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Response Surface Method Approach for Optimizing Roasting Condition in Robusta Coffee Cupping Test Quality

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ABSTRACT

The Roasting process was an important step to generate good-quality roasted coffee beans. Two factors that affected coffee bean perfection were roasting time and temperature. An appropriate time and temperature will emphasize the greatest coffee bean aroma, color, and flavor, while the speed of the roasting process depends on the number of stirring fins in a roasted machine. The purpose of this study was to optimization time, temperature, and stirring fin number in the roasting process to generate the best cupping test roasted coffee beans. The Central Composite Design (CCD) was used in this study to determine Response Surface model. Minitab 17 and Design Expert 4.0 software used to determine the combination for all variables. Robusta green bean was taken from Kota Agung Timur, Lampung, which had density of 701—750 g/L. The result recommended roasted coffee bean was at 213oC for 16.7 minutes and used 3 stirring fins. This condition will generate cupping test score 84.92 which is define as Excellent in score notation criteria. CCD methods has develop an equation from optimal process to predict roasted coffee bean cupping test quality i.e., $Y = 85.6 – 0.0088X1 – 1.2X2 – 11.06X3 + 0.000043X12 – 0.038X22 – 0.70X32 + 0.01000X1X2 + 0.0625X1X3 + 0.300X2X3$.

1. INTRODUCTION

Coffee is the most popular drinks around the world due to its distinctive taste and aroma characteristic. Coffee bean is have a great economic benefit and play an important role as nation convertibility among another agriculture crops. Indonesia is the fourth largest coffee-producing country in the world, after Brazil, Vietnam, and Colombia (ICO, 2019). Arabica, by far, is the tastier and smoother among another, which increase its palatability.

The essential factors that affect coffee bean quality are plant species, geographical location, altitude, planting area, fermentation process, and storage method (Ciesarová, 2016). In general, coffee diversity that produced by different processing methods will generate different chemical components. During roasting process these components will develop a distinctive taste for each type coffee bean. Roasting process will affect the color appearance, number, and type of volatile compounds produced due to physicochemical reactions that appear (Claus *et al*., 2008). The roasting process is carried out using high temperatures (160–250°C) and will lead the changes in coffee bean chemical composition such as carbohydrates and amino acids that play an important role in maillard reaction and the formation of coffee flavor (Linge, 2001; Albouchi *et al*., 2018).

Coffee bean roasting is an important process to determine coffee quality. The roasting process will change coffee bean physical shape and transform the volatile compounds by producing around 1000 aroma components, so it is very obvious that a proper roasting process is necessary to produce premium tasting coffee (Blank, 2005; Akillioglu & Gökmen, 2014; Baggenstoss *et al*., 2008).

Nowadays, roasting process are normally used a simple equipment, for instance a clay cauldron with manual stirring on top of direct fire. This process is carried out at atmospheric pressure with hot air media or combustion gases (Cagliero *et al.*, 2016). The most common roasting machine is a horizontal stainless steel cylinder. Hot air flow will be regulated as a current and cross flow in the roasting machine (Caporaso *et al.*, 2018).

The roasting process is divided into 3 types i.e., light roasts using temperatures between 160-180°C, medium roasts using temperatures between 180-200°C, and dark roasts using temperatures of 210-250°C (Martín *et al.*, 1999). The average moisture content lost in light roasts, medium roast, and dark roast are 3-5%, 5-8% and 8-14% respectively (Amrein *et al.*, 2003; Budryn *et al.*, 2018). Time and temperature determination in roasting process were varies, mostly depend on every Roastery signature coffee product especially due to significant chemical changes (Bottazzi *et al.*, 2012).

Roasting is a crucial process to determines coffee color and taste before its consumed. The changes in coffee bean color can be used as the basis to a simple classification system (Budryn *et al*., 2015). This subjectiveness, will result in non-uniformity of roasted coffee bean over time.

The roasting perfection was influenced by two main factors, namely temperature, and time. An appropriate temperature and time will bring out maximum coffee aroma, color, and distinctive taste. However, there were variation among the roastery to generated good quality roasted bean, even though they used the same bean at ones. Therefore, it is necessary to optimize the coffee roasting process not only to succeed coffee bean quality equitably but also to reduce non-uniformity.

Several studies have been conducted with the aim of optimizing the coffee roasting process in order to obtain premium-tasting coffee. Among them were shown the effect of roasting degree on volatile compound formation (Hashim & Chaveron, 1995; De Maria *et al.*, 1996; Huang *et al.*, 2007). Another study conducted by Mendes *et al.*, (2001) was the optimization of robusta coffee roasting using acceptability tests and Response Surface Methodology (RSM).

Response Surface Methodology (RSM) could be considered as a decisive sequential technique for the developing pioneer processes, improving design and formulation of new products, and optimizing their performance. It is a set of mathematical and statistical methods used in modeling and analysis, which aims to see the effect of several quantitative variables on a response variable and to optimize the response variable (Montgomery, 2001).

The objectives of this research is to determine (1) the optimum time, temperature and stirring fin number to produced good quality of roasted coffee bean based on cupping test result and (2) formulated the equation to predict cupping test quality based on the trials result.

2. MATERIAL AND METHODS

2.1. Materials

Dried robusta coffee bean was obtained from Kota Agung Timur, Tanggamus Regency, plastic packaging. The appliance include horizontal cylinder stainless steel roaster, analytical scales, bulk density meters, digital thermometers, DC motors, gas stoves, sealer.

2.2. Experimental Design

The design of the roasting machine process conditions and responses was carried out using Minitab 17 statistical software to determine the fixed and independent variables Central Composite Design applied to find roasting optimum conditions. Three independent variables were chosen as roasting temperature (X1), roasting time (X2), and stirring fin number (X3), meanwhile fixed variable was cupping test score. The determination of independent variables and trial codes were presented in Table 1.

Table 1. Determination of independent variables and treatment codes in the research

Independent variable	**Codes**	**Range and Level**		
		-1	**0**	**+1**
Temperature (^{0}C)	X_1	160	180	200
Time (minute)	X_2	10	12,5	15
Number of stirrers (pieces)	X_3	1	2	3

2.3. Procedure

2.3.1 Coffee Bean Density Measurement

Coffee bean density is carried out for determination initial roaster temperature before the beans was put into roaster, determine the final temperature, and roasting level. Coffee bean density is measure by a bulk density meter.

2.3.2 Coffee Bean Roasting

Coffee beans were roasted using 20 trials based on CCD (Table 2). The roaster drum rotate at 60 rpm. Temperature and time used in this study were ranged between 160-200^{0}C for 10-15 minutes (modified from Choo, 2013), and 1 – 3 stirrer fin number.

2.3.3 Cupping Test

The cupping test was carried out by panelists at Puslitkoka Jember. Cupping test was carried out following the American Specialty Coffee Association (SCAA) technical standards which included fragrance/aroma, flavor, aftertaste, salt/acid, bitter/sweet, mouth feel/body, uniform cups, balance, clean cups, overall.

Table 2. Central Composite Design (CCD) trials for temperature, time, and stirrer fin number variables

Standard order	Run order	Temperature (^{0}C)	Time (minute)	Stirrers fin number
8	1	200	15	3
4	2	200	15	1
6	3	160	15	3
17	4	180	12.5	2
5	5	160	10	3
10	6	180	16.7	2
7	7	200	10	3
15	8	180	12.5	2
20	9	180	12.5	2
3	10	200	10	1
18	11	180	12.5	2
19	12	180	12.5	2
16	13	180	12.5	2
13	14	180	12.5	1
12	15	213.6	12.5	2
9	16	180	8.3	2
11	17	146.4	12.5	2
2	18	160	15.	1
14	19	180	12.5	3
1	20	160	10	1

2.3.4 Roasting Process Conditions Optimization

The 2nd order polynomial equation is used to express the response variable as a function of the independent variables based on the following equation.

$$Y = \beta_0 + \sum_{i=0}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=2}^{k} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

Where X_i and X_j are independent variables, Y is the response variable, while β_0, β_i, β_{ij}, β_{ii} are regression coefficients and *k* is the number of variables. Based on this equation, the response variable is a function of the independent variable according to the following equation:

$$Y_i = \beta_0 + \beta_1 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_2^2 + \beta_{33} X_3^3 \quad (2)$$

Experimental data were analyzed and predictive response variables were calculated using Minitab 17 statistical software. The optimization process and predictive response curves in 2D and 3D form structure were also carried out in Minitab 17 statistical software. The significance of the response variable was carried out by analysis of variance (ANOVA) at 95% confidence level (p<0.05). After optimization using RSM, additional experiments were carried out to verify and validate the existing equation.

3. RESULT AND DISCUSSION

3.1. Cupping Test Prediction Model Development

The effect of roasting temperature, roasting time, and stirrer fins number are shown in Table 3. Fixed from Table 3, an appropriate model to predict the relationship between trails and cupping test response is chosen that can explain the closest relationship between fix and independent variable as indicated by a high coefficient of determination (R^2). The quadratic equation shows that the temperature, roasting time as well as stirrer fins number were significantly (P<0.05) (Table 4) affect the cupping test quality.

Table 3. Effect of roasting temperature, roasting time, and stirrer fins number on cupping test quality

Standard order	Run order	Temperature (^{0}C)	Time (min)	Number of stirrer	Cupping test score
8	1	200	15	3	81.50
4	2	200	15	1	75.00
6	3	160	15	3	71.00
17	4	180	12.5	2	74.50
5	5	160	10	3	69.00
10	6	180	16.7	2	74.00
7	7	200	10	3	76.50
15	8	180	12.5	2	74.50
20	9	180	12.5	2	74.50
3	10	200	10	1	74.00
18	11	180	12.5	2	74.50
19	12	180	12.5	2	74.50
16	13	180	12.5	2	74.50
13	14	180	12.5	1	73.25
12	15	213.6	12.5	2	78.75
9	16	180	8.3	2	74.00
11	17	146.4	12.5	2	70.50
2	18	160	15.	1	70.50
14	19	180	12.5	3	75.00
1	20	160	10	1	70.50

Score notation: 6.0 – 6.75 = Good; 7.0 – 7.75 = Very good; 8.0 – 8.75 = Excellent; 9.0 – 9.75 = Outstanding

Based on the equation temperature, time, and the stirrer fins number variables were very precise in cupping test quality as indicated by high determination (R^2) i.e., 0.96. This shows that the quadratic model is suitable equation to describe the relationship between experimental data and predictive data. ANOVA result (Table 4) show that The P-value is 0.1247> 0.05, which indicates the equation could describe cupping test response. This mean that this equation is suitable for predicting the conditions of the coffee roasting process that produces the optimum cupping test quality.

Table 4. Analysis of variance based on response surface with the quadratic model for cupping test quality

Parameters	DF	Predicted Coefficients	Standard Error	P Value
Model	9	85.6	1,00712	0,0100
X_1	1	-0.088	0,90746	0,0310
X_2	1	-1.21	0.225	0,0165
X_3	1	-11.06	0.189	0,0121
X_1^2	1	0,000043	0.0327	0,9930
X_2^2	1	-0.0381	1.34	0,3132
X_3^2	1	-0.740	0.361	0,4470
X_1X_2	1	0.01000	0.279	0,0041
X_1X_3	1	0.0625	0.0349	0,0012
X_2X_3	1	0.300	2.23	0,0011
R^2		0,96		
Lack of fit		0,1247		

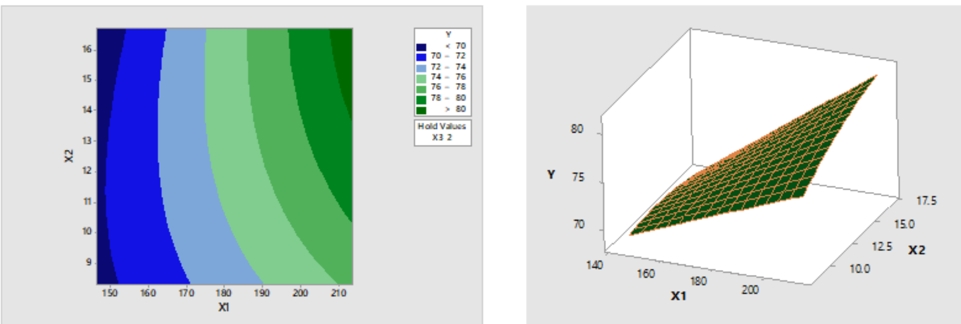
This is a quadratic equation to predict the cupping test score

$$Y = 85{,}6 - 0{,}088X_1 - 1{,}21X_2 - 11{,}06X_3 + 0{,}000043X_1^2 - 0{,}0381X_2^2 \\ -0{,}740X_3^2 + 0{,}01000X_1X_2 + 0{,}0625X_1X_3 + 0{,}300X_2X_3 \quad (3)$$

This equation was then validated to measure the preciseness. Table 5, showed that the validation trial for optimum conditions resulted in 81.5 cupping taste score and achieve 95.9% accuracy for predicting the actual score.

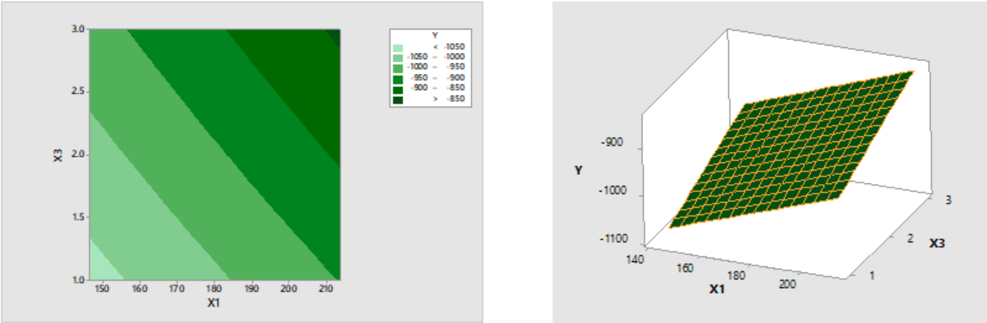
3.2. Surface Response Effect of Roasting Temperature, Roasting Time, and Stirrer Fins Number

The 2D and 3D surface response profiles of cupping test quality are shown in Figure 1-3. Figure 1 shows that the final roast temperature has a significant effect on cupping test quality. As final temperature increase during roasting process it is positively correlated with cupping taste alteration. The final temperature roasting has a significant effect (P>0.05) to cupping test quality and suitable to ANOVA results (Table 4). Even though roasting temperature depends on coffee flavor that came whether using manual brew or espresso, its also affected by the type of roasted bean that we wanted, whether it's light, medium, full city, or dark roast. Figure 2 shows the significant effect of roasting time on cupping cup quality.



(a) (b)

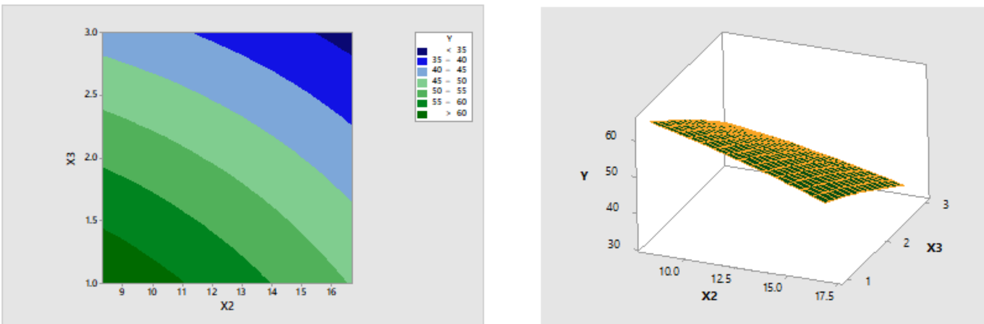
Figure 1. Contour (a) and surface plot (b) of cupping test score vs final temperature, roasting time



(a) (b)

Figure 2. Contour (a) and surface plot (b) of cupping test score vs final temperature, stirrer fins number

ANOVA result (Table 4) show that roasting time affect the cupping test quality (P>0.05). There are 3 phases in the coffee roasting process, namely dehydration phase, Maillard reaction phase, and development phase. Every phase has a different time duration. The roasting duration time will affect roasted coffee bean color change from very light to very dark, depend on the type of roasted bean that we wanted. This result was accordance with research conducted by Nugroho *et al.* (2009), Purnamayanti *et al.* (2017), and Saloko *et al.* (2019), which was shown that roasting temperature, roasting duration and interaction between them had a significant effect on all test parameters, namely moisture content, ash content, caffeine, antioxidant activity, yield, L value and HUE value of color, browning index, aroma and taste (hedonic and scoring test). Figure 3 shows that the stirring fins number have a significant effect on cupping test quality.



(a) (b)

Figure 3. Contour (a) and surface plot (b) of cupping test score vs roasting time, stirrer fins number

The addition of the stirring fins number roasting process is positively correlated with cupping test quality, this shown in ANOVA result (P>0.05) (Table 4). During the roasting process coffee bean will loss their water content and its identic to the water movement as drying in a rotary dryer. Drying duration in a rotary dryer with a lot of stirring fins at the same drying temperature will be faster than drying with a few stirring fin (Lisboa *et al.*, 2007). The analogy to this phenomenon is roasting process rate will be influenced by the stirring fins in the roaster.

4. CONCLUSION

The best cupping test quality were obtained from 213°C in 16.7 minutes and 3 fins number in roasting machine. This optimum condition will obtain cupping test score 84.92 which is define as excellent in score notation criteria. The equation from optimal process is $Y = 85.6 - 0.0088X_1 - 1.2X_2 - 11.06X_3 + 0.000043X_1^2 - 0.038X_2^2 - 0.70X_3^2 + 0.01000X_1X_2 + 0.0625X_1X_3 + 0.300X_2X_3$.

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