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SPECIAL ISSUE ARTICLE

Optimization of Roasting Conditions of Salak Seed as Coffee Substitute and Its Physicochemical Properties

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ABSTRACT

The growing attention towards utilizing salak seeds as a substitute for coffee has increased due to the presence of caffeine and its health-enhancing properties. The present study aimed to determine the optimum roasting conditions for salak seed coffee (SSC) with high total phenolic content (TPC) and desirable lightness (L^*) using response surface methodology (RSM). Regular SSC was produced at optimal roasting temperature and time of 189.36 ˚C and 39.54 min, respectively. An instant SSC was produced by hot water extraction at 90 $^{\circ}C$ of regular SSC, followed by freeze drying. Physicochemical and antioxidant properties of regular and instant SSC were compared. The moisture, TPC, pH, and solubility of instant SSC were significantly higher ($p < 0.05$) than those of regular SSC. Furthermore, instant SSC appeared to be lighter than that of regular SSC. The IC_{50} of instant SSC was 0.23 mg/mL, indicating higher antioxidant capacity than that of regular SSC (0.37 mg/mL). There was no significant difference ($p > 0.05$) in terms of caffeine content between regular and instant SSC. The total number of volatile compounds identified in instant and regular SSC was 140 and 65, respectively. The quantitative descriptive analysis (QDA) results showed that the intensity for all the sensorial attributes (e.g. colour, nutty flavour, bitterness, aftertaste and body) tested was higher in instant SSC. The retention of flavor compounds, enhanced solubility and antioxidant capacity of instant SSC indicated that the commercialization of SSC as a coffee substitute is promising.

Keywords: Antioxidant, Coffee substitute, Instant coffee, Optimization, Salak seed

Introduction

Coffee is one of the most popular beverages in the world. It is consumed as an energizer to reduce fatigue and diminish the risk of developing Parkinson's disease.[1,2] Despite these benefits, coffee is also the primary dietary source of caffeine, and excessive consumption has been associated with stress, insomnia, anxiety, and osteoporosis.[2] Alternatively, decaffeinated coffee containing 97% extracted coffee with 1 to 5 mg/150 mL of caffeine, as compared to 60 to 180 mg/150 mL in general coffee, has been long introduced. Decaffeinated coffee generally has a weaker flavour, taste, and aroma than regular coffee, making it less preferred by consumers. Various coffee substitutes have since been developed. Fruit seed has been used as a coffee substitute due to its low caffeine content, reducing caffeine intake.[1] Coffee substitution

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involves replacing coffee beverages without changing the overall taste of coffee.[3] The production of coffee beverages has expanded, with other fruit seeds used to produce coffee powder, including durian seed, date palm seed, and baobab seed.[1,4,5]

Salak fruit (*Salacca zalacca*) is an exotic fruit grown in Indonesia, Malaysia, Thailand, and Myanmar. The skin and seed of the Salak fruit are normally discarded as waste, although studies have shown both parts of the fruit are rich in nutrients, including carbohydrates, protein, and fat, and antioxidants.[6,7] For example, salak has been applied in various fields from the food industry as a natural colourant in bubble pearl until the medical field in the production of natural soap to help in skin problems due to its high total phenolic content (TPC).[6,8] More interestingly, the salak fruit seed was proven to have lower caffeine content than other commercialized coffees such as mocha and Arabica coffee.

Roasting is essential to coffee production to heat the beans to high temperatures, which affect 30% of coffee taste.[9,10] The aroma of roasted coffee is the result of many mixtures of volatile compounds, with over 800 volatile compounds identified, which include alcohols, aldehydes, ketones, carboxylic acids, esters, furans, furanone, and phenols.[11] It is important to halt the roasting process at a point where the desired antioxidants are optimized. The commercialization of newly introduced coffee and/or coffee substitutes would be more successful when improved functional properties are achieved.

Despite increasing interest in salak seed as a potential coffee substitute, limited studies have examined how roasting conditions influence its bioactive compounds and related functional properties. Specifically, there is a lack of systematic optimization using statistical methods. To address this gap, this study explores the effects of roasting conditions on salak seed's bioactive compounds and physicochemical properties, aiming to identify the optimal roasting process for producing salak seed as a coffee substitute. The regular SSC made under the optimized conditions is further processed into instant SSC, and a comparison study of the properties between instant and regular SSC was conducted, focusing on physicochemical, functional, and sensory characteristics.

Materials and methods

List of chemicals and reagents

Gallic acid solution, 2,2-Diphenyl-1-picrylhydrazyl (DPPH), and ascorbic acid were purchased from Sigma-Aldrich (St. Louis, USA). Sodium carbonate anhydrous and dichloromethane (analytical reagent grade) were obtained from Bendosen. Folin-Ciocalteu reagent, ethanol, and methanol (gas chromatography grade) were obtained from Merck (Darmstadt, Germany), and caffeine standard from Millipore, Bedford, MA, USA.

Table 1. The coded and uncoded values are used in the optimization of roasting conditions.

Roasting Parameters (Independent Variables)	Range & Levels				
	Lowest	Low	Centre	High	Highest
	$-\alpha$	–1	0	+1	$+\alpha$
Temperature (°C), X_1	180	195	210	225	240
Time (min), X_2	30	37.5	45	52.5	60

Optimization of roasting conditions of salak seeds

Fifty kilograms (50 kg) of salak fruits were purchased from a local market in Kota Bharu, Kelantan, Malaysia. The preparation of salak seeds for roasting followed the methods of Prayogo et al. 12 and Purnamayanti et al. 10, with modifications. First, the salak seeds were manually removed from the flesh before being washed of any dirt and residue. Then, the salak seeds were dried in a cabinet dryer at 50 °C for 24 h before being coarsely pounded and roasted.

The optimum roasting conditions of salak seeds were determined using RSM. MINITAB 19 statistical software was used for experimental design and analysis. The central composite design (CCD) was employed to study the combined effect of two independent variables, which include roasting temperature and time. These two independent variables were coded as X_1 and X_2 and each variable set at the 3 levels was –1, 0 and +1 as shown in Table 1.

Roasting temperature and time were carried out within the range using an electrical baking oven by considering the roasting conditions adopted from Natania & Wijaya[1] and Susila et al.[7] The TPC (mg GAE/100 g) and lightness (L^*) of roasted salak seeds were taken as the responses, Y. Following the method described by Montgomery,[13] the response functions (Y) were partitioned into linear, quadratic, and interactive components and were represented using the second-order polynomial function as shown in Eq. (1) below:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_1X_1 + b_4X_2X_2 + b_5X_1X_2 \quad (1)$$

Where Y represents the predicted response variables, b_0 is the value for the fixed response variables at the central point of the experiment, b_1 and b_2 are linear coefficients, b_3 and b_4 are square (or quadratic)

coefficients, and b_5 is the interaction coefficient. Meanwhile, X_1 and X_2 are independent variables in coded values.

Once the roasted salak seeds had cooled to the temperature of the surrounding room, they were ground using a multifunctional grinder machine (GM-800S1, KGC, China) and then sieved through a 60-mesh sieve to produce coffee powder. Prior to analysis, the coffee grounds were stored in aluminium foil at room temperature.

Preparation of regular and instant salak seed coffee (SSC)

The regular SSC produced at optimised roasting conditions was brewed with hot water (90 ˚C) at an SSC: water ratio of 1:16, respectively. The brewed extract was placed in a freezer at –40 ˚C. Then, it was transferred into a freeze dryer (ALPHA 1-4 LD plus, Martin Christ Gefriertrocknungsanlagen GmbH, Osterode am Harz, Germany). The frozen extract was then turned into a thin solid film before it was crushed into granules to obtain instant SSC.

Determination of colour, pH, and solubility of regular and instant salak seed coffee (SSC)

The colour of the sample was determined by using a chromameter (CR-400 Konica Minolta, Tokyo, Japan) based on the $L^*a^*b^*$ colour system as described by Tsai et al.[14] In this system, L^* represents darkness to lightness (0 to 100), a* (positive a^*: red, negative a^*: green) and b^* (positive b^*: yellow, negative b^*: blue).[14] The chromameter was touched on the surface of SSC, which was placed in a petri dish not more than half full. The net color difference between regular and instant SSC was evaluated following Chugh et al.[15] using the parameters L^*, a^*, and b^* using Eq. (2):

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

The pH of the SSC extract was measured with a pH meter (HANNA Instruments, Woonsocket, RI, USA). The moisture content of SSC was measured using an A&D MX-50 Moisture Analyzer (A&D Company Ltd., Tokyo, Japan). The total soluble solid (TSS) of the coffee extract was measured using a handheld refractometer following Rohaya et al.[16]

The solubility of SSC was determined using a gravimetric method. One gram (1 g) of SSC was mixed with 50 mL of distilled water by constantly stirring until a saturated solution was attained. The solution was filtered using Whatman filter paper No. 41. Ten milliliters (10 mL) of the filtrate was pipetted into a known weight watch glass. The watch glass, together with 10 ml filtrate, was weighed before drying at 100 ˚C in a drying oven, cooled, and reweighed. The drying process was repeated until a constant weight was obtained. Solubility was calculated as part of water required to dissolve 1 part of SSC using Eq. (3), as described by Qureshi et al.,[17] as shown below:

$$Solubility = \frac{(w_2 - w_3)}{(w_3 - w_1) \times \text{Density of water}} \quad (3)$$

Where;

- w_1 = Weight of empty watch glass (g)
- w_2 = Weight of watch glass + 10 ml solution (g)
- w_3 = Weight of watch glass + dry solution (g)
- Density of water = 1 g/ mL

Determination of total phenolic content (TPC) and 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity

The extracts of roasted SSC were prepared following the methodology outlined by Odžaković et al.[18] The SSC was subjected to hot deionized water extraction at a temperature of 90 ˚C using a ratio of 0.5:100 (m/v). The extraction process involved stirring continuously for 5 minutes. The sample was subjected to centrifugation at a speed of 2000 rev/min for 5 minutes. The supernatant was stored at a temperature of –20 ˚C until it was ready for analysis.

The TPC of SSC extract was determined spectrophotometrically (UV/Vis Thermo Scientific Genesys 20 spectrophotometer, Waltham, MA, USA) as described by Brzezińska et al.[19] 40 μL of extract was diluted with deionised water (3.16 ml) and mixed with Folin-Ciocalteu reagent (200 μL) and 75 % w/v sodium carbonate solution (600 μL). The absorbance was measured at 765 nm after 2 hours of storage in a dark place. Gallic acid (0.0–0.8 mg/mL) was used as a standard solution, and the results were expressed as mg of gallic acid per 100 g of sample (mg GAE/100 g). The standard curve for absorbance versus different concentrations of gallic acid was plotted, and the TPC in the sample was determined using Eq. (4), following the procedure described by Brzezińska et al.,[19] as shown below:

$$\text{TPC (mg GAE/100 g)} = \frac{\left[\frac{(Absorbance_{sample} - Absorbance_{blank})}{slope}\right]\left[\frac{Total\ volume\ of\ extract}{Volume\ of\ extract\ used}\right]}{Weight\ of\ sample \times 1000} \times 100 \quad (4)$$

The antioxidant activity of SSC extract was assessed using the DPPH method as described by Seow et al.[20] with some modifications. The extract was subjected

to testing at five concentrations (0.0–0.8 mg/ml). A 0.1% concentration of DPPH in ethanol was prepared, with ascorbic acid serving as the positive control. The absorbance of the mixture was determined at a wavelength of 517 nm. The capacity of SSC to remove DPPH radical was assessed using Eq. (5) following the method described by Seow et al.:[20]

$$\text{Scavenging (\%)} = \left(\frac{\text{Absorbance}_{\text{control}} - \text{Absorbance}_{\text{sample}}}{\text{Absorbance}_{\text{control}}}\right) \times 100 \quad (5)$$

Then, the DPPH scavenging activity of SSC extract was expressed as 50 % inhibition concentration (IC_{50}).

Determination of caffeine in salak seed coffee (SSC)

The caffeine content was quantified following Ihsan et al.[21] Caffeine (0.005–0.04 mg/mL) was used as a standard solution. A sample extract was prepared by dissolving 50 mg of coffee powder in 100 mL of distilled water, which was then heated to a temperature of 90 ˚C and stirred for 30 minutes using a magnetic stirrer. The solution was filtered into a 100 mL volumetric flask and diluted to the mark with distilled water. An aliquot of 25 mL was extracted with an equal volume of dichloromethane using a separatory funnel. Then, the aqueous phase was extracted three times again with 25 mL of dichloromethane for each extract. The organic phase was transferred into a 100 mL volumetric flask, marked up with dichloromethane, and then used as a test solution for caffeine content identification. The solution was measured using a Lambda 365 UV/Vis spectrophotometer with UV Lab software at a wavelength of 275 nm, which corresponds to the reported absorption maximum of caffeine in dichloromethane as stated by Ihsan et al.[21] The caffeine concentration in the sample was calculated using Eq. (6), expressed in % (w/w), as described by Ihsan et al.[21]

$$\text{Caffeine content (\%)} = \left(\frac{\text{Caffeine mass obtained}}{\text{Sample mass}}\right) \times 100 \quad (6)$$

Identification of volatile organic compounds (VOCs) in salak seed coffee (SSC)

The volatile compound of the sample was determined using the method prescribed by Aprilia et al.[11] A sample of 2g was wrapped in filter paper before being placed in the Soxhlet apparatus. Methanol was placed in a 250 mL round flask before the heating mantle was turned on, and the sample was extracted until it was cleared. The extract was concentrated using a rotary evaporator.

The profiling of volatile compounds was performed using Gas Chromatography-Mass Spectrometry (GC-MS) (7890A-Agilent Technologies, Santa Clara, CA, USA) with electron impact mass spectrometry equipped with a capillary column and coupled to an ion trap mass spectrometer. Helium gas was used as the carrier gas with a flow rate of 45.3 cm^3/s. The oven temperature was set to 40 ˚C for 4 min. Then, it increased to 280 ˚C at 20 ˚C/min, then held for 13 min. The injection temperature was set at 240 ˚C. The ion surface and interface temperature were set to 200 ˚C. The ionization energy was 70 eV, and the scan mass was within a range of 50–600 m/z. 1 μL of extract was injected into the port with an injection temperature of 40 ˚C.

Quantitative descriptive analysis (QDA) of brewed salak seed coffee (SSC)

The quantitative descriptive analysis (QDA) was carried out following Nascimento et al.[22] and Cai et al.[23] The brewed coffee was prepared by dissolving 50 g of SSC powder in 500 mL of hot water (80 ˚C) for 6 min before filtration. All samples were served at the same time to avoid bias. A volume of 20 mL of samples was placed in a small 30 mL plastic cup bearing a three-digit random number. Panelists were provided with mineral water to serve as a neutralizer.

The descriptive sensory panel consisted of 10 trained panelists. The determination of sample attributes was carried out in the first session. Each panelist was instructed in the identification and differentiation of the fundamental sensory characteristics of a coffee. Descriptive vocabulary pertaining to sensory attributes of coffee, adopted from Nascimento et al.[22] was furnished to the panelists to facilitate their discussion. The selection of core sensory attributes was based on both a review of coffee sensory literature and outcomes of panel consensus. The list of descriptors was refined to a set of five core sensory attributes consistently perceived across the samples, which were appearance (color), flavor (nutty), bitterness, aftertaste, and body. These descriptors represent the most perceptually dominant and relevant characteristics commonly used in the sensory evaluation of coffee and coffee substitutes, particularly in studies involving Coffea arabica and fruit-seed-based coffee analogues.[22,23] The second session involved the first evaluation of the intensity of regular and instant SSC, which was done individually using the dominant attributes on a numerical ordinal of 10. The last session involved the final QDA testing, conducted by the panelists who assessed the intensity of designated attributes using a 10-unit ordinal scale.

Table 2. Effect of roasting temperature and time on two independent variables.

	Independent variables		Dependent variables			
			Y_1		Y_2	
Run	X_1	X_2	Experimental	Predicted	Experimental	Predicted
1	195	37.5	40.77	38.906	53.62	52.876
2	225	37.5	22.18	20.682	43.41	42.931
3	195	52.5	36.57	36.568	50.49	49.826
4	225	52.5	19.78	20.144	42.16	41.761
5	188.79	45	47.96	48.969	49.24	49.999
6	231.21	45	23.98	24.471	36.88	37.264
7	210	34.39	20.38	22.447	50.93	51.558
8	210	55.61	20.98	20.413	48.06	48.574
9	210	45	25.80	25.760	43.38	43.152
10	210	45	25.80	25.760	43.38	43.152
11	210	45	25.80	25.760	43.38	43.152
12	210	45	26.40	25.760	43.40	43.152
13	210	45	26.40	25.760	43.40	43.152

X_1 = temperature (°C); X_2 = time (min); Y_1 = TPC, total phenolic content (mg GAE/100 g); Y_2 = lightness (L^*). Experimental values are expressed to two decimal places according to measurement precision, while predicted values are shown to three decimal places as generated by the model.

Statistical analysis

All measurements were performed three times (n = 3). The values were analysed statistically using an independent samples t-test. The significant difference was set at 5 % level ($p < 0.05$). The optimum conditions predicted by the MINITAB software 19 were used for a new run of the experiment. The experimental value of responses (e.g., TPC and lightness) was compared to the predicted value of the response. This means that the optimum conditions predicted by MINITAB software were accepted if there was no significant difference at 5 % level.

Results and discussion

Optimization of the roasting conditions of salak seed

The experimental values for TPC and lightness of salak seeds under different roasting conditions are presented in Table 2. The regression coefficients for the second-order polynomial equations and the results for the linear, quadratic, and interaction terms are presented in Table 3. The second order polynomial model for predicting TPC and lightness is given in Eqs. (7) and (8), respectively.

$$Y_1 = 25.760 - 12.249\,X_1 - 1.017\,X_2 + 10.96\,X_1X_1 - 4.33\,X_2X_2 + 0.90\,X_1X_2 \quad (7)$$

$$Y_2 = 43.152 - 6.367\,X_1 - 1.492\,X_2 + 0.479\,X_1X_1 + 6.914\,X_2X_2 + 0.940\,X_1X_2 \quad (8)$$

Where Y_1 is the TPC, Y_2 is the lightness, and X_1 and X_2 are the coded variables for temperature and time, respectively.

Referring to Table 2, the proposed model was adequate with very satisfactory values of the coefficients of determination (R^2) of 98.38 % and 98.50 % for TPC and lightness, respectively. In comparison, the adjusted R^2 for TPC and lightness (L^*) were 97.22 % and 97.42 %, respectively. These high values of R^2 and adjusted R^2 (>75%) demonstrated a strong correlation between the experimental and predicted response values (i.e., goodness of fit of the regression model) and hence validated the results obtained.[24]

The linear and square effects of the independent variables, as well as their interactions in the response were evaluated by analysis of variance (ANOVA) to fit the response function and experimental data.[9] The model fit well with experimental data, as indicated by a significant p-value ($p < 0.05$). The lack-of-fit was used with a non-significant result ($p > 0.05$) was desirable, which demonstrated the relationship between factors (e.g. temperature and time of roasting) and the responses (e.g. TPC and lightness).[9] As shown in Table 3, both lack-of-fit was not significant for TPC and lightness (L^*) of roasted salak seeds. Therefore, the proposed Eqs. (1) and (2) were adequate with no significant lack-of-fit, and high R^2 values for all responses.[25]

As shown in Fig. 1, the interaction between variables (e.g., temperature and time) was significant, considering both contour plots of TPC (Fig. 1a and L^* (Fig. 1b)) were elliptic in shape. Consistent with the findings of Chung et al.,[25] the surface plot in Fig. 1b showed that the TPC of coffee extract decreased

Table 3. Estimated regression coefficients of second-order polynomial model for optimization of total phenolic content (TPC) and lightness (L^*) of roasted salak seeds.

Regression coefficient	TPC (mg GAE/100 g)	Lightness (L^*)
b_0	25.760*	43.152*
b_1	−12.249*	−6.367*
b_2	−1.017*	−1.492*
b_3	10.960*	0.479*
b_4	−4.330*	6.914*
b_5	0.900	0.940
R^2	0.984	0.985
$Adj\ R^2$	0.972	0.974
Lack-of-fit	0.061	0.142

*Significant at $p < 0.05$.

with increasing roasting temperature and time. This observation was also in line with that reported by Hasbullah et al.[26] In addition, the surface plot shown in Fig. 1d revealed that the L^* value decreased with increased roasting temperature and time, which was in line with Halim-Lim et al.[9]

The optimal roasting temperature and time were 189.36 ˚C and 39.54 min, respectively. At these optimized conditions, the predicted TPC and lightness of roasted salak seeds were 47.89 mg GAE/100 g and 52.88, respectively. The results of the current study were consistent with those of Susila et al.7, who recommended that the roasting temperature of salak seeds should be within the range of 180–200 ˚C for optimal coffee quality. Medium-light roast color (L* ≈ 37–57) is considered favorable for maintaining phenolic content, as lighter roasts are associated with reduced thermal degradation of heat-sensitive compounds.[20] Accordingly, samples with higher L* values are expected to exhibit greater TPC.

Physicochemical characteristics of salak seed coffee (SSC) powder

The physicochemical characteristics of regular and instant SSC were compared and evaluated based on their color, moisture content, pH, solubility, TSS, TPC, antioxidant activity, and caffeine content (Table 4). The L^*, a^*, and b^* values of instant SSC were significantly higher ($p < 0.05$) than those of regular SSC, making it appear slightly lighter. Furthermore, the color difference between regular and instant SSC could be quantified based on the value of ΔE. Based on this classification system, ΔE can be categorized as: 0 to 0.5 = “not noticeable”, 0.5 to 1.5 = ”slightly noticeable” and >1.5 = ”noticeable”.[27] The total color difference (ΔE) was 1.9, suggesting that the process of making instant SSC resulted in a noticeable instrumental colour difference. Although instant coffee is known to be lighter (i.e., higher lightness), the increase in redness makes it meet the criteria for desirable coffee.[28]

The moisture content of regular SSC (6.52 %) was significantly ($p < 0.05$) lower than that of instant SSC (9.88 %). Similarly, the moisture content of regular SSC was 6.24% as reported by Susila et al.[7] These results were considered acceptable for not exceeding 12.5% as stipulated by Othman & Muhammad.[29] The pH of instant SSC (6.81) was significantly higher ($p < 0.05$) than that of regular SSC (5.94). This could be due to acid degradation during the extraction and freeze-drying process of instant coffee, resulting from the application of heat.[30] Solubility is the maximum amount of a substance dissolved in a solvent at a given temperature and volume.[30] The results showed that more solvent (698.77 mL) was required to dissolve one part of solute in regular SSC than in instant powder (22.53 mL). The regular and instant SSC were considered slightly soluble and soluble, respectively, based on Qureshi et al.[17] The increased solubility of coffee could have been due to mass transfer of most thermostable polysaccharides, such as cellulose and hemicellulose, into the coffee extract during hot water extraction, rendering it an instant beverage.[31]

The TSS of instant SSC (1.27) was significantly higher ($p < 0.05$) than that of regular SSC (0.93), which is very much affected by the presence of organic acid and hence translated into high antioxidant capacity. For example, instant brewed coffee was expected to have a high value of total soluble solid as it has high antioxidant activity.[16]

TPC of instant SSC (139.09 mg GAE/100 g) was significantly higher ($p < 0.05$) than that of regular SSC (47.16 mg GAE/100 g). This was expected because instant coffee was made by sublimating frozen coffee extract to remove water, which subsequently increased the TPC.[32] However, the results from the current study were much lower than those reported in sun-dried salak seeds by Susila et al.7, 443.29 mg GAE/100 g). The lower TPC in the current study could be due to an elevated drying temperature of 50 ˚C used for salak seeds. It is known that increasing drying and roasting temperature could decrease TPC.[20] IC_{50} is the ability of a compound to inhibit the oxidizing agent by 50 % of its initial amount, expressed as mg/mL.[16] The lower the IC_{50}, the stronger the ability of a compound to inhibit oxidation, thus protecting the body’s cells from damage caused by free radicals.[33] The result indicated that the IC_{50} of coffee extract in instant SSC (0.23 mg/mL) was significantly ($p < 0.05$) higher than that of coffee extract in regular SSC (0.37 mg/mL). On the contrary, Arief & Asnawi[34] reported that the IC_{50} of fresh salak seed

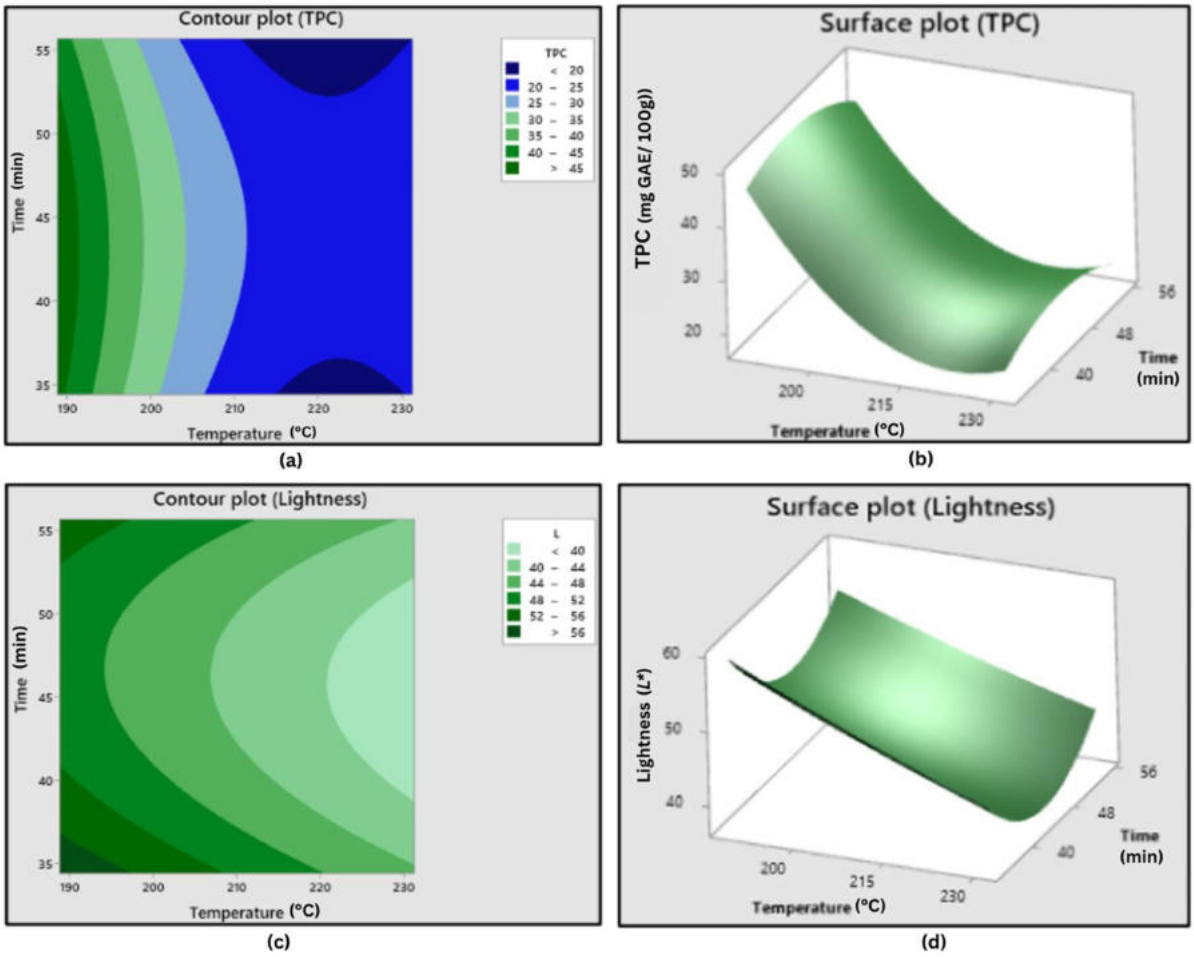

Fig. 1. Contour and surface plots of total phenolic content (TPC) and lightness (L*) of roasted salak seeds at the optimum roasting conditions (189.36 °C, 39.54 min): (a) contour plot of TPC, (b) surface plot of TPC, (c) contour plot of *L**, and (d) surface plot of *L**.

Table 4. Physicochemical properties of salak seed coffee (SSC).

	SSC	
Physicochemical parameters	Regular	Instant
Color		
*L**	52.74 ± 0.30^{b}	53.13 ± 0.06^{b}
*a**	9.64 ± 0.05^{b}	9.76 ± 0.06^{b}
*b**	22.07 ± 0.06^{b}	23.30 ± 0.12^{b}
Moisture content (%)	6.52 ± 0.23^{b}	9.88 ± 0.07^{b}
pH	5.94 ± 0.02^{b}	6.81 ± 0.02^{b}
Solubility (Part solvent required for 1 part solute)	698.78 ±1 .46^{a}	22.53 ±0 .41^{a}
Total soluble solids (°Brix)	0.93 ± 0.06^{b}	1.27 ± 0.12^{b}
Total phenolic content (mg GAE/100 g)	47.16 ±1 .25^{b}	139.09 ±1 .20^{b}
Antioxidant activity IC_{50} (mg/ ml)	0.37 ± 0.01^{a}	0.23 ± 0.01^{a}
Caffeine content (%)	0.16 ± 0.04^{a}	0.17 ± 0.06^{a}

Mean within each row with different superscript letters are significantly different at $p < 0.05$.

was 0.11 mg/mL, which is expected because the fresh salak seed was not subjected to any treatment that led to degradation of bioactive compounds.

The caffeine content of regular SSC (0.17 %) was not significantly different ($p > 0.05$) from that of instant SSC (0.16 %). Arief & Asnawi[34] reported that salak seed coffee contained 0.1009 % of caffeine, which is much lower than coffee derived from coffee beans such as mocha (0.82 %), Arabica (1.16 %), Liberica (2.19 %), and Robusta (4.5 %). These results presented SSC as a potential coffee substitute with reduced caffeine due to low caffeine intake.

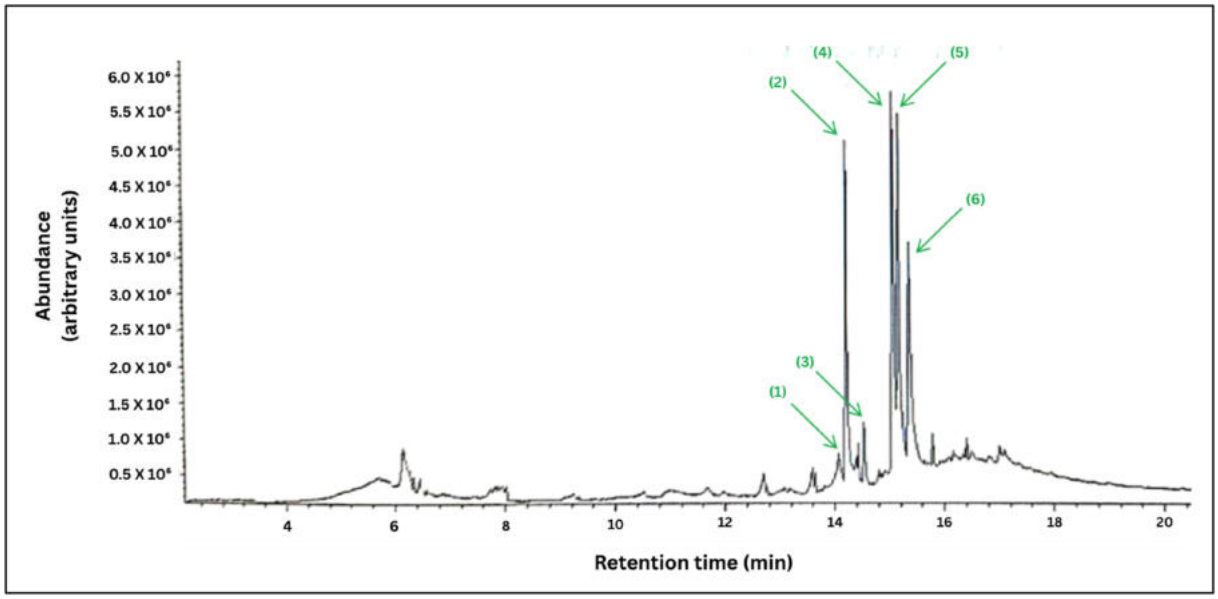

Fig. 2. Chromatogram spectrum of regular SSC extract. The x-axis represents retention time (min) and the y-axis represents ion abundance (arbitrary units), corresponding to the signal intensity detected during analysis.

Profiles of volatile organic compounds (VOCs) in salak seed coffee (SSC)

From this study, it was found that instant SSC retains more flavor compared to regular SSC. This result is consistent with the higher TSS content in instant SSC, as well as sensory testing. In coffee processing, roasting causes the loss of volatile compounds. However, the sublimation process during freeze-drying at low temperatures used to prepare instant SSC slows down volatilization and degradation, thereby preserving a larger array of heat-sensitive compounds.[35] As shown in Fig. 2, regular SSC was dominated by lipid-soluble fatty acid methyl ester, including methyl 14-methylpentadecanoate (1), methyl palmitate (2), ethyl palmitate (3), methyl elaidate (4), methyl stearate (5), and ethyl linoleate (6). These esters contribute nutty, floral, fruity, and spicy aroma notes,[11] and achieving an appropriate balance among them is essential to maintain flavor quality. However, having an excess of these fatty acid methyl esters can complicate the experience for tasters in evaluating the true taste of coffee.[36]

In contrast, the volatile organic compound profile of instant SSC, as shown in Fig. 3 showed the presence of compounds such as isobutyl formate (1), 2,3-dimethyl-2-butenoic acid (2), maltol (3), and 5-(hydroxymethyl)-2-(dimethoxymethyl)furan (4), which contribute to the caramel-like flavor and aroma of coffee, providing complexity and depth to the sensory experience. Compounds like maltol and 5-(hydroxymethyl)-2-(dimethoxymethyl)furan have flavors reminiscent of caramel or toffee. These compounds provide a pleasant taste in addition to having high antioxidant properties. A notable feature of instant SSC was the predominance of the organosilicon compounds (from peak at RT 12.741 min to 17.929 min), including hexadecamethyl cyclooctasiloxane, octadecamethyl cyclononasiloxane, and eicosamethyl cyclodecasiloxane. The presence of these organosilicons in salak seed plays a role in strengthening cell walls and making them resistant to pests, diseases, and environmental stress such as drought and floods.[37] Previous research has suggested that silicon plays a role in seed germination and seedling growth.[38] Siloxane compound has an immunomodulatory activity and antimicrobial activity, which can modulate the immune system. As a nutrient uptake factor for salak palms, silicon could potentially enhance the absorption of nutrients, thereby promoting the overall growth and development of salak palm trees.[39] Besides that, some compounds present in small amounts include trehalose, D-arabinitol, N-(carboxymethyl)-1-valine, threitol, isobutyl hexyl oxalate, 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one, or DDMP and 3,6,6-trimethyl-2-norpinanol. It cannot be denied that these compounds contribute to the sweetness and texture of the coffee and enhance the overall flavor profile. A compound like DDMP is known as a strong antioxidant in glucose-histidine Maillard reaction products.[40] In coffee, it could help neutralize harmful free radicals, providing potential health benefits.[41]

The marked difference in the chemical profiles of regular and instant SSC can be attributed to the distinct processing methods. Hot-water extraction used

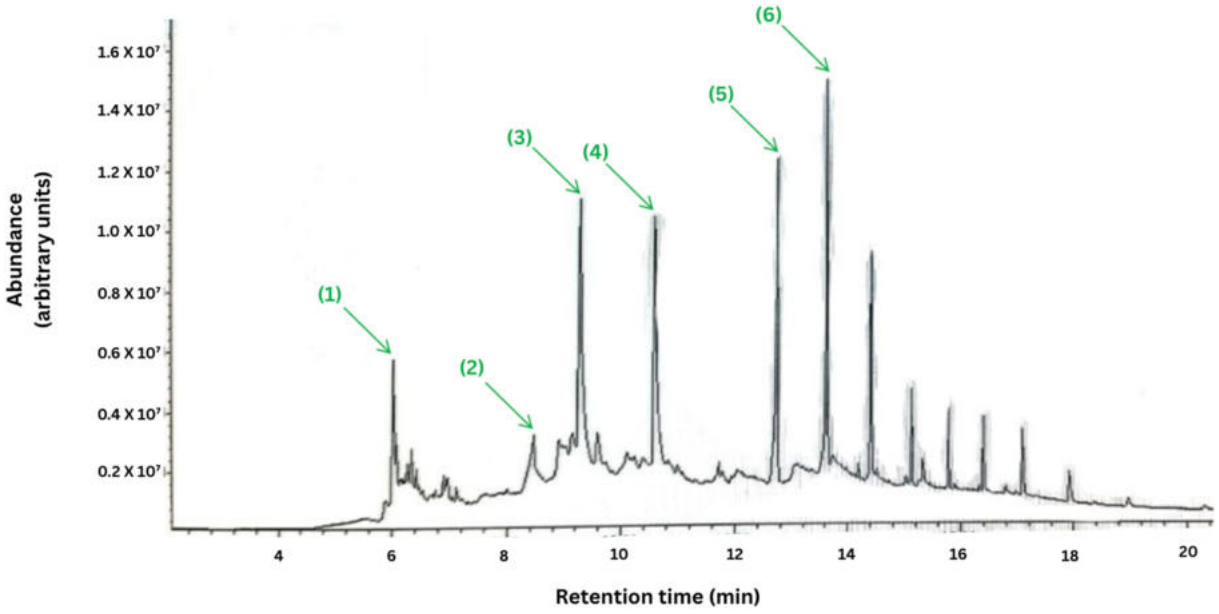

Fig. 3. Chromatogram spectrum of instant SSC extract. The x-axis represents retention time (min) and the y-axis represents ion abundance (arbitrary units), corresponding to the signal intensity detected during analysis.

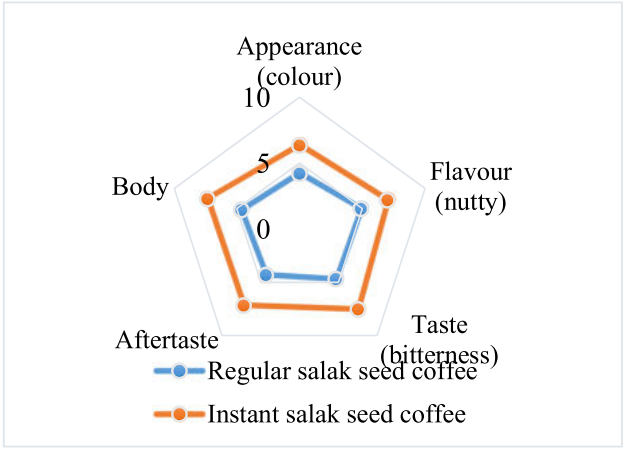

Fig. 4. Spider web for quantitative descriptive analysis (QDA) of salak seed coffee.

in producing instant SSC enhances the release of soluble phenolic, furanic, and antioxidant compounds, while the subsequent freeze-drying process preserves thermolabile volatile constituents that would otherwise degrade during roasting.[30,32,35] As a result, instant SSC exhibited a substantially greater diversity of VOCs (140 compounds) compared to regular SSC (65 compounds). Compounds such as maltol and furan derivatives formed through mild Maillard reactions during extraction impart caramel-like aroma[11] and antioxidant benefits. In contrast, the fatty acid methyl esters predominant in regular SSC are more susceptible to oxidation and ester cleavage during roasting, producing smaller, less complex aroma molecules. Meanwhile, the low-temperature freeze-drying step contributes to the retention of heat-sensitive organosilicon compounds that would otherwise degrade or volatilize under roasting conditions. Therefore, the combined effect of aqueous extraction and freeze-drying enhances both the complexity and stability of flavor-active and bioactive compounds, leading to improved aroma depth, antioxidant potential, and overall sensory appeal in instant SSC.

Table 5. Mean ratings of panelists (n=10) of brewed SSC.[1]

Descriptive attributes[2]	Regular[3]	Instant[3]
Brown color	4.19 ± 0.33^{b}	6.33 ± 0.26^{a}
Nutty flavor	4.89 ± 0.50^{b}	7.02 ± 0.55^{a}
Bitterness	4.71 ± 0.62^{b}	7.54 ± 0.35^{a}
Aftertaste	4.32 ± 0.55^{b}	7.19 ± 0.43^{a}
Body	4.63 ± 0.48^{b}	7.33 ± 0.35^{a}

[1]The sample was prepared by brewing 50 g of SSC powder with 500 mL of hot water (80 °C) for 6 min.
[2]Attributes were rated on a numerical, ordinal 10-unit scale.
[3]Mean within the same row (attribute) with different superscripts are significantly different ($p < 0.05$).

Sensory profiles of brewed salak seed coffee (SSC) using quantitative descriptive analysis (QDA)

Mean ratings by panelists of attribute intensities for color, flavor, bitterness, aftertaste, and body were listed in Table 5. All data were normally distributed, and the standard deviations were relatively low, indicating well-calibrated panelists. Significant

differences ($p < 0.05$) were found between regular and instant SSC for all selected attributes. A spider plot was also created by plotting average intensity values on each scale and then joining the points to create a visual profile or 'fingerprint' of SSC attributes, as shown in Fig. 4. Based on Table 5 and Fig. 4, it was confirmed that the sensorial attributes of instant SSC were more intense than those of regular SSC.

Conclusion

This study successfully applied RSM to determine optimum roasting conditions for producing SSC. Under optimized roasting conditions, the instant SSC demonstrated improved physicochemical properties, including higher lightness, solubility, TSS, and antioxidant capacity compared with regular SSC, while exhibiting comparable caffeine levels. The volatile compound analysis and QDA further indicated that instant SSC retained more desirable flavour attributes. Overall, the enhanced quality characteristics and favourable sensory profile suggest strong potential for instant SSC to be developed and commercialized as a viable coffee substitute.

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Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images that are not ours have been included with the necessary permission for republication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at Universiti Teknologi MARA Shah Alam.

Authors' contribution statement

A.M.S., S.R.A.M. and W.S.S.W.K. conceived the study. A.M.S. conceptualized the study. A.M.S. and S.R.A.M. designed the proposed methodology. S.A.I.A. and A.M.S. provided resources. A.B. performed the investigation. A.B. and W.S.S.W.K. curated the data. A.M.S. and S.R.A.M. validated the data. All authors contributed to the formal analysis. S.A.I.A. prepared the visualizations. A.M.S., S.R.A.M., and W.S.S.W.K. supervised the work and administered the project. A.B. and A.M.S. wrote the original draft. S.R.A.M., W.S.S.W.K., J.M.J., and A.M.S. reviewed and edited the manuscript. All authors read and approved the final version of the paper.

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تحسين شروط تحميص بذور السالاك كبديل للقهوة وخصائصها الفيزيائية-الكيميائية

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الملخص

يشهد الأهتمام بإستخدام بذور السالاك (Salacca zalacca) بوصفها بديلاً للقهوة تزايداً ملحوظاً، وذلك نظراً لإحتوائها على الكافيين وما تتميز به من خصائص معززة للصحة. تهدف هذه الدراسة إلى تحديد الظروف المثلى لتحميص قهوة بذور السالاك (Salak Seed Coffee, SSC) بما يحقق محتوىً مرتفعًا من الفينولات الكلية (Total Phenolic Content, TPC) ومستوى مرغوبًا من الفاتحية (Lightness, L*) بإستخدام منهجية سطح الاستجابة (Response Surface Methodology, RSM). وقد تم الحصول على القهوة المحمَّصة العادية من بذور السالاك عند درجة حرارة مثلى بلغت 189.36 درجة مئوية وزمن تحميص مقداره 39.54 دقيقة. كما جرى إعداد القهوة الفورية من السالاك باستخلاص القهوة العادية بالماء الساخن عند 90 درجة مئوية، أعقبته عملية التجفيف بالتجميد. وتمت مقارنة الخصائص الفيزيائية والكيميائية ومضادات الأكسدة لقهوة بذور السالاك العادية والفورية. حيث تميّزت القهوة الفورية بمستويات أعلى من الرطو بة، والمحتوى الكلي من الفينولات، وقيمة الأس الهيدروجيني(pH) ، وقابلية الذوبان مقارنةً بالقهوة العادية بشكل ملحوظ ($p<0.05$). كما إتسمت القهوة الفورية بدرجة فاتحية أعلى. بلغت قيمة التركيز المثبط النصفي (Inhibitory Concentration, IC_{50})للقهوة الفورية 0.23 ملغم/مل، بما يشير إلى قدرة مضادّة للأكسدة تفوق نظيرتها في القهوة العادية (0.37 ملغم/مل). ولم يُلاحظ فرق كبير($p>0.05$) في محتوى الكافيين بين القهوة العادية والفورية. وكان العدد الكلي للمركبات المتطايرة (Volatile Compounds) التي تمت تحديدها في القهوة الفورية 140 مركبًا، مقابل 65 مركبًا في القهوة العادية. كما بيّنت نتائج التحليل الوصفي الكمي (QDA) أن شدة جميع الخصائص الحسية (مثل اللون، والنكهة الجوزية، والمرارة، والمذاق اللاحق، والقوام) كانت أعلى في القهوة الفورية. وتُبرز هذه النتائج أن إحتفاظ القهوة الفورية بمركبات النكهة، مقرونًا بارتفاع قابليتها للذوبان وتعزيز قدرتها المضادّة للأكسدة، يجعل من تسويق قهوة بذور السالاك (SSC) بديلاً تجارياً واعداً للقهوة.

الكلمات المفتاحية: مضاد الأكسدة، القهوة البديلة، القهوة الفورية، بذور السلاك.