Optimization of microwave roasting of *Vigna radiata* as an innovative caffeine-free and gluten-free coffee substitute

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Summary

Optimization of the microwave roasting process of *Vigna radiata* beans containing aroma and flavour compounds similar to coffee beans after roasting was investigated. *V. radiata* beans were roasted at 180 W, 360 W and 600 W for 8, 14 and 20 min. In order to determine the influence of microwave roasting power and roasting time on moisture, colour density, antioxidant activity and sensory characteristics of the beans, a three-level two-factor (3^2) full factorial design was employed. Roasting power and exposure time affected the quality characteristics of *V. radiata* beans significantly ($p < 0.05$). The optimal roasting power and roasting time for producing a desirable coffee-like beverage were determined by the response surface methodology. Optimum region was found using the superimposed contour plot. The quadratic models generated sufficiently identified the relationship between the dependent and independent variables. The results of the study revealed that *V. radiata* beans have a potential to be a caffeine-free coffee substitute and microwave roasting could be used as a quick and practical method.

Keywords

roasting; *Vigna radiata;* response surface; antioxidant activity

Coffee is one of the most popular beverages and its consumption is increasing all over the world. One of the limitations to increase coffee consumption is that coffee is linked to fears about its negative health effects. Coffee bean is one of the most well-known sources of caffeine [1]. Caffeine is commonly linked with anxiety, insomnia, hypertension and higher stress [2]. Due to these negative effects of caffeine, the demand for decaffeinated coffee is increasing [3]. Although coffee is decaffeinated industrially, the operation is generally expensive and the flavour of the product can be lost [4], so many consumers are not willing to consume decaffeinated coffee. Several caffeine-free coffee substitutes known as herbal coffee are consumed to avoid side effects of caffeine [5, 6], e. g. *Pistacia terebinthus* [7], maize [8], or date seeds [9].

Vigna radiata bean, commonly known as Mung bean, is recognized for being rich in proteins, dietary fibre and phenolics, as well as to have high antioxidant activity [10]. Roasted *V. radiata* beans contain aroma and flavour components similar to classical coffee beans [11, 12]. Therefore, *V. radiata* has a potential to be a caffeine-free coffee alternative [13]. Roasting is a crucial process in this regard because it provides formation of many aroma and flavour components. During roasting, the aroma and flavour components occur as a result of reactions such as Maillard reaction or caramelization. The degree of roasting is very important for the formation of desirable aroma and flavour. In order to obtain the desirable aroma and flavour profile, choosing proper roasting method and roasting time is very important. Pan roasting, conventional roasting, microwave roasting, fluidized-bed roasting and ultra-fast roasting are used commonly. Pan roasting is performed with conductive heat and it often results in non-homogenously roasted product. Conventional roasting requires high temperatures and long times. Since surface of the food items may be over-roasted while its centre is under-roasted, pan and conventional roasting cause non-homogenous and partially burned products. Non-homogeneously roasted products have undesirable aroma and flavour. Ultra-fast roasting may be an alternative but the development of the desired aroma and

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flavour components is insufficient when using this process.

Microwave roasting has an advantage of energy saving, precise process control and speed of operation. Thanks to operating directly in the centre of the food materials, microwave roasting is intensified along the whole interior of food materials. NEBESNY and BUDRYN [14] found that the highest level of volatile aroma compounds in a relatively short time was achieved by microwave roasting. HOJJATI et al. [15] stated that microwave roasting preserves the taste of almonds better than the other roasting methods.

Response surface methodology (RSM) is an important method for analysing process parameters with the least number of trials [16]. RSM-based optimization of roasting parameters was successfully used for pistachio nuts [17], arabica coffee beans [18] and *Pistacia terebinthus* beans [7]

Although *V. radiata* beans have high nutritional value and have a potential to be a caffeine-free coffee alternative, only a few studies have been conducted pertaining to roasting of *V. radiata* beans and microwave roasting has not been used for this aim. Therefore, this study aimed to determine the quality characteristics and sensory properties of microwave-roasted *V. radiata* beans and generate predictive models to find the optimal microwave-roasting region by RSM for the production of coffee-like beverages with desirable quality attributes. The fact that microwave roasting can be used as a fast and practical method, and that *V. radiata* beans have a potential to be a caffeine-free alternative, constitute the original value of this study.

MATERIALS AND METHODS

Materials

V. radiata beans were obtained from a garden in Gaziantep, Turkey and they were stored at –18 °C for further analysis in sealed polyethylene bags. Beans uniform in size were used for roasting trials. The approximate thickness, width and length of the beans were 3.96 ± 0.2 mm, 3.98 ± 0.4 mm and 5.49 ± 0.2 mm, respectively.

Experimental design

The samples of roasted *V. radiata* beans were prepared according to a full factorial design consisting of a three-level two factor (3^2; Tab. 1). The factors were microwave power (x_1) and roasting time (x_2). Three levels of factors were used – microwave power at 180 W, 360 W and 600 W, and roasting times of 8 min, 14 min and 20 min with intervals of 2 min. The responses were consumer acceptance scores for sensory attributes of the coffee-like beverages and the instrumentally measured colour parameters, moisture content, density and antioxidant activity of the roasted *V. radiata* beans.

Tab. 1. Experimental design including process variables and their levels.

Treatment	Coded variables		Uncoded variables	
	x_1 (*MP*)	x_2 (*t*)	*MP* [W]	*t* [min]
1	–1	–1	180	8
2	–1	0	180	14
3	–1	+1	180	20
4	0	–1	360	8
5	0	0	360	14
6	0	+1	360	20
7	+1	–1	600	8
8	+1	0	600	14
9	+1	+1	600	20

Experimental runs were performed in random order.
MP – microwave power (factor x_1), *t* – roasting time (factor x_2).

It was presumed that some functions (f_n), depending factors (x_i), and responses (y_n) subsisted. The factors were associated with the responses using a second-degree polynomial using Eq. 1 [19].

$$y_n = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \\ + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 \qquad (1)$$

Experimental design is shown in Tab. 1.

Roasting process

A digitally programmable commercial microwave oven HF12G540 (Siemens, Munich, Germany) operating at 230 V, 50 Hz and a microwave frequency of 2 450 MHz was used in microwave roasting experiments. The microwave oven could operate at five different microwave powers (90 W, 180 W, 360 W, 600 W and 800 W). The oven had a rotating plate (245 mm in diameter). *V. radiata* beans (90 g) were weighed and 20 ± 0.5 g amounts at each time were used in the form of a hollow circle in order to ensure uniform roasting and to minimize differences in the roasting degree. The experiments were conducted in triplicate at 180 W, 360 W and 600 W for 8 min, 14 min and 20 min at each roasting power. The roasting power and times were selected on the basis of preliminary experiments (data not shown).

Coffee brew preparation

For sensory analysis, the roasted beans were ground in a laboratory mill MLU-202 (Bühler, Uzwil, Switzerland) with the particle size of 300 μm. The coffee-like brew samples were produced by an electric coffee maker equipped with a paper filter. An amount of 50 g of roasted *V. radiata* bean powder was treated by passing 300 ml of bottled table water (Erikli, Kestel, Turkey) for 5 min. The temperature of water was 80 °C.

Colour measurement

L^*, a^*, b^* values of *V. radiata* beans were measured during microwave roasting by a Chroma Meter CR-200 (Minolta, Osaka, Japan). Calibration was carried out with the white colour calibration tile before the measurements. Ten replicates were measured.

Moisture content

Moisture content was measured according to the AOAC method 925.10 [20]. Approximately 2 g of samples were dried in an oven at 104 °C until the weight became consistent.

Density

Density of the beans was determined according to the procedure proposed by Lerici et al. [21] by a pycnometer using glycerin ($\rho_{20\,°C}$ = 1.26 kg·dm^{-3}).

Antioxidant activity

1,1-Diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging activity was measured using DPPH radical assay based on the method proposed by Singleton et al. [22]. The absorbance of the samples was measured by a Multiskan Sky UV-VIS spectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) at 517 nm. Based on the mean of three measurements, the DPPH radical-scavenging activity (*RSA*) was calculated using Eq. 2 and expressed in percent:

$$RSA = \frac{A_C - A_t}{A_C} \times 100 \qquad (2)$$

where A_c *is* absorbance of the control and A_t is absorbance of the sample solution.

Total phenolics content

Total phenolics content was determined using Folin-Ciocalteu reagent [23]. One ml diluted extract was mixed with 0.4 ml methanol. Then, 0.5 ml of Folin–Ciocalteu reagent was added and the mixture was shaken. After waiting for 5 min, 1 ml of 36% Na_2CO_3 solution was added to the mixture. The content was incubated in the dark for 2 h and absorbance was measured at 725 nm. The results were expressed as gallic acid equivalent.

Sensory analysis

The *V. radiata* coffee-like beverages were evaluated by 110 semi-trained panelists (52 male and 58 females) according to ISO 8586 [24]. The panelists were regular coffee drinkers and they evaluated the coffee-like beverages by comparing them to coffee. A 5-point hedonic scale (1 – dislike very much, 2 – dislike slightly, 3 – neither like nor dislike, 4 – like slightly, 5 – like very much) was used in order to evaluate four parameters (appearance, odour, flavour and overall impression) [25]. The sensory evaluation was performed according to the norm ISO 8589 [26]. A total of 9 coffee-like *V. radiata* beverages were tested on odour-free ceramic cups labelled with a 3-digit code in a random order.

Statistical analysis

Analysis of variance (ANOVA) was conducted for the independent variables. The regression coefficients of linear, quadratic and interaction terms were determined. Adequacy of the model was tested by model analysis, coefficient of determination (R^2), and lack-of-fit test. Significance of the equation was found by calculating the F-value at a probability (p) of 0.001, 0.01 or 0.05. The regression coefficients were used to create contour plots using the multiple regression analysis by Minitab Release 16.1 statistical software (Minitab, Coventry, United Kingdom).

RESULTS AND DISCUSSION

Colour

Colour is of crucial importance to the foods because it can actually change consumers' acceptability perception [27]. Furthermore, colour is one of the parameters used for process control during roasting [28]. The changes in the colour of roasted *V. radiata* beans are shown in Fig. 1. L^* value of beans tended to decrease while a^* and b^* values increased during the roasting. The increase in a^* value shows the increase in the reddish colour. However, the decrease in L^* and b^* values show a darker colour of beans (Tab. 2). This trend could be attributed to the non-enzymatic browning reactions responsible for the formation of dark coloured compounds such as melanoidins. Similar results were obtained by Uysal et al. [29], who roasted hazelnuts using a microwave–infrared roaster.

In order to achieve models for colour values, the experimental data were fitted to Eq. 1. The fitness and adequacy of the models were analysed by ANOVA (Tab. 3). The evaluation revealed that

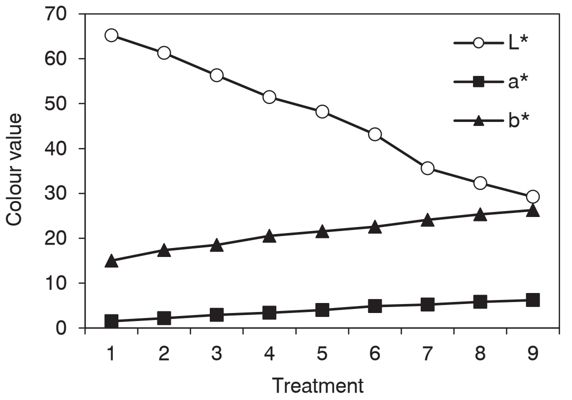

Fig. 1. Colour values of roasted *V. radiata* beans.

Parameters of treatments 1–9 are given in Tab. 1.

Tab. 2. Colour values of *V. radiata* beans during roasting.

Treatment	*MP* [W]	*t* [min]	*L**	*a**	*b**
1	180	8	65.2	1.5	15.0
2	180	14	61.3	2.2	17.4
3	180	20	56.3	2.3	18.5
4	360	8	51.5	3.4	20.5
5	360	14	48.2	4.0	21.5
6	360	20	43.1	4.9	22.6
7	600	8	35.6	5.2	24.1
8	600	14	32.3	5.9	23.6
9	600	20	29.2	6.2	26.3

Values are mean of ten separate determinations ($n = 3$). *MP* – microwave power, *t* – roasting time.

Tab. 3. Analysis of variance for the colour values of roasted *V. radiata* beans.

Source	Degrees of freedom	*L**	*a**	*b**
Regression model	5	2656.00 ***	44.94 ***	228.62 ***
Linear effect	2	2647.16 *	44.10 ***	222.81 ***
Quadratic effect	2	4.82 *	0.79 ***	5.15 ***
Cross-product	1	4.01 **	0.03	0.65 *
Residual (error)	12	5.66	0.25	1.38
Lack of fit	3	1.30	0.09	1.24
Pure error	9	4.37	0.15	0.14
Corrected total	17	2661.66	45.18	230.00
Coefficient of determination R^2		0.99	0.98	0.99

Significance level: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$.

the linear and quadratic terms were significant at $p < 0.05$ for L^* value. However, the terms were significant at the level of $p < 0.001$ for a^* and b^* values. The interaction of them was significant at $p < 0.01$ for L^* value and significant at $p < 0.05$ for b^* value. However, their interaction had no significant effect on the a^* value. The lack of fit was insignificant ($p > 0.05$) for L^*, a^* and b^* value suggesting that the models sufficiently defined the relationship between the dependent and independent variables. The regression coefficients of colour values are shown in Tab. 4. In order to better describe the relationship between the dependent and independent variables, contour plots were developed by using the regression equations (Fig. 2).

Tab. 4. Regression coefficients of the second order polynomials for response parameters of colour values of roasted *V. radiata* beans.

β_k	*L**	*a**	*b**
	$k = 1$	$k = 2$	$k = 3$
β_{k0}	45.5663 ***	4.3879 ***	22.4000 ***
β_{k1}	−14.3300 ***	1.8458 ***	4.1650 ***
β_{k2}	−3.8547 ***	0.5651 ***	1.2289 ***
β_{k11}	0.9499 **	−0.4554 ***	−1.1433 ***
β_{k22}	−0.5867	0.0350	−0.2075
β_{k12}	0.7060 **	−0.0664	−0.2856*

β_k – regression coefficients of Eq. 1 (factor 1 – roasting power, factor 2 – roasting time), k – coefficient of the intercept.
Significance level: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$.

Moisture, density and antioxidant activity

The moisture content and density are widely used criteria to specify the quality of roasted coffee beans [30]. These criteria were employed for roasted *V. radiata* beans. Although heat treatment generally destroys vitamins and various nutritional compounds that have antioxidative characteristics, certain antioxidative Maillard reaction products occur during roasting [31]. Chemical properties of roasted *V. radiata* beans are given in Tab. 5. The beans had a high antioxidant activity, which should be taken into account during roasting. The changes in the moisture content, density

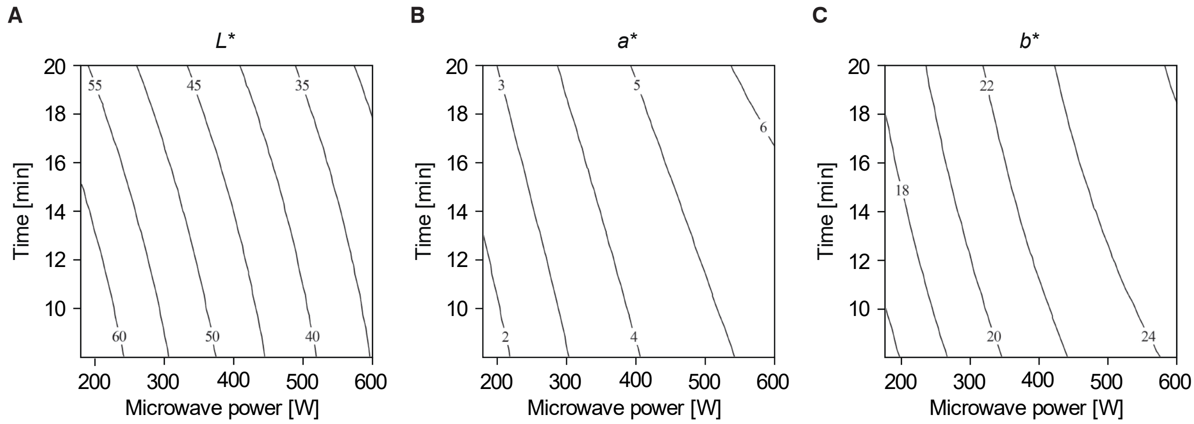

Fig. 2. Contour plots for colour values of roasted *V. radiata* beans.

A – L^* value, B – a^* value, C – b^* value.

and antioxidant activity of *V. radiata* beans during roasting are given in Fig. 3.

In order to obtain models for these values, the experimental data were fitted to Eq. 1. ANOVA (Tab. 6) revealed that the models generated for the moisture content, density and antioxidant activity were significant at $p \leq 0.001$ suggesting that the models adequately described the relationship between the dependent and independent variables. Roasting power, roasting time and quadratic effects of them had the same level of significance ($p \leq 0.001$) on the moisture content, density and

Tab. 5. Chemical and antioxidant properties of roasted *V. radiata* beans.

Treatment	*MP* [W]	*t* [min]	Moisture content [g·kg^{-1}]	Density [kg·dm^{-3}]	*RSA* [%]	Total phenolics content [mg·kg^{-1}]
1	180	8	0.8	0.8	10	2 053.2
2	180	14	0.8	0.8	20	2 111.2
3	180	20	0.7	0.7	20	2 193.6
4	360	8	0.7	0.6	20	2 154.2
5	360	14	0.6	0.6	30	2 228.5
6	360	20	0.6	0.5	30	2 381.2
7	600	8	0.5	0.5	30	2 302.6
8	600	14	0.5	0.4	40	2 523.6
9	600	20	0.4	0.4	40	2 851.3

Values are mean of three separate determinations ($n = 3$).
MP – microwave power, *t* – roasting time, *RSA* – radical-scavenging activity.

Tab. 6. Analysis of variance for the moisture content, density and antioxidant activity of roasted *V. radiata* beans.

Source	Degrees of freedom	Moisture content	Density	*RSA*
Regression model	5	0.323441 ***	0.428088 ***	0.161468 ***
Linear effect	2	0.320073 ***	0.420616 ***	0.158719 ***
Quadratic effect	2	0.003319 ***	0.007239 ***	0.002191 ***
Cross-product	1	0.000049	0.000234 ***	0.000558 *
Residual (error)	12	0.000200	0.000158	0.000406
Lack of fit	3	0.000148	0.000135	0.000395
Pure error	9	0.000052	0.000023	0.000011
Corrected total	17	0.323641	0.428246	0.161874
Coefficient of determination R^2		0.99	0.99	0.99

Significance level: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$. *RSA* – radical-scavenging activity.

antioxidant activity whereas their interaction for density and antioxidant activity were significant at $p < 0.001$ and $p < 0.05$, respectively. The lack of fit was insignificant ($p > 0.05$) for moisture content, density and antioxidant activity values suggesting that the models sufficiently defined the relationship between the dependent and independent variables. Regression coefficients of the second-order polynomial models are shown in Tab. 7.

Taking into consideration the regression equations, contour plots were generated (Fig. 4). As the roasting power and time increased, the moisture content of beans decreased. The decrease in moisture content was probably due to dehydration during roasting. As the roasting power and time increased, density of the beans decreased. The decrease in density could be attributed to the internal gas formation owing to heat-induced reactions that increased the bean volume and de-

Tab. 7. Regression coefficients of the second order polynomials for response parameters of moisture content, density and antioxidant activity for roasted *V. radiata* beans.

β_k	Moisture content	Density	*RSA*
	$k = 1$	$k = 2$	$k = 3$
β_{k0}	0.582444 ***	0.539111 ***	0.313705 ***
β_{k1}	−0.156417 ***	−0.179667 ***	0.107333 ***
β_{k2}	−0.049549 ***	−0.056993 ***	0.042770 ***
β_{k11}	0.029361 ***	0.043556 ***	−0.023649 ***
β_{k22}	−0.002833	0.001250	−0.003833
β_{k12}	0.002471	0.005392 ***	−0.008324 *

β_k – regression coefficients of Eq. 1 (factor 1 – roasting power, factor 2 – roasting time), k – coefficient of the intercept.
Significance level: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$.
RSA – radical-scavenging activity.

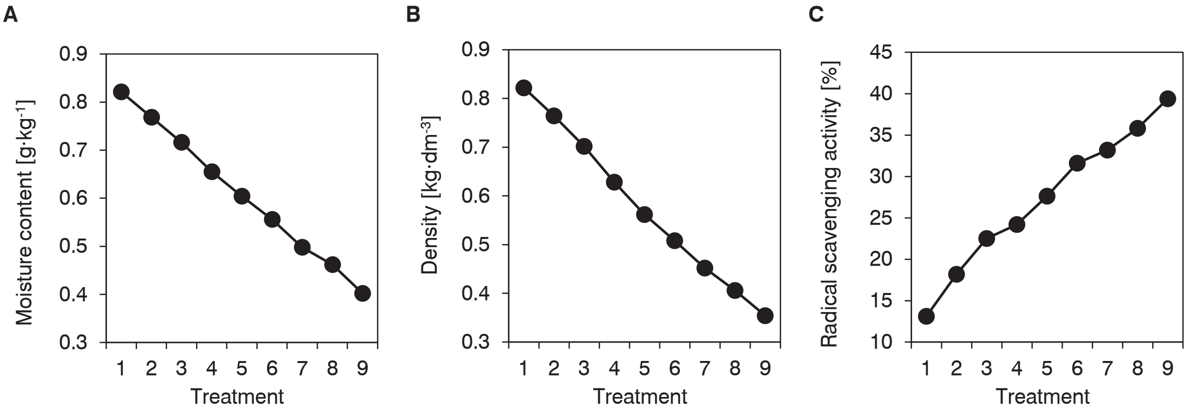

Fig. 3. Moisture content, density and antioxidant activity of roasted *V. radiata* beans.

A – moisture content, B – density, C – radical-scavenging activity.

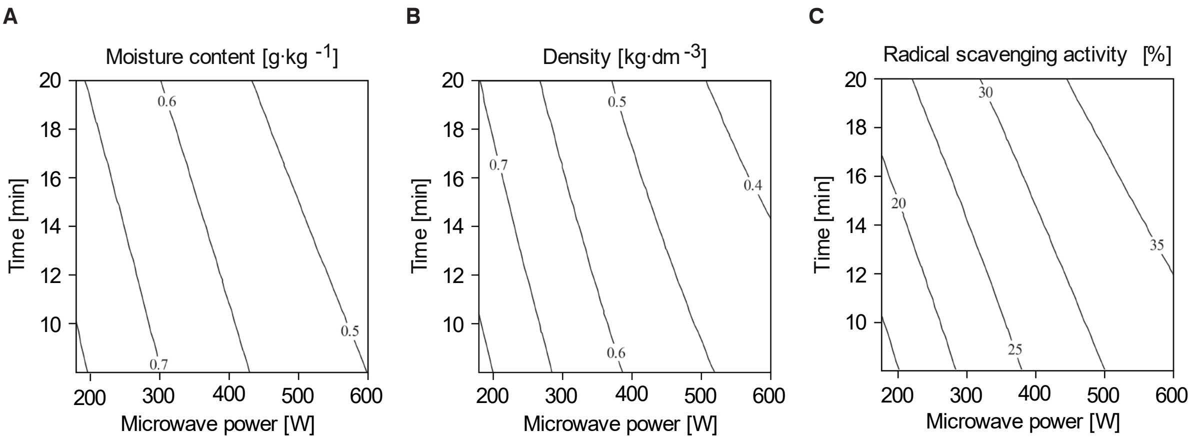

Fig. 4. Contour plots for chemical and antioxidant properties of roasted *V. radiata* beans.

A – moisture content, B – density, C – radical-scavenging activity.

stroyed volatiles, which caused a decrease in bean mass [32]. The roasting process affected antioxidant activity of *V. radiata* beans. Antioxidant activity of *V. radiata* beans gradually increased during roasting. The increase in antioxidant activity could be attributed to the effects of novel antioxidant substances that were formed during the roasting process, such as Maillard reaction products [33].

Sensory properties

Roasting is crucial for improving sensory characteristics of coffee. Thus, it was hypothesized that optimization of roasting parameters can increase the share of *V. radiata* in well-accepted commercial coffee-like beverages. Appearance, odour, flavour and overall impression are the substantial sensory properties of coffee beverages [34]. The same attributes could be used for *V. radiata* coffee-like beverage (Tab. 8). Data on changes in the sensory attributes of *V. radiata* coffee-like beverages are given in Fig. 5. The sensory scores were fitted to Eq. 1 to generate models for sensory properties. ANOVA (Tab. 9) revealed that the models generated for the appearance, odour, flavour and

Tab. 8. Sensory properties of roasted *V. radiata* beans.

Treatment	*MP* [W]	*t* [min]	Appearance	Odour	Flavour	Overall impression
1	180	8	1.8	1.5	1.8	2.0
2	180	14	3.1	3.2	3.2	3.1
3	180	20	3.1	3.1	3.0	2.9
4	360	8	2.7	2.6	2.4	2.3
5	360	14	4.7	4.7	4.9	4.9
6	360	20	3.3	3.7	3.9	3.9
7	600	8	2.3	2.9	2.9	2.3
8	600	14	3.0	3.1	3.2	2.9
9	600	20	1.2	1.3	1.3	1.2

Values are mean of three separate determinations ($n = 3$).
MP – microwave power, *t* – roasting time.

Tab. 9. Analysis of variance for the sensory properties of roasted *V. radiata* beans.

Source	Degrees of freedom	Appearance	Odour	Flavour	Overall impression
Regression model	5	15.3035 ***	17.0535 ***	16.3609 ***	15.9940 ***
Linear effect	2	1.3764 **	0.5721	0.5783	2.0019
Quadratic effect	2	10.6226 ***	10.7982 ***	11.1368 ***	11.7272 ***
Cross-product	1	3.3045 ***	5.6832 ***	4.6458 ***	2.2703 ***
Residual (error)	12	0.7308	0.7768	2.3539 ***	2.4083
Lack of fit	3	0.7302	0.7713	3.3437	2.4031
Pure error	9	0.0005	0.0055	0.0103	0.0052
Corrected total	17	16.0343	17.8303	18.7149	18.4076
Coefficient of determination R^2		0.95	0.95	0.87	0.87

Significance level: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$.

Tab. 10. Regression coefficients of the second order polynomials for response parameters of sensory properties of roasted *V. radiata* beans.

β_k	Appearance	Odour	Flavour	Overall impression
	$k = 1$	$k = 2$	$k = 3$	$k = 4$
β_{k0}	4.42580 ***	4.46278 ***	4.54417 ***	4.4651 ***
β_{k1}	−0.26167 *	−0.09667	−0.08500	−0.2708 *
β_{k2}	0.09617	0.11750	0.13383	0.2139
β_{k11}	−1.10858 ***	−1.16667 ***	−1.15306 ***	−1.2765 ***
β_{k22}	−1.21833 ***	−1.18417 ***	−1.23167 ***	−1.1742 ***
β_{k12}	−0.64052 ***	−0.84000 ***	−0.75948 ***	−0.5309 **

β_k – regression coefficients of Eq. 1 (factor 1 – roasting power, factor 2 – roasting time), k – coefficient of the intercept.
Significance level: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$.

overall impression were significant ($p \leq 0.001$) at descibing the relationship between the dependent and independent variables. The interaction of roasting power level, exposure time and quadratic effects of them for sensory values were significant at $p \leq 0.001$. The lack of fit was insignificant ($p > 0.05$) for sensory values suggesting that the model adequately defined the relationship between the dependent and independent variables. R^2 of the sensory values exceeded 0.80, which can be regarded as adequately high for sensory variables determined by a hedonic scale. PRASAD and NATH [35] stated that the R^2 should be at least 0.80 to fit into the model. The regression coefficients of the second-order polynomial equations for the sensory properties are given in Tab. 10.

Taking into consideration the regression equations, contour plots were generated (Fig. 6). As the roasting power and roasting time increased, the sensory scores increased and then decreased. The panelists gave the lowest scores to very lightly roasted and very dark roasted beans. This result can be explained by insufficient development of aroma and flavour components during light roasting, and by degradation of aroma and flavour components formed in dark roasted beans. These findings are also supported by results of CHUNG et al. [36] who roasted coffee beans.

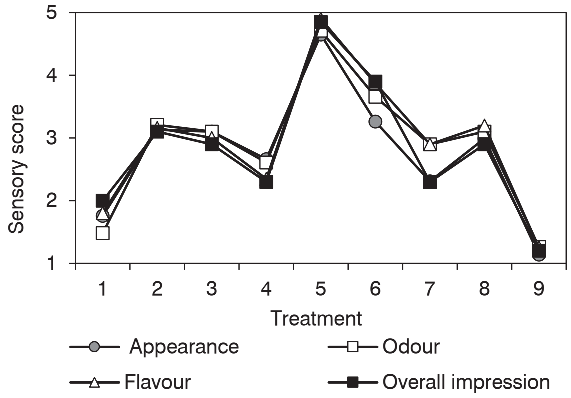

Fig. 5. Sensory scores of *V. radiata* coffee-like beverages.

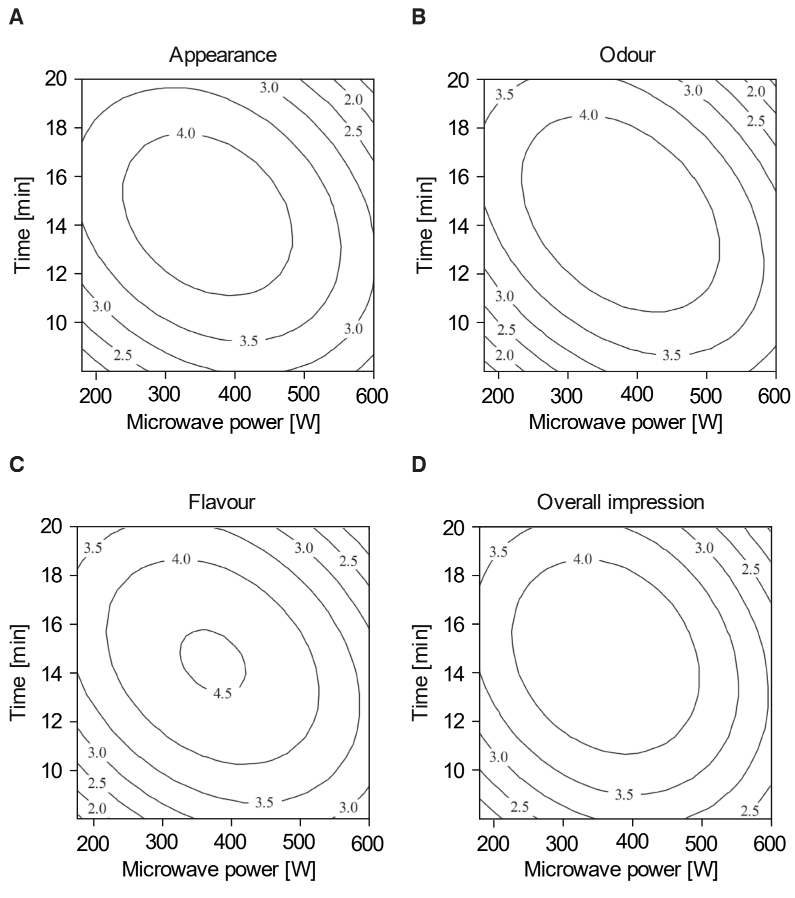

Fig. 6. Contour plots for sensory properties of roasted *V. radiata* beverages.

A – appearance, B – odour, C – flavour, D – overall impression.

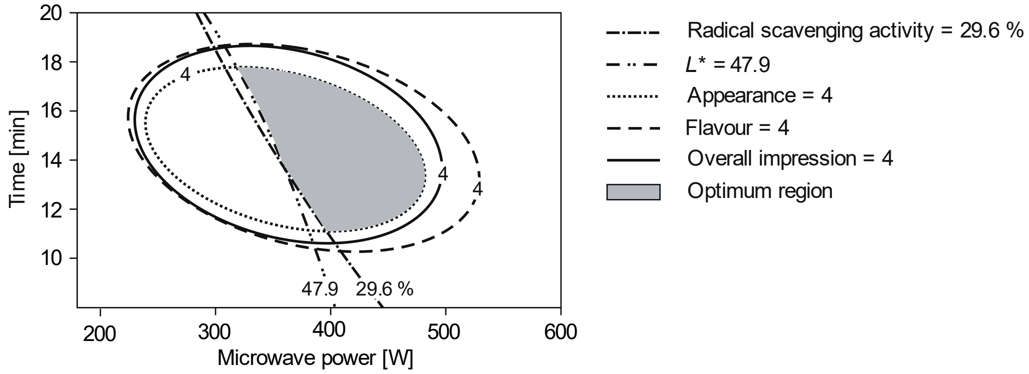

Fig. 7. Optimum region of microwave roasting of *V. radiata* beans.

Tab. 11. Predicted and experimental values at optimum conditions.

Response	Predicted value	Experimental value	
		Mean	Range
*Colour value L**	46.52	45.33	45.12 – 47.36
Moisture content [g·kg^{-1}]	0.58	0.57	0.56 – 0.59
Density [kg·dm^{-3}]	0.54	0.53	0.52 – 0.54
Radical-scavenging activity [%]	30.1	29.3	28.1 – 30.5
Overall impression	4.80	4.5	3.8 – 4.7

Mean of three replications. is given. Roasting was carried out at 360 W for 16 min.

Optimum roasting region and model validation

Since the characteristic aroma and flavour components develop intensively at a high roasting level, the optimum region of the superimposed contour plots was determined by the L^* value lower than 47.90 [7], *RSA* greater than 29.6 %, appearance scores greater than 4, flavour score greater than 4 and overall acceptability score greater than 4. The developed plots for the L^* value, *RSA*, appearance, flavour and overall impression, together with criteria outlined above, generated an optimum region in the superimposed plot (Fig. 7). Adequacy of the models at the predicted optimum conditions were analysed by a separate experiment involving *V. radiata* beans roasted at 360 W for 16 min (Tab. 11). The results showed that predicted and experimental results were statistically indifferent ($p > 0.05$). Furthermore, the predicted and experimental results had strong correlation suggesting that the generated models were sufficiently defining the relationship between the dependent and independent variables. The predicted values of L^*, moisture content, density, *RSA* and overall impression were determined to be 46.52, 0.58 g·kg^{-1}, 0.54 kg·dm^{-3}, 30.1 % and 4.80, respectively.

CONCLUSIONS

Microwave oven-roasting conditions for *V. radiata* beans were optimized to obtain roasted beans with high antioxidant activity and desirable sensory characteristics. Roasting increased antioxidant activity and developed positive sensory characteristics of *V. radiata* beans. Predictive models sufficiently identified the roasting characteristics and sensory properties as a function of roasting power and exposure time. Optimum microwave-roasting conditions were found by predictive models using RSM. These results are substantial to acquire roasted *V. radiata* beans of favourable quality even using microwave ovens used in homes in a practical and appropriate way. Successful optimization of the *V. radiata* beans roasting processes was achieved by using the desirability functions of RSM. Future studies should be planned to determine the effects of other roasting techniques on aroma and flavour development in *V. radiata* beans.

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