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Optimum condition of roasting process of Liberica coffee towards the local and international preference

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Abstract

Coffea liberica is one of the common coffee species grown in most Southeast Asia countries, especially in Malaysia. However, its production accounts for just 2% globally. In general, coffee beans' roasting temperature and roasting time are critical factors determining the acceptance of roasted coffee by customers. However, there is still a gap in knowledge on the ideal roasting conditions of Liberica coffee based on the critical parameters. In this research, the central composite design (CCD) was used to assess the roasting time and the temperature in 13 treatments. The temperature ranged from 160 to 220°C and the time ranged from 15 to 30 mins. In the sensory analysis, 30 drinking panellists from local and international countries assessed the coffee brews' acceptability and the sensory attributes considered were colour, aroma, taste, and mouthfeel. By using response surface methodology (RSM), the optimum roasting conditions were determined based on the sensory analysis applied. The colour value of both roasted and ground coffee ($p<0.05$) was significantly influenced by roasting temperature and time, but only roasting temperature ($p<0.05$) affected the sensory acceptability of the coffee brew. The optimal roasting conditions were shown to be 197°C for 12.30 mins, corresponding to the roasting characterised by the following colour of the roasted Liberica beans: L* 30.43, a* 11.33 and b* 15.77 respectively. The disparity between Liberica coffee preference by two-region panellists was also examined by a two-sample T-test, proving no difference between local and international selection.

1. Introduction

Coffee is one of the most widely consumed drinks globally and is the secondary commodity exchanged in the global market, after crude oil (Haile and Kang, 2019). It is obtained from the genus *Coffea* tree and Brazil is one of the leading coffee producers followed by Vietnam, Indonesia, Colombia and other 66 countries (de Melo Pereira *et al*., 2019). *Coffea arabica*, *Coffea canephora* (Robusta), and *C. liberica* are the main three coffee species used as a beverage (Cao *et al*., 2014). The global production of coffee in the year 2020/21 is estimated to rise by 1.9% to 171.9 million bags and world coffee consumption is also predicted to increase by 1.3% to 166.63 million bags in 2020/21 (ICO, 2021). The main coffee species planted in Malaysia are Liberica (73%) and Robusta (27%) at their optimum growth temperature of 18°C to 28°C (maximum at 34°C). Simultaneously, Arabica can only be grown at temperatures below 23°C and only planted in highland areas in minor quantities (Ismail *et al*., 2014). Liberica coffee bean has a bigger size than Robusta and Arabica and it also has perceived smell and colour (Duaja *et al*., 2019). However, Liberica coffee is considered to have less commercial value and has less demand in the market compared to Robusta and Arabica (Mubarak *et al.*, 2019).

Coffee is mainly used to produce a coffee beverage and this product is necessary to meet the consumers' demand as it influenced the economy of coffee leading producers (Sanchez and Chambers IV, 2015). Since the early 20th century, coffee has developed into one of the world's most popular beverages and is now part of our daily routine and lifestyle (Yeretzian, 2017). The coffee beverage contains many bioactive compounds mainly

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polyphenols, such as phenolic acids, ferulic and *p*-coumaric and mostly chlorogenic in green beans and caffeine can be found after roasting (Król *et al.,* 2020). According to Dong *et al.* (2017), besides the aroma and bitter taste, coffee also has attracted many by contributing to health benefits such as reducing colorectal cancer, cardiovascular disease and type 2 diabetes. Besides, improvements in mental alertness and the gastrointestinal tract and gut microbiota are also the positive impacts of coffee consumption (de Melo Pereira *et al.*, 2020). Furthermore, coffee has a comprehensive sensory experience that can be characterised by 4-four components which are: physical and chemical food properties, consumption process, neurological makeup and psychology, and cognitive traits (Yeretzian, 2017).

Roasting coffee beans is a technique that is believed to be crucial for the quality of the final product since it involves heating the beans at high temperatures, causing physical and chemical changes in the beans, such as colour and aroma (Ruosi *et al.,* 2012). Three steps categorise the roasting process of coffee, first is the dehydration of the coffee beans, followed by the Maillard and Strecker reactions, which produce the coffee's aroma, changes of colour and composition of the beans (Esposito *et al.*, 2020). Coffee roasting produces different flavour pounds from the coffee bean components through multiple reaction processes, pyrolysis, thermal degradation and Maillard reactions (Mahmud *et al.*, 2020). According to Fadai *et al.* (2017), the first stage of roasting is the removal of water with the temperature at 180°C and the humidity inside the bean decreasing to 2.5%, followed by physicochemical transformation at 200–300°C generating flavour development. During the roasting process, the coffee beans' chemical composition and biological activity change (Mubarak *et al.*, 2019). Based on a previous study by Mubarak *et al.* (2019), medium-dark roasted *C. liberica* at 222-226°C showed a significantly increased total phenolic content when compared to the unroasted *C. liberica* ($p<0.05$). Such an increase in total phenolic content is probably due to the degradation of other components to heat. Besides that, aromatic compounds of coffee are also produced during the roasting process due to different reactions, such as the Maillard reaction, Strecker degradation, the depletion of sugars and the breakdown of amino acids, which are essential for generating colour, flavour and aroma (Endeshaw and Belay, 2020). Bitterness, astringency, and sweetness are among the flavour attributes produced by them during the roasting process (Toledo *et al.,* 2016). Besides chemical changes, physical changes during the roasting process also enhance final coffee bean volume and colour alteration (Pimenta *et al.*, 2018).

An optimisation is required to obtain the best roasting methods and avoid the profound changes that occur during the extraction of volatile aroma compounds (Mahmud *et al.*, 2020). Both temperature and time are the main factors affecting the roasting process of coffee beans (Perdana *et al.*, 2018). As stated by Bhumiratana *et al*. (2011), the roasting process regulates the occurrence progress of the volatile compounds producing a complexity of coffee aroma with different roast degrees and conditions. During the roasting process, the colour of the green coffee beans will gradually change, from grey, greenish to brown, dark brown, and black (Perdana *et al.*, 2018). Depending on the coffee type, the typical accepted temperature and duration required for the roasting process is 188-282°C and the roasting duration is between 8-15 minutes (Yılmaz *et al*., 2017). Based on a previous study by Ismail *et al*. (2013), the roasting process of Liberica coffee ended after 21 mins at 210°C and the coffee beans were observed to change in colour to dark brown, and coffee beans become oily. This occurred due to cellulose rupture in the cell wall of coffee beans due to the pressure of carbon dioxide gas being more robust than cellulose walls.

Despite Liberica green beans possessing a higher antioxidant capacity than Robusta and Arabica green beans, coffee consumption is still the lowest, and the world's coffee production is only 2% (Saw *et al*., 2015). Furthermore, there is also a limited study on Liberica coffee on optimizing roasting time and temperature on physicochemical attributes such as colour and overall acceptability of the coffee.

In the present study, dried green beans of Liberica coffee were formulated as a coffee beverage. Response surface methodology (RSM) was employed to determine the optimal roasting time and coffee beans' temperature to produce coffee brew without compromising the physicochemical properties and sensory attributes. As Liberica Coffee has higher production in Malaysia and is rich in nutritional content, this approach allows coffee species to be utilised to their optimum potential and improve the acceptance of Liberica coffee by Malaysian and international consumers. Furthermore, this study can enhance the local coffee industry growth by identifying the optimum roasting condition of roast coffee beans for domestic and export.

2. Materials and methods

2.1 Roasting of Liberica coffee beans and coffee beverage preparation

Fermented and dried green Liberica coffee beans were purchased from a coffee factory-MY Liberica (Johor, Malaysia). The coffee beans that are uniform in size and have no defects were used for roasting. The coffee beans were weighed at 150 g and were roasted in a baking oven and the temperature is between 160-220°C and the time is between 15-30 mins. Roasting conditions were set by Central Composite Design (CCD), as shown in Table 1. The coffee beans were put into the oven when the oven reached the desired temperature. After roasting, the coffee beans were cooled at room temperature (Chung *et al.,* 2013) and followed by a coffee grinder (Zainol, 2020) and sieved into a size of 600 microns. Next, the grounded coffee samples were vacuum packed in PP plastic bags and stored up to 3 days before the sensory evaluation. The coffee beverages were prepared by putting 5.5 g of grounded coffee onto filter paper and then pouring 100 mL of 93°C water onto grounded coffee (de Figueiredo Tavares and Mourad, 2020), letting it all wet, then slowly pouring the rest of the water into the centre. The brewed coffee streamed into a container below (Caprioli *et al.,* 2015).

Table 1. Experimental design for the optimisation of the roasting process of Liberica coffee

Treatment	Codified		Decodified	
	Temperature	Time	Temperature (°C)	Time (min)
1	-1	-1	160.000	15.000
2	0	0	190.000	22.500
3	0	0	190.000	22.500
4	0	-1.41	190.000	11.893
5	1.41	0	232.426	22.500
6	-1.41	0	147.574	22.500
7	0	1.41	190.000	33.107
8	-1	+1	160.000	30.000
9	0	0	190.000	22.500
10	0	0	190.000	22.500
11	0	0	190.000	22.500
12	+1	+1	220.000	30.000
13	+1	-1	220.000	15.000

2.2 Colour analysis

Both roasted coffee beans and ground coffee samples were measured by the colour by a chromameter (Konica Minolta, R-300) using CIELAB system (illuminator = D65, angle of observation = 10°) (Bolek and Ozdemir, 2017b).

2.3 Sensory evaluation

The sensory test was conducted using thirty panellists that consists of fifteen Malaysian people and fifteen international people who are students and staff from Universiti Putra Malaysia. Two Thais, three Iranians, four Nigerians, four Indonesians, one Yemeni, and one Somalian were among the fifteen international panellists' nationalities. The type of sensory test performed is affective testing using a 9-point hedonic scale (Lawless and Heymann, 2010). The participants' informed consent was obtained through written signatures after an oral presentation of the trial according to Dirler, Winkler, and Lachenmeier (2018). The coffee brews were served to the panels in a random order in an odourless cup, labelled with a 3-digit code. The colour, flavour, texture, appearance, and overall acceptance of the coffee were evaluated using the 9-point Hedonic scale (1 = extremely poor, 2 = very poor, 3 = poor, 4 = below fair above poor, 5 = fair, 6 = below good above fair, 7 = good, 8 = very good, 9 = excellent). The intensity of the brown colour of coffee brew samples (light brown– black-brown) and flavour indicates the degree of roasting perceived, ranging from lightly roasted to burnt food or burning wood smoke using a nine-point hedonic scale (Geel *et al*., 2005) (Pathare *et al*., 2013).

2.4 Response surface methodology (RSM)

Optimisation of the Liberica coffee was performed using RSM (Minitab 17 Software; Minitab Inc., State College, PA, USA) as used in a previous study by (Wan-Mohtar *et al*., 2020) on optimised mixed-ratio chicken patty, through the central composite design (CCD) 2^2 factorial design with a total of 13 runs. The independent variables were the roasting temperature (X_1) (160-220° C) and roasting time (X_2) (15-30 mins) (Table 1). The dependent variables or responses (Y) are the colour parameters (L*, a*, b*) and the score of sensory qualities (colour, aroma, flavour, mouthfeel, and overall acceptability) of the brews prepared from the roasted coffee beans. The responses were fitted to a second-order polynomial model below.

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

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 the interaction coefficient.

2.4.1 Statistical analysis

Statistical analyses were conducted using the Minitab 17 software. Two-way analysis of variance (ANOVA) with Tukey's multiple comparisons and multiple regression analysis were performed. The values were expressed as a mean ± standard deviation to determine the significant differences among all testing means at $\alpha = 0.05$.

3. **Results and discussion**

3.1 Colour analysis

Colour is a vital measure of the roasting point of

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coffee beans for quality control (Malaquias *et al*., 2018). The colour values of roasted coffee and ground coffee are not significantly different ($P \geq 0.05$). The models for L*, a* and b* values were obtained by fitting the experimental data to a second-degree polynomial equation. The models for roasted coffee and ground coffee were tested for adequacy and fitness by analysis of variance (ANOVA). The coefficients of determination for L*, a*, and b* in roasted coffee are reasonably high ($R^2 > 0.90$), and the coefficients of determination is higher than in ground coffee. The coefficients of determination show the validity of each regression, and the lack of fit was not significant for any model ($P >$ 0.05) meaning that these models can adequately represent the relationship between the responses and factors (Bolek and Ozdemir, 2017b). Contour plots (Figure 1) were generated from the reduced optimise equations to better understand the relationship between the factors and responses. The L* value represents lightness; black (0) and white (100), a* value represents red (+) and green (-) colour and the b* value represents yellow (+) and blue (-) colour.

According to Figure 1, with increasing roasting time and temperature, the result shows a decrease of L* and b* values. L* dropped more quickly at the beginning at a higher temperature, but its decreasing pace got slower after some time. The parameter L* showing whiteness of coffee beans decreased progressively with the increased roasting degrees and duration, and the colour of the beans turned more brownish (Somporn *et al.,* 2011). Based on the study shown by Wei and Tanokura (2015), the higher the degree of roasting, the lower the L value (for lightness in the CIELAB colour space). According to Pramudita *et al.* (2017), the L* values decreased at a slower pace relative to the roast loss. The temperature affected how fast the decrease was at temperatures below 220°C. The greenish-brown colour of green beans turned to dark brown during roasting is caused by the brown pigment formation or melanoidins due to the Maillard reaction (Herawati *et al.,* 2019). Melanoidins are the high molecular weight molecule or nitrogen-containing compounds produced in the final stages of the Maillard reaction of coffee bean roasting involving the interaction of carbohydrates, amino acids, and phenolic compounds such as chlorogenic acid (CGA) (Zhang *et al.,* 2019). The reaction is important in determining coffee quality since melanoidins are the main contributor to the characteristic aroma and brown colour of roasted coffee (Wang and Lim, 2017). In addition, for a* value, the value decreased and then tended to increase again in Figure 1. According to Wang and Lim (2014), during the early phase of roasting, yellow colour can be clearly seen and as the roasting continues, both a* and b* values decreased asymptotically, indicating that all coffee beans stabilized to the same hue despite different roasting temperature; 220, 230, 240, and 250°C.

3.2 Sensory evaluation

Sensory evaluation of the colour, aroma, flavour, mouthfeel, and overall acceptability of the coffee brews was carried out for 30 panellists: 15 local panellists and 15 international panellists. To assess the acceptability of roasted coffee, the coffee brews prepared from the roasted beans under different roasting temperatures and times (temperature range is 160 – 220°C and time range is 15 – 30 mins) were tested and scored by 30 panellists.

Based on Figure 2, treatment 2; the roasting temperature is 190°C and the roasting time is 22.5 mins,

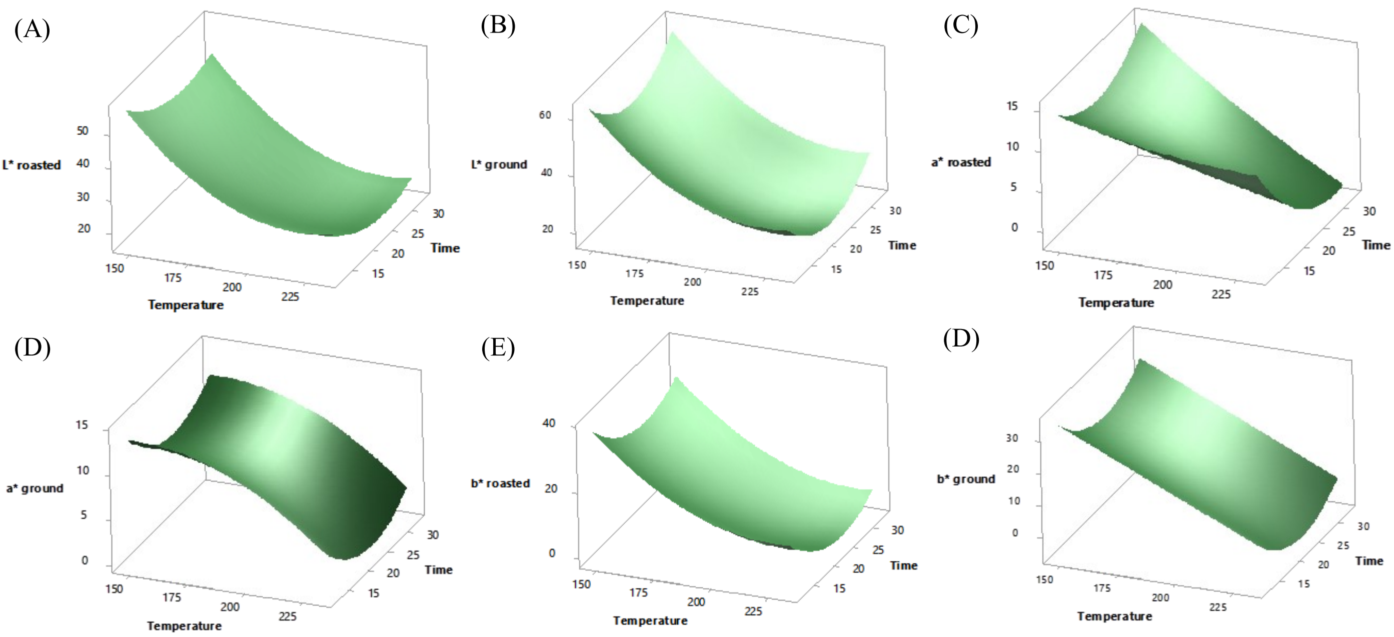

Figure 1. Response surfaces of L* value of roasted coffee (A), L* value of ground coffee (B), a* value of roasted coffee (C), a* value of ground coffee (D), b* value of roasted coffee (E), and b* value of ground coffee

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which indicates the highest colour and mouthfeel scores (7.20 and 5.70, respectively). On the other hand, in treatment 6; the roasting temperature is 147.6°C and the roasting time is 22.5 min, and in treatment 8; the roasting temperature is 160°C and the roasting time is 30 min, were too pale due to the low roasting temperature and time and directly affected panellists' mouthfeel. The main reactions involved during roasting are the Maillard reaction and pyrolysis reactions. Maillard reaction or the non-enzymatic browning reaction starts when the roasting temperature of coffee beans increases to 154°C (Hu *et al.,* 2019). Temperatures above 160°C are the ideal temperatures to obtain the best taste and long-lasting flavour (Fitri *et al.*, 2021). On the other hand, pyrolysis is a thermochemical treatment performed at high temperatures in absence of oxygen, breaking down the main polymers of biomass such as hemicellulose, cellulose and lignin in liquid (bio-oil), solid (biochar) and gas fractions (Del Pozo *et al.,* 2020). The water in the coffee beans is evaporated and carbohydrates components including sucrose and cellulose are caramelized and decomposed during coffee bean roasting (Samodro *et al*., 2020).

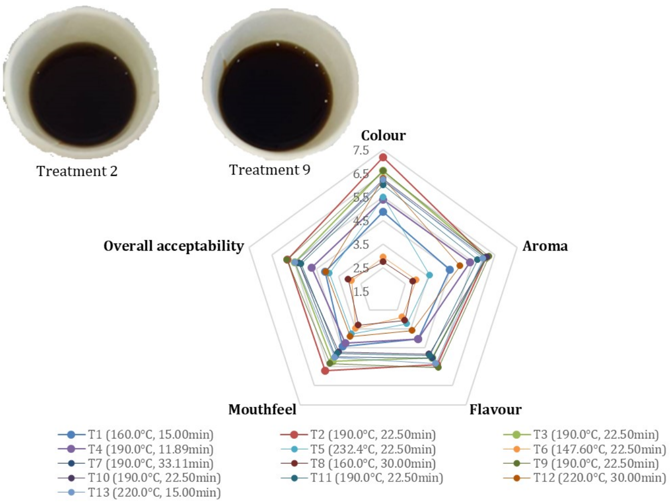

Figure 2. The radar chart indicating the sensory attributes. A total of thirty panellists' assessed the coffee brews to evaluate colour, aroma, flavour, mouthfeel, and overall acceptability using the 9-point hedonic scale.

According to Figure 2, in both treatment 9 and treatment 10; the roasting temperature is 190°C and the roasting time is 22.5 mins, ranked the highest (6.2) while in treatment 8; the roasting temperature is 160°C and roasting time is 30 mins had the lowest (2.8) for aroma attribute. Meanwhile, the flavour of treatment 9; the roasting temperature is 190°C and the roasting time is 22.5 mins, was accepted the most by the panellists (5.50) and the least was treatment 6 (2.90). During roasting, many different compounds appear pyrazynes, furans, and volatile phenolic compounds. Pyrazines are responsible for roasted and nutty flavours, whilst furans are responsible for sweet/almond, caramel, spicy flavours, and volatile phenolics are responsible for phenolic/cravo/astringent flavours (Toledo *et al.*, 2016). Furans are classified as the main group of volatile compounds which contributes to the formation of aroma formed after coffee beans' roasting (Amanpour and Selli, 2016). Pyrazines are also one of the main aroma compounds produced during the interaction of sugar and amino acids during the Maillard reaction (Gloess *et al.,* 2018). The main phenolic compound or apparent bioactive compound in coffee is chlorogenic acids including various acids such as caffeic, coumaric, or ferulic acid and during roasting, the phenolics incorporated into melanoidins increase to up to 29% of the total phenolic compounds found in the coffee brew (Rufián-Henares and Pastoriza, 2015).

In summary, in Figure 2, both treatment 2 and treatment 9; the roasting temperature is 190°C and the roasting time is 22.5 mins were accepted by the panellist and achieved an overall acceptability score of 5.80. Colour, aroma, flavour, mouthfeel, and overall acceptability are important sensory attributes for roasted coffee beans (Chung *et al.*, 2013). Similarly, the most critical coffee quality attributes concerning consumer acceptance are aroma and taste (Mahmud *et al.*, 2020).

The difference between local and international panellists' preference for roasted Liberica coffee for sensory evaluation was determined by a two-sample T-test (at $P \leq 0.05$). As a result, there is no difference between the local and international panellists' preference toward Liberica coffee ($P > 0.05$). The purpose of the assessment was initially to assess the potential bias due to different nationalities of the panellist towards the acceptance test in the sensory analysis as the culture may have an impact on the sensory of the panellist (Lee and Lopetcharat, 2017). Results confirmed there is no biasness due to the nationality of the panellist. Coffee is considered a popular drink around the world, and countries around the world formed their own rituals around coffee drinking (Jolliffe, 2010).

3.3 Fitting the model from the response surface methodology (RSM)

Central composite design (CCD) 2^2 factorial design with a total of 13 runs was performed in this study. The Central Composite Design (CCD) is a useful design for predicting multifactor response surfaces, and it has been used to optimise coffee roasting time and temperature. CCD has been used in similar studies by Mendes *et al.* (2001), Madihah *et al.* (2013), Chung *et al.* (2013) and Anisa *et al*. (2017).

The colour of roasted coffee beans contributes to the best sensory attributes obtained by the optimised temperature and time from the regression models of the colour values (Table 1); L* value of 30.43, a* value of 11.33, and b* value of 15.77. Table 2 shows optimization methods, roasting parameters, and colour and sensory evaluation of the Liberica coffee. Colour analysis and sensory evaluation were conducted, thus likely to show great potential for Liberica coffee production and consumption. As shown in Table 2, the predicted optimum condition of temperature is 197 °C and the time is 12.30 min resulting in the product that has an L* value of 30.43, a* value of 11.33, and b* value of 15.77. In addition, among all 13 treatments, treatment 2 and treatment 9 (190°C and 22.50 min) gives the highest overall acceptability: 5.80. Other studies have the absence of colour values or absence of a* and b* values as well as overall acceptability. Roasted Liberica coffee produces the highest L* = 30.43 compared to roasted P. terebinthus beans (L* = 22.12) and roasted Arabica coffee (L* = 26.50). The reading indicates the lower the roasting temperature, the higher the value of L*. Perdana *et al.* (2018) tested three samples; Liberica, Arabica and Robusta coffee and observe the colour changes after roasting visually as light, medium and dark. Both Giacalone *et al.* (2019) and Chung *et al.* (2013) did not test for colour analysis.

Chung *et al.* (2013) reported Arabica coffee L. cv. Colombia Organic Tamata also applied the same optimization method; Central Composite Design (CCD) and has predicted optimum temperature condition of 180°C and the time is 7.40 mins. The overall acceptability obtained is 6.71 from the treatment at 180°C and 6 min which is the highest compared to all studies. The lowest acceptability by panellists is 4.10 from treatment at 282.22°C and 14 mins (Bolek and Ozdemir, 2017a) which predicts optimum condition using full factorial design. Based on similar studies, only Perdana *et al.* (2018) did not test for sensory evaluation.

4. Conclusion

This study indicates the predicted optimum condition of roasting temperature is 197°C and roasting time is 12.30 min resulting in the product that has an L* value of 30.43, a* value of 11.33, and b* value of 15.77. The sensory evaluation shows coffee brew from treatment at 190°C and 22.50 min validates the predicted optimum condition of temperature and acceptable by the panellists. Liberica coffee roasted at optimum condition creates a platform for increased coffee consumption, market share, and Liberica coffee production.

Conflict of interest

The authors declare no conflict of interest.

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Table 2. Roasting parameters and physicochemical properties of Liberica coffee and comparison with similar studies

Coffee	Optimisation	Roasting Time	Roasting Temperature	Colour	Acceptability	Reference
Liberica Coffee	Central composite design (CCD)	12.30 min	197°C	L* = 30.43 a* = 11.33 b* = 15.77	5.8	*Current work*
Liberica, Arabica and Robusta coffee	OFAAT	21 min	200°C and 230°C	Visual Observation	NA	Perdana *et al.* (2018)
P. terebinthus beans	Full Factorial Design	14 min	282.22°C (540W)	L* = 22.12	4.1	Bolek and Ozdemir (2017a)
Arabica coffee	OFAAT	11.25 min	210°C	NA	6	Giacalone *et al.* (2019)
50% Arabica coffee and 50% steamed Preto Verde Ardido defective coffee	OFAAT	Arabica coffee L* = 26.5 Preto Verde Ardido coffee = 16 min	Arabica coffee = 230°C Preto Verde Ardido coffee = 158.92°C (5 bar)	Arabica coffee L* = 26.5 Preto Verde Ardido coffee = NA	6.7	Kalschne *et al.* (2019)
Arabica coffee L. cv. Colombia Organic Tamata	Central composite design (CCD)	7.40 min	180°C	NA	6.71	Chung *et al.* (2013)

OFAAT: One factor at a time, NA: Not available

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