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RESEARCH ARTICLE

Optimization of Roasting Conditions according to Antioxidant Activity and Sensory Quality of Coffee Brews

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Abstract Response surface methodology (RSM) was used to determine the optimal roasting temperature and roasting time of coffee beans used for preparing brews with high antioxidant activity and sensory quality. Green coffee beans (*Coffea arabica* L. cv. Colombia Organic Tamata) were roasted at temperatures ranging from 140 to 220°C for 2-10 min and were then brewed with dripping hot water. The effects of the roasting conditions on the browning index, antioxidant activity, color, aroma, taste, and overall acceptability of the coffee brewed from the bean were investigated using a second-order central composite design. The quality indicators except the taste were significantly affected by roasting temperature and time, tending to increase and then decrease with increasing roasting temperature and time. Superimposed contour plots indicated that the optimal roasting temperature was 182°C and optimal roasting time was 7 min.

Keywords: coffee, roasting, brewing, response surface methodology

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Introduction

Coffee beans are one of the most commonly traded agricultural commodities in the world. Their reported biological activities and therapeutic effects include antioxidant activity (1), antibacterial activity (2), anticancer effects (3), and antidiabetic effects (4). These perceived effects as well as coffee's sensory characteristics and stimulating effects make brewed coffee prepared from roasted beans one of the most popular beverages over the world.

Roasting coffee beans is the key procedure in the preparation of coffee brews, as it is roasting that produces the characteristic aroma and flavor of the brews. In the food industry, roasting is used to improve and alter food quality (5-7), to extend the shelf-life of foods (8), and to improve the processing efficiency of subsequent treatment (9,10). These benefits of roasting are decisively affected by the roasting temperature and time. The required optimal roasting temperatures and times depend on several factors, such as the degree of roast required, the roaster type, and the type and variety of the raw material (11). To improve the effects of roasting, the roasting temperature and time can be optimized using a statistical technique, such as response surface methodology (RSM), which is based on changes in the quality indicators that occur during roasting.

RSM is a useful tool for describing quality indicators during food processing (12). The roasting conditions for robusta coffee beans (11), pistachio nuts (13), and hazelnuts (14) have been optimized by RSM procedures. However, much has been not reported on the roasting conditions for organic coffee beans with a consideration of the antioxidant activity and sensory quality of coffee brews. Therefore, to ensure the best coffee brews, roasting conditions for coffee beans should be optimized by considering adequate quality indicators.

The purpose of this study was to investigate the effects of roasting temperature and time on the antioxidant and sensory quality indicators of the coffee brews prepared from roasted organic coffee beans and to establish the optimal roasting conditions for the production of coffee brews that have high antioxidant activity and sensory quality.

Materials and Methods

Plant material Green coffee beans (*Coffea arabica* L. cv. Colombia Organic Tamata) were purchased from a commercial market in Daegu, Korea. Beans that were uniform in size and defect-free were roasted. The weight of 100-beans was approximately 15.18 g.

Experimental design and statistical analysis The roasting temperatures and times were selected according to a central composite design (CCD). The independent variables, temperature (X_1) and time (X_2), were varied from 140 to 220ºC and from 2 to 10 min, respectively. These ranges reflect those commonly used in conventional roasting. Each independent variable had 5 levels: –2, –1, 0, +1, and +2. Ten combinations were randomly chosen according to a CCD configuration for 2 independent variables. The experimental design of the coded and actual levels of the variables is summarized in Table 1. The dependent variables (responses, Y) were the browning index, DPPH radical scavenging activity, and the score of sensory qualities (color, aroma, taste, and overall acceptability) of the brews prepared from the roasted coffee beans. The responses were related to the independent variables by a second-degree polynomial using the following equation.

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_{12}X_1X_2+\beta_{11}X_1^2+\beta_{22}X_2^2$$

In this equation, β_0 is constant, β_1 and β_2 are linear coefficients, β_{11} and β_{22} are quadratic coefficients, and β_{12} is interaction coefficient.

Table 1. Central composite experimental design used for the roasting process of coffee beans

Experiment no.	Temperature (ºC, X_1)		Time (min, X_2)	
	Coded	Actual	Coded	Actual
1	1	200	1	8
2	1	200	-1	4
3	-1	160	1	8
4	-1	160	-1	4
5	0	180	0	6
6	0	180	0	6
7	2	220	0	6
8	-2	140	0	6
9	0	180	2	10
10	0	180	-2	2

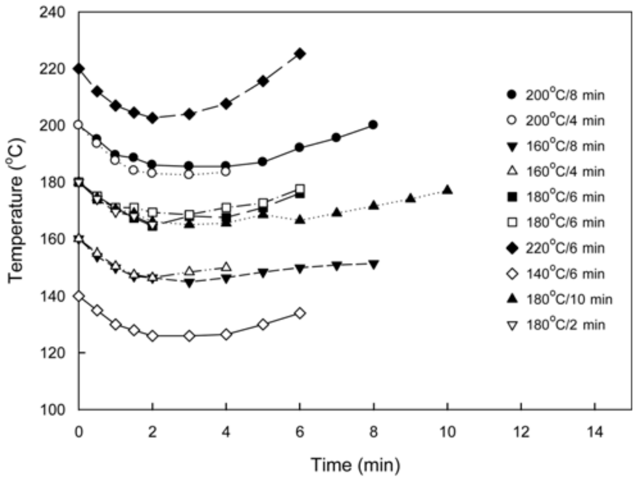

Fig. 1. Changes in temperature of the roasting drum in relation to the roasting conditions.

Analysis of variance (ANOVA), a partial *F*-test for individual terms, and an analysis of residuals were performed. ANOVA tables were generated, and the effects and regression coefficients of individual linear, quadratic, and interaction terms were determined. The degrees of significance of all the terms in the polynomial were statistically determined by calculating the *F*-value at a probability (p) of 0.001, 0.01, or 0.05. The regression coefficients were used to make statistical calculations to generate contour maps from the regression models. All statistical analyses were performed using a SAS statistical package (9.1; SAS Institute, Inc., Cary, NC, USA).

Roasting and brewing of beans Coffee beans (40 g) were poured into the roasting drum of a laboratory-scale electric rotary drum roaster with 100 g capacity (PRE 1Z; Probat-Werke von Gimbom Maschinenfabrik GmbH, Germany) and roasted under the conditions selected for each experiment. Changes in the temperature of the roasting drum were recorded during roasting (Fig. 1). The roasted beans were cooled to room temperature, ground using a mill, and sieved to a size of 1 mm. The ground beans were brewed using a household coffeemaker (AR1; Moulinex, Ecully Cedex, France). In other words, the ground beans (8 g) were placed into an extraction funnel and then extracted for 5 min by dripping 150 mL of deionized water heated to 80ºC over the beans. The brews were subjected to tests that analyzed the quality indicators. The roasting and extraction processes were replicated thrice, and the average values are reported.

Browning index The absorbance of the 10-fold diluted solution of the coffee brews was measured at 420 nm using a spectrophotometer (UV1601; Shimadzu, Kyoto, Japan).

DPPH radical scavenging activity The radical scavenging activity of the coffee brews was determined using DPPH radical (15). A 0.2 mL sample of the brews was added to 0.8 mL of 0.4 mmol/L DPPH radical in ethanol. The mixture was vigorously shaken and left for 10 min. The absorbance of the resulting solution was measured at 525 nm with a spectrophotometer (Shimadzu). The radical scavenging activity was calculated using the following formula: Percentage inhibition=$[1-(Abs_{sample}/Abs_{control})\times100]$.

Sensory analysis Sensory test was conducted using 20 panels that consisted of university students. The test was carried out in a room illuminated with a fluorescent lamp. The coffee brews were served to the panels in a random order as 40 mL sample in white cups, each labeled with 3-digit codes. The panels were instructed to cleanse their mouths between the samples using distilled water. The panels evaluated the sensory qualities of coffee brews, such as color, aroma, taste, and overall acceptability, using a 9-points scale (1=extremely weak or dislike and 9=extremely strong or like) (11).

Results and Discussion

Statistical analysis The experimental values of the browning index, DPPH radical scavenging activity, sensory color, aroma, taste, and overall acceptability of the coffee brews prepared from the ground roasted beans are presented in Table 2. A summary of the linear, quadratic, and cross-product terms for the coffee brews is given in Table 3. The linear terms (X_1, X_2) were highly important for the browning index, DPPH radical scavenging activity, sensory color, and aroma. The quadratic terms (X_1^2, X_2^2) were important for the browning index, aroma, taste, and overall acceptability. The cross-product (X_1X_2) terms were important for the browning index. The correlation coefficient (R^2) of the proposed equation for all quality indicators of the coffee brews was more than 0.86, with the lack of fit being insignificant ($p>0.05$). This result indicates that the proposed equation was adequate, possessed no significant lack of fit, and showed high values for R^2 for all responses. The significance scores of the effect of roasting temperature and time on browning index, DPPH radical scavenging activity, sensory color, aroma, taste, and overall acceptability of the coffee brews are summarized in Table 4. Roasting

Table 2. Experimental data for response parameters of coffee brews in relation to roasting conditions

Experiment number	Browning index (Abs at 420 nm)	DPPH radical scavenging activity (%)	Sensory property			
			Color	Aroma	Taste	Overall acceptability
1	0.08	83.57	6.36	4.86	3.79	4.14
2	0.15	85.56	5.21	4.07	3.21	3.57
3	0.26	86.91	6.43	5.36	4.71	5.00
4	0.62	86.69	3.29	2.86	2.36	2.43
5	0.58	82.97	7.00	6.43	6.43	6.71
6	0.73	79.85	7.14	6.36	5.86	6.50
7	0.66	80.98	7.14	4.14	3.21	3.79
8	0.62	61.58	2.21	2.79	2.50	2.36
9	0.57	55.17	7.29	4.79	4.79	4.71
10	0.66	61.10	1.50	2.00	1.79	1.64

Table 3. Analysis of variance for qualities of coffee brews

Source	Degree of freedom	Sum of square					
		Browning index	DPPH radical scavenging activity	Color	Aroma	Taste	Overall acceptability
Model	5	0.48**[1)]	1,295.55*	41.53*	19.13*	18.44	23.09*
Linear	2	0.31**	1,019.21**	32.42**	7.53*	6.80	7.99
Quadratic	2	0.14*	86.18	8.13	10.87**	10.86*	14.09*
Cross product	1	0.03*	190.16	0.99	0.73	0.78	1.00
Residual	4	0.02	36.57	2.49	1.01	2.99	2.91
Lack of fit	3	0.02	35.93	2.48	1.00	2.82	2.89
Pure error	1	0.00	0.64	0.01	0.00	0.16	0.02
R^2		0.96	0.97	0.94	0.95	0.86	0.89

[1)]Significant at $*p<0.05$ and $**p<0.01$

Table 4. Analysis of variance for the overall effect of roasting conditions on the quality of coffee brews

Source	Degree of freedom	Sum of square					
		Browning index	DPPH radical scavenging activity	Color	Aroma	Taste	Overall acceptability
Temperature	3	0.27**[1)]	740.92**	17.72*	9.55*	10.13	12.58
Time	3	0.31**	785.74**	28.66*	15.54**	14.14	18.28*

[1)]Significant at *p<0.05 and **p<0.01

Table 5. Regression coefficients of the second-degree polynomial for the relationship between roasting conditions and changes in the quality of coffee brews

Coefficient	Browning index	DPPH radical scavenging activity	Color	Aroma	Taste	Overall acceptability
β_0	-9.7110**[1)]	-196.6250	-70.8186*	-72.3442**	-75.7021*	-84.4443*
β_1	0.0838**	2.3882*	0.6314*	0.6974**	0.7421*	0.8129*
β_2	0.7217*	33.8656**	4.8034	4.4094*	4.2707	4.9777
β_{12}	-0.0023	-0.1724*	-0.0124	-0.0107	-0.0110	-0.0125
β_{11}	-0.0002*	-0.0046	-0.0014*	-0.0017**	-0.0019*	-0.0020*
β_{22}	-0.0212**	-0.5123	-0.1586*	-0.1763**	-0.1590*	-0.1951*

[1)]Significant at *p<0.05 and **p<0.01

temperature and time significantly (p<0.05) affected the browning index, DPPH radical scavenging activity, sensory color, and aroma, the overall acceptability was significantly (p<0.05) affected by roasting time alone. In case of pistachio nuts (13) and hazelnuts (14), it was reported that the quality properties are significantly affected by roasting temperature and time.

Effects of roasting temperature and time The regression coefficients of the second-order polynomial equations are listed in Table 5. The response surfaces and contour plots for the browning index, DPPH radical scavenging activity, sensory color, aroma, taste, and overall acceptability of the coffee brews are presented in Fig. 2.

Roasted foods brown generally because of the development of nonenzymatic reactions, called the Maillard reaction and sugar caramelization (16,17). The Maillard reaction products are brown-colored compounds with a typical aroma and functional properties including antioxidant activity (18,19). Browning index is generally considered an indirect measure of the contents of pigment compounds produced from browning reactions (20). The browning index increased and then decreased with increasing roasting temperature and time (Fig. 2). The browning index was found to be a function of the linear (p<0.01) and quadratic (p<0.05) effects of the roasting temperature, and a function of the roasting time with linear (p<0.05) and quadratic effects (p<0.01) (Table 5). The highest browning index was obtained for a roasting temperature of 191.34°C and a roasting time of 6.72 min (Fig. 2A). The changing pattern of browning index during roasting was similar to that of Job's tears (21).

The DPPH radical scavenging activity was investigated to determine the antioxidant activity of the coffee brews. The DPPH radical scavenging activity increased and then decreased with increasing roasting temperature and time (Fig. 2B). The DPPH radical scavenging activity was linearly related to the roasting temperature (p<0.05) and time (p<0.01), and there was significance in the interaction effect between temperature and time (p<0.05) (Table 5). The highest antioxidant activity was obtained for a roasting temperature of 168.80°C and a roasting time of 4.79 min. The results of this study are consistent with previously reported findings (1,22). It is known that the highest antioxidant activity is found in coffee brews prepared from medium dark roasted beans (22,23). This is due to the balance between the degradation of naturally occurring phenolic compounds and the generation of Maillard reaction products during the roasting process (22,23). Therefore, the application of the correct conditions for roasting beans prior to preparing coffee brews can increase the antioxidant activity of the coffee brews.

The color, aroma, taste, and overall acceptability were scored to assess the sensory quality of the coffee brews prepared from the roasted beans under different roasting temperatures and times. Color is an important quality indicator of roasted coffee beans (11), hazelnuts (17), sesame seeds (24), and pistachio nuts (13), and can be used as a quality control indicator during roasting processes. The color score increased and then decreased with increasing roasting temperature and time (Fig. 2C). The color score was a function of the roasting temperature with linear (p<0.05) and quadratic effects (p<0.05), whereas it was only quadratically related to time (p<0.05) (Table 5).

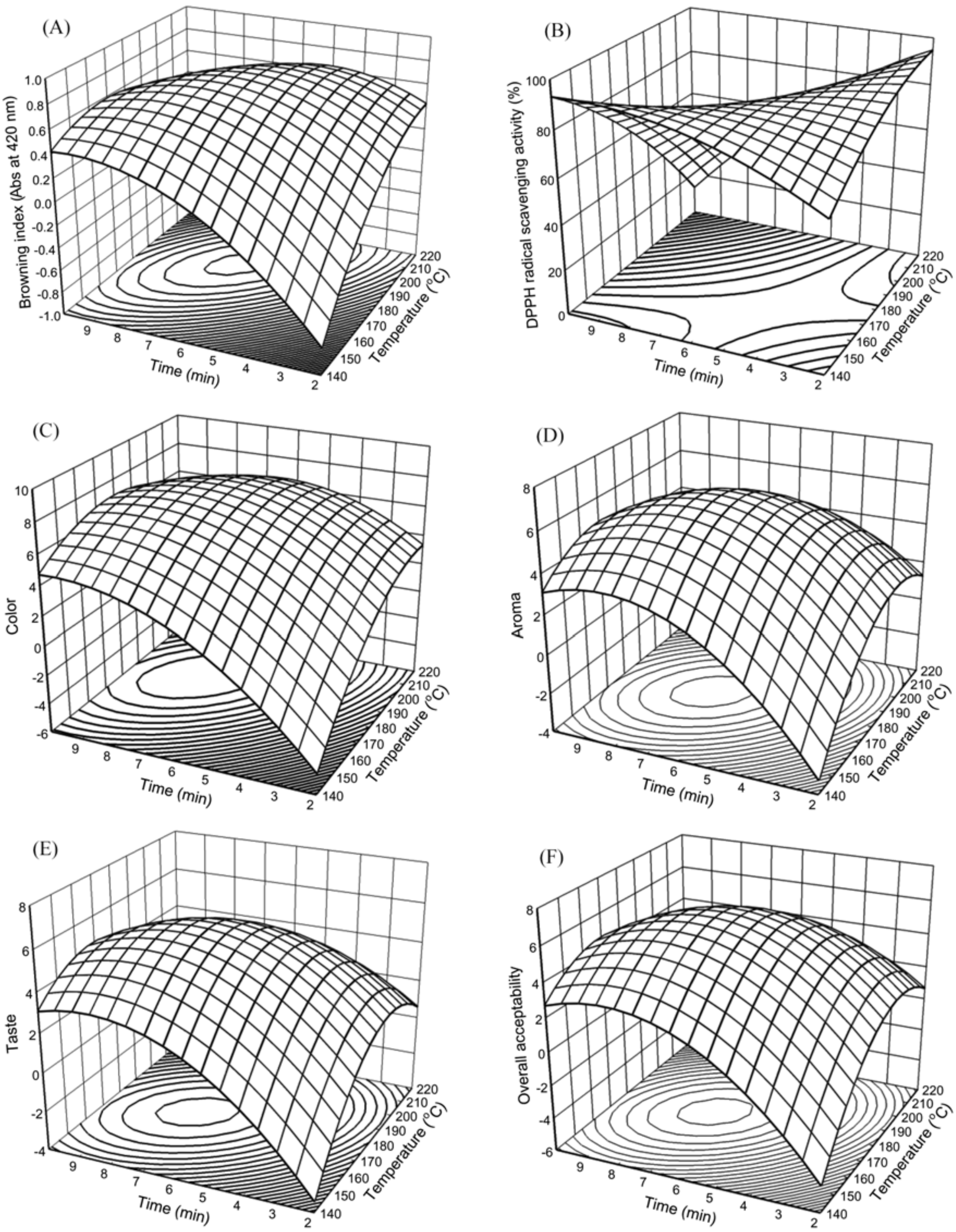

Fig. 2. Response surfaces and contour plots of browning index (A), DPPH radical scavenging activity (B), color (C), aroma (D), taste (E), and overall acceptability (F) of coffee brews as a function of roasting temperature and time.

The highest color score was obtained for a roasting temperature of 189.79°C and a roasting time of 7.70 min (Fig. 2C).

Aroma is considered an important quality indicator of coffee brews. The aroma score increased and then decreased with increasing roasting temperature and time. The highest aroma preference score was obtained for a roasting temperature of 180.96°C and a roasting time of 7.02 min (Fig. 2D). The aroma score was a function of the roasting temperature with linear ($p<0.01$) and quadratic effects ($p<0.01$), and a function of the roasting time with linear ($p<0.05$) and quadratic effects ($p<0.01$) (Table 5).

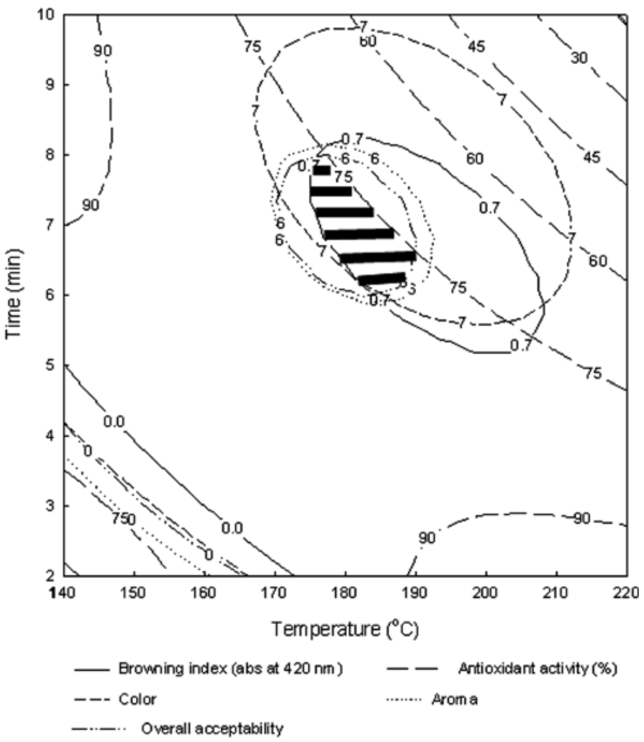

Fig. 3. Superimposed contour plots of browning index, DPPH radical scavenging activity, color, aroma, and overall acceptability of coffee brews as a function of roasting temperature and time.

The taste score increased and then decreased with increasing roasting temperature and time. The highest taste score was obtained for a roasting temperature of 177.81°C and a roasting time of 7.25 min (Fig. 2E). The taste score was a function of the roasting temperature with linear ($p<0.05$) and quadratic effects ($p<0.05$), whereas it was only quadratically related to time ($p<0.05$) (Table 5).

The overall acceptability score increased and then decreased with increasing roasting temperature and time (Fig. 2F). The overall acceptability score was a function of the roasting temperature with linear ($p<0.05$) and quadratic effects ($p<0.05$), whereas it was only quadratically related to time ($p<0.05$) (Table 5). The highest overall acceptability score was obtained for a roasting temperature of 180.19°C and a roasting time of 6.98 min (Fig. 2F).

Optimization of roasting conditions The optimal roasting temperature and time were obtained by superimposing the contour plots of the responses except the taste. A region of the optimal roasting conditions for preparing brews from coffee beans is shown in Fig. 3. The optimal area of the superimposed contour plots was determined using a browning index greater than 0.7, a DPPH radical scavenging activity greater than 75%, a sensory color score greater than 7, an aroma score greater than 6, and an overall acceptability score greater than 6. The results show that the optimal roasting temperature and time for preparing brews from coffee beans are 182°C and 7 min, respectively. This optimal roasting temperature and time may be depended on the quality indicators that used to decide the roasting degree, the type of roaster, and the kind of coffee beans (11).

In conclusion, the temperature and time for roasting coffee beans prior to brewing significantly affected the browning index, antioxidant activity, sensory color, aroma, and overall acceptability of the brews. These quality indicators of coffee brews can be correlated with roasting temperatures and times by using second-order polynomials. The optimal roasting temperature and time were obtained graphically using contour plots in order to prepare coffee brews with high antioxidant activity and sensory quality.

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