International Food Research Journal 24(6): 2285-2294 (December 2017)

Journal homepage: *http://www.ifrj.upm.edu.my*

Optimization of roasting time and temperature for brewed hararghe coffee (*Coffea Arabica* L.) using central composite design

[1]Anisa, A., [2,3] Solomon, W.K. and [3]Solomon, A.

[1]*Department of dairy and meat technology, College of Land Resource and Agro Industry Haramaya University, P.O. Box 226 Chiro, Ethiopia*

[2]*Department of Food and Nutrition Sciences, Faculty of Consumer Sciences, P.O.Box Luyengo, University of Swaziland*

[3]*School of Food Technology and Process Engineering, Haramaya University, P.O.Box 138 Dire Dawa, Ethiopia*

Article history

Received: 14 September 2016
Received in revised form: 19 October 2016
Accepted: 20 October 2016

Keywords

Hararghe
Coffee
Roasting
Optimization

Abstract

This study was conducted to optimize roasting time and temperature that would result in acceptable quality of brewed Hararghe coffee in terms of different sensory attributes. A Face Centered Central Composite Design (FCCD) was used to carry out the study. Coffee beans were roasted in oven using roasting time and temperature combination of 220, 225 and 230°C for 10, 20 and 30 minutes. Physical properties of roasted coffee beans (density, size, weight, texture, color, and susceptibility to breakage) and sensory properties of brewed coffee (color, aroma, flavor, taste, overall acceptability and body) were evaluated. The results showed that roasting time temperature and their interaction significantly ($p<0.05$) affected physical properties of roasted coffee bean and sensory properties of brewed coffee. The results of optimization indicated that the best results were obtained with roasting time ranging from 14 to 27 minutes and roasting temperature of 221 to 223°C. Under these ranges of roasting conditions the overall acceptability, aroma and flavor scores were between like and moderately like; color was between light brown to brown, taste was between slightly bitter and moderately bitter whereas the body was between slightly thin and slightly heavy.

Introduction

Ethiopia is a leading Arabica coffee producer in Africa. Arabica coffee is developed in highlands of Ethiopia; Hararghe, Sidamo, Gimbi/Nekemte, Yergachefe, and Limu, where the climate is cool by tropical standards and rainfall is fairly high (Willson, 1999; International Coffee Organization, 2015). Coffee is the leading export commodity crop of the Ethiopia and more than 60% of the annual foreign exchange earning of the country originates from this single crop (Melaku and Samuel, 2000). The Hararghe coffee is the most widely available of fancy Ethiopian coffees (Davids, 2001). It has slight overtone with a unique fruit like or spicy flavor, taste of medium acidity and heavy body.

The characteristics of coffee flavor results from the combination of hundreds of chemical compounds produced by the reactions that occur during roasting. Roasting is primarily intended to cause chemical changes in the coffee bean resulting in the formation of desirable flavor compounds. The roasting process controls the developmental progress of the volatile compounds, resulting in differences in complexity of coffee aroma with different roast degrees and conditions (Schenker *et al*., 2002; Bhumiratana *et al*., 2011). The degree of roasting is controlled by roasting time and temperature such that the time-temperature combination is sufficient for the required chemical reactions to occur without burning the beans and compromising the flavor of the beverage (Mendes *et al.,* 2001). Physical changes in coffee during roasting include reduction in mass due to loss of moisture and decomposition of carbohydrates, increase in volume of coffee beans, lowering of density due to puffing and increase in brittleness. Roasting time and temperature have been reported to have effect on the textural and physical properties of roasted coffee bean (Pittia *et al*.,2001; Francia *et al*., 2003; Juliana *et al*., 2009), physicochemical, chemical and sensory properties of brewed coffee (Gikuru and Jindal, 2007; Alemayehu, 2007; Bhumiratana *et al*., 2011). Optimization of roasting conditions based on pyrazines and acrylamide has been reported (Madihah *et al*., 2013). However, research on the optimization of roasting conditions condition like roasting time and temperature for multiple sensory response variables is still limited

*Corresponding author.
Email: *email wsolomon@uniswa.sz, solowkj@yahoo.com*

(Mendes 2001). Moreover, research on the effect and optimization of roasting conditions on brewed hararghe coffee is non-existent in literature. Apart from hararghe coffee beans, the results of the study could be used as baseline information for other coffee beans.

Central Composite Design (CCD) is a useful design for estimating multifactor response surface and has been used in optimizing roasting time and temperature of coffee and other products (Mendes *et al.*, 2001; Madihah, 2013). This study was initiated to investigate the effect of roasting time and temperature on the physical properties of roasted coffee beans and optimize the roasting time and temperature for acceptable sensory qualities of the brewed coffee made from Hararghe coffee using CCD.

Materials and Methods

Materials

East Hararghe coffee beans of export standard were obtained from Oromiya regional state coffee farmer's cooperative union. Coffee beans were checked for defects and damaged beans and cleaned before being used for experimentation.

Experimental design

The experiment was conducted using Face Centered Central Composite Design (FCCD) with three points at the center having a total of 11 runs. Each test was replicated three times. The roasting time levels were 10, 20 and 30 minutes whereas the roasting temperatures were 10, 20 and 30 minutes. The upper and the lower levels of the factors were selected based on coffee roasting studies reported in literature (Luciane *et al.*, 2000; Pittia *et al.*, 2001; Gikuru and Jindal, 2003; Juliana *et al.*, 2009) and preliminary experiment.

Coffee roasting

Roasting was carried out using laboratory convective hot air oven equipped with thermostat for temperature control (M15A Scientific, South Africa) at temperature and time combination presented in Table 1. Hundred grams of green coffee beans were spread on thin stainless steel wire mesh in single layer and placed in the oven (Pittia *et al.*, 2001; Nebeesny and Budryn, 2006; Juliana *et al.*, 2008). The wire mesh was selected for its advantage that all the beans will be exposed to hot air and ensure uniformity of roasting. Roasted beans were collected at pre-determined time and water was sprinkled lightly as a cooling agent in order to avoid excessive heating and was packed in airtight jar after cooling for 5 minutes (Schwartzberg, 2002).

Bulk density

The volume of 100 g of coffee beans was measured using a 1000 ml measuring cylinder. The Coffee beans were filled into the cylinder under free flowing conditions from the height of 15 cm above the cylinder without compacting the bean inside the cylinder. The bulk density was calculated as the ratio of mass of beans to volume of the cylinder (Gikuru and Jindal, 2003).

True density

The density of the coffee beans was measured by putting 4 g of coffee beans in to measuring cylinder and then adding 10 ml of toluene till the mixture reach 10 ml of the measuring cylinder. The toluene left in the measuring cylinder was taken as volume of coffee beans and then the true density was determined as the ratio of sample mass to the true volume of the beans using toluene displacement method with three replications (Zewdu and Solomon, 2007).

Total weight loss (WL)

The total weight loss measures the weight reduction as a result of roasting expressed as g/100 g. It was determined by weighing coffee samples before (WI) and after (W) roasting, (Pittia *et al.*, 2001) and using Equation 1.

$$BS = \frac{W_1 - W}{W_1} \times 100 \qquad (1)$$

Where

WL = total weight loss (g/100 g)

W_1 = weight of coffee sample before roasting (g)

W = weight of coffee sample after roasting (g)

Susceptibility to breakage

A 30 g sample of the roasted coffee beans were ground using laboratory coffee grinder (Mikal, Japan coffee grinder NCG- 904) for 30 seconds. The fraction by weight of ground sample passing through sieve No. 18 with 1 mm opening was assumed to indicate the breakage susceptibility (Gikuru and Jindal, 2003) defined as follows in Equation 2.

$$BS = \frac{W_s}{W_t} \times 100 \qquad (2)$$

Where:

BS = breakage susceptibility of coffee beans, %

W_s = weight of ground coffee passing through US standard sieve No. 18 with 1 mm opening size (g)

W_t = total weight of ground coffee sample (g).

Rheological (mechanical) properties of coffee beans

The changes in the textural and mechanical characteristics to which the coffee bean undergo during roasting play a relevant role in the quality of the roasted beans. The textural/rheological characteristics of roasted coffee could be related to the effects of some chemical and physical changes induced on the raw bean components by the severe thermal process. Reaching of a certain degree of brittleness is very important for the grinding to which coffee beans have to be subjected to before brewing (Pittia *et al*., 2000, 2007). The roasted coffee beans were subjected to instrumental texture analysis using TA-Plus Texture analyzer (Ametek, Lollyd Instruments, 2002, UK). Uniaxial compression test was equipped with Nexygen software to collect the data during the test Twenty five beans from each treatment were taken at random and placed individually along its longest side on the flat side up between two parallel metal plates of the Texture analyzer. Compression force was applied at a rate of 0.83 cm/s until failure occurs (Pittia *et al*., 2001). Breaking force (N) corresponding to force at the major failure event was recorded. It was considered as empirical measure of strength (Pittia *et al*., 2001).

Coffee grinding

Adequate amount of roasted coffee beans were ground by using laboratory coffee grinder (Mikal, Japan coffee grinder NCG- 904). Grinding was done for about 14 seconds to get medium particle size and sieved using 1mm opening sieve. The ground coffee was kept in the airtight jar until it is used for brewing (Zurich, 2008).

Coffee brewing

Coffee beverages were prepared as reported by Almeida *et al.* (2006). Twenty gram of ground coffee was added to 150 ml of spring water in the beaker immediately after grinding, the beaker was placed in to thermostatistically controlled water bath adjusted at 90°C for brewing. The mixture was agitated continuously while in the water bath for 5 min to extract the beverages and after extraction the brew was kept for 1 minute to settle the residue. The beverages were analyzed for sensory properties.

Sensory quality

The roasted coffee bean and brewed coffee were evaluated for their sensory attributes. A total of 50 panelists were involved in the sensory evaluation. The roasted coffee bean was presented for the panelists to evaluate the color in scale of 5 and overall appearance in scale of 7 and the brewed coffee was presented for panelists to evaluate the color in scale of 3, body in scale of 6, aroma, favor and overall acceptability in 7-point hedonic scale, and taste in scale of 4.

Statistical analysis

The statistical software Stat-Ease Design-Expert 7.0 was used to analyze the data and generate response function of the following form to optimize roasting time and temperature.

$$Y_i = \beta_0 + \sum_{i=1}^{2} \beta_i x_i + \sum_{i=1}^{2} \beta_{ii} x_i^2 + \beta_{ij} x_{ij} + \varepsilon \quad (3)$$

Where:

Y_i = response variables;

x_i = roasting temperature (ºC) or roasting time (min)

The model adequacy was checked by R^2, and $R^2_{adjusted}$. Superimposed contour plots were developed to search for optimum conditions for the selected responses.

Results and Discussion

Bulk density

The values of bulk density for different roasting time and temperatures are presented in Table 1a. The bulk density of roasted coffee beans was significantly ($P<0.05$) affected by roasting time and temperature and also by their interaction (Table 3). Roasting time has the most significant influence whereas the interaction between roasting time and temperature had the least significant effect as indicated by the p-value and F-ration (Table 3). A second-degree polynomial in the form of Equation 3 adequately described the changes in the bulk density as a function of roasting time and temperature. The values of the model coefficients and the associated degree of fit are presented in Table 3. The bulk density decreased with increase in roasting time and temperature. The roasting time temperature combination resulted in bulk density of coffee beans ranging from 0.241 to 0.281 g/cm^3. The highest bulk density were observed at 220°C and 10 minutes whereas the lowest were at 230°C and 30 min. This can be explained by the fact that the volume of the coffee beans increases with time and temperature due to expansion of the tissue particles while at the same time the beans loose moisture and volatile compounds, as time and temperature increases.

The trends observed in this study and the ranges of values were in agreement with earlier findings of (Gikuru and Jindal 2003; Melissa *et al*., 2003). The increase in Coffee bean volume resulted from the softening of the cellulose bean structure coupled to the increase in pressure from the release of pyrolysis products (Sivetz and Desrosier, 1979). Bulk density reduction is attributed to increase in volume and internal gas formation of characteristic porous structure in the roasted coffee bean (Pitta *et al.*, 2001).

True density

The values of the true density are presented in Table 1a. True density of roasted coffee beans was significantly affected by the main factors of roasting temperature and time, and also by their interaction (P<0.05) (Table 3). The change in the true density was adequately described by a second-order response function (Table 2)

The true density ranged from 0.455 g/cm^3 to 0.66 g/cm^3 associated to time temperature combinations of 230^{o}C/30 min and 220^{o}C/10 min, respectively. True density decreased with increase in roasting time and temperature. Similar trends have been reported in literature and the decrease in the true density could be attributed to the simultaneous increase in volume and decrease in weight associated with the loss of water and volatile components (Schenker *et al.*, 2000; Dutra *et al.*, 2001; Delisa *et al.*, 2003; Franca and Oliveira, 2008).

Weight loss

Table 1a presents the data obtained in weight loss of the coffee beans after roasting. The weight loss was significantly affected by roasting time and temperature (P<0.05). A first-order response function described the relationship between roasting conditions and weight loss (Table 2). The individual effects of the roasting conditions are presented in Table 3. The lowest weight loss 10.62% occurred at the combination of lowest roasting temperature (220°C) and shortest roasting time (10 minute). The highest weight loss (18.86%) was exhibited when the highest roasting temperature (230°C) combined with the longest roasting time (30 minute).

During the roasting process, the constituent water in the green beans evaporates, and dry matter is partially transformed into volatiles. Moreover, a substantial amount of water is generated as a result of chemical reactions, and is also evaporated. Roasting generally results in a weight loss of the beans from 14 to 20% (Schenker *et al*., 2000). The increase in weight loss can be attributed to an intensive release of water, organic compounds and CO_2 during pyrolysis. The weight loss observed in this study (10.62-18.86%) can be attributed to the application of high level of temperature for relatively longer time, types of roasting machines (oven) which usually require high temperature with long roasting time to conduct such studies, as well as type of coffee used. Similar trends have been reported in literature (Rodrigues *et al*., 2003).

Susceptibility to breakage

The percentage susceptibility to breakage (SB) of coffee beans roasted at different time and temperature are presented in Table 1a. A first-order response function with interactions adequately describe the dependence of susceptibility to breakage on the roasting condition (Table 2). The SB were significantly (P<0.05) affected by roasting time and temperature as indicated by the p-value and F-ration (Table 3) The highest susceptibility to breakage was 85.52% at a combination of 230°C and 30 minute while the lowest value was 70.95% obtained for a combination of 220°C and 10 minute. The result of this study also showed that susceptibility to breakage increased as the roasting temperature and time increased because prolonged exposure of the coffee beans to high temperature increased the degradation of pectins and other structural components making it weak. Both extreme conditions of susceptibility to breakage have negative impact on brewed coffee quality. If susceptibility to breakage is high the brewed coffee will have undesirable taste i.e. harsh and bitter because of fine suspended particles remaining in the liquid beverage. On the other hand, low susceptibility to breakage brings about coarse, less extracted aroma and flavor resulting in unattractive taste. Similar trend have been reported by Gikuru and Jindal, (2003). Susceptibility to breakage is associated with the brittleness and level of grinding. The grind level and particle size influences the extraction and thus the quality of prepared beverage. Too fine a coffee grind could produce a low volume and bitter coffee due to over extraction while too coarse a grind could decrease extraction due to reduction in surface area resulting in a weak insipid coffee brew (Sunarharum *et al*., 2014).

Breaking force

The breaking force for coffee beans roasted under different conditions is presented in Table 1a. The breaking force was significantly affected by roasting temperature and time (P<0.05). Roasting time had the most significant influence compared to roasting temperature (Table 3). A second-order response function adequately described the changes in breaking force as a function of roasting conditions (Table 2). The breaking force was found to decrease with increasing roasting time and temperature due to the degradation of the structural component of the

Table 1a. Physical properties of coffee beans roasted under different roasting time and temperature conditions

Coded values		Actual values		BD (g/cm³)	TD (g/cm³)	WL	SB	strain	BF
Time	Temp	Time	Temp			(g/100 g)	(%)	(%)	(N)
1	-1	30	220	0.263±0.002	0.561±0.01	15.35±3.25	78.08±0.05	55.67±1.63	12.71±0.56
0	-1	20	220	0.281±0.002	0.615±0.00	12.41±0.19	74.64±0.07	48.89±1.26	16.1±3.19
-1	-1	10	220	0.296±0.001	0.667±0.01	10.62±0.21	70.95±0.07	44.38±2.48	21.38±1.93
-1	1	10	230	0.266±0.002	0.523±0.00	14.79±0.03	78.46±0.04	47.29±1.88	13.65±1.96
0	0	20	225	0.269±0.001	0.567±0.01	14.63±2.51	76.66±0.4	36.89±2.02	10.57±1.55
0	0	20	225	0.270±0.002	0.567±0.03	14.62±2.41	76.00±0.6	39.36±2.50	10.57±1.75
0	0	20	225	0.269±0.001	0.567±0.02	14.64±2.61	76.70±0.3	35.36±2.44	13.88±1.36
-1	0	10	225	0.286±0.00	0.618±0.00	12.39±1.24	73.74±0.31	32.71±2.65	22.74±1.87
1	0	30	225	0.256±0.001	0.522±0.01	16.38±2.51	80.31±0.04	41.14±3.08	14.19±1.79
1	1	30	230	0.241±0.002	0.455±0.00	18.86±0.14	85.52±0.03	51.15±2.79	8.02±1.04
0	1	20	230	0.254±0.00	0.486±0.03	16.74±0.11	81.69±0.04	48.91±0.91	11.67±1.91

BD = bulk density, TD = true desnsity, BF = Breaking force, SB = susceptibility to breakage, WL = weight loss

constituents of the coffee beans. The force required to break the coffee beans ranged between 22.74 to 8.02 N, the highest value obtained at 225°C and 10 minute and the lowest value at 230°C and 30 minute. The water loss caused by heating affected mainly the stiffness and the toughness of the coffee beans, or, in other words, their resistance to fracture under compression (Pittia *et al*., 2001). The findings of this study agree with results reported by earlier studies, which showed that coffee beans that underwent progressively longer heating times resulted in the force-deformation curves which are more irregular and irreproducible. At the same time, a decrease was noticed in the breaking force. The density of the bean also influenced the strength of the coffee (Pittia *et al*., 2001)

Roasted coffee color

The color scores of roasted coffee beans roasted under different conditions are presented in Table 1a. Roasting temperature, time and interaction has a significant effect on the color of roasted beans ($P<0.05$). Roasting temperature had the most significant influence compared to roasting time (Table 3). The color scores ranged from 1.8 to 4.40. Most of the values, however, remained below 3 which indicated that the color of the roasted coffee beans were between shiny brown and dull brown. Due to the non-enzymatic browning and pyrolysis reactions during roasting, a change in the coffee bean color took place. Consequently, the yellow-green color of the raw coffee bean changes in to brown-black roasted color (Trugo (1985; Pittia *et al*., 2001).

Overall acceptance of roasted coffee

The overall acceptability scores for roasted coffee beans are presented in Table 1b. The overall acceptability was significantly ($p<0.05$) influenced by the interaction of roasting time and temperature (Table 3). The results indicated that the highest overall acceptability scores 5.86 (moderately like) was attained by combining 220°C with 20 minute. On the other hand the lowest score (3.57) happened to be at combination 220°C and 10 minute. Thus the overall acceptability varied considerably from intensity between dislike and neither like nor dislike to that between like and moderately like. Coffee roasted at lower time and temperature was found to be dull in color and not attractive having score of dislike in scale of 7. On the other hand, coffee roasted at high temperature and time was darker in color. However, those coffee beans roasted at medium temperature and time were shiny brown in color and more liked by the sensory panel.

Taste of brewed coffee

Table 1b presents average taste scores of the brewed coffee. A second-order response function adequately described the changes in taste as a function of roasting conditions (Table 2). Roasting temperature had the most significant effect ($P<0.05$) on the taste of brewed coffee (Table 3). The results clearly showed that increase in roasting temperature resulted in increase in bitterness. The contour plot (Figure 1 (a)) also indicated the higher the temperature the closer the taste to moderately bitter. As the temperature decreased the taste shifts from moderately bitter to slightly bitter. The roasting process influenced the taste of the beverage by changing physical and chemical condition of the coffee bean. The higher the roasting temperature and time the more susceptible to breakage and grinding which could result in higher extraction of bitter substances. After roasting, acidity

Table 1b. Sensory properties of roasted coffee beans and brewed coffee

Coded values		Actual values		Color	Roasted	Taste	Aroma	Flavor	Color	Body	OAC
Time	Temp	Time	Temp	roasted	OAC	brewed	brewed				
1	-1	30	220	2.0±0.45	5.77±0.76	2.6±1.03	6.33±0.81	6.18±0.75	1.86±0.78	2.64±1.19	5.72±1.03
0	-1	20	220	1.8±0.61	5.86±1.15	1.9±1.37	5.67±0.79	5.7±0.79	1.6±0.67	1.92±0.72	5.56±1.21
-1	-1	10	220	2.17±0.94	3.57±0.97	2.64±1.10	4.57±0.88	4.0±1.29	2.17±0.67	2.74±0.92	3.87±1.24
-1	1	10	230	2.57±1.12	5.33±0.79	2.6±0.67	4.87±1.05	5.0±0.45	1.8±0.61	2.87±1.05	5.27±0.79
0	0	20	225	2.27±0.74	5.67±0.65	2.94±0.81	5.72±0.76	5.31±1.21	2.23±0.76	3.93±0.69	5.36±1.22
0	0	20	225	2.26±0.75	5.66±0.64	2.94±0.79	5.71±0.86	5.3±1.31	2.24±0.78	3.94±0.67	5.36±1.32
0	0	20	225	2.27±0.73	5.67±0.66	2.94±0.83	5.72±0.95	5.32±1.11	2.22±0.74	3.93±0.70	5.36±1.12
-1	0	10	225	2.91±1.28	5.81±0.75	3.0±0.85	5.26±0.91	5.23±1.19	2.08±0.70	3.26±1.38	4.47±1.94
1	0	30	225	3.1±0.70	4.77±1.01	2.8±0.87	5.94±0.76	4.77±0.90	2.39±0.49	3.63±0.98	5.13±0.94
1	1	30	230	4.4±0.53	4.27±1.08	2.92±0.88	4.42±1.33	4.16±1.40	2.58±0.67	3.56±0.97	4.36±1.24
0	1	20	230	3.41±1.30	5.53±1.30	2.9±1.01	4.43±1.08	4.24±1.35	2.31±0.76	4.87±0.81	3.45±1.29

OAC = Overall acceptability

and sugar are reduced and bitterness is strongly enhanced. Bitter taste is attributed to some furan derivatives and pyridines generated upon roasting (Nebesny and Budryn, 2006). The medium roasts better preserves the true coffee bean as the darker roasts burn off some of the natural coffee oils and cause it to have a harsher taste. The medium roasts allow better savor the way the coffee bean was intended to taste Dutra *et al.* (2001). Beans roasted darkly could be too finely grounded so that during brewing there will be too much surface area. Thus high rate of extraction and produce a bitter, harsh, over-extracted taste. At the other extreme, an overly coarse grind coffee produces weak coffee taste (Zurich, 2008).

Aroma of brewed coffee

Aroma scores of brewed coffee under different roasting conditions are presented in Table 1b. A second-order response function described adequately the dependence of aroma on roasting time and temperature (Table 2). Roasting temperature, time and their interaction had a significant ($p<0.05$) influence on the aroma of brewed coffee (Table 3). The highest score 6.33 (aroma level between moderately like and extremely like) was attend by a combination of longest time (30 minute) and the lowest temperature (220°C). The lowest aroma level was found with the 20 and 30 minute time combined with the roasting temperature of 230°C. This trend is also shown on the contour plot for aroma (Figure 1 (b)) where decrease in roasting temperature and increase in roasting roasting time resulted in shifting the aroma score from like to moderately like. This result might be due to rapid loss of sucrose during the roasting process which might disappear entirely in darker roast (Ball *et al*., 2008). The higher roasting time and temperature the less desirable the aroma will be and the stronger the bitterness. Conversely, low roasting temperatures with short time fail to fully develop the expected aromas, and acidity. Generally medium roast is where most odorants are fully developed and concentrated (Bhumiratana *et al*., 2011). Relatively low temperature roasting is favourable for accumulation of relevant volatile compounds (Nebesny and Budryn, 2006). The aroma, produced in the final stage of the roasting process, arises from moderately volatile compounds more sensitive to small variations in temperature than the flavor compounds (Mendes *et al*., 2001). Aroma quantities of a number of important compounds were reported to decrease when the roasting was terminated at a medium degree of roast. Therefore, high degrees of roasting do not necessarily result in a higher aroma (Shenker *et al*., 2002). During roasting, aromatic oils, acids, and caffeine weaken, changing the flavor and other oils start to develop (Ball *et al*., 2008). One of these oils is caffeol, created at about 200°C, which is largely responsible for coffee's aroma and flavor.

Flavor of brewed coffee

The result on flavor scores of brewed coffee is presented in Table 1b. A second-order response function described the dependence of flavor on the roasting time and temperature. The model coefficients and the associated indicators for the degree of fit and presented in Table 2. The interaction between the roasting time and temperature had the most significant influence followed by roasting temperature (Table 3). The highest score (6.18) was attained at a combination of 220 °C and 30 minute which is between moderately like and extremely like. The lowest score (4.00) that is neither like nor dislike was obtained at roasting time and temperature of 10 minute and 220°C and. The low flavor scores are associated with long time and high temperature and short time low temperature conditions. The contour plot for the flavor (Figure 1 (c)) also depicts this trend where high flavor scores

Table 2. Coefficients of the Polynomial Models and the Degree of Fit for the Different Parameters Based On Equation (3)

Parameter	Coefficient							R^2	R^2_{adj}	Sig.
	β_0	β_1	β_2	β_{12}	β_{11}	β_{22}	$\beta_{11}\beta_2$			
Bulk density	-5.48	-0.011	0.055	4.0E-005	2.63E-006	-1.27E-005		0.998	0.995	0.0001
True density	-31.8	-0.048	0.30	1.9E-004	1.95E-005	-7.2E-004		0.999	0.998	0.0001
Weight loss	-94.51	0.956	0.466	-3.3E-003				0.990	0.985	0.0001
SB	-93.54	0.143	0.743	-3.5E-004	7.05E-003			0.963	0.938	0.0002
BF	226.91	-4.95	-0.868	+0.0152	0.029			0.791	0.651	0.031
Color Roasted	15.54	-2.04	-0.053	0.01	4.56E-003			0.938	0.897	0.0009
OAC roasted	-70.21	3.97	0.324	-0.016	-7.58E-003			0.758	0.60	0.046
Aroma	-1282.2	2.52	11.32	-.011		0.025		0.982	0.970	0.0002
Flavor	-547.23	3.50	4.68	-.015	-2.18E-003	-9.92E-003		0.836	0.672	0.048
Color	345.25	1.213	3.14	5.45E-003	-	7.5E-003		0.842	0.736	0.014
Taste	-675.4	8.20	6.31	0.036	0.195	-0.015		0.893	0.732	0.059
Body	-869.9	-22.5	8.50	0.101	0.541	-0.021	-2.43E-003	0.999	0.998	0.0001
BOAC	-1016.9	22.34	8.16	-0.099	-0.48	-0.016	2.13E-003	0.914	0.785	0.039

associated with low roasting temperature and long roasting time. Roasting of green coffee beans is an essential step in the coffee production process as it induces chemical reactions that lead to the formation of the characteristic coffee flavors and melanoidins, the latter being the dark-colored components (Koen, 2008). The impact of roasting on flavor comes from the degradation and formation or release of numerous chemical compounds through Maillard reactions, Strecker degradation, break down of amino acids, degradation of trigonelline, quinic acid, pigments, lipids and interaction between intermediate products (Sunarharum *et al*., 2014). The low temperature and longtime roasting (220°C and 30 minute) which is medium roasting might have contributed for the retention most flavors, aromatic oils and acids as can be observed from the result. Relatively low temperature is beneficial for retaining volatile compounds and preventing development of burnt aroma (Nebesny and Budryn, 2006). As time and temperature increased the flavor score decreases and also slight roasting which is the lowest time and temperature made the flavor not come out the result was the least. Darker roasts are generally smoother, because they have less fiber content with more sugary flavor (Cipolla, 2007).

Brewed coffee color

The scores of brewed coffee color are presented in Table 1b. A second-order response function in the form of Equation 3 adequately described the relationship between color and roasting conditions. The values model coefficients and the indicators of the degree of fit are presented in Table 2. Roasting time, temperature and their interaction significantly ($p<0.05$) influenced the color. The interaction of roasting time and temperature had the most significant effect Table 3. The results showed that combination of 220°C and 20 minute resulted in the lowest score (1.6) which is between light brown and brown whereas treatment combination of 230°C and 30 minute resulted in the highest score (2.58) indicating between brown and dark brown. With increase in roasting time and roasting temperature the color of brewed coffee approached dark brown. This trend is also shown in the contour plot for color (Figure 1(d)) .Most of the average scores indicated that the color of the brewed coffee was between brown and dark brown in scale of 3. Roasted coffee color became darker with increasing temperature and time which contributed to the black color of the brewed coffee. The color of ground coffee was more visible than whole roasted beans which had direct influence on brewed coffee color. It was also observed that roasted coffee beans color decreases more rapidly during the pyrolysis stage and that the difference in color values between roasted coffee beans and brewed coffees observed as roasting time and temperature increases (Melissa *et al*., 2003).

Body of brewed coffee

The sensory score for body are presented in Table 1b. A second-order response function in the form of Equation 3 adequately described the relationship between body and roasting conditions. The values model coefficients and the indicators of the degree of fit are presented in Table 2. The roasting temperature, time and their interaction had significant ($p<0.05$) influence on the body scores (Table 3). The lowest score (1.92) which indicated thin body score was at 220°C and 20 min whereas the highest score (4.87) was at 230°C and 20 minutes that represents body level of close to heavy. Most of the scores fall between slightly thin and slightly heavy. The trend in

Table 3. p-value and F-ratio of variables for all Target responses

Responses	P and F-values	Variables (t = time; T = temperature)					
		t	T	t×T	t^2	T^2	t^2×T
Taste	F	0.04	18.64	1.21	1.69	12.67	9.19
	P	0.851	0.013	0.33	0.264	0.024	0.039
Aroma	F	49.69	101.92	91.93		79.36	
	P	0.0004	0.0001	0.0001		0.0001	
Flavour	F	0.87	6.87	15.28	0.81	1.04	
	P	0.395	0.047	0.0138	0.410	0.353	
Colour	F	7.98	8.88	14.89		4.13	
	P	0.014	0.0245	0.010		0.008	
Body	F	187.98	5325.2	190.95	668.1	819.78	2398.97
	P	0.0002	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
OAC	F	3.56	18.58	15.9	0.24	3.42	12.62
	P	0.132	0.0125	0.0163	0.647	0.138	0.024
BD	F	1107.95	892.91	13.73	0.15	22.78	
	P	<0.0001	<0.0001	0.014	0.714	0.005	
TD	F	1742.7	34.34	51.78	1.38	111.95	
	P	<0.0001	<0.0001	0.0008	0.293	0.0001	
WL	F	352.03	310.4	1.41			
	P	<0.0001	<0.0001	0.274			
SB	F	589.4	662.07	0.010	2.09	44.13	
	P	<0.0001	<0.0001	0.924	0.208	0.0012	
BF	F	12.35	6.77	0.33	3.2		
	P	0.013	0.041	0.588	0.124		
CR	F	9.69	55.06	16.99	9.65		
	P	0.021	0.0003	0.006	0.021		
ROAC	F	0.007	0.0036	11.84	6.98		
	P	0.934	0.954	0.0138	0.038		

Note: variables with p-value less than 0.05 had significant influence at α= 0.05

increment of body score with increase in temperature is displayed in the contour plot for body (Figure 1(e)). A second-order response function adequately described the dependence of body on roasting conditions (Table 3).

"Body" is recognized to be one of the most important sensory characteristics determining the quality of coffee beverages Body is the feeling that the coffee has in the mouth. It is the viscosity, heaviness, thickness, or richness that is perceived on the tongue. Body can develop during raw coffee processing. High body scores correspond to the richness of aroma and increased viscosity and density of brews (Navarini *et al.*, 2004; Nebesny and Budryn, 2006). Brewed coffee was found to have higher body due to the fact that this coffee had passed through dry processing method. Dry-processing, also known as the natural method produces coffee that is heavy in body, sweet, smooth, and complex.

Overall acceptability of brewed coffee

The overall acceptability score for brewed coffee is presented in Table 1b. A second-order response function well described the relationship between overall acceptability of brewed coffee and roasting conditions (Table 2). The roasting temperature and the interaction between the roasting time and temperature had the most significant effect ($p<0.05$) on the overall acceptability. The combination of the roasting temperature and time indicated that the highest overall acceptability scores 5.72 which indicated like moderately was attained at combination of 220°C with 30 minute. On the other hand the lowest score (3.45) attained by the combination of 230°C and 20 minute. As shown in the Table 2 the overall acceptability varied considerably from intensity between dislike and neither like nor dislike to that between like and moderately like. These indicated that roasting time and temperature significantly affected the overall acceptability of brewed coffee.

The score of liking tended to decrease with increasing roasting time due to the occurrence of sour taste. This trend is presented in the contour plot for overall acceptability (Figure 1(f)). The overall score was based on the flavor experience of the individual taster as a personal appraisal. The degree to which coffee is roasted is extremely important for the overall acceptability of brewed coffee because roasting changes the chemical properties of the coffee bean. Roasting for long time gives bitter taste to the coffee and too little roasting hinders the release of enough volatile resulting in weak coffee. The coffee that have got high score of overall acceptability are those roasted at 220°C and 30 minute. Coffee roasted to this temperature and time had high score for roasted coffee color, and brewed coffee color, aroma and

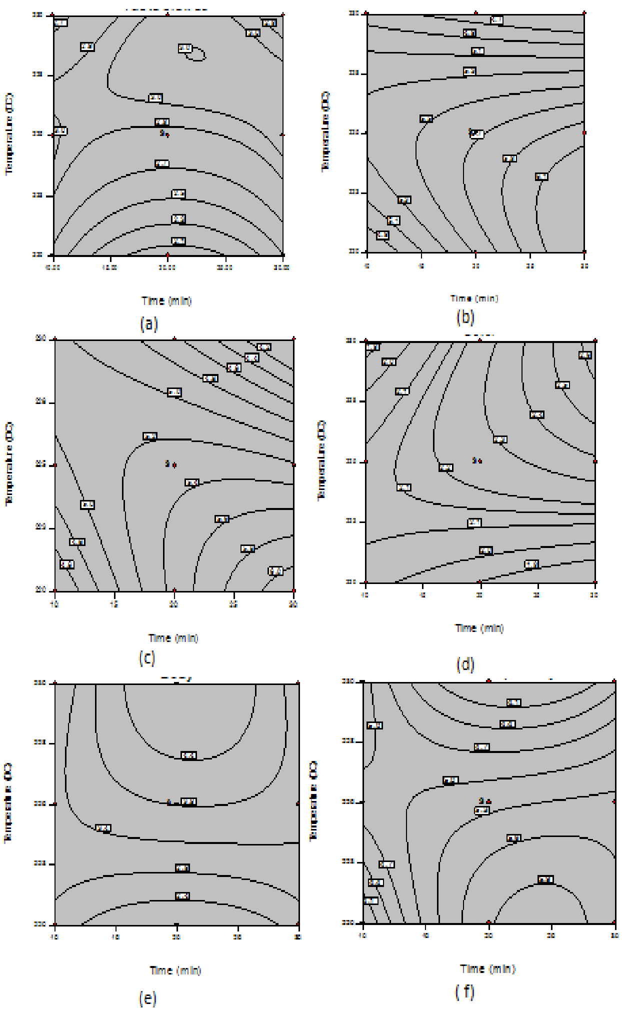

Figure 1. Contour plot for taste (a), aroma (b), flavor (c), color (d), body (e) and overall acceptability (f) of brewed coffee

flavor. According to Dutra *et al*. (2001) flavor strength and richness increases with increasing darkness of the coffee color at roasting. Roasting to high level of temperature makes the coffee flavor harsher with burnt taste. Medium roast, however, produces a more mellow taste and results in greatest aroma formation rates. The coffee bean no longer relies on the flavors from its origin and leans more on the burnt flavor that results from the darker roasting process. High temperature conditions may alter the aroma profile and should be avoided (Schenker *et al*., 2002; Gikuru and Jindal, 2007; Bhumiratana *et al*., 2011).

Searching for the optimum

To determine a region for optimal roasting time and temperature aimed at obtaining an acceptable product in terms of color, flavor, aroma, taste, body and overall acceptability, there is a need to superimpose the contour maps of the six responses in a single contour plot (overlay plot). The optimum region obtained by superimposing the six contour

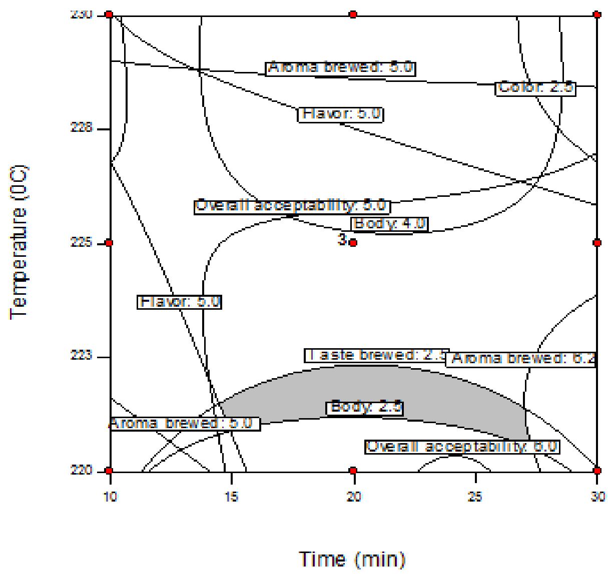

Figure 2. Superimposed contour plots of color, taste, flavor, aroma, and overall acceptability of brewed coffee

maps is depicted in the shaded region of Figure 2. This optimum region provides the coordinates of possible optimal levels of roasting time and temperature. The criteria for the optimal region were taste - between slightly bitter to moderately bitter; aroma, flavor and overall acceptability - between like and moderately like; color – between light brown to brown; and body – between slightly thin and heavy.

Conclusion

The results of the study indicated that the color, bulk density and true density of roasted coffee beans were significantly affected by roasting time, temperature and their interaction whereas the weight loss, susceptibility to breakage and breaking force were significantly affected by roasting time and temperature. Among the sensory attributes of brewed coffee, color and aroma were affected by roasting time, temperature and their interaction whereas flavor and overall acceptability were significantly affected by roasting temperature and the interaction between roasting conditions. The study revealed that the acceptability of brewed Haraghe coffee can be improved by selecting an optimum range of roasting time and temperature. Roasting time and temperature in the ranges of 14 to 27 minutes and 221 to 223°C, respectively could result in brewed coffee of good acceptability in terms of color, flavor, aroma, taste, body and overall acceptability. A numerical optimization to come up with best roasting condition and comparing the sensory attributes with commercial high quality roasted coffee could be considered for further study.

References

Alemayehu, K. 2007. Effects of roasting temperature and roasting time on caffeine content in coffee using optical method. Addis Ababa, Ethiopia: Addis Ababa University, MSc thesis.

Almeida, A. A. P., Farah, A., Silva, D. A. M., Nunan E. A. and Gloria, M. B. A. 2006. Antibacterial activity of coffee extracts and selected coffee chemical compounds against enterobacteria. Journal of Agricultural and Food Chemistry 54: 8738–8743.

Ball, T., Guenther, S., Labrousse, K. and Wilson, N. 2008. Coffee roasting. Retrieved on July 18, 2007 from WSU website:*http://www.wsu.edu:8080/~gmhyde/433_web_pages/coffee/student-pages/6roasting/roasting.htm.*

Cipolla, M. 2007. Educational primer degrees of roast. Retrieved on July 19, 2007 from Bellissimo Coffee Info Group website: *http://www.virtualcoffeecommay/educate.html.*

Davids , K. 2001. Coffee: A guide to buying, brewing, and enjoying, 4th ed. New York: St. Martin's Griffin.

Dutra, E. R., Oliveira, A. S. F., Ferraz, V. P. and Afonso, R. J. C. F. 2001. A preliminary study on the feasibility of using the composition of coffee roasting exhaust gas for the determination of the degree of roast. Journal of Food Engineering 47: 241-246.

Franca, A. S. and Oliveira, L. S. 2008. Chemistry of defective coffee beans. In Koeffer, E. N. (Ed). Food Chemistry Research Developments, p.1-34. New York: Nova Publishers.

Gikuru, M. and Jindal V. K. 2003. Coffee drying in a rotary conduction-type heating unit. Journal of Food Process Engineering 27: 143-157.

Gikuru, M. and Jindal V. K. 2007. Change in properties of coffee brew due to roasting. World Applied Science Journal 2(5): 527-535.

ICO (International Coffee Organization), 2015. Total production by all exporting countries. , Retrieved on October 12, 2015 from ICO website: *http://www.ico.org/prices/po-production.pdf*

Juliana, C. F., Mendonça, Adriana, S. F. and Oliveira, S. L. 2009. Physical characterization of non-defective and defective Arabica and Robusta coffees before and after roasting. Journal of Food Engineering 92: 474–479.

Koen, E. B. 2008. Coffee brew belanoidins. Structural and functional properties of brown-colored coffee compounds. Wageningen, Netherlands: Wageningen University, PhD thesis.

Madihah, K. Y., Zaibunnisa, A. H., Norashikin, S., Rozita, O. and Misnawi, J. 2013. Optimization of roasting conditions for high-quality Arabica coffee. International Food Research Journal 20(4): 1623-1627.

Melaku J. and Samuel A. 2000. The status of coffee berry disease in oromiya. In Proceeding of the workshop on control of coffee berry disease in Ethiopia, p. 9. Addis Ababa: Ethiopia.

Mendes, L. C., Menezes, H. C. and Silva, M. A. A. P. 2001. Optimization of the roasting of robustacoffee (*C. canephora* conillon) using acceptability tests and RSM. Journal of Food Quality and Preference 12: 153-162.

Nebesny, E. and Budryn, G. 2006. Evaluation of sensory attributes of coffee brews from robusta coffee roasted under different conditions. European Food Research and Technology 224: 159–165.

Pittia, P., Dalla Rosa, M. and Lericis, C. R. 2001. Textural changes of coffee beans as affected by roasting conditions. LWT - Food Science and Technology 34: 168-175.

Pittia, P., Nicoli, M. C. and Sacchetti, G. 2007. Effect of moisture and water activity on textural properties of raw and roasted coffee beans. Journal of Texture Studies 38: 116–134.

Rodrigues, M. A. A., Borges, M. L. A., Franca, A. S., Oliveira1, L. S. and Corrêa, P. C. 2003. Evaluation of physical properties of coffee during roasting. Agricultural Engineering International 5: 1-12

Schenker, S., Heinemann, C., Huber, M., Pompizzi, R., Perren, R. and Escher, F. 2002. Impact of roasting conditions on the formation of aroma compounds in coffee beans. Journal of Food Science 67(1): 60-66.

Schenker, S., Handschin, S., Frey, B. Perren, R. and Escher, F. 2000. Pore structure of coffee beans affected by roasting conditions. Journal of Food Science 65(3): 452-457.

Schwartzberg, H. G. 2002. Modelling bean heating during batch roasting of coffee beans. In Welti-Chanes, J., Barbosa-Canovas, G. and Aguilera, J. M. (Eds). Engineering and Food for the 21st Century, p.836-855. New York: CRC Press LLC.

Sivetz, M. and Desrosier, N. W. 1979. Coffee technology. Westport: Avi Publishing Company.

Sunarharum, W. B., Williams, D.J. and Smith, H.E. 2014. Complexity of coffee flavor:a compositional and sensory perspective. Food Research International 62: 315-325.

Trugo, L. C. 1985. Carbohydrates. In Clarke, R. J. and Macrae, R. (Eds). Coffee Chemistry, p. 83-114. London: Elsevier Applied Science Publisher.

Zewdu, A. D and Solomon, W. K. 2007. Moisture – dependent physical properties of tef seed. Biosystems Engineering 96(1): 57-63.

Zurich, 2008. Coffee roasting and quenching technology – formation and stability of aroma compounds. London: Elsevier Applied Science.