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Effect of coffee roasting on the cupping quality of coffee

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ABSTRACT

Coffee roasting is considered an important process that influences coffee cupping quality, nutrient composition, and consumer preference. Complex chemical reactions during the roasting process can change the chemical constituents of green coffee, thereby affecting its flavor and compositions. To the best of our knowledge, using the same roasting time, roasted bean color, or final roasting temperature but different time-temperature profiles will cause different cupping qualities. This study aimed to determine and quantify how the different roasting time-temperature profiles affect light-roasted coffee cupping qualities, such as flavor, aftertaste, acidity, body, balance, and overall. Herein, arising (ROR) temperature rate between 150 °C and 185 °C was found to be the most important roasting stage affecting the cupping quality of light-roasted coffee. Moreover, the roast profile was not found to influence the coffee body during light roasting.

Key words: Coffee roasting; Coffee cupping test; Flavor; Design of experiments.

1 INTRODUCTION

Coffee belongs to the Rubiaceae family, one of the largest families of angiosperms (France, 2014). The chemical substance in green coffee and the complicated chemical reaction during the roasting process are associated with cup quality. For example, the temperature increase during the roasting process also causes the degradation of chlorogenic acids (CAs), resulting in new nutrient composition and antioxidant properties (Endeshaw; Belay, 2020). Suspected toxic substances, such as acrylamide (AA), can be generated at an early stage in the roasting process (Schouten et al., 2021). A prior study (Petisca et al., 2013) concluded that different roasting speeds affect the pyridines and ketones formation even in the same roasting degree. Therefore, coffee roasting is an important process for determining the chemical changes, and cupping qualities of roasted coffee. A previous study revealed six compounds highly relative of low cupping score and roasting also play a role in variation to compounds (Sichaya et al., 2020). However, using the same roasting time, roasted bean color, or roasting final temperature but different bean temperature profiles for roasting will cause different flavor qualities in brewed coffee (Figure 1) (Stefan, 2017).

To the best of our knowledge, the previous study did not investigate how different roasting profiles influence light-roasted coffee cupping quality despite the cupping test being the most popular method to verify the coffee quality. A prior study (Petisca et al., 2013) roasted test samples separately at three different speeds: 4 min, 8 min, and 15 min using different temperature and airflow speeds to keep test samples in medium roasting degree. But, the roasting profile information

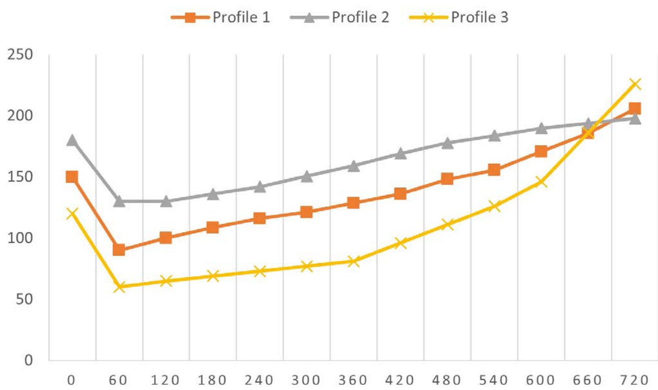

Figure 1: Roasting time (s) - bean temperature (°C) profiles under different conditions.

was not revealed by the study. A previous study (Münchow et al., 2020) separated the roasting process into two stages according to the popping sound. The stage before popping was defined as the 'time to first crack' stage, and the stage after popping was defined as the development stage. Based on the study findings, the development stage has a more important influence on coffee flavor than the 'time to first crack' stage. Because previous research included roasting degrees from light roast degrees to dark roast degrees, it was not possible to determine how the roast profile affected brew coffee flavor quality under similar roast degrees, as shown in Figure 1. A prior study (Flambeau; Lee; Yoon, 2017) reported that coffee is better if the bean is not roasted beyond the light-medium degree, which enables better discrimination quality. Thus, this study was limited to the light roast degree in the quest to determine how the roast profile affected brew coffee cupping quality under similar roast degrees.

This study used the design of experiments (DOE) full factorial design (FFD) method and coffee cupping test to determine the effect of 4 roasting stages on the cupping quality of brewed coffee subjected to a light roasting degree. Moreover, ANOVA was used to determine whether the main and interaction effects of the four roasting stages significantly influenced the coffee cupping quality.

2 MATERIAL AND METHODOLOGY

2.1 DOE

To determine how the time-bean temperature profile affects the cupping quality of coffee under a similar roast degree, the roast profile was separated into four stages, as shown in Figure 2.

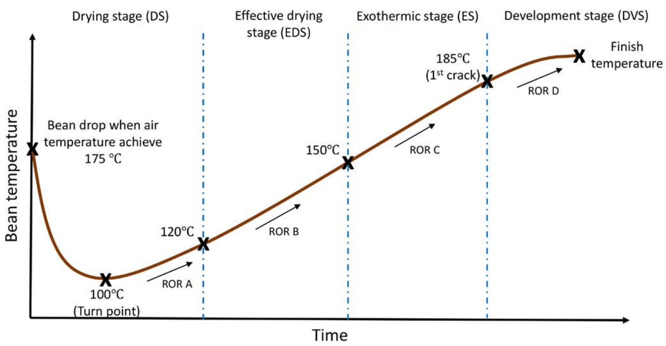

Figure 2: Roasting stage.

The first roasting stage starts when the bean is placed into the roaster chamber, which increases to 120 °C. In the first stage, the initial temperature is < 100 °C because bean storage occurs at room temperature; however, this changes when the bean is placed into the roast chamber. In the chamber, the bean temperature increases to 120 °C, thereby exceeding the boiling point of water. At this stage, the bean remains hard and in a glassy state. Accordingly, the water content in beans is at a sufficiently high level, and the bean volume only slightly increases. Herein, the first stage is called the drying stage (DS).

The second stage occurs at a temperature between 120 °C and 150 °C. During this stage, the bean temperature increases over 120 °C, which is the temperature triggered by Maillard reactions (Schouten et al., 2021). Therefore, Maillard reactions start at this stage. The temperature then continues to increase to the over-glass transition temperature (Tg) at 130 °C (Schenker, 2000). Thus, in the second stage, the bean is transferred to a rubbery state. The Tg is the critical temperature for softening the bean, and the more pronounced the rubbery state, which enables more water content to evaporate from the inside of the bean and allow for bean expansion. Herein, the second stage is called an effective drying stage (EDS).

The third stage starts at a temperature from 150 °C to 185 °C. Based on a previous research a temperature of 150 °C would cause the chemical reactions in coffee beans to change from an endothermic reaction to an exothermic reaction, which affects the heat transfer direction. Further, a previous study revealed that exothermic reactions trigger temperatures of 140 °C or 160 °C (Schenker, 2000). Therefore, in this study, the third-stage temperature was set at the lower boundary of 150 °C. During the third stage, the exothermic reactions start when the evaporation of the water content of the coffee beans is terminated (Bottazzi; Farina; Milani, Montorsi, 2012). Thus, the bean starts to generate heat on its own. The third stage is referred to as the exothermic stage (ES).

The next key stage starts after perceiving the first crack-popping sound (Yang et al., 2016). Previous studies have shown that the first crack starts at a bean temperature of approximately 175–185 °C, which depends on the green bean structure, such as hardness and compactness. When beans start popping, volatile organic compounds (VOCs) are released from the bean (Gloess et al., 2014). In the fourth stage, the bean experiences its first crack, and a popping sound can be perceived. In most cases, a popping sound is detected by humans. To avoid human errors in judgment, the development stage (DVS) was defined to start once a bean temperature of 185 °C was achieved for roasting. Thus, the stage after the first crack is defined as the DVS.

Each stage was an independent variable comprising of three levels. We defined the roasting bean temperature ROR as an independent variable level, as shown in equation 1. ROR A represents ROR ranging from 100 °C (turn point) to 120 °C, ROR B represents ROR ranging from 120 °C to 150 °C, ROR C represents ROR ranging from 150 °C to 185 °C, and ROR D represents ROR ranging from 185 °C to the finish temperature. The roasting times of DS, EDS, and ES were dependent on ROR A, ROR B, and ROR C. A higher ROR was associated with a shorter roasting time while a lower ROR was associated with a longer roasting time. The DVS roasting time was fixed at 70 s. The DVS finish temperature was dependent on ROR D. A higher ROR D resulted in a higher finish temperature and lower ROR D with a lower finish temperature. In this study, batch-type hot-air roasters were used. For warm-up, the roaster was switched on before roasting began. After the hot air temperature reached 175 °C, the bean was placed in the roaster chamber.

$$ROR = ((Et - St) / Rt) \times 60, \quad (1)$$

ROR: Bean temperature rising of rate per minute
Et: End temperature of each stage (°C)
St: Start temperature of each stage (°C)
Rt: Roasting time of each stage (Seconds)

As per the DOE, the experiment must be repeated. Thus, three Specialty Coffee Association (SCA)-qualified coffee cupping experts performed the cupping test. The three experts repeated the experiment three times. Table 1 shows the four factors × three levels × three blocks FFD.

2.2 Sample preparation

Arabica is one of the most popular varieties of coffee. Many previous studies have assessed the roasting, flavor, and chemometrics content of *Arabica* coffee. Therefore, *Arabica* was also used in the present study. Herein, the green bean defect was not believed to affect the experimental results as the G1 grade high-quality green coffee bean was employed. To avoid the different porosity that affects the heat and moisture loss rate (Oliveros et al., 2017), Ethiopia Yirgacheffe Reko G1 grade green coffee that belongs to the 'Operation Cherry Red' action launched by the Dutch green coffee importer, Trabocca, was purchased as the single coffee bean source for this research. The green beans were subjected to a wet process to ensure that they were high-quality green beans. The green bean moisture was 10.8%, and the density was 866 g/L, as measured using a Lighttells MD500 moisture/density meter.

2.3 Roasting equipment

The DOE method requires independent variables to be 'independent'. Thus, the independent variables should not affect each other. The drum roasters have thermal inertia because the cast iron drum temperature cannot rapidly increase due to the heating fire or undergo fast cooling owing to airflow. For example, if ROR A is at a high level, it will affect ROR B. This makes it difficult for ROR B to decrease rapidly to a low level. This study employed the ADM FAB MINI-PLUS hot air roaster shown in Figure 3 to ensure that all types of ROR were independent of each other. The ADM FAB MINI-PLUS roaster was a full-hot air roaster. The micro control unit (MCU) uses proportional–integral–derivative (PID) control to

Table 1: The 4 factors x 3 levels x 3 blocks FFD.

Independent variable		Level 1		Level 2		Level 3	
Factor	Name	ROR	Roast time (s)	ROR	Roast time (s)	ROR	Roast time (s)
A	DS	20.0	40.0	25.0	48.0	30.0	60.0
B	EDS	10.0	90.0	15.0	120.0	20.0	180.0
C	ES	15.0	70.0	22.6	93.0	30.0	140.0
D	DVS	8.6	70.0 (Finish temp 195 °C)	11.1	70.0 (Finish temp 198 °C)	13.7	70.0 (Finish temp 201 °C)

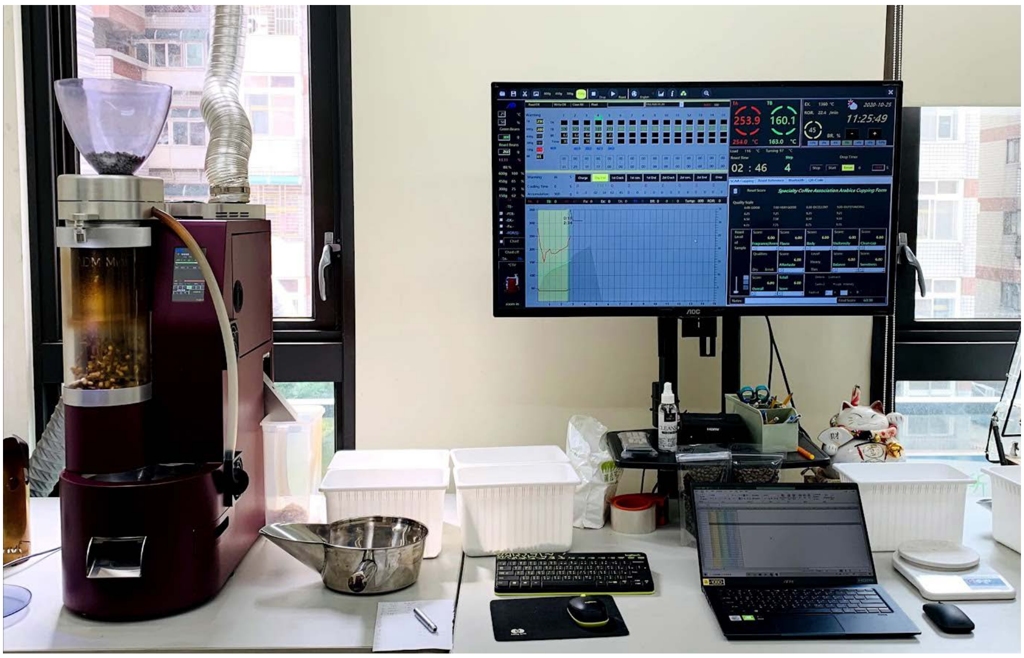

Figure 3: ADM FAB MINI-PLUS.

maintain roast bean temperature according to the roast profile design. Roasting was carried out by setting the roasting profile on a personal computer, then controlling the roast temperature by MCU. Accordingly, roasting temperature variation due to human operation error can be avoided during roasting as heating and cooling rapidly occur. Thus, the different types of ROR do not affect each other.

2.4 Roasting condition

All FFD samples were roasted on the same day, at a room temperature of 24 °C, relative humidity (RH) of 50%, and StnPres 999 hPa. In each batch, 150 g of green beans was roasted. The first batch of beans was only used to warm-up the roasting equipment; thus, this batch was not used in the experiment. The green bean and roasted bean weight, roasted whole bean color, roasted coffee ground color, and first crack temperature were recorded. The color of the roasted whole bean and roasted coffee ground was measured using a Lighttells CM-100 coffee roast degree analyzer.

2.5 Cupping test condition

The coffee cupping test (Specialty Coffee Association - SCA, 2003) is the most popular method for quality coffee analysis. Despite the cupping method being criticized due to its subjectivity, and variation in ratings among tasters (Baqueta; Coqueiro; Valderrama, 2019). This analysis is employed to evaluate coffee quality (Di Donfrancesco; Gutierrez; Chambers, 2014) and determine the fraction of the world coffee roasting competition (Official Rules and Regulations, 2020).

A prior study (Giacalone et al., 2020) concluded the within-assessor reproducibility of cupping experts was high despite the inter-rater reliability (IRR) of experts to be low. Despite inconsistency was observed between experts, prior research has already proven that the “average absolute” difference for total cup quality is small in the cupping test. Ultimately, the study revealed that the cupping test scores were sufficiently reproducible and could provide reliable coffee quality grading information (Worku; Duchateau; Boeckx, 2016). A previous study (Borém et al., 2020) has used the cupping test result by four cupping experts to study the coffee quality in the Mantiqueira region of Brazil. A prior study (Baqueta; Coqueiro; Valderrama, 2019) verifies the correlation of sensory responses of cupping test by two expert tasters to the near-infrared (NIR) spectra. Therefore, this study used cupping tests to evaluate the correlation of roasting time-temperature profile to the quality of coffee.

In this study, the coffee cupping test was carried out at 48 h after roasting. Three Licensed SCA Sensory Skill Intermediate cupping experts tested the samples on the same day using the SCA coffee cupping standard form shown in Figure 4, which was downloaded from the SCA store’s SCA Arabica Cupping Form (Digital). Cupping scores for ten attributes, namely aroma, flavor, acidity, body, aftertaste, balance, overall, uniformity, clean cup, and sweetness, were assigned and added to obtain the total score. Each cupping score ranged from 0 to 10.0, and the scoring step was 0.25. Because this study used the G1 grade green bean with high quality, bean defects were not the target of investigation. Therefore, uniformity, clean cup, and sweetness score were set to 10.0, and the cupping of two cups were used for each sample. In cupping testing, it is better to test from a lighter roast degree to a darker roast degree to avoid a decrease in the expert’s cupping sensitivity which might occur when darker samples are tested before lighter samples. The cupping test order was separated into three groups according to the ROR C level. The sample group with ROR C level 3 was the first to be tested, and the sample group with ROR C level 1 was tested last. In each group, the cupping test was ordered using a random order blind test. The experts were blinded to the test order. The SCA cupping specialty coffee protocol (Specialty Coffee Association - SCA, 2003) was employed. A copping total score < 80.0 indicates below specialty quality, 80-84.99 indicates very good, 85-89.99, indicates excellent, and 90-100 indicates outstanding specialty quality.

For cupping result analyzed a total of 1,458 cupping score responses (81 samples were evaluated for six cupping attributes by three experts), and 324 roasted bean measuring data (first crack temperature, bean weight after roast, roast degree whole bean, roast degree ground) were obtained. Due to the dimensions of the table, these results are presented in Table 2.

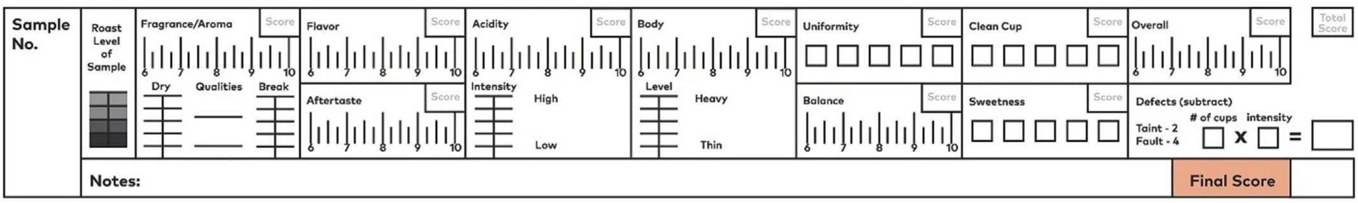

Figure 4: SCA coffee cupping form.

Table 2: Summary of the data for the dependent variables.

Dependent variable	N	Mean	SD	SE	95% Conf. interval	
First crack temp (°C)	81	186.53	0.99	0.11	186.31	186.75
Bean weight after roast (g)	81	132.87	1.20	0.13	132.60	133.13
Roast degree whole bean	81	76.54	2.36	0.26	76.02	77.06
Roast degree ground	81	103.83	4.87	0.54	102.75	104.91
Roast degree diff. (ground - whole bean)	81	27.29	3.68	0.41	26.47	28.10
Aroma	243	7.50	0.25	0.02	7.47	7.54
Flavor	243	7.43	0.25	0.02	7.40	7.47
Acidity	243	7.51	0.24	0.02	7.47	7.54
Body	243	7.47	0.20	0.01	7.44	7.49
Aftertaste	243	7.38	0.28	0.02	7.34	7.41
Balance	243	7.43	0.22	0.01	7.41	7.46
Overall	243	7.49	0.25	0.02	7.45	7.52
Total score	243	82.21	1.17	0.08	82.06	82.36

2.6 Analysis tools

The data analysis and figure plot were carried out using the Minitab 17 statistical software and Python 3. In Python 3, the following modules were employed: NumPy, Pandas, Researchpy, Scipy.stats, Statsmodels.api, Matplotlib.pyplot, Seaborn, Statsmodels.formula.api, Pingouin, Statistics, Statsmodels.graphics.factorplots,Mpl_toolkits.mplot3d, Matplotlib, and Matplotlib.ticker.

3 RESULT

3.1 Data overview

Table 2 briefly provides a summary of the dependent variables. The average first crack temperature was 186.53 °C, average weight after the roast was 132.87 g, and average weight loss rate (WLr) was 11.42%, as determined using equation 2.

$$WLr = ((GBw - RBw) / GBw) \times 100\%, \quad (2)$$

WLr: Roasted beans weight loss rate
GBw: Green beans weight
RBw: Roasted beans weight

The average whole bean roast degree was 76.54, and the coffee ground roast degree was 103.83. Such findings indicate that all samples were in a light roasting degree. The roast degree difference between the whole bean surface and coffee grounds was 27.29. Of note, the uniformity, clean cup, and sweetness were assigned a score of 10. The total score included scores for uniformity, clean cup, and sweetness.

Some experts prefer to use a larger score range to evaluate coffee quality while some prefer to use a smaller score range. This preference variation is shown in Figure 5 (a). In the present study, the z-score standardization method was used to standardize the data of the dependent variable before starting the analysis. Figure 5 (b) shows the total score data after standardization. The total score displayed a similar distribution among the three experts (Blocks 1, 2, and 3) after standardization. This finding indicates that the three experts had similar cupping quality appraisals for all samples.

Figure 6 shows a plot of all the independent variables. The x-axis appears from left to right. The y-axis is arranged in the following order: aroma, flavor, acidity, body, aftertaste, balance, overall, total score, and area under the curve (AUC). The AUC is the total area under the roasting curve. Equation 3 shows the AUC formula:

$$AUC = \int_{t_{turn}}^{t_1} (m_1 x + T_{turn})dx + \int_{t_1}^{t_2} (m_2 x + T_1)dx + \int_{t_2}^{t_3} (m_3 x + T_2)dx + \int_{t_3}^{t_4} (m_4 x + T_3)dx \quad (3)$$

m_1~m_4: Slope of ROR A–ROR D
t_{turn}: Time when the temperature reaches the turn temperature.
t_1~t_4: Time when temperature reaches the upbound of DS, EDS, ES, and DVS.
t_{turn}: Temperature at the turn point.
T_1~T_4: Upbound temperature of DS, EDS, ES, DVS.

Based on Figure 6, the flavor, aftertaste, balance, and overall had a positive correlation with the total score. Table 3 shows the normality of flavor, aftertaste, balance, overall and total score, which depicts that the cupping test data show normal distribution ($p > 0.05$).

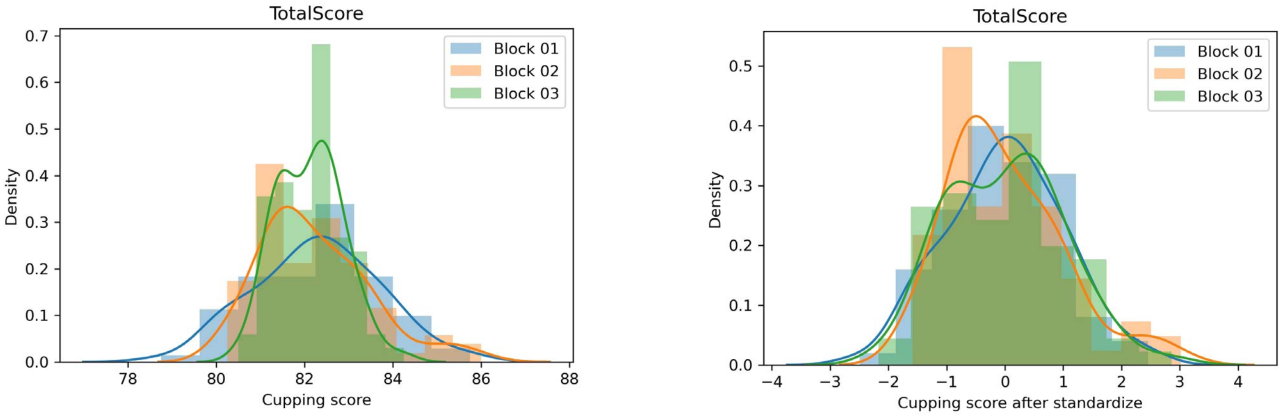

Figure 5: Total score distribution (a) before standardization and (b) after standardization.

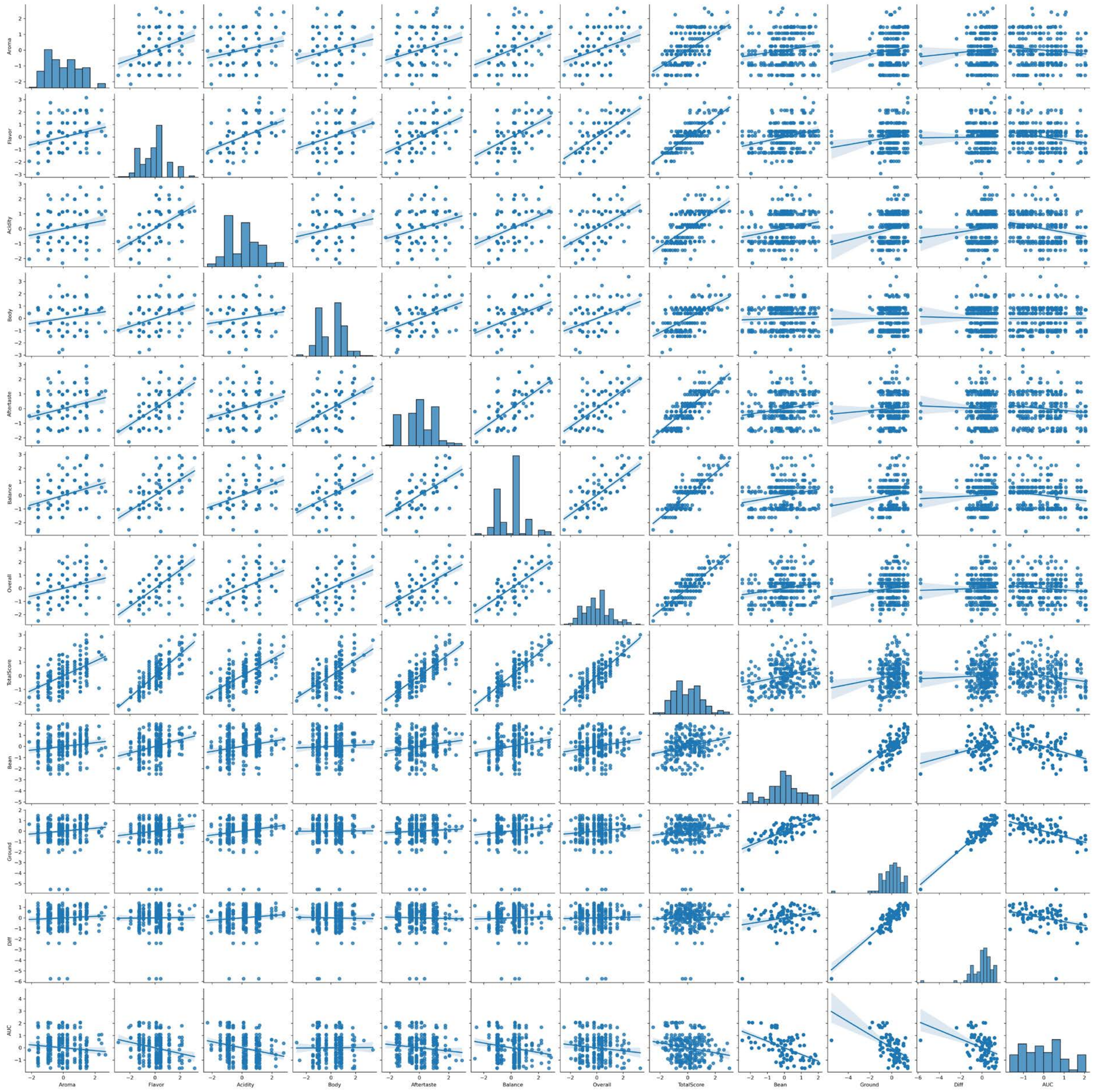

Figure 6: Pair plots of cupping quality.

Table 3: Normality test.

Variable	p-value
Flavor	0.296
Aftertaste	0.063
Balance	0.057
Overall	0.145
TotalScore	0.069

Table 4 lists the results of Pearson's correlation and Spearman's rank correlation test between the flavor, aftertaste, balance, and overall, and the total score. Pearson's correlation and Spearman's rank correlation values of -1 or +1 imply an exact linear relationship, while 0 implies no correlation. Table 4 shows the positive correlation between flavor, aftertaste, balance, and overall, and the total score. This finding indicates that flavor, aftertaste, balance, and overall cupping qualities are important contributors to the total score.

Table 4: Correlation test.

Correlation	Pearson's correlation test (r)	Spearman's rank correlation test (ρ)
TotalScore vs Flavor	0.791*	0.773*
TotalScore vs Aftertaste	0.786*	0.780*
TotalScore vs Balance	0.825*	0.786*
TotalScore vs Overall	0.851*	0.819*

(* represents p-value < 0.01, indicating that the samples are correlated).

3.2 Analysis of the experimental design

Figure 7 shows the main effect plot of the total scores. The main effect plot shows that ROR C had the highest main effect on the total score. Therefore, higher ROR C resulted in a higher total score. ROR D had the lowest main effect herein. In a prior study (Münchow et al., 2020), the DVS roast time ranged from 10 s to 405 s, and the roast degree included light roast degree to dark roast degree. In the present study, the DVS roast time was fixed to 70 s and all samples were subjected to light roasting degrees. In this study, ES was identified as the most important main effect on light roasting degree.

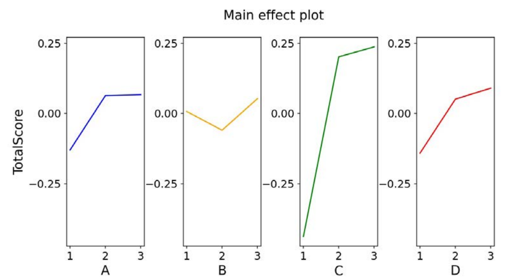

Figure 7: Main effect plot of the total score.

Table 5 includes all the main effects on all the dependent variables. Table 5 indicates that ROR C had the highest main effect on aroma, flavor, acidity, aftertaste, balance, overall, and total score. Thus, the main effect table shows that ES is the most important stage that influences the cupping quality of most light roast brew coffee; this finding may be due to the low water content of beans in ES. Based on our knowledge, the Maillard reaction is important for the cupping quality of roasted coffee. Although the Maillard reaction is triggered at 120 °C, a previous study found that decreased water content can cause increased volatile generation in the Maillard reaction (Chih-Ying et al., 2005). Increased temperature also increases aromatic character in both high- and low-molecular-weight products (Benzing-Purdie; Ripmeester; Ratcliffe, 1985). Such notion might explain the greater main effect of the ES than DS and EDS. Equation 4 is the transition state theory developed by Eyring. The equation indicates that the Maillard reaction rates correlate with activation entropy and enthalpy (Martins; Jongen; van Boekel, 2001); a higher temperature (T) generates a higher reaction rate constant (k). In addition, because ES is exothermic, $\Delta H^{\neq}$ is a negative number that generates a higher k. Thus, in light roasting degree, the time-temperature variation at DVS is not as large as ES, which causes the ES to be more important than DVS.

$$k = \frac{k_B T}{h} \exp\left(-\frac{\Delta G^{\neq}}{RT}\right) = \frac{K_B T}{h} \exp\left(-\frac{\Delta H^{\neq}}{RT}\right) \exp\left(\frac{\Delta S^{\neq}}{R}\right) \quad (4)$$

k: Rate constant
kb: Boltzmann's constant (1.4 x 10^{-23} JK^{-1})
h: Planck's constant (6.6 x 10^{-34} Js)
R: the gas constant (8.3 $Jmol^{-1}$ k^{-1})
T: Absolute temperature (K)
$\Delta G^{\neq}$: activation Gibbs energy($Jmol^{-1}$)
$\Delta H^{\neq}$: Activation enthalpy($Jmol^{-1}$)
$\Delta S^{\neq}$: Activation entropy ($Jmol^{-1}k^{-1}$)

3.3 Analysis of variance

ANOVA was employed to determine the importance of knowing the main effect and interaction effect of ROR A, B, C, and D on cup quality. The ANOVA test results are presented in Table 6. Table 6 indicates that the aroma, flavor, acidity, overall balance, and total score were influenced by ROR C ($p < 0.05$). Moreover, no main effects or interaction effects were found to influence the body. This study hypothesized that this phenomenon occurs because the body is related to the total solids (TS) content (Dong et al., 2019). However, a previous study indicated that TS did not show a general trend of being influenced by the roasting profiles (Gloess et al., 2014).

Table 5: Main effect summary table.

Factor	A level	B level	C level	D level	Aroma	Flavor	Acidity	Body	Aftertaste	Balance	Overall	Total Score
A	1-2				-0.009	0.199	0.350	0.063	0.097	0.171	0.145	0.193
A	2-3				0.132	0.117	-0.090	-0.121	0.033	-0.087	-0.056	0.003
B		1-2			-0.188	-0.025	0.103	-0.237	0.084	0.030	-0.096	-0.067
B		2-3			0.192	0.087	-0.163	0.258	0.067	0.110	-0.001	0.112
C			1-2		0.459	0.546	0.665	0.242	0.217	0.586	0.506	0.639
C			2-3		-0.027	0.198	0.262	-0.265	0.075	-0.065	0.051	0.036
D				1-2	0.044	0.307	0.094	0.243	0.056	0.073	0.151	0.192
D				2-3	-0.050	-0.055	0.125	0.004	0.030	0.128	0.025	0.039

Table 6: ANOVA results for sensory quality versus ROR A, ROR B, ROR C, and ROR D. (List by p-value).

Factor	Aroma	Flavor	Acidity	Body	Aftertaste	Balance	Overall	Total score
Linear	0.095	0.000	0.000	0.276	0.704	0.008	0.016	0.000
A	0.640	0.090	0.054	0.759	0.702	0.536	0.630	0.338
B	0.377	0.828	0.546	0.214	0.640	0.631	0.761	0.760
C	0.005	0.000	0.000	0.198	0.170	0.000	0.000	0.000
D	0.941	0.081	0.341	0.223	0.863	0.418	0.455	0.271
2-Way Interactions	0.575	0.377	0.674	0.799	0.152	0.057	0.148	0.261
AB	0.666	0.595	0.953	0.727	0.789	0.462	0.830	0.830
AC	0.869	0.525	0.490	0.251	0.227	0.653	0.443	0.447
AD	0.131	0.398	0.615	0.533	0.427	0.163	0.134	0.205
BC	0.799	0.843	0.916	0.476	0.645	0.027	0.028	0.253
BD	0.254	0.053	0.208	0.925	0.002	0.022	0.354	0.030
CD	0.385	0.318	0.164	0.591	0.999	0.811	0.400	0.928
3-Way Interactions	0.350	0.307	0.838	0.868	0.750	0.894	0.718	0.807
ABC	0.320	0.623	0.986	0.397	0.734	0.841	0.893	0.614
ABD	0.344	0.124	0.595	0.727	0.787	0.784	0.387	0.686
ACD	0.723	0.424	0.340	0.643	0.572	0.585	0.576	0.677
BCD	0.199	0.368	0.605	0.925	0.317	0.589	0.439	0.546
4-Way Interactions	0.776	0.173	0.787	0.594	0.939	0.776	0.239	0.723
ABCD	0.776	0.173	0.787	0.594	0.939	0.776	0.239	0.723

Aftertaste was not affected by the main effect. In fact, aftertaste was only obviously influenced by ROR B and ROR D interactions. This is because most aftertastes are related to heavy and low water-soluble bitter melanoidins (Münchow et al., 2020). Melanoidins generate a complex Maillard reaction of the breakdown products with the amino groups in the advanced Maillard reaction products (Martins; Jongen; van Boekel, 2001). The color of the roasted beans is influenced by the caramelization reaction (Leme et al., 2019). Different degrees of roast have different contents of melanoidins. In this study, all the DOE samples had a light roast degree. However, they did not have marked melanoidin content variance at similar roast degrees that cause aftertaste, which is not significantly influenced by the roasting profile.

4 DISCUSSION

This study surmises that ES is the major Maillard reaction occurrence stage for the degree of light roasting. Changes in ROR C also change Maillard's reaction time. The interaction effects of ROR B and ROR C were found to have relatively high effects on balance and overall. Further, the interaction effects of ROR B and ROR D had relatively strong interaction effects on the aftertaste, balance, and total score, as shown in Table 7. Such finding indicates that the interaction with ROR B also has a strong effect on cup quality. This study hypothesizes that although Maillard reactions in EDS have a smaller rate constant k than ES and DVS, $\Delta H^{\neq}$ is a positive number for the endothermic reaction. Some chemical reaction products in EDS

Table 7: 2-Way Interactions effect table.

Factor	B level	C level	D level	Aftertaste	Balance	Overall	TotalScore
BC	1-2	1-2		0.347	0.547	0.160	0.205
BC	1-2	2-3		-0.605	-1.177	-0.999	-0.808
BC	2-3	1-2		-0.278	0.067	-0.151	-0.088
BC	2-3	2-3		0.384	0.597	1.076	0.615
BD	1-2		1-2	0.027	-0.159	-0.180	0.197
BD	1-2		2-3	-0.245	0.159	0.010	-0.349
BD	2-3		1-2	-1.007	-0.723	-0.409	-0.695
BD	2-3		2-3	-0.218	-0.315	-0.044	-0.196

may influence the chemical reactions in ES and DVS (Boekel, 2006). For example, a previous study found a glycine/glucose model system. The total amount of volatiles increased by > 60% in the coffee beans with 13% water content, which caused some of the aroma variables to increase, for example, burnt toast, acrid, slightly nutty, and biscuity (Ames; Guy; Kipping, 2001).

5 CONCLUSIONS

This study sought to determine how roasting time-temperature profiles influence the cup quality of light-roasted coffee. Herein, ROR in the range of 150 °C to 185 °C was found to be the most important factor affecting coffee cup score. Further, flavor, aftertaste, balance, and overall were positively correlated with the total score. In contrast, aroma, acidity, and body were not correlated with the total score. The interaction between ROR B and ROR C or ROR D has an important influence on the cupping quality of coffee. For example, ROR B level 1-2 and ROR C level 2-3 interactions have a high effect on balance; and ROR B level 2-3 and ROR D level 1-2 interactions have a high effect on the aftertaste. Herein, the roasting time-temperature profile was not found to influence the body in light roasting degrees. Any main effect does not influence the aftertaste and is only obviously affected by ROR B and ROR D interaction.

This study focused on light roast coffee and only used *Arabica* green beans made by a wet process. Thus, this study did not determine whether the roast profile influences the medium roast degree and dark roast degree, or how the roast profile influences the different coffee varieties. Therefore, modifying the experiment to determine how the roasting time-temperature profiles influence the medium roast degree, dark roast degree, and different bean varieties of coffee are important future works.

6 AUTHORS' CONTRIBUTION

Conceptual idea: KF, Ting.; Methodology design: KF, Ting.; JC, Chen.; TL, Chen.; Data collection: KF, Ting.; Data analysis and interpretation: KF, Ting.; JC, Chen.; TL, Chen.; and Writing and editing: KF, Ting.; JC, Chen; TL, Chen.;].

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