramelization, pyrolysis and expansion take place, resulting in desirable color, flavor and texture [26]. Roasting of nuts, oilseeds, cereals and legumes in snack food production are often time performed by traditional methods and varies extensively by producers [15, 17]. In general, hazelnut is first deshelled and heated at 100-120°C for 5-30 min to remove outer skin, which is also called "whitening". Deskinned hazelnut is then roasted at 120-160ºC for 5-20 min to develop sensory properties [30]. Pistachio and peanut are processed into snack foods in a similar manner to hazelnut, except for that pistachio is roasted without deshelling. As for sunflower and pumpkin seeds, a two-stage process is widely practiced. Nondeshelled seeds are slightly wetted, salted and roasted at 150-175ºC for 10-15 min. In the production of nondehulled roasted corn, sweet corn with 15-20% moisture is preferred and roasted at 120-150ºC for 3-5 min. Like nondehulled roasted corn, wheat is also roasted at 120-150ºC for 3-5 min to obtain roasted wheat snack with acceptable texture and flavor [15]. Of the legumes, chickpea is used to produce two types of roasted snack foods that are known as "leblebi", namely nondehulled roasted chickpea [white leblebi] and dehulled roasted chickpea (yellow leblebi) [17]. White leblebi is produced using thin-hulled Kabuli-type chickpea, where it is first immersed for 1-2 min in boiling water, which contains low levels of sodium bicarbonate and titanium dioxide as expanding and whitening agents, respectively. Upon resting at room temperature for 10-30 min, the chickpea is roasted at 120-130ºC for 1-2 min [16, 17]. Yellow leblebi production however involves a series of heat-moisture treatments and dehulling process prior to roasting. For this purpose, thick-hulled Kabuli-type chickpea with 15-18% moisture is heated at 60-90ºC for 10-30 min and then rested for 2-3 weeks in cotton bags at room temperature. This heat-moisture treatment process is repeated twice or three times. Roasting process is also performed in two stages. The first roasting is carried out 100-110ºC for 2-5 min prior to removal of hull by abrasion. The second or last roasting is usually performed at retail market prior to consumption at 130-150ºC for 1-2 min to develop desired color, flavor and crunchy texture [17].

The purpose of this study was to determine total antioxidant capacities (lipophilic plus hydrophilic) and total phenolic contents of roasted snack foods commonly consumed in Turkey. Additionally, effects of roasting process on antioxidant capacities of certain snack foods and acrylamide contents of legume- and cereal-based roasted snacks were determined.

MATERIALS AND METHODS

Materials

A total of nine different roasted snack foods, namely hazelnut, pistachio, peanut, sunflower seed, pumpkin seed, white chickpea (white leblebi), yellow chickpea (yellow leblebi), corn and wheat, were used in the study. Except for roasted wheat samples, which were of home-made sources, all roasted snacks were collected from five different major snack producers in Turkey. Additionally, unroasted raw samples of snack foods were acquired, when available, prior to roasting to study effects of roasting process on antioxidants. A grand total of 44 roasted snacks and 7 unroasted raw samples were separately analyzed. Roasted and unroasted samples were stored at 4°C until analysis. Prior to analysis, shelled snacks (pistachio, sunflower seed and pumpkin seed) were deshelled manually. All snack foods and unroasted raw samples were then milled with a hammer mill (Polymix PX-MFC, Kinematica AG, Luzern, Switzerland) to pass through a 1-mm screen. All analyses were conducted on deshelled edible parts of ground snacks. All chemicals were of analytical grade and purchased from Sigma and Merck (Ankara, Turkey).

Extraction of Antioxidants

Ground roasted snacks and raw materials were subjected to a two-step sequential extraction procedure to recover both hydrophilic and lipophilic antioxidants (total antioxidants). For this purpose, extraction procedure of Saura-Calixto and Goni [31] was followed by modifying sample to solvent ratio. Ground sample (0.5 g, dry basis) and 10 mL of acidified methanol/water mixture (50/50, v/v; pH 2) were combined in a 15-mL centrifuge tube and shaken at 100 rpm in a shaking water bath (Memmert WB-22, Schwabach, Germany) at 25°C for 1 hour. The tube was then centrifuged (Hettich EBA 200S, Schwabach, Germany) at 2500x*g* for 10 min. Upon collection of 5 mL of hydrophilic extract, the remaining supernatant was carefully drained. In the second step of extraction, 10 mL of acetone/water mixture (70/30, v/v) was added to the pellet remaining in the tube, shaken in the water bath (25°C, 100 rpm) for 1 hour, centrifuged (2500x*g*, 10 min) and 5 mL of lipophilic extract was collected. Hydrophilic and lipophilic extracts were then combined, vortexed and immediately sampled for total antioxidant capacity and total phenolic assays.

Determination of Total Antioxidant Capacity

Total (hydrophilic plus lipophilic) antioxidant capacities (TAC) of snacks and raw materials were determined by employing Trolox-equivalent antioxidant capacity (TEAC) and ferric-reducing antioxidant power (FRAP) tests. TEAC was conducted by the method of Pellegrini and coworkers [32]. Briefly, an equal mixture of 7 mM aqueous ABTS and 2.45 mM aqueous potassium persulfate was stored in a dark place at room temperature for 16 hours to yield ABTS radical cation (ABTS'+). Absorbance of ABTS'+ stock solution at 734 nm was adjusted to 0.700±0.200 with methanol in advance of analysis. ABTS'+ working solution (3 mL) and snack extract (100 µL) were combined in a spectrometer cuvette, left at room temperature for 15 min and absorbance at 734 nm (Perkin Elmer Lambda 265 UV/Vis, USA) was recorded. Based on the standard curve of Trolox® solutions, TEAC of samples were calculated as "µmol TE/g sample". FRAP values of snacks and raw samples were measured by Benzie and Strain [33]. First, 300 mM sodium acetate buffer (pH 3.6), 20 mM aqueous ferric chloride solution and 10 mM aqueous TPTZ solution were mixed at 10/1/1 ratio to obtain the FRAP working solution. Then, FRAP working solution (3 mL) and snack extract (100 µL) were combined in a spectrometer cuvette, left at room temperature for 30 min and absorbance at 593 nm was recorded. Using the standard curve of Trolox® solutions, FRAP of samples were calculated as "µmol TE/g sample".

Determination of Total Phenolic Contents

Total phenolic (TP) contents of snacks and raw materials were determined using Folin-Ciocalteu phenol reagent by Singleton and colleagues [34]. In brief, Folin-Ciocalteu reagent (250 µL, 2 N), snack extract (250 µL) and 5.5 mL of distilled water were first mixed in a 15-mL centrifuge tube and stored at room temperature for 8 min. Then, 2.5 mL of 7% aqueous sodium carbonate and 5 mL of distilled water were added to the tube, mixed well and stored at room temperature for 2 hours. The absorbance was read at 750 nm. Based on the standard curve of gallic acid solutions, TP contents of samples were calculated as "mg GAE/100 g sample".

Determination of Acrylamide Contents

Roasted chickpea, corn and wheat snacks were analyzed for their acrylamide contents. Extraction of acrylamide from samples was performed by slightly modifying the method of Cavalli and coworkers [35]. For this purpose, ground snack sample (1.0 g, dry basis (db)) and 7.0 mL of 10 mM formic acid were combined in a 15-mL centrifuge tube. The tube was first mixed in shaking water bath (50°C, 100 rpm) for 30 min and then centrifuged at 6000 rpm for 30 min. An aliquot (2-3 mL) was sampled by syringe from aqueous phase of the tube. The extract was first subjected to clean-up procedure using solid-phase extraction cartridge (Isolute Multimode SPE cartridge, Biotage, Hengoed, UK) and then filtered through a 0.22-µm nylon filter. Acrylamide in snack food extract was separated and quantified on an HPLC system (Perkin Elmer 200 series, Waltham, MA, USA) using IonPac ICE-AS1 - 4x250 mm column (Dionex, Sunnyvale, CA, USA). HPLC conditions were as follows [35]: column temperature of 30ºC, mobile phase of acetonitrile/water (30/70, v/v) containing 3.0 mM formic acid, mobile phase running rate of 0.15 mL/min, UV detector set at 202 nm. Using the standard curve of acrylamide solutions, acrylamide content of sample was calculated as "µg/kg sample".

Statistical Analysis

TEAC, FRAP, TP and acrylamide data, collected from unroasted and roasted snack foods of different origin, were subjected to the one-way analysis of variance and means were compared by the Duncan's multiple comparison test using SPSS software (Lead Technologies, Charlotte, NC, USA).

RESULTS AND DISCUSSION

Total Antioxidant Capacities and Total Phenolic Contents of Roasted Snack Foods

Total (hydrophilic and lipophilic) antioxidants capacities, determined by TEAC and FRAP methods, and total phenolic (TP) contents of roasted snack foods are listed in Table 1. The large variations in minimum and maximum values of TAC and TP contents of snack foods indicated that TAC and TP contents of roasted snacks varied significantly by their sources. TEAC and FRAP antioxidant capacity tests on snack foods produced somewhat different values; yet they were quite in agreement with each other (Table 1) and showed a strong positive correlation (Figure 1). Similar correlations were also established on white beans [36]. Furthermore, the results of TEAC and FRAP antioxidant tests correlated strongly with TP contents, indicating that phenolics were of major contributors to TAC of roasted snacks.

Except for roasted sunflower seed, pistachio and corn snacks, TAC and TP contents of snack foods are lower and comparable to each other (Table 1). For healthy nutrition, it is recommended that adults consume 60 mg of vitamin-C (ascorbic acid) and 12 mg of vitamin-E (mainly tocopherols), sum of which corresponds to 400 µmol TE by TEAC and 580 µmol TE by FRAP [31]. Given a typical portion size of 30 g for snack foods, the results indicate that roasted sunflower seed and pistachio could respectively provide almost three times and twice more antioxidant capacities than sum of the recommended vitamin-C and vitamin-E. Other roasted snacks, however, could only supply about one-fifth of the antioxidant capacity provided by the sum of those antioxidant vitamins.

Of the nuts, roasted pistachio samples had much higher average TAC (TEAC 28.9 µmol TE/g, FRAP 22.3 µmol TE/g) and TP contents (530.5 mg GAE/100 g) than those of roasted hazelnut samples (TEAC 2.6 µmol TE/g, FRAP 3.9 µmol TE/g, TP 138.5 mg GAE/100 g). Hazelnut was determined to be rich in tocopherols and phenolic antioxidants [8, 18, 37, 38], whereas pistachio is an affluent source of phenolic anthocyanidins, flavonoids and lutein [20, 38].

Table 1. Total antioxidant capacity, total phenolics and acrylamide contents of roasted snack foods

Type of snack food	Snack food (n= number of samples)	Moisture content (%)	Total antioxidant capacity (TAC)		Total phenolic (TP) content (mg GAE/100g)[a]	Acrylamide content (µg/kg)[a]
			Trolox-equivalent antioxidant capacity - TEAC (µmol TE/g)[a]	Ferric-reducing antioxidant power - FRAP (µmol TE/g)[a]		
		Mean ± sd (min - max)	Mean ± sd (min - max)	(Mean ± sd (min - max)	Mean ± sd (min - max)	Mean ± sd (min - max)
Nuts	Roasted hazelnut (n=5)	1.7±0.1 b[b] (1.2 - 2.1)	2.6±0.4 a (1.8 - 4.2)	3.9±0.4 a (3.2 - 5.3)	138.5±15.l abc (110.0 - 188.1)	-[c]
	Roasted pistachio (n=5)	1.8±0.2 b (1.2 - 2.5)	28.9±10.8 c (13.0 - 71.1)	22.3±8.3 c (11.1 - 54.4)	530.5±121.3 d (361.2 - 1006.7)	-
Oil seeds	Roasted peanut (n=5)	1.8±0.1 b (1.5 - 2.4)	2.4±2.2 a (1.8 - 3.1)	4.6±0.3 a (3.8 - 5.2)	265.1±30.1 c (162.3 - 350.1)	-
	Roasted sunflower seed (n=5)	0.7±0.2 a (0.5 - 0.9)	46.6±1.2 d (43.7 - 49.8)	63.9±0.8 d (63.6 - 66.2)	1021.5±13.3 e (988.6 - 1064.0)	-
	Roasted pumpkin seed (n=5)	2.0±0.2 b (1.6 - 2.5)	2.8±0.2 a (2.3 - 3.3)	2.9±0.1 a (2.7 - 3.2)	37.2±3.5 a (24.4 - 45.5)	-
Legumes	Roasted dehulled chickpea (yellow leblebi) (n=5)	2.7±0.3 bc (1.3 - 3.8)	2.7±0.2 a (2.1 - 3.0)	4.1±0.2 a (3.6 - 4.5)	98.5±6.8 ab (76.4 - 114.4)	< LOD[d]
	Roasted nondehulled chickpea (white leblebi) (n=5)	4.1±0.1 c (3.7 - 4.5)	3.1±0.2 a (2.3 - 3.7)	3.9±0.1 a (3.6 - 4.3)	85.4±4.l ab (79.6 - 101.3)	<LOQ[e]
Cereals	Roasted nondehulled corn (n=5)	4.4±0.1 c (3.4 - 4.8)	5.6±0.5 b (4.5 - 7.0)	10.6±0.7 b (9.4 - 12.5)	178.0±10.6 bc (158.3 - 206.5)	126.1±92.3 (59.7 - 231.4)
	Roasted nondehulled wheat (n=4)	4.0±0.3 bc (2.1 - 4.6)	3.3±0.6 a (1.8 - 4.9)	5.7±0.8 a (3.9 - 7.7)	81.3±14.0 ab (48.3 - 117.0)	193.9±137.3 (<LOQ - 290.9)

[a]Dry-matter basis. [b]Different letters within a column indicate significant differences (P<0.05). [c]Not analyzed. [d]LOD: Limit of detection (59.6 µg/kg).[e]LOQ: Limit of quantitation (17.9 µg/kg

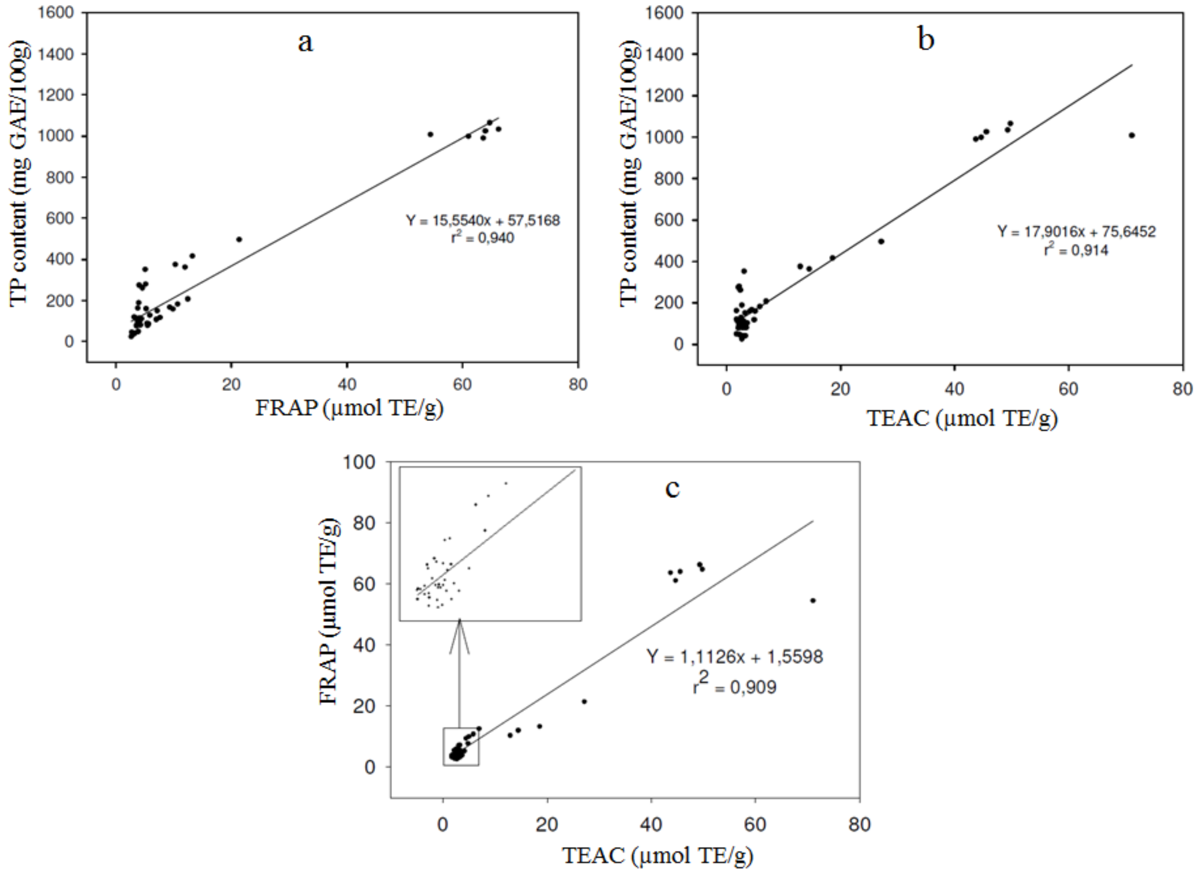

Figure 1. Correlations between (a) total phenolic (TP) content and ferric-reducing antioxidant power (FRAP), (b) TP content and Trolox-equivalent antioxidant capacity (TEAC) and (c) FRAP and TEAC of roasted snack foods

Among the roasted oilseeds of peanut, sunflower seed and pumpkin seed (Table 1), samples of sunflower seed had the highest TAC and TP contents. Kosinska and Karamac [39] also determined that roasted sunflower seed had much higher TAC (TEAC 43 µmol TE/g) and TP content (1480 mg GAE/100 g) than sesame seed, pumpkin seed and soybean. Sunflower seed is a well-known source of tocopherols [7]. Of the oilseeds, roasted peanut samples contained comparable levels of TAC and TP to that of roasted hazelnut. Peanut is reported to be rich in tocopherols, phenolic flavonoids, especially isoflavones [38, 40]. Like hazelnut, phenolic procyanidins are concentrated in the skin of peanut [41]. As for pumpkin seed samples, they had the least TP contents (Table 1), which is consistent with the finding of Kosinska and Karamac [39]. The common antioxidants of pumpkin seed are carotenoids, namely zeaxanthin, ß-karoten, kryptoxanthin and lutein [42].

Chickpea, a leguminous grain, is used to produce two types of roasted snacks foods: nondehulled roasted chickpea (white leblebi) and dehulled roasted chickpea (yellow leblebi) [15, 17]. Although raw materials and processing methods are quite different, both types of chickpea snack in this study had lower and comparable TAC and TP contents (Table 1). It was reported that isoflavones, β-carotene and tocopherols are among the major antioxidant compounds of chickpea [21].

Of the two cereal-based snacks investigated in the study, roasted non-dehulled corn samples had higher levels of TAC and TP than roasted wheat snacks. TAC and TP contents of roasted corns were also much higher than those of the roasted chickpea snacks, indicating that roasted corn is the best in terms of antioxidant potential among grain-based roasted snack foods. Both corn and wheat are rich sources of phenolic antioxidants; however, corn kernel contains more carotenoids and tocopherols than wheat grain [22].

Effects of Roasting on Total Antioxidant Capacities and Total Phenolic Contents

Samples were collected for seven snack raw materials prior to roasting process and their TAC and TP contents were compared with those of their roasted snacks. As seen in Table 2, TAC and TP contents of hazelnut and peanut decreased significantly ($P<0.05$) upon roasting, while those of sunflower seed, pumpkin seed, corn and wheat varied to a lesser extent.

Raw hazelnut sample in this study had quite a high TEAC value of 30.4 µmol TE/g, which is comparable to the value of 29.0 µmol TE/g obtained by Shahidi and Alaşalvar [37]. Roasting caused a reduction of 85-95% in TAC and 50-80% in TP contents of hazelnut and peanut (Table 2). The decrease in TAC and TP contents of hazelnut was somewhat caused by the heat treatment during roasting and, to a major extent, by removal of skin, which is rich in phenolic antioxidants [8, 18]. Similarly, TAC and TP reductions in peanut could also be resulted from heat treatment and unavoidable skin removal during roasting process. Shahidi and Alaşalvar [37] found that hazelnut skin contained 3-5 times more phenolics and antioxidants than hazelnut cotyledons. Arcan and Yemenicioğlu [25] determined that roasted hazelnut had reduced antioxidant capacity and total phenolics, due mainly to skin removal of hazelnut during roasting process.

As opposed to nuts and oilseeds, however, roasting did not markedly alter TAC and TP contents of roasted chickpea, corn and wheat (Table 2). This result is fairly in harmony with the findings of Jogihalli and coworkers [26] that microwave roasting of chickpea resulted in significant increases in total phenolics (8.0-27.9 mg GAE/g) and antioxidant activities (22.9-46.7%). Overall, the results of roasting study imply that reductions in TAC and TP contents of certain snack foods, i.e., hazelnut and peanut, were a primary consequence of skin removal rather than heat treatment during roasting process.

Table 2. Effects of roasting process on total antioxidant capacity and total phenolic contents of snack foods

Source of snack food	Unroasted or Roasted	Total antioxidant capacity (TAC): Trolox-equivalent antioxidant capacity - TEAC (μmol TE/g)[a]	Total antioxidant capacity (TAC): Ferric-reducing antioxidant power - FRAP (μmol TE/g)[a]	Total phenolic (TP) content (mg GAE/100g)[a]
Hazelnut	Unroasted	30.4±2.1 b[b]	26.4±2.7 b[b]	488.1±6.7 b[b]
	Roasted	2.3±0.1 a	3.4±0.5 a	116.9±2.0 a
Peanut	Unroasted	38.9±6.9 b	29.1±2.9 b	780.6±42.8 b
	Roasted	3.1±0.2 a	5.1±0.6 a	350.1±10.0 a
Sunflower seed	Unroasted	53.6±5.6 b	66.7±3.3 a	1089.7±24.5 b
	Roasted	43.7±3.7 a	63.6±5.0 a	988.6±11.2 a
Pumpkin seed	Unroasted	2.8±0.4 b	2.7±0.3 a	31.1±0.13 a
	Roasted	2.3±0.2 a	2.8±0.3 a	45.5±3.4 b
Dehulled chickpea (yellow leblebi)	Unroasted	3.4±0.4 b	3.8±0.3 a	89.3±9.2 a
	Roasted	2.1±0.2 a	3.6±0.5 a	76.4±3.4 a
Nondehulled corn	Unroasted	3.7±0.3 a	11.1±1.1 a	236.6±4.3 b
	Roasted	4.5±0.7 a	9.4±0.5 a	166.3±6.8 a
Nondehulled wheat	Unroasted	2.8±0.3 a	6.4±0.6 a	161.5±16.3 b
	Roasted	3.3±0.4 a	5.5±0.6 a	78.8±3.4 a

[a]Dry-matter basis. [b]Different letters within the same snack type in the same column indicate significant difference (P<0.05).

Acrylamide Contents of Roasted Grain-Based Snacks

Acrylamide, a probable human carcinogen, is known to occur in carbohydrate-rich foods that were subjected to heat processing, such as frying, baking and roasting [43]. Although acrylamide contents of many foods around the world have been heavily investigated, limited research is available on such traditional foods as roasted snacks [12, 13]. Cereal and legume-based roasted snacks of leblebi, corn and wheat were analyzed for acrylamide in this study. As listed in Table 1, roasted dehulled and nondehulled chickpea snacks contained acrylamide levels, respectively, below the limit of detection (LOD: 59.6 μg/kg) and limit of quantitation (LOQ: 17.9 μg/kg) of the HPLC-UV method. Roasted corn and wheat snacks contained acrylamide levels ranging respectively from 59.7-231.4 μg/kg (mean 126.1 μg/kg) and <LOQ-290.9 (mean 193.9 μg/kg). Ölmez and coworkers [13] determined that roasted chickpea snacks contained 10-33 μg/kg acrylamide, whereas roasted corns had acrylamide levels of 100-288 μg/kg. Koh [44] found that severely roasted corn contained acrylamide levels ranging from 116 to 400 μg/kg. The acrylamide contents of roasted grains obtained in our study are quite in agreement with the findings of Koh [44] and Ölmez and coworkers [13]. To the best of our knowledge, there is no study on acrylamide content of roasted wheat; however, heavily roasted barley, which is used in the production of traditional tea-like extracts in Korea and Japan, was reported to have acrylamide contents ranging from 116 to 600 μg/kg [44, 45].

CONCLUSIONS

The roasted snacks included in the study showed large variations in TAC and TP contents by their sources, indicating that raw material properties and/or roasting process differed by the producers. Although TEAC and FRAP antioxidant capacity tests produced slightly different values for a given snack, they exhibited a strong correlation. Additionally, there were strong correlations between TP contents of snack foods and their TEAC or FRAP antioxidants capacities, which demonstrate that phenolic compounds are major contributors to TAC of snack foods. Of the snack foods, roasted sunflower seed contained the highest level of TAC and TP contents, followed by roasted pistachio and corn snacks. Other snacks (roasted hazelnut, peanut, pumpkin seed, chickpea and wheat) had lower levels of TAC and TP contents with comparable values. It was determined that roasting process caused a significant reduction in TAC and TP contents of hazelnut and peanut, due mainly to skin removal and partly to heat process during roasting. TAC and TP contents of other snacks (sunflower seed, pumpkin seed, chickpea, corn, wheat) were however slightly influenced by roasting process, probably because no anatomical parts were removed during roasting process. A typical portion of roasted sunflower seed (30 g) is likely to provide TAC three times more than the daily recommended amounts of 60 mg vitamin-C plus 12 mg vitamin-E, while a portion of roasted pistachio and corn can respectively deliver about 150% and 50% of TAC supplied by sum of vitamin-C and vitamin-E. The rest of the roasted snacks, however, can only provide one-fifth of the TAC supplied by vitamin-C plus vitamin-E.

The study shows that most of the traditionally roasted snack foods are rich sources of health-promoting antioxidants. However, other nutritional attributes of snack foods, such as total fat, dietary fiber, digestion rates etc., should be taken into consideration in proper selection of snack foods. In this respect, preference of roasted chickpea, corn or wheat might be an appropriate choice, as they are low-fat, high-fiber and slowly digested snacks [15] with moderate levels of antioxidant capacities.

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