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Effect of roasting conditions on color, antioxidant, and sensory properties of lotus seed coffee as a coffee alternative

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Abstract - This research explored lotus seeds as coffee alternative, aiming to investigate the effect of different roasting conditions on color properties, roasting level, antioxidant capacity, and sensory attributes. Dried and ground lotus seeds were roasted at various temperatures ranging from 110°C to 160°C for 5, 10, and 15 minutes. The results indicated that increasing roasting time and temperature led to a rise in lightness, yellowness, and redness (represented by L*, a*, and b* values) as well as the browning index. The ground lotus seeds roasted at 110-120°C were categorized as light to light-medium roasting exhibited the lowest total phenolic content (TPC) when compared to those roasted at 130°C (58.51 ± 0.66-69.78±0.69) and 140°C for 5 minutes (58.11 ± 0.99) (medium roasting). However, dark-roasted lotus seeds (140°C for 10 and 15 minutes) showed a lower TPC compared to the sample roasted at 140°C for 5 minutes. The DPPH assay showed a pattern of increased antioxidant capacity at 130°C for 15 minutes (69.78 ± 0.69), followed by a decrease with rising roasting temperature and time at 140°C for 5 minutes (35.98 ± 0.88). Only the samples roasted at 140°C received 80% acceptability on a 9-point hedonic scale. Among the various roasting durations at 140°C, the

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sample roasted for 5 minutes exhibited the highest antioxidant properties in terms of TPC and DPPH. Therefore, lotus seed samples roasted at 140°C for 5 minutes to a medium-dark level demonstrated acceptable sensory characteristics and significant antioxidant properties.

Keywords: Coffee alternative, lotus seed, antioxidant activities

1. Introduction

Coffee alternatives are non-coffee products that mimic the color, flavor and taste of traditional coffee brewed from regular coffee. They are increasingly sought due to economic and health considerations, particularly by consumers who prefer a healthier, caffeine-free, and gentler alternatives apart from coffee beans (Mostafa *et al*., 2021). Coffee alternatives are regarded as a rich source of nutrients in addition to several health benefits. Basically, coffee alternatives made mainly from roasted cereals, chicory (Wojtowicz *et al*., 2015), and sugar beets (Majcher *et al*., 2013). In addition, acorns (Díaz-rojas *et al*., 2019), Jerusalem artichoke or almonds (Komes *et al*., 2015) could be employed as sources for coffee alternatives. These coffee alternatives provide a good flavor, aroma, and coffee-like color. They are enriched with bioactive compounds, such as phenolic compound (Geel *et al*., 2005; Gorjanović *et al*., 2017; Zawirska-Wojtasiak *et al*., 2014), and positive sensory characteristics (Torma *et al*., 2019).

Lotus seeds (*Nelumbo nucifera*) are widely integrated into Thai and Asian cuisines due to their delicious taste and nutritional values. The composition of fresh lotus seeds includes 10.5% moisture, 10.6-15.9% protein, 1.93-2.8% crude fat, 70-72.17% carbohydrates, 2.7% crude fiber, 3.9-4.5% ash, and an energy content of 348.45 calories per 100 g (Indrayan *et al*., 2005; Punia *et al*., 2020). Lotus seeds also contain various phytochemical substances, including phenolic compounds that known for their antioxidant properties and potential health benefits. Quercetin and apigenin are main flavonoids in lotus seeds, while chlorogenic acid is a significant phenolic compound (Zhu *et al*., 2017; Jiang *et al*., 2021). These phenolic compound, proteins, and sugars contents found in lotus seed play an important role in roasting process for developing coffee alternatives (Echavarría *et al*., 2012; Antonietti *et al*., 2022). During heating, the Maillard reaction which is a complex chemical reaction between amino acids from proteins and reducing sugars occurs. This reaction leads to the browning of the seed, the development of flavor, and the changes in texture. Products of the Maillard reaction have several health effects, such as antioxidant, antimutagenic, antimicrobial, antihypertensive and cytotoxic activities (Carvalho *et al*., 2016). This phenomenon is possibly similar to the roasting and heating of cereal grains, which can also be used as coffee alternatives.

Roasting is a process that significantly influences the chemical composition of food and consequently its sensory characteristics. The roasting temperature and duration are recognized as crucial factors in the process, with potential consequences for sensory characteristics and the antioxidant activity of the roasted products (Samsonowicz *et al*., 2019). Previous studies explored the impact of roasting on grains and seeds used in the preparation of coffee alternatives. The roasting process induces the formation of brown pigments, resulting in a darker coloration in azuki beans that could enhance sensory properties (Bolek, 2022). Furthermore, a study shown that increasing roasting temperature and time intensified the color of barley grains, as evidenced by the browning index (Ali, 2023). Therefore, determining optimal roasting conditions involves considering the level of roasting. The degree of roasting can be assessed by observing changes in color, flavor, and aroma development, all of which reflect alterations in the chemical composition (Fikry *et al*., 2019). Additionally, roasting also impacts antioxidant capacity. A study focused on the roasting conditions of baobao seeds for producing coffee-like beverages revealed a significant increase in antioxidant capacity (Marcolino *et al*., 2023). Therefore, roasted lotus seeds may have the potential to serve as coffee alternatives for consumers, presenting an opportunity for development. The objective of this research is to utilize lotus seeds as a coffee alternative. Effects of different roasting conditions on color properties, roasting level, antioxidant capacity, and sensory attributes are investigated.

2. Materials and methods

2.1 Materials and experimental design

Whole dried lotus seeds were purchased from a local market in Pathum Thani, Thailand. The moisture content of dried lotus seeds determined by moisture analyzer (Infrared Moisture Analyzer Mode MA37, Sartorius, Germany) was 8.00%. All chemicals and reagents used in the experiment were analytical grade. The experimental design utilized a completely randomized design (CRD) with three replications to investigate the effects of roasting conditions. Four temperature levels (110, 120, 130, and 140°C) and three duration levels (5, 10, and 15 minutes) were investigated to determine dependent variables, including color properties (CIE Lab and browning index), as well as antioxidant and sensory properties.

2.2 Lotus seed roasting and brewing process

In a preliminary roasting study aimed at achieving an L* value in the dark range, whole dried lotus seeds were compared with ground samples. The results reveal that the ground samples demonstrated higher antioxidant activity (data not shown). In this experiment, whole dried lotus seeds were finely ground using an Ultra Centrifugal Mill (model ZM200, Retsch, Germany) to obtain a powder sieved through a mesh size of 50. Ground lotus seeds (100 g) were spread in a single layer on a stainless-steel wire mesh tray placed in the center of the oven during hot-air roasting at various conditions. The roasted lotus seed were cooled in a desiccator at room temperature and kept in sealed aluminum bags at room temperature prior to further analysis. Unroasted ground lotus seeds were used as the control to compare the effect of roasting conditions.

The hot brewing process was used to prepare lotus seed coffee alternatives. A 10-gram sample of roasted ground lotus seeds was infused with 100 mL of water at 80°C to produce brewed samples. Subsequently, these brewed samples were analyzed for parameters such as browning index, total phenolic content (TPC), DPPH antioxidant activity, and sensory properties.

2.3 Color measurement

The color of lotus seed coffee samples was analyzed using a trichromatic reflection colorimeter (Chroma Meter CR-410, Konica Minolta, Inc., Osaka, Japan) with a D65 illuminant and CIE: 2° standard observer. The instrument was calibrated against a reference white plate (CR-A44) before a measurement. Ground roasted lotus seed samples were evenly spread to a depth of 1 cm in a Petri dish. Color values were measured in 10 replicates, and the average values were reported as L* for lightness ranging from 0 for black to 100 for white, a* for greenness (−a*) and redness (+a*), and b* for blueness (−b*) and yellowness (+b*) at various points on each sample.

The correlation between the roasting level and L* values follows the classification outlined by (Bolek & Ozdemir, 2017). To determine the degree of roasting, the L* value serves as an important parameter to monitor color changes during roasting and is compared to typical coffee. L* values ≥57 are categorized as very light, 42-56.99 as medium light, 37-41.99 as medium, 29-36.99 as medium dark, and 20.1-28.99 as dark, while values ≤20 are classified as very dark.

2.4 Browning index

Browning index (BI) of lotus seed coffee was measured by the method previously outlined by Żyżelewicz *et al*. (2014). This index provides insight into the extent of browning compounds generated from caramelization and the Maillard reactions, including melanoidins. The brewed lotus coffee were centrifuged at 12,000 rpm for 10 minutes. Subsequently, 50 µL of the supernatant was diluted with distilled water to 2 mL. To determine the browning index, the absorbance of the samples were measured at 420 nm after 2-minute incubation in a 3-mL cuvette with a 1-cm path length at room temperature. The measurements were performed using a UV-vis spectrophotometer (Model Libra S22, Biochrom, England).

$$BI = A_{420} \text{ x dilution factor x } P^{-1}$$

where A420 represents the absorbance and P denotes the percentage content (w/w) of roasted ground lotus seed in a brewed sample.

2.5 Total polyphenols content

The TPC was determined using the Folin-Ciocalteu reagent via a spectrophotometric method (Samsonowicz *et al*., 2019). The supernatant of centrifuged brewed lotus coffee (0.1 mL) was added to 0.3 mL of Folin-Ciocalteu reagent, stirred, and left for 3 minutes. The reaction solution was then mixed with 0.5 mL of 14% (w/w) sodium carbonate, followed by the addition of 4 mL of water. The reaction solutions were left in the dark for 1 hour and absorbance at 764 nm was measured via a UV-vis spectrophotometer (model Libra S22, Biochrom, England). The absorbance values were converted to the TPC using the calibration curve prepared for gallic acid. The TPC were expressed as gallic acid equivalent (mg GAE/g of sample)

2.6 Analyses of antioxidant activities

The antioxidant activity determination was performed by a modified Brand-Williams method with synthetic DPPH radical (Brand-Williams *et al*., 1995). The supernatant from centrifuged brewed lotus coffee (0.05 mL) was added to 2.5 mL of a methanolic solution containing DPPH. The samples were incubated in the dark at room temperature for 30 min. The ability of lotus seed to inhibit the stable DPPH radical was determined by measuring the absorbance at 515 nm using a UV-vis spectrophotometer (model Libra S22, Biochrom, England). Antioxidant activity was expressed as the percentage of the DPPH radical inhibition after incubation with the test solutions with reference to the control sample.

2.7 Sensory test

The sensory test was performed in a sensory panel room using 50 volunteers panelists that consisted of 32 females and 18 males with ages ranging from 20 to 45 years old. Panelists were served with hot brewed lotus seed coffee alternatives in a random order. A 40-mL sample was presented in a white paper cup labeled with a 3-digit code. Panelists were instructed to cleanse their palates between samples using distilled water. The panels assessed sensory attributes, including color, aroma, taste, and overall acceptability, using a scale ranging from 1 (extremely dislike) to 9 (extremely like). A sensory evaluation of the coffee was conducted using a 9-point hedonic scale test in a room illuminated by a fluorescent lamp.

2.8 Statistical analysis

Results were presented as average ± standard deviation of three parallel experiments (n=9). The statistical significance between lotus coffee samples was tested by the one-way ANOVA followed by LSD test. Values with $p < 0.05$ were defined as statistically significant. The results of the study were statistically analyzed using the software SPSS 20.

3. Results and discussion

3.1 Color

Color is the most important indicator of typical coffee and can be used as a quality control parameter during the roasting processes of lotus seeds to produce coffee alternatives. Lightness (L*), red-green scale (a*), and yellow-blue scale (b*) were measured for roasted lotus seed. The statistical analysis of all color results is presented in Table 1 and found to be significant ($p < 0.05$). L* of roasted lotus seed varied significantly among roasting temperatures and time in the range from 22.03 ± 0.01 to 60.49 ± 0.00. The L* value increased from 21.35 to 71.36% after roasting, indicated that ground lotus seed became darker at higher temperature and longer duration. The a* value indicates the degree of the red-green color, with a higher positive a* value indicating more redness. The a* value of the lotus seed significantly increased with increasing temperature and time ($p < 0.05$), ranging from 10.19 ± 0.01 to 20.02 ± 0.00. The b* value indicates the degree of the yellow-blue color, with a higher positive b* value indicating more yellowness. The yellowness of roasted lotus seeds significantly increased, ranging from 15.63 ± 0.01 to 24.70 ± 0.03($p < 0.0$).

Therefore, ground lotus seeds become darker with increased redness and yellowness after roasting.

Based on the L*-value classifications outlined in Table 1, the roasting level of lotus seeds ranges from 'light' to 'dark.' A roasting temperature of 110°C for 5 minutes falls under the 'light' level, while 10 and 15 minutes at 120°C was classified as 'light-medium' level. Lotus seeds roasted at 120°C for 15 minutes was considered 'medium.' The 'medium-dark' level included lotus seeds roasted at 130°C for 10 and 15 minutes and at 140°C for 5 minutes. Finally, 'dark' roasted lotus seeds were those roasted at 140°C for 10-15 minutes.

The Browning Index (BI) is a measurement used to quantify the production of browning associated with the browning reaction during roasting processes. As indicated in Table 1, an increase in temperature and roasting time leads to a significant rise in the BI. The highest BI value of 0.181 ± 0.001 was observed at a roasting temperature of 140°C and a roasting time of 10 minutes. However, it decreased after 15 minutes of roasting at 140°C due to the seeds turned into a darker color (Figure 1).

Increasing roasting time and temperature of lotus seed samples induces changes in L*, a*, and b* values due to non-enzymatic browning reactions, which may include the Maillard reaction and sugar caramelization. In caramelization, lotus seeds primarily contain glucose and other sugars (Tu *et al*., 2020) that play a key role in this process. Specifically, when the samples are roasted at temperatures exceeding 120°C (Kroh, 1994), caramelization is initiated, leading to the development of brown color pigments in those samples. In the Maillard reaction, which occurs when reducing sugars and amines interact during thermal processing, various products are produced, including melanoidin (Hofmann, 1998). This aligns with the findings of Murthy *et al*. (2008) on wheat seed roasting, discussing melanoidin formation. Melanoidins contribute to the reddish hue of roasted lotus seeds, intensifying a* values for coloration, while decreasing L* values signify deeper shades. These changes, along with alterations in a* and b* values, lead to overall darker shades.

Table 1. Color properties, level of roasting, and browning index of roasted lotus seeds at various roasting conditions.

Temperatures (°C)	Time (min)	L*	Level of roasting[A]	a*	b*	Browning index
Unroasted		76.91 ± 0.00[a]	-	10.19 ± 0.01[m]	15.63± 0.01[m]	0.009 ± 0.001[m]
110	5	60.49 ± 0.00[b]	Light	12.09 ± 0.01[l]	17.06± 0.01[l]	0.084 ± 0.001[l]
	10	57.14 ± 0.01[c]	Medium Light	13.52 ± 0.01[k]	18.56± 0.03[k]	0.099 ± 0.002[k]
	15	51.30 ± 0.02[d]	Medium Light	13.59 ± 0.01[j]	18.56± 0.03[j]	0.104 ± 0.000[j]
120	5	47.70 ± 0.02[e]	Medium Light	13.99 ± 0.01[i]	19.03 ± 0.03[i]	0.114 ± 0.001[i]
	10	45.80 ± 0.02[f]	Medium Light	14.19 ± 0.01[h]	19.43 ± 0.03[h]	0.124 ± 0.000[h]
	15	41.33 ± 0.02[g]	Medium	14.03 ± 0.02[g]	19.01 ± 0.02[g]	0.132 ± 0.001[g]
130	5	37.36 ± 0.00[h]	Medium	15.22 ± 0.02[f]	19.94 ± 0.03[f]	0.135 ± 0.001[f]
	10	35.26 ± 0.01[i]	Medium Dark	15.98 ± 0.00[e]	20.58 ± 0.00[e]	0.145 ± 0.000[e]
	15	32.67 ± 0.01[j]	Medium Dark	17.03 ± 0.04[c]	21.79 ± 0.01[d]	0.155 ± 0.000[d]
140	5	30.22 ± 0.00[k]	Medium Dark	16.87 ± 0.01[d]	21.57 ± 0.01[c]	0.158 ± 0.002[c]
	10	25.36 ± 0.00[l]	Dark	18.26 ± 0.00[b]	22.95 ± 0.03[b]	0.181 ± 0.001[b]
	15	22.03 ± 0.01[m]	Dark	20.02 ± 0.00[a]	24.70 ± 0.03[a]	0.124 ± 0.001[a]

Means in the same column followed by a different letter (a-m) are significantly different (p<0.05) with LSD test.

[A]L* values ≥57 are categorized as very light, 42-56.99 as medium light, 37-41.99 as medium, 29-36.99 as medium dark, and 20.1-28.99 as dark, while values ≤20 are classified as very dark.

Figure 1. The physical appearance of roasted lotus seeds at various temperatures (110-140°C) and heating duration (5-15 min)

3.2 Total phenolic compound

The total phenolic compound content (TPC) monitors the variation of antioxidant compounds in roasted lotus seeds under different roasting conditions. The TPC values are presented in Table 2. Unroasted lotus seeds exhibited a TPC of 28.58 ± 0.73 mg GAE/g dry matter, in agreement with the reported values in the range of 20.91-29.68 mg/g (Feng *et al*., 2016). Roasting lotus seeds at 110°C for 5 and 10 minutes yielded a lightly roasted product that showed a significant increase in TPC compared to the unroasted lotus seeds. The medium roasting conducted at 110°C and 120°C for various duration resulted in a TPC in the range of 29.10 ± 0.42 to 58.28 ± 0.53 mg GAE/g dry matter. The TPC in roasted lotus seeds at 130°C for 5, 10, and 15 minutes were 58.51 ± 0.66, 60.58 ± 0.77 and 69.78 ± 0.69 mg GAE/g sample, respectively. However, dark roasted lotus seeds, when subjected to 140 °C roasting for 10- and 15-minute durations, exhibited a significant decrease in TPC compared to the seeds roasted at 130°C.

Based on the TPC results, elevated roasting temperature and extended roasting time were associated with an increase in TPC. This phenomenon could be attributed to the heating process, which lead to intracellular water evaporation, leading to chemical reactions that alter the lignocellulosic structure and induce protein denaturation (Lemos *et al*., 2012). These might contribute to an increased availability of phenolic compounds within the lotus seed matrix which is phenolic acid, flavanols and flavones (Chen *et al*., 2022). Moreover, the roasting process can also facilitate the formation of new phenolic compounds, thereby augmenting the TPC (Antonietti *et al*., 2022). In a related study, roasting azuki beans at 200°C for 9 minutes led to a notable increase in the TPC, reaching up to 25.32 mg GAE/g (Bolek, 2022). Similarly, another study found that the TPC and antioxidant activity of a coffee-like beverage made from baobab seeds increased with roasting time, reaching 8.51 mg GAE/g after 80 minutes of roasting (Marcolino *et al*., 2023). However, the excessive temperature and roasting duration, i.e., 140°C for 10-15 min, led to a decrease in TPC values. This possibly due to the degradation of the phenolic compounds caused by the excessive heat (Żyżelewicz *et al*., 2016).

3.3 Antioxidant capacity

The DPPH scavenging assay was conducted to explore the impact of different roasting conditions on the hydrogen-donating ability of lotus seed coffee alternatives. Although there was a tendency for the DPPH scavenging ability to increase at higher doses, significant differences among samples were observed only at 1 mg/mL concentration. As shown in Table 2, unroasted lotus seeds exhibited a DPPH scavenging activity of 11.14 ± 0.69% at 1 mg/mL. Meanwhile, those roasted at 110°C and 120°C showed enhanced activities within the range of 13.66-14.95% and 25.11-26.11%, respectively. The antioxidant activities increased to 32.30 ± 0.92%, 35.61 ± 0.87%, and 40.98 ± 0.79% when the lotus seeds were roasted at 130°C for 5, 10, and 15 minutes, respectively. However, the DPPH scavenging abilities of lotus seeds roasted at 140°C were significantly lower than those observed at 130°C for 10 and 15 minutes ($p < 0.01$). As a result, the roasting condition of 130°C for 15 minutes showed the highest antioxidant capacity, correlating with the TPC results. Roasted lotus seeds showed the higher antioxidant activity compared to unroasted lotus seed coffee. These findings are related with the observed patterns in BI and the TPC shown in Table 1 and Table 2, respectively.

Table 2. Total phenolic compound and DPPH antioxidant activity of roasted lotus seed at various temperatures and heating duration.

T (°C)	Time (min)	Total Phenolic Content (mg/1 g roasted lotus seed)	DPPH Radical Scavenging Activity (%)
Control		11.14 ± 0.69[j]	28.58 ± 0.81[f]
110	5	29.10 ± 0.42[ef]	13.66 ± 0.91[i]
	10	30.75 ± 0.11[e]	14.16 ± 0.61[h]
	15	38.00 ± 0.98[e]	14.95 ± 0.83[h]
120	5	50.98 ± 0.99[c]	25.11± 0.99[g]
	10	58.14 ± 0.77[b]	25.91± 0.77[g]
	15	58.28 ± 0.53[b]	26.11± 0.82[f]
130	5	58.51 ± 0.66[b]	32.30 ± 0.92[d]
	10	60.58 ± 0.77[b]	35.61 ± 0.87[c]
	15	69.78 ± 0.69[a]	40.98 ± 0.79[a]
140	5	58.11 ± 0.99[b]	35.98 ± 0.88[b]
	10	57.44 ± 0.80[b]	35.11 ± 0.95[b]
	15	50.98 ± 0.83[c]	29.33 ± 0.80[e]

Values in the same column followed by a different letter (a-j) are significantly different ($p<0.05$) with LSD test.

The significant antioxidant activity, evaluated through DPPH scavenging, is largely attributed to the formation of Maillard reaction products, including melanoidins. During roasting, lotus seeds undergo complex interactions between sugars and amino acids, giving rise to these compounds (Echavarría *et al*., 2012). Additionally, phenolic compounds, identified by TPC results, also form independent complexes with sugars and amino acids (Bekedam *et al*., 2007; Nunes & Coimbra, 2010; Antonietti *et al*., 2022) leading to the generation of Maillard products. These compounds, contribute significantly to the antioxidant activity observed in roasted lotus seeds, as confirmed by DPPH assay results (Tamanna & Mahmood, 2015). This is related to the Browning Index results in Table 1, which indicates the melanoidin content, providing supportive data for this relationship. These outcomes align with findings in coffee brews (Bobková *et al*., 2020), coffee-like maize beverages (Youn *et al*., 2012), and carob coffee alternatives (Şahin *et al*., 2009). Therefore, the increased antioxidant activity with higher roasting degrees was attributed to the development of Maillard reaction products and TPC during roasting.

3.4 Sensory properties

Lotus seed coffee brews from 12 different roasting treatments were assessed for sensory properties, including color, aroma, taste, and overall acceptability. As shown in Table 3, preferences for color, taste, and aroma increased with higher roasting temperatures and time. The peak color score (8.04) was observed at 140°C for 10 minutes, while the highest taste score (7.37) occurred at 140°C for 15 minutes, displaying a pattern of increase followed by a decrease with rising temperature and time. The highest aroma score was recorded at 140°C for 5 minutes. However, samples roasted at 140°C for 10-15 minutes received lower preference in aroma.

Overall acceptability scores rose with increased roasting temperatures and duration. Coffee brews roasted at 110-130°C had notably lower acceptability than those roasted at 140°C. The highest overall acceptability score, ranging narrowly from 7.39 to 7.41, was consistently achieved at 140°C, irrespective of the roasting duration. Temperatures below 140°C resulted in significantly lower overall acceptability scores.

Table 3. Sensory properties of brewed lotus seed coffee at various temperatures and heating duration.

Temperatures (°C)	Time (min)	Color	Aroma	Taste	Overall acceptability
110	5	4.91 ± 0.67[e]	3.34 ± 0.79[h]	4.02 ± 0.65[g]	4.69 ± 1.00[e]
	10	4.13 ± 0.67[e]	4.24 ± 0.89[g]	4.21 ± 0.49[e]	4.61 ± 0.80[e]
	15	4.91 ± 0.34[e]	4.42 ± 0.34[f]	4.21 ± 0.99[e]	5.42 ± 0.67[d]
120	5	5.03 ± 0.76[e]	4.42 ± 0.76[f]	4.32 ± 0.65[f]	6.05 ± 0.34[c]
	10	6.04 ± 1.20[d]	4.43 ± 0.45[f]	4.20 ± 0.98[e]	6.05 ± 0.71[c]
	15	6.01 ± 0.94[d]	4.53 ± 0.94[e]	5.21 ± 0.99[c]	6.02 ± 0.67[c]
130	5	6.03 ± 0.76[cd]	5.82 ± 0.76[d]	5.32 ± 0.65[d]	6.05 ± 0.34[c]
	10	6.34 ± 1.20[c]	6.43 ± 0.45[c]	5.20 ± 0.98[c]	6.12 ± 0.71[c]
	15	6.81 ± 0.94[bc]	6.53 ± 0.94[c]	6.30 ± 0.99[b]	6.32 ± 0.67[b]
140	5	8.03 ± 0.76[a]	7.22 ± 0.76[a]	7.02 ± 0.65[ab]	7.40 ± 0.34[a]
	10	8.04 ± 0.90[a]	7.03 ± 0.45[b]	7.30 ± 0.98[ab]	7.41 ± 0.71[a]
	15	8.01 ± 0.94[a]	7.00 ± 0.94[b]	7.37 ± 0.99[a]	7.39 ± 0.67 [a]

Values in the same column followed by a different letter (a-h) are significantly different (p<0.05) with LSD test.

The color preference changes were a result of increased BI due to Maillard reactions, with the highest BI observed at 140°C (Table 1). Taste and aroma attributes also associated with the duration and temperature increase, indicating that higher temperatures and prolonged heating cause the darker color and favorable bitter taste of lotus seed coffee, enhancing the acceptability of its color and taste attributes. The decline in aroma preference scores beyond 140°C may be due to high roasting temperatures, potentially degrading aromatic compounds (Rojas *et al*., 2020).

Aromatic compounds, like pyrazines, typically peak around 120°C, indicating their generation at moderate temperatures (Müller *et al*., 2010; Rojas *et al*., 2020), thereby contributing to the overall decrease in aroma preference. For color preference, the roasting temperature of 140°C results in a darker roast for coffee, favored by panelists compared to other levels. On the other hand, coffee brews made from lotus seeds roasted at 110-130 °C, receiving scores below 7 for color, aroma, taste, and overall acceptability. This may be because the attributes associated with the dark roast coffee (Table 1) could not be achieved at the lower roasting temperatures. In addition, Thai consumers generally prefer the characteristics of dark roast coffees resulting from the roasting process (Pinsuwan *et al*., 2022).

Overall, the roasting process of lotus seed coffee occurred within a temperature range of 130-140°C, leading to the formation of antioxidant melanoidins (Table 2). Among various roasting times at 140°C for a medium-dark roast, a 5-minute duration resulted in the sample with the highest antioxidant properties. The sample roasted at 140 °C obtained the highest scores across all sensory attributes, with a rating exceed 7, indicating 80% acceptability on a 9-point hedonic scale. Therefore, lotus seeds roasted at 140°C for 5 minutes in a medium-dark roast exhibited both significant sensory qualities and high antioxidant properties.

4. Conclusions

This research demonstrates the significant effects of roasting lotus seeds at various temperatures and durations on their color properties, roasting level, antioxidant capacity, and sensory attributes. Increasing roasting time and temperatures contribute to darker, more yellow, and red hues, which are related to the browning index. Light and light-medium roasted lotus seeds exhibit lower antioxidant properties in terms of TPC and DPPH compared to those roasted at a medium level. Conversely, dark-roasted lotus seeds display a decline in TPC and DPPH associated with the degradation of phenolic compounds. All coffee alternatives brewed from medium-dark roasted lotus seeds at 140°C received acceptability ratings of more than 80%. Among these groups, the sample roasted for 5 minutes exhibited the highest antioxidant properties. Therefore, lotus seed samples roasted at 140°C for 5 minutes to a medium-dark level demonstrate acceptable sensory characteristics and significant antioxidant properties. Further research should investigate the impact of this roasting conditions on the aroma profile of lotus seed coffee alternatives, as it is an important factor defining the sensory experience of coffee.

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