PAPER

EFFECTS OF CHIA (*SALVIA HISPANICA* L.) SEED ROASTING CONDITIONS ON QUALITY OF COOKIES

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ABSTRACT

Our aims were to analyze physical changes and antioxidant properties of chia seeds roasted under various conditions (160-200°C, 5-15 min) and to investigate the effects on quality characteristics of cookies. Weight loss and water-holding capacity rapidly changed after roasting at 180°C. Fatty acid composition showed no significant change, while antioxidant activity of roasted seeds increased. Cookies were prepared by replacing 3% of flour with roasted chia seeds (180°C, 0-15 min). Baking loss, hardness, and brightness were inversely proportional to roasting time. Roasting of chia seeds affected texture and sweetness scores in a consumer preference test.

Keywords: chia seed, cookie, cooking quality, roasting, sensory evaluation

1. INTRODUCTION

Cookies are low-moisture, tasty, and crispy baked products comprising three main ingredients: flour, sugar, and butter. Cookies are loved by all generations owing to the unique taste and long shelf life. The increase in the awareness about a healthy lifestyle and nutrition among consumers has encouraged many studies on the nutritional ingredients of cookies (JAN *et al*., 2016; PARK *et al*., 2015).

Seeds of chia (Salvia hispanica L.), an annual plant originating from Central America, were used as a staple food by ancient Aztecs in pre-Columbian times (VALDIVIA-LÓPEZ and TECANTE, 2015). Chia seeds are rich in protein (15-25 g per 100 g), fats (30-33 g per 100 g), dietary fiber (18-30 g per 100 g), and unsaturated fatty acids (17.83 g per 100 g) (ÁLVAREZ-CHÁVEZ *et al*., 2008; MARTÍNEZ-CRUZ and PAREDES-LÓPEZ, 2014). In addition, chia seeds exert a strong antioxidant effect, owing to the presence of phenol compounds such as quercetin, kaemferol, caffeic acid, and chlorogenic acid (REYES-CAUDILLO *et al*., 2008; TAGA *et al*., 1984). For culinary uses, chia seeds are processed into flour, seed oil, or whole seeds. Studies on the application of chia seeds to bread, ice-cream, pound cake, and sausage have been carried out (CAMPOS *et al*., 2016; LEE, 2013; PIZARRO *et al*., 2013; SCAPIN *et al*., 2015).

The ancient Aztec roasted chia seeds and used them in the preparation of chiapinolli, a type of flour used in tortillas, tamales, and beverages (CAHILL, 2003). Roasting is a food-processing method employed to impart a unique flavor and color to a food. Roasting is mainly used for the manufacture of coffee, cocoa, and barley tea. Roasting promotes extraction of seed oils and antioxidants owing to modification of the cellular structure of the seed (KIM *et al*., 2002). In addition, roasting is accompanied by a browning reaction, resulting in the production of brown pigments and aroma components. These amino-carbonyl reactants are known to have antioxidant properties and to improve the taste and flavor of the food (DEWANTO *et al*., 2002; LIN *et al*., 2016).

Given the changes in the characteristics of chia seeds after roasting, different qualities of cookies with chia seeds may be obtained by controlling roasting conditions. Few studies have shown the changes in roasted chia seeds and their applications in food industry. The aims of this study were to investigate the effects of roasting on physicochemical and antioxidant properties of chia seeds and to find the optimal roasting conditions by evaluation of the quality characteristics of cookies containing roasted chia seeds.

2. MATERIALS AND METHODS

2.1. Raw materials

Soft flour (CJ Cheiljedang Co., Ltd., Incheon, Korea), sugar (CJ Cheiljedang Co., Ltd.), butter (Seoul Dairy Co., Ltd., Seoul, Korea), and eggs were purchased at a retail market located in Seoul to prepare cookies. Chia seeds, produced in Paraguay in September 2014, were purchased from a supplier (Chowonherb, Seoul, Korea).

2.2. Roasting

The roasting temperature was set to 160°C, 180°C, or 200°C. Chia seeds (10 g) were roasted for 5, 10, or 15 min in an oven (Zippel DE68-04072D, Samsung, Seoul, Korea). Roasted chia seeds were sufficiently cooled at room temperature (25°C) and stored in the freezer (-20°C) until analysis.

2.3. Physical analysis of chia seeds

Changes in the mass of chia seeds during roasting were measured using a scale (Libror EB-2200HV, Shimadzu, Kyoto, Japan). The water-holding capacity (WHC) of the roasted chia seeds was measured by the modified method of ALFREDO *et al*. (2009). Briefly, 1 g of chia seeds was placed in a flask containing 10 mL of distilled water in a water bath (BS-20, Jeio Tech, Gimpo, Gyeonggi) for 24 h incubation at 25°C. The suspension was centrifuged (Universal 32 R, Hettich, Tuttlingen, Germany) at 3,000 rpm for 20 min, and the supernatant was weighed. WHC was expressed as the weight of water held per gram of the sample. The browning index (BI) was measured by the method of MASKAN (2001). Briefly, 10 g of roasted chia seeds was placed on a Petri dish (∅ 90 mm × 15 mm). Color values (CIE L*, a*, b*, and ΔE) of the chia seeds on the petri dish surface were measured with a colorimeter (CR-400, Konica Minolta, Osaka, Japan) in triplicate. Chromameter was calibrated with a standard whiteboard (L = 96.90, a = 0.45, b = 1.49). BI was calculated via the following formula:

$$\text{Browning Index (BI)} = \frac{[100(x - 0.31)]}{0.17}$$

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)}$$

2.4. Analysis of fatty acids of chia seeds

The fatty acid composition of chia seeds was analyzed for fatty acid methyl esters (FAMEs) by gas chromatography with the methods of AOCS Ce 2-66 and Ce 1-62 (AOCS, 1998). An Agilent Technologies 7890N gas chromatograph with a flame ionization detector and a fused silica capillary column (SP™-2560, 100 m × 0.25 mm internal diameter [i.d.] × 0.2 μm film thickness, Supelco) was used for the analysis. The operating conditions were as follows: split ratio 200:1, flow rate 1.0 mL He/min, injector temperature 225°C, detector temperature 285°C, initial oven temperature 100°C for 4 min, and endpoint oven temperature 240°C for 17 min (an increase at a rate of 3°C/min). FAMEs were identified by comparing their retention times with those of the standards, and their relative concentrations were calculated as grams per 100 grams of a sample.

2.5. Content of total phenols and flavonoids

Total polyphenol content of roasted chia seeds was analyzed by the Folin-Denis method (SINGLETON and ROSSI, 1965). The results were expressed in terms of gallic acid equivalents (mg GAE/g). Total flavonoid content was measured by the method suggested by DAVIS (1947) and expressed as quercetin equivalents (mg QE/g).

2.6. Antioxidant activities of chia seeds

DPPH (1,1-diphenyl-2-picrylhydrazyl) antioxidant activity was measured by the method of MOLYNEUX (2004), and ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical-scavenging activity was measured by the procedure of RE *et al*. (1999). Ascorbic acid (Sigma Aldrich, Darmstadt, Germany) was used as a reference. The percentage inhibition at various concentrations (100, 50, 33.3, 25, 20, and 16.66 mg/mL) of each sample was calculated using the following formula to estimate the half-inhibitory concentration (IC_{50}; mg/mL) values of DPPH and ABTS:

$$Percentage\ inhibition = \left(\frac{A_{control} - A_{sample}}{A_{control}}\right) \times 100$$

Where $A_{control}$ is the absorbance of 100 μl of ethanol, A_{sample} is the absorbance of a 100 μl sample.

2.7. Cookie preparation

Raw chia seeds (group RT0) and chia seeds roasted at 180°C for 5 min (group RT5), 10 min (RT10), and 15 min (RT15) were freeze-dried (FD8508, Ilshin Biobase Co., Ltd., Gyeonggi, Korea). The unroasted and roasted seeds were pulverized by a high-speed grinder (CRT-04, Hungchuan Machinery Enterprise, Taipei, Taiwan) and filtered through a 40-mesh sieve. Cookies were prepared by the AACC method 10-52 (AACC, 2000) from flour (300 g), butter (180 g), sugar (120 g), and eggs (60 g). Each chia seed powder (groups RT0, RT5, RT10, and RT15) was added to cookies via replacement of 3% (9 g) of the flour. Butter was creamed by means of a mixer (KM400, Kenwood, Havant, Britain) and mixed with sugar and eggs for 5 min. Sieved flour and chia seed powder were added to the mixture. The cookie dough was rolled out, cut into a cylindrical shape (∅ 40 mm × 5 mm), and baked for 20 min at 170°C in an oven (Zipel DE68-04072D, Samsung, Seoul, Korea). The cookies were cooled for 1 h at room temperature (25°C) and then subjected to analysis.

2.8. Cookie properties

2.8.1 Dough density, baking loss, the spread factor, and pH

Dough density was measured as an increase in the volume of water. Baking loss of cookies was calculated by the comparison between cookie mass and dough mass. The spread factor of cookies was calculated by the procedure of AACC (2000). Briefly, six randomly selected cookies were stacked in a line, and their diameter and thickness were measured. The spread factor was calculated by dividing the diameter of a cookie by its thickness. The pH level of dough was measured with a pH meter (SP-701, Suntex Instruments Co., Ltd., Taipei, Taiwan).

2.8.2 Quantification of the color of cookies

The photographs of cookies with roasted chia seeds were taken by a digital camera (Canon IXUS 500, Tokyo, Japan). Color values (CIE L*, a*, and b*) of six cookies randomly selected from each group were evaluated with a chromameter. The total color difference (ΔE) values were calculated as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Where ΔL, Δa, and Δb are the difference of L, a, and b value between white board (L: 96.90, a: 0.45, b: 1.49) and sample, respectively.

2.8.3 Hardness of cookies

This parameter was measured repeatedly 15 times for each sample using a rheometer (Compac-100II rheometer Sun, Sun Scientific Co., Ltd., Tokyo, Japan) with a No. 5 probe (∅ 5 mm). The operating conditions were as follows: mastication test mode (mode 20), 5 mm distance, and 120 mm/min table speed.

2.9. Sensory evaluation

A consumer preference test of the cookies was conducted by a panel of 30 people (age 25-35 years, 15 males and 15 females). Samples were served on a white plate with water. Cookies were evaluated for appearance, flavor, texture, an oily taste, sweetness, savory taste, and aftertaste. A method with a 7-point scale, 1 = strongly dislike and 7 = strongly like, was employed to measure the seven parameters.

2.10. Statistical analysis

All results obtained by measurements were subjected to one-way analysis of variance (ANOVA) in the SPSS software ver. 23.0 (SPSS Inc., Chicago, IL, USA). Data are presented as mean ± standard deviation (SD). The significance of each experimental value was analyzed by Duncan's multiple-range test ($p < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Physical analysis of chia seeds

The mass loss and WHC of roasted chia seeds are shown in Table 1. At all temperatures, the mass loss increased with roasting time. The mass of roasted chia seeds decreased with an increase in the temperature. In particular, the mass loss of chia seeds roasted at 180°C or 200°C was significantly higher than that of the unroasted samples. Wang and lim (2014) described weight loss as a general indicators for determining the roasting degree, and it was divided into two stages: the first stage mainly due to vaporize, and the another stage by formation of CO2 and volatiles compounds. Since the moisture content of the raw chia seed was 7.00% (data not shown), further mass reduction can be presumed to be due to several volatile compounds such as CO2, aldehydes, ketones, alcohols and pyrazines produced by the Maillard reaction between sugars and amino acids (XIAO *et al*., 2014). WHC of the roasted chia seeds significantly decreased with roasting time. Protein denaturation and extraction of seed surface oil during heat treatment may contribute to the rapid decrease in WHC. ÖZTÜRK *et al*. (2002) reported that WHC affects the hardness and spreadability of cookies. Thus, the process of roasting of chia seeds was expected to affect the quality of cookies. During the roasting process, the food color gradually darkened due to the formation of a brown pigment from the Maillard reaction and caramelization. This change is related to the roasting temperature and time, which are the major parameters that control roasting conditions and processes (KAHYAOGLU and KAYA, 2006). The BI measurement results on chia seeds roasted at 160°C, 180°C, and 200°C are presented in Fig. 1. An increase in the BI is an indicator of the nonenzymatic browning process such as the Maillard reaction and caramelization (HELOU *et al*., 2016). The BI showed no significant change at 160°C but increased at temperature >180°C as a function of roasting time. These results indicated that the Maillard reaction proceeded actively in chia seeds above 180°C.

Table 1. Mass loss and water-holding capacity (WHC) of chia seeds roasted under.

Roasting condition		Mass loss (g / 100 g)	WHC (g of water retained /g of sample)
Temperature (°C)	Time		
-	0	-	7.67±0.01[a]
	5	3.27±0.31[f]	7.16±0.01[b]
160	10	5.93±0.12[d]	6.71±0.00[c]
	15	6.87±0.50[c]	3.99±0.00[e]
	5	5.53±0.50[de]	7.69±0.01[a]
180	10	6.93±0.50[c]	4.59±0.00[d]
	15	7.93±0.31[b]	3.84±0.01[e]
	5	5.00±0.72[e]	7.65±0.01[a]
200	10	7.47±0.23[bc]	3.88±0.01[e]
	15	9.40±0.60[a]	3.95±0.01[e]

[a,b,c,d,e,f]Means with different superscript letters in each column are significantly different according to Duncan's multiple-range test ($p < 0.05$).

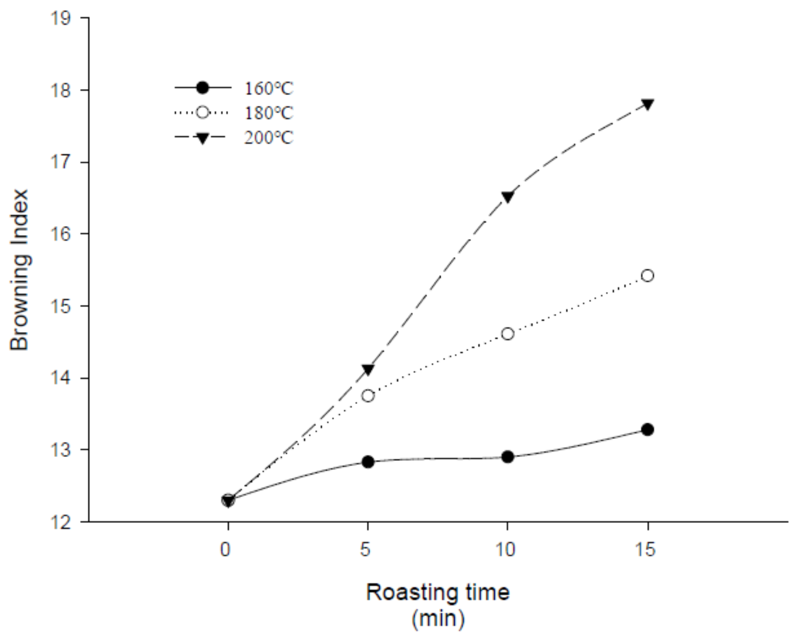

Figure 1. Changes in the browning index (BI) of roasted chia seeds with roasting time.

3.2. Fatty acid composition

It is known that the fatty acid composition of seed oil determines the physicochemical and nutritional characteristics of seed oil, and can be changed by roasting (HAMA, 2017). There was no significant difference in the fatty acid composition between raw chia seeds and those roasted under different conditions (Table 2). It is expected that there will be no significant change in the quality of seed fat in the temperature and time conditions that we set. YOSHIDA and TAKAGI (1997) reported no significant difference in the quality of sesame oil roasted at temperatures below 200°C. Because the roasting conditions in our study were set within the range of normal baking temperatures (160-200°C), the mechanism underlying the change in the fatty acid composition after roasting at higher temperatures and for longer periods remains unclear. YEN (1990) reported that the fatty acid composition of sesame, which is similar to that of chia seeds, changed rapidly (to linoleic acid in particular) after roasting at temperatures above 240°C. Further studies are needed to evaluate the effect of roasting of chia seeds above 200°C.

Table 2. Fatty acids composition of chia seeds roasted under various temperature and time conditions.

Roasting condition		palmitic acid (g/100 g)	stearic acid (g/100 g)	oleic acid (g/100 g)	linoleic acid (g/100 g)	α-linoleic acid (g/100 g)
Temperature (°C)	Time					
-	0	6.28±0.04[NS]	3.26±0.10[NS]	6.94±0.22[NS]	18.90±0.99[NS]	65.22±0.06[NS]
	5	6.31±0.19	3.24±0.02	6.86±0.09	18.40±0.00	64.76±0.31
160	10	6.25±0.03	3.19±0.01	6.74±0.07	18.33±0.16	65.06±0.19
	15	6.55±0.48	3.37±0.15	6.70±0.17	18.42±0.18	64.10±0.92
	5	6.26±0.19	3.23±0.04	6.80±0.10	18.44±0.07	64.85±0.15
180	10	6.27±0.07	3.26±0.01	6.83±0.07	18.47±0.05	64.90±0.05
	15	6.21±0.07	3.22±0.07	6.76±0.09	18.33±0.15	65.06±0.37
	5	6.33±0.00	3.32±0.03	6.85±0.00	18.78±0.02	64.34±0.00
200	10	6.18±0.05	3.21±0.01	6.76±0.07	18.43±0.27	64.99±0.36
	15	6.49±0.07	3.33±0.06	7.03±0.13	18.74±0.33	64.12±0.68

NS = not significant in each column according to Duncan's multiple-range test ($p < 0.05$).

3.3. Antioxidant activities of chia seeds

Polyphenol compounds act as antioxidants and can be obtained from fruits, vegetables, and plants. Table 3 shows that the total polyphenol and flavonoid content of chia seeds increased with roasting time. These results were similar to those observed for roasted almonds and sesame seeds (JEONG *et al*., 2004; LIN *et al*., 2016). The amino-carbonyl products formed by the Maillard reaction act as new antioxidants, thereby enhancing the antioxidant properties (DEWANTO *et al*., 2002; NICOLI *et al*., 1999). LEE *et al*. (2013) reported higher total polyphenol and flavonoid contents for green beans as compared to coffee extracts roasted at 190°C. Nonetheless, the reverse observation at a high temperature was reported (over 200°C). Under all temperature conditions, the IC_{50} value of DPPH and ABTS decreased with roasting time (Table 3). Although no significant difference was observed in the IC_{50} of DPPH at 180°C and 200°C, the antioxidant activity tended to increase with an increase in roasting temperature. JEONG *et al*. (2004) mentioned that roasting of sesame seeds at different temperatures and for various periods enhances the antioxidant activities, which positively correlate with the production of melanoidin. DURMAZ and ALPASLAN (2007) demonstrated an increase in the antioxidant activity after the Maillard reaction. Overall, the roasting process was able to enhance the antioxidant activity of chia seeds.

Table 3. Antioxidant activities of chia seeds roasted under various temperature and time conditions.

Roasting condition		Total Polyphenols (μg GAE/ g)	Total Flavonoids (μg QE/ g)	DPPH IC_{50} (mg/mL)	ABTS IC_{50} (mg/mL)
Temperature (°C)	Time				
-	0	358.00±5.62^{f}	286.07±2.68^{e}	26.99±9.51^{a}	38.70±0.62^{a}
	5	369.70±3.12^{ef}	299.21±17.05^{e}	14.94±0.56^{b}	33.96±0.70^{b}
160	10	438.14±24.01^{d}	359.51±6.50^{c}	14.75±0.79^{b}	28.32±1.28^{d}
	15	512.87±1.56^{ab}	394.25±16.34^{b}	11.68±0.63^{b}	23.75±0.46^{f}
	5	383.21±6.79^{ef}	299.38±5.44^{e}	15.29±1.24^{b}	31.08±2.15^{c}
180	10	476.85±48.73^{c}	351.49±11.96^{c}	12.50±0.11^{b}	24.20±0.71^{ef}
	15	517.37±8.68^{ab}	380.41±19.84^{b}	10.32±0.19^{b}	21.36±1.01^{g}
	5	393.12±6.80^{e}	323.37±4.76^{d}	13.47±0.19^{b}	25.44±1.15^{ef}
200	10	493.96±5.63^{bc}	392.93±7.05^{b}	12.47±0.32^{b}	25.94±1.30^{e}
	15	538.09±8.11^{a}	421.58±5.20^{a}	11.67±0.29^{b}	21.36±1.01^{g}

[a,b,c,d,e,f,g]Means with different superscript letters in each column are significantly different according to Duncan's multiple-range test ($p < 0.05$).

3.4. Cookie properties

3.4.1 Dough density, baking loss, the spread factor, and pH

On the basis of the above results, we roasted chia seeds at 180°C for 5, 10, or 15 min for further experiments. Table 4 shows the properties of cookies containing roasted chia seeds. The density and pH of the dough are major indicators of cookie quality, owing to their effects on the hardness, flavor, and color of a cookie (HADINEZHAD and BUTLER, 2009). No significant difference was observed in dough density (range 1.23-1.26) among the treatment groups. The duration of roasting of chia seeds had no significant effect on pH of the dough; however, pH of the control (6.63) was slightly higher as compared to that of other groups. This observation may be related to the pH difference between the chia seed powder (5.42) and wheat flour (6.82). The baking loss of cookies containing chia seeds, including unroasted seeds, was lower as compared with that of the control (15.82%). These results indicated that the amount of water released during the baking process was smaller because the moisture content (7.00%) of chia seed powder was lower than that of wheat flour. The spread factor determines cookie quality, and high spreadability is indicative of a better cookie (MILLER and HOSENEY, 1997). The spread factor was the lowest in group RT0; RT10 and RT15 had a higher spread factor than the control did. Cookie spreadability tends to decrease with an increase in the concentration of dietary fiber, owing to the increase in the WHC of cookies (MANCEBO *et al*., 2015). Studies have shown 34.4 g of dietary fiber per 100 g of chia seeds (MUÑOZ *et al*., 2013), explaining the lower spread factor for RT0 as compared with that of the control. Nevertheless, WHC significantly decreased after roasting of chia seeds, suggesting that spreadability increased with roasting time.

3.4.2 Quantification of the color of cookies

A photograph of the cookies is presented in Fig. 2. Longer roasting time of chia seeds corresponded to darker and larger cookies. The *L* (lightness) value of the control sample was higher than that of the cookies with chia seeds and tended to decrease with roasting time. The *a* (redness) value was higher in groups RT10 and RT15 (2.96 and 4.11, respectively). The *b* (yellowness) value was significantly lower for cookies with chia seeds as compared with that of the control (28.44). ΔE (total color difference) was the lowest (38.03) in the control group and increased with roasting time. The dark color of cookies is attributed to the Maillard reaction or caramelization (WALKER *et al*., 2012). The dark color of chia seeds affected ΔE of cookies. Higher pH of cookies contributes to a better browning reaction (MARTINS *et al*., 2000).

Figure 2. Photographs of cookies containing roasted chia seed powders.
Control: without added chia seeds, RT0: with chia seeds (raw), RT5: with roasted chia seeds (180°C, 5 min), RT10: with roasted chia seeds (180°C, 10 min), RT15: with roasted chia seeds (180°C, 15 min).

3.4.3 Hardness of cookies

This parameter is known to be influenced by moisture content, pore development, and density of cookie dough (CHABOT, 1979). As illustrated in Table 4, the difference in hardness between groups control and RT0 was likely to be associated with the high concentration of dietary fiber (in chia seeds) that increases WHC. In comparison to RT0, groups RT5, RT10, and RT15 showed a decreasing trend of hardness; this phenomenon may be due to the inverse relation between hardness and moisture retention. WHC of roasted chia seeds decreased with roasting time. Sugar loss during the Maillard reaction (WONG *et al*., 2008) is reported to affect the hardness of cookies. Our results are in line with those reported by VETTER *et al*. (1986) who found a positive correlation between cookie hardness and the amount of added sugar.

3.5. The consumer preference test

Table 5 shows the results of the survey of consumer preferences regarding the cookies containing chia seeds powder. There were no significant differences in the appearance, flavor, oily taste, sweetness, savory taste, and aftertaste among all the groups. Nonetheless, groups RT5, RT10, and RT15 yielded higher texture scores than the control group did, whereas RT0 had the lowest score. Hardness was found to be the highest for RT10 (36.19 N). These results are similar to those reported in another study (on cookies containing oak mushroom powder), wherein an inverse relation was observed between mechanical strength and texture preference (JUNG and JOO, 2010). On the other hand, our results contradict the observations reported by JOO and CHOI (2012). As a consequence, RT5 and RT15 showed a high score in overall preference.

Table 5. Sensory preference scores for cookies containing roasted chia seed powders.

	Appearance	Flavor	Texture	Overall preference
Control	5.25±1.25^{NS}	4.70±1.34^{NS}	4.60±1.35^{ab}	4.66±1.33^{b}
RT0	4.75±1.07	4.75±1.45	4.05±1.61^{b}	4.61±1.30^{b}
RT5	5.00±1.08	5.05±1.05	5.20±1.24^{a}	5.09±1.10^{a}
RT10	4.70±1.17	4.90±1.41	5.45±1.28^{a}	4.97±1.25^{ab}
RT15	4.90±1.29	4.95±1.43	5.35±1.27^{a}	5.16±1.27^{a}

Control: without added chia seeds, RT0: with chia seeds (raw), RT5: with roasted chia seeds (180°C, 5 min), RT10: with roasted chia seeds (180°C, 10 min), RT15: with roasted chia seeds (180°C, 15 min).

^{a,b}Means with different superscript letters in each column are significantly different according to Duncan's multiple-range test ($p < 0.05$).

NS = not significant.

4. CONCLUSIONS

In this study, the effects of roasting conditions on chia seeds and cooking quality of cookies containing chia seeds were investigated. This study confirmed that roasting at 160-200°C changes WHC, the BI, and color as well as increases the antioxidant activity of chia seeds. Cookies with roasted chia seeds, especially RT10 and RT15, were superior in spreadability, hardness and overall preference than control. In conclusion, roasting chia seeds for 10 min at 180°C is preferable for making cookies.

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