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Optimising consumer acceptability of Cauca specialty coffee through roasting profiles on acidity and body sensory attributes

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Abstract: The roasting coffee process is the compilation of time-temperature-dependent physical and chemical transformations induced by heat. Through the study of the time-temperature curve, the correct definition of the degree of roasting of coffee is an area of active and non-trivial research, which intervenes in obtaining consistent roasting profiles reflected in the acceptability of the drink perceived by consumers. This paper used the methodology of response surfaces (RSM) with the central composite design (CCD). A consumer study was conducted with 104 individuals, each tasting 13 cups of specialty coffee from Cauca-Colombia. Predictive equations for acidity and body perception were obtained. The roasting profile points in charge, turning point, yellow, brown, first crack, and drop step were included. Mathematical models predict the acidity and body perceptions by integrating the roasting profile points characteristics of coffee. The Cauca coffee beans produced using the optimied conditions contribute to obtaining a roasting time/temperature of 468 s at 192 °C, respectively, with acidity (9/15) and body (5.5/15) in the (0–15) intensity consumer's perception scale.

Keywords: coffee industry 4.0; consumer perception; optimisation; roasting specialty coffee; response surface methodology – central composite design (RSM–CCD)

Specialty coffee is a product with traceability throughout the entire cycle of the coffee process, from the choice of the factors that influence the parameters of coffee cultivation to the beverage of the coffee to the final consumer (Campo-Ceballos and Gaviria-López 2019; Solis et al. 2021). One of the open problems in the coffee roasting process is determining the optimal time and temperature conditions to obtain consistent and replicable profiles depending on the emphasisto generate a perception of a particular flavour to the coffee consumer. Roasting levels are established from the time-temperature profiles. However, these profiles are not uniform from batch to batch, producing a perception of flavour change (Giacalone et al. 2019). In Colombia, research on the effect of numerical optimisation of roasting conditions of specialty coffee genotypes based on consumer preferences is still limited. Only one study has been reported to optimise the roasting

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of healthy and brocade coffee blends based on process temperature and shutdown water, where no significant differences in quality are obtained between healthy and brocade grains (Castrillón Castaño and Quintero Sánchez 2001). However, the relationship between the consumer's perception and the parameters of the roasting profiles to achieve a consistent key of the organoleptic properties, such as acidity and body, which are desirable in Cauca coffee, has not yet been demonstrated. Previous works have used the combination of response surfaces methodology (RSM) and CCD statistical design to optimise coffee roasting profiles concerning roasting profile conditions or the emphasis on chemical properties in roasted coffee (Campo-Ceballos and Gaviria-López 2019). This work differs from those other studies in that the factors to be optimised are the subjective acidity and body organoleptic properties of coffee in the cupping process perceived by final consumers who have not had specialised training in cup coffee cupping. For this purpose, a survey has been used where consumers evaluate these attributes using a 15-point scale, following a protocol that contemplates preliminary training of the respondents in the perception of different beverages used as referents of acidity and body levels.

This paper reports how the time and temperature conditions of the roasting process for the Castillo Tambo variety, widespread in most of the Cauca region of Colombia, can be optimised. These methods promote consistency in the perception of acidity and body in cupping tests acceptable by final consumers of coffee who have yet to undergo training in the cupping process previously. This result is of potential importance for the coffee roasting industry because it would allow having systematic procedures that will enable them to achieve consistency. The perception of the final consumers of specialty coffees provides for obtaining a differentiated value in the coffee consumption experience.

MATERIAL AND METHODS

Raw coffee

The study was carried out with the following raw materials. Coffee cherries of Arabica Castillo Tambo were harvested in May 2019. The crop is in Cajibío-Cauca, southwestern Colombia, between the Western Mountain Range and Central Mountain Range (N2 35.086 W76 32.959), altitude of 1 765 m a.s.l., distinguished by its volcanic soils. The cherries pass through a pulper that removes the skin surrounding the inner seed. Fermentation was 12 h at room temperature (17–20 °C) following a washed coffee processing method, and the seeds were put to dry on tarps in diffused sunlight until they reached 11 to 12% moisture. Grains density average: 750 $g \cdot L^{-1}$. Grain size average: mesh 17–18/64 inches. Specialty-grade coffee beans have zero primary defects and only 0–3 total secondary defects.

Experimental design

The RSM applying central composite design (CCD) (Ait-Amir et al. 2015) was used to and optimise the roasting profile based on time and temperature data with 13 runs. The 13 roasting profiles ranged from 177 to 195 °C and 420 to 501 s, respectively, as shown in Table 1. Colourimeter measurements follow the visual development of the colour of the roasted beans according to the Specialty Coffee Association (SCA) Agtron Roast Colour Kit.

Roasting coffee

Roasting reference. The reference curve sets the loading temperature and gives guidelines for the ranges of volume gain and mass loss of roasted coffee beans that guarantee consistency in the process. Experimental roasting profiles were obtained by adjusting the actual roasting temperatures and times to the reference ones. The roasting reference profiles trials ranged from high-temperature short time (HTST) to low-temperature long time (LTLT) roasting and from medium to a dark roast degree, according to Gloess et al. (2014). HTST profiles aim to accentuate the acidity, and the LTLT seeks to emphasise the body.

Roasting samples. Green coffee bean batches of 200 g were roasted in a gas-driven Sample Roaster (PROBAT AG, Germany), with a precision of ±1 °C equipped with a time-temperature data logging and a control system connected to the Artisan scope software (ARTISAN 2022). Experimental samples come from 13 different combinations of time and temperature in the range of 175–195 °C and between 400 and 501 s (see Table 1). According to Campo-Ceballos and Gaviria-López (2019), CCD with modulation allows for the roasting points (SCAA 2015; Poltronieri and Rossi 2016; Benítez Urbano and Campo-Ceballos 2018). The charge temperature was 170 ± 1 °C, considering the density and size of the bean's variety. The sample-to-sample time was 300 s monitoring the roaster cylinder preheating in a controlled manner. After each roasting process, a fan rapidly cooled the roasted coffee beans to room temperature. This process was standard for all samples

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Table 1. 13 Cauca specialty coffee perception experiment data and the critical roasting points

Std	Run	*t* (s)	*T* (°C)	Acidity (0–15 scale)	Body (0–15 scale)	Colour (SCA)	Roasting profiles points								
							charge *T*	turning point		dry or yellow		first crack		drop	
							(°C)	*t*	*T*	*t*	*T*	*t*	*T*	*t*	*T*
13	1[c]	460	186	8	5	85	178.9	82	80.2	233	138.4	398	177.8	460	184.9
1	2[f]	420	180	13	1	95	179.3	81	82.0	230	139.9	393	177.5	418	180.3
5	3[a]	403	186	13	1	85	179.0	78	78.7	223	137.3	392	183.9	410	186.3
12	4[c]	460	186	12	2	85	180.7	73	76.5	229	138.0	423	182.8	455	185.8
9	5[c]	460	186	12	2	85	179.7	60	77.5	228	142.2	423	183.2	459	185.7
6	6[a]	517	186	7	7	85	178.8	70	77.4	224	136.9	424	179.8	517	186.1
3	7[f]	420	192	11	2	75	180.8	74	85.1	223	138.0	400	187.7	419	192.1
10	8[c]	460	186	10	4	85	179.2	78	83.3	206	135.8	437	185.3	459	186.8
8	9[a]	460	194	10	6	75	178.3	79	80.5	209	133.2	440	192.7	458	194.8
2	10[f]	501	180	8	5	95	181.1	71	84.8	222	141.8	440	177.3	500	180.1
11	11[c]	460	186	12	2	85	179.8	62	86.8	226	143.3	428	182.0	460	185.9
4	12[f]	501	192	5	9	75	177.9	66	83.3	241	139.4	471	187.0	500	192.5
7	13[a]	460	177	14	1	95	179.7	76	80.2	243	142.1	460	177.5	460	177.5

[a, c, f]axial, central and factorial points – central composite design (CCD); *t* – time, *T*– temperature; std – order of run execution; run – each roasting curve; 0–15 point intensity scale (0 – not at all, 2 – barely detectable, 4 – identifiable, but not very intense, 6 – slightly intense, 8 – medium intense, 10 – intense, 12 – very intense, 15 – extremely intense); SCA – Specialty Coffee Association

and took an average of 180 s. Quantik IR-800 (Quantik Industries S.A.S, Colombia) colourimeter analyses coffee beans' colour colour to determine the degree of roasting in the 8-colour disk of Specialty Coffee Association of America (SCAA) – roast colour kit (Coffeee Roast Colour CRC-80; Agtron, Poland) (25 darkness to 95 light colour disk). The coffee samples were packed in a sealed plastic bag and stored at room temperature.

Brewing sample preparation

The beverages were prepared according to (SCAA 2015) in the specialised coffee laboratory of TECNiCAFÉ considering the water quality in total dissolved solids (TDS) of 125–175 ppm, a water temperature of 93 °C, and a coarse grinding mill with a coffee grinder (Mahlkönig EK43; HEMRO AG, Germany) to obtain the ground coffee. Coffee cups were prepared with 18 g of coffee per 250 mL in a French press at 93 °C. A French press allows coffee to be immersed and saturated in a repeatable manner for this experiment, which produces a homogeneous cup of coffee and helps to reduce the bias in consumer testing.

Sensory data

In this experiment, 104 participants are pre-trained to assign numbers to their acidity and body perception of 13 coffee samples relative to how strong each sensation feels. Citric acid solutions (2-Hydroxy-1,2,3-propane tricarboxylic acid hydrate) were prepared for acidity training. Commercial coffee solutions allow training the body intensity in the 15-point reference. Data collection consists of a direct face-to-face survey, after the pre-training step, with the 13 coffee samples from the experimental design.

Statistical methods

The RSM allows us to model and analyse the roasting process in which the roasting variables affected the responses of acidity and body. Design-Expert® software (Stat-Ease 2022, https://www.statease.com/software/design-expert/) for RSM and CCD supports the design, analysis, and post-analysis process considering lack of fit, model comparison statistics, correlation, and analysis of variance (ANOVA). The mathematical models integrate time, temperature, and acidity-body perception using a quadratic parametric adjustment by ANOVA.

RESULTS AND DISCUSSION

According to the experimental setup, the mean values of roasting profiles were obtained from this step and are present in Figure 1.

For all batches, the mean charge temperature was 180 °C. The turning point was achieved on average

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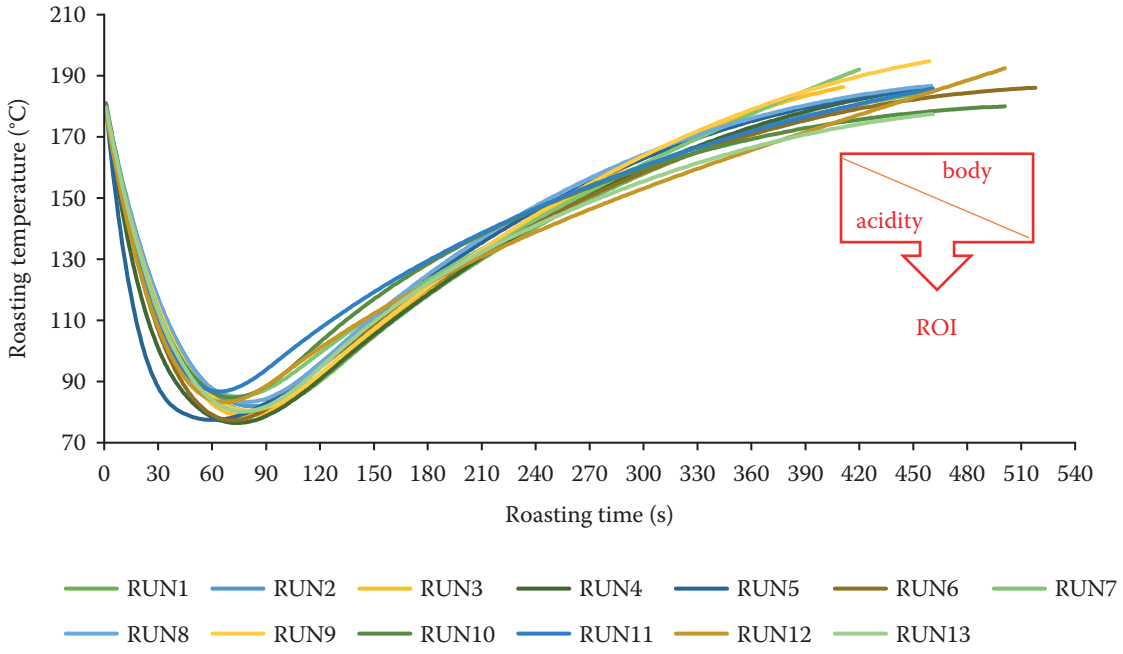

Figure 1. Roasting profiles from experimental data

First crack to drop – region of interest (ROI)

for all roasting profiles in 73 s and at a temperature of 81 °C. In the same way, the yellow or drying stage reached an average of 226 s and 139 °C of temperature. On the other hand, the first crack had different points of occurrence due to the experimental approach and the objective of each roasting curve, as expected according to the experimental knowledge of the behaviour of roasted coffee. These red points are shown in Figure 2, where the coffee drops the roasting drum to be cooled to room temperature for 120 s. The com-

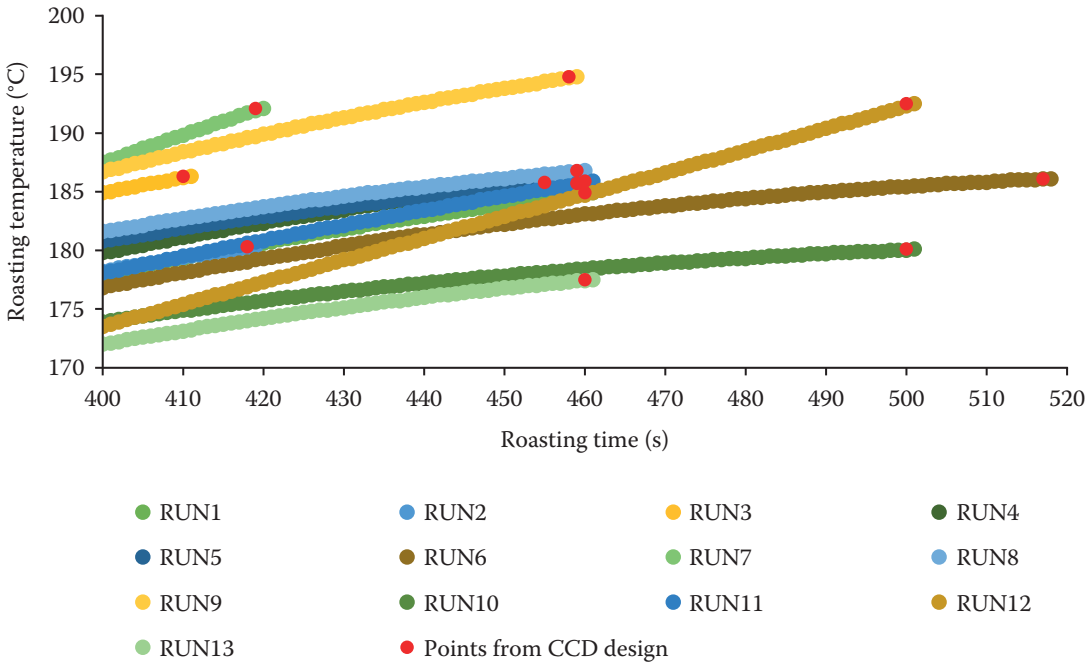

Figure 2. Region of interest in the experimental roasting profiles

CCD – central composite design

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plete experimental data are presented in Table 1. The roasting evolution points (charge temperature, turning point, dry/yellow, first crack and drop) were the tool for the acidity and body traceability of the coffee beans. Figure 2 also shows the experimental regions of interest (ROI) to study how roasting affects the acidity and body perceived in coffee. Table 1 shows the factor data and profile data for that ROI. Generally, HTST profiles aim to accentuate acidity, and the LTLT accentuates the body. This data supports the relationship between acidity and the body from consumer perceptions, which is one of the objectives of this work.

Figure 3 shows the correlation graph of roasting variables for normal data ($P > 0.05$). This analysis shows the correlations between the variables of the coffee roasting process for this study.

The colour of roasted coffee shows a fairly strong negative correlation (–0.99) with the increase in temperature, which is evident in practice by the change in colour that the roasted coffee bean undergoes. The perception of acidity shows a negative correlation with the body (–0.89), which suggests the two variables are inversely associated, which can be studied during the roasting process. Likewise, a moderate and negative relationship exists between the perception of acidity and roasting time (–0.71) and a positive relationship between the perception of body and roasting time (0.72). In this sense, the initial results show that the perception of acidity and body can be affected by the time and temperature profiles, keeping a point-to-point record in the roasting profile. For example, while the body has a positive relationship of 0.58 with temperature, acidity only shows a negative relationship of –0.34 with the

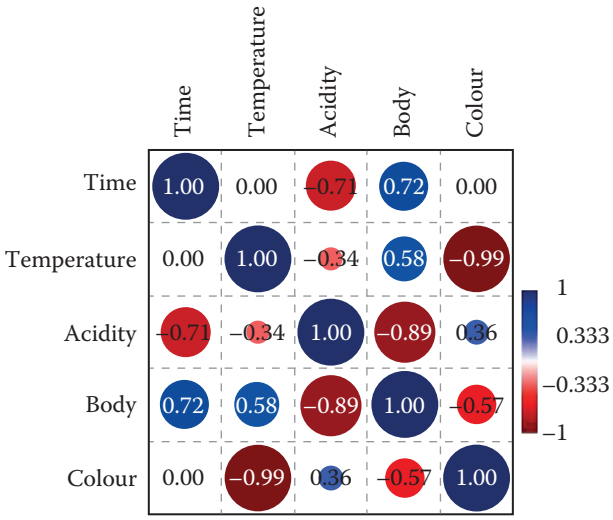

Figure 3. Correlation for the 13 experimental variables for the coffee roasting process

same variable. To lead in detail to the relationships described above, see Figure 4. The correlation between perceptions of acidity and body against the roasting time of the coffee sample is reported for the first time. In both cases, the marked dependence of both acidity and the body is clear. Figure 4A presents a behaviour when the temperature increases. The negative correlation (above –0.7) indicates a decreasing slope of the perception of acidity. In contrast, in Figure 4B, the positive correlation (above 0.7) between the body and the roasting time shows increased body perception when the roasting temperature increases.

In addition, it is possible to show how to influence the acidity and body consumer's perception

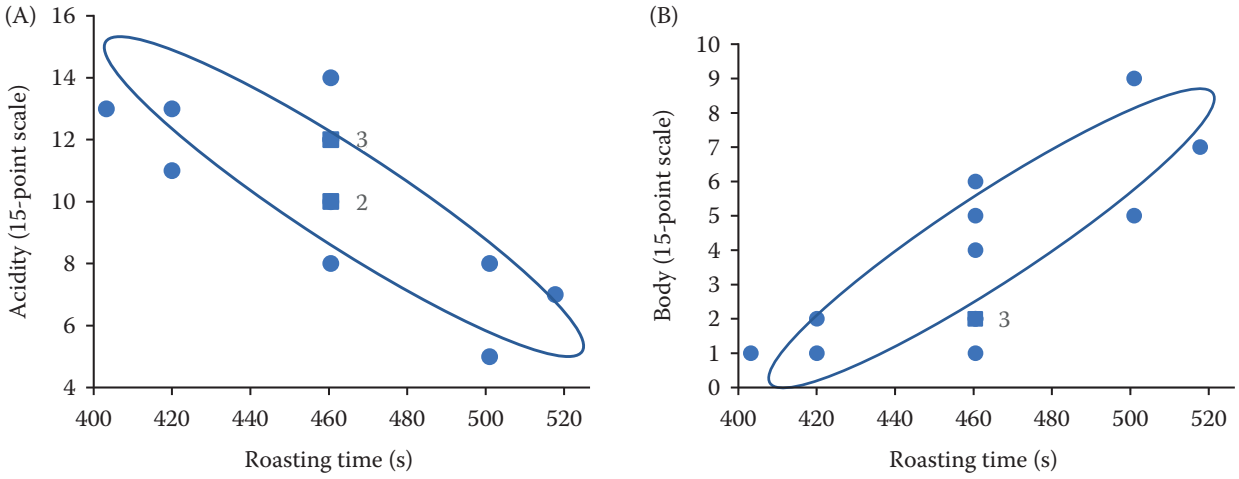

Figure 4. Correlation points of roasting time and (A) acidity and (B) body consumer's perception

Squares – 3 or 2 coffee samples with the same consumer's perception; circles – perception of each coffee sample

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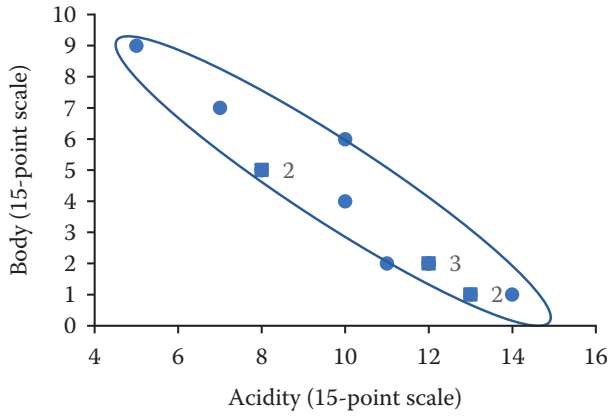

Figure 5. Acidity – body correlation

Squares – 3 or 2 coffee samples with the same consumer's perception; circles – perception of each coffee sample

through the proposed roasting profiles. Figure 5 represents this potential relationship. The correlation value above –0.9 means a solid inverse relationship in the perception of acidity and body due to the roasting profiles.

Table 2. The final equation for coffee acidity perception in terms of actual factors

Acidity	Roasting conditions
+39.555340	–
+0.601474	time
–1.427420	temperature
–0.001029	time × temperature
–0.000511	time²
+0.004514	temperature²

The coffee acidity perception model. According to this information, parameters of the mathematical model that describe the acidity by consumers' perceptions in the roasting conditions were obtained. The mathematical model from acidity in terms of real factors presented in Table 2 can be used to make predictions about the coffee acidity perception for given levels of each factor (time-temperature profiles).

The contour diagram and response surface of the acidity perceived by consumers in the designed experiment are shown in Figure 6.

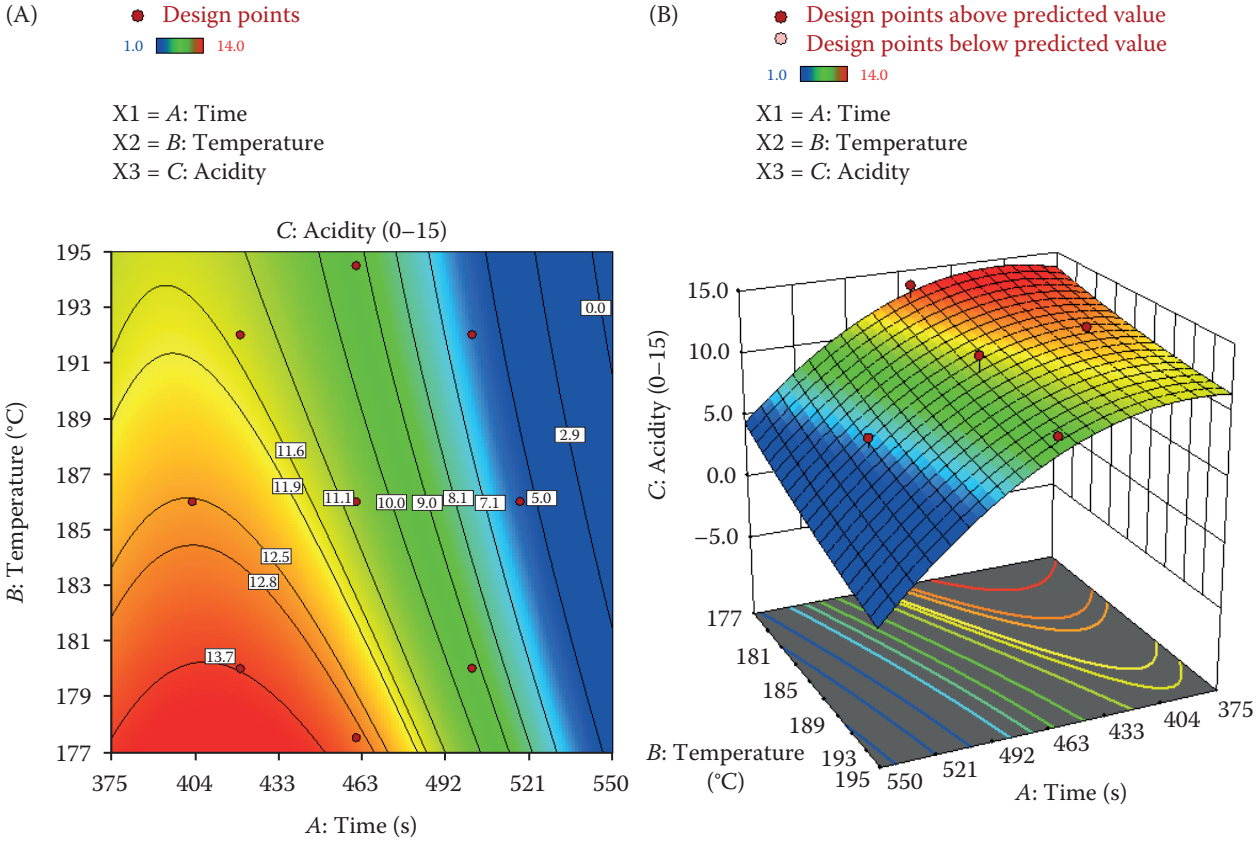

Figure 6. Acidity perceived by consumers. (A) contour plot, and (B) response surface for acidity perception between 5 (min) to 14 (max) on the 15-point scale

Source: Own ellaboration based on Design-Expert® Software

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The contour plot is a two-dimensional (2D) representation of the response plotted against combinations of numeric factors. It can show the relationship between the responses of acidity consumers' perception. The design points in the figure with a red circle allow us to analyse consumers' predicted perception of acidity related to the roasting profiles. The contours plot on the left, close to the HTST roasting profiles, have a curvature that leads to a perception of high acidity. The central contours show a homogeneous trend and relate the roasting run profiles 9 and 10, obtaining a predicted acidity in the range of 10–9 (green region) on the 15-point scale used in this work. This result shows a consistent area for acidity values from the selected time and temperature profiles.

On the other hand, the predicted perception of acidity for LTLT roasting profiles shows low acidity values. Consumers perceived lower values of acidity in the range of 5 to 7.1 blue regions in the contour plot. The acidity perception considers the appropriate roasting profiles to accentuate or not this attribute.

Table 3. The final equation for coffee body perception in terms of actual factors

Body	Roasting conditions
+634.069690	–
–0.864872	time
–5.044820	temperature
+0.003086	time × temperature
+0.000381	time^2
+0.010417	temperature^2

The coffee body perception model. The mathematical model of the body perception in terms of actual factors is shown in Table 3.

The model, in terms of actual factors, can be used to make predictions about the response for given levels of each factor, as shown in Table 3. The response surface and contour plots of the coffee body perceived by consumers in the designed experiment are shown in Figure 7.

One of the characteristics of Cauca coffee is its medium-low body; thus, from Figure 7, the values in the

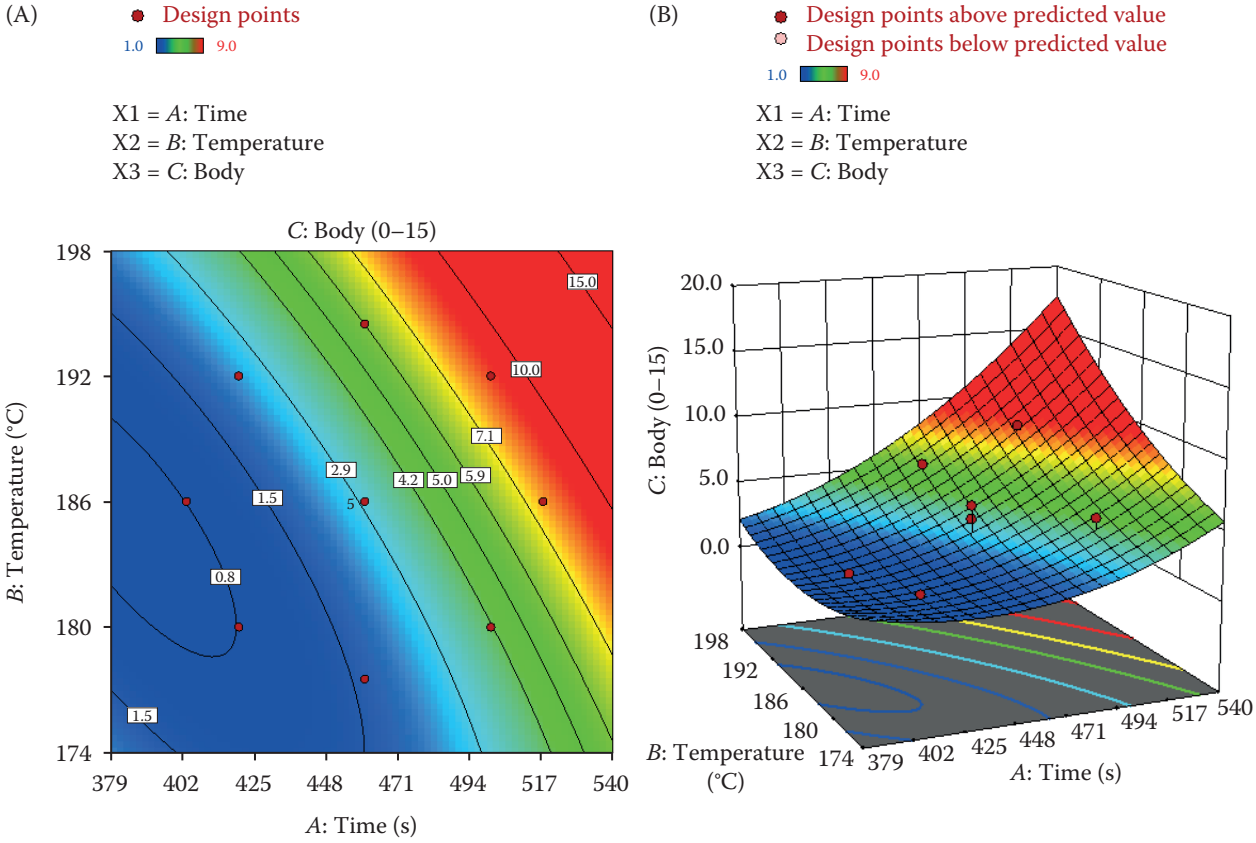

Figure 7. Body perceived by consumers. (A) contour plot, and (B) response surface for body perception between 1 (min) to 9 (max) on the 15-point scale

Source: Own ellaboration based on Design-Expert® Software

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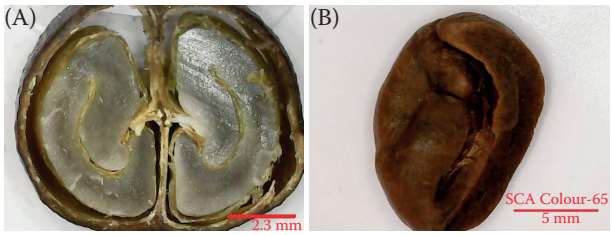

Figure 8. Sample coffee bean's initial and final state in the optimised roasting experiments

SCA – Specialty Coffee Association

range of 4.2–5.9 on the scale of 0–15 points, show the profiles 10 and 9 (design points), respectively, to obtain these intensities. The prediction of the coffee body perception value is restricted to the width of the homogeneous contour regions. In this case, contour regions encompassing the roasting profiles mentioned above can predict this perception.

Colour is a parameter used to perceive the changes generated in the roasting process of the coffee bean. A sample of coffee beans in the initial and final state is shown in Figure 8. The average colour of roasted coffee beans was 65 on the Agtron SCA scale, measured with the QUANTIK IR-800 colourimeter.

CONCLUSION

With the RSM-CCD experimental design, a quadratic mathematical model was proposed for the consumer's perception of acidity and the body. These models join in three additional factors, time × temperature, temperature^2, and time^2, essential for defining roasting profiles at the charge, turning points, yellow, first crack, and drop. It was possible to establish a consistent perception prediction interval for the body and acidity perceptión in 468 s at 192 °C roasting profile. According to the contour graphs, acidity is the attribute most significantly affected by temperature changes. In contrast, the body perception was influenced considerably by the time in the roasting process. Optimising time and temperature conditions includes varying the duration and intensity of the Maillard reaction and recording its effects on the profile to obtain consistent coffees acceptable to consumers. The combined use of RSM-CCD has been used before in similar studies. Still, in this study, we have considered the attributes of acidity and body of coffee in a cup perceived by consumers without previous training in coffee cupping by applying a 15-point scale to evaluate these attributes. The results demonstrate that with this combination of methods, it is possible to achieve consistency in the perception of the characteristics of acidity and body perceived in the cupping process from the optimisation of the roasting profile. It is essential for the coffee roasting industry, which seeks to obtain products of exceptional quality for specific sectors of consumers. The perception of the optimised samples was validated, combining RSM-CCD and the 0–15 intensity scale techniques approach to get insights into how consumers perceive Castillo Specialty Coffee from Cauca Colombia.

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