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Effect of extraction processing parameters using a ribbon blender on the physicochemical properties of coffee

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ABSTRACT

In this study, we investigated the impact of water-coffee ratio, time, and stirring speed on percolation in a horizontal ribbon blender. We analyzed their influence on total soluble solids, extraction rate, titratable acidity, and extraction yield. The coffee extract was obtained in a pilot unit at a constant temperature of 85°C and varying the water-coffee ratio (w/w) from 4:1 to 10:1; the stirring speed between 30 and 95 RPM and the extraction time from 10 to 60 min. It was determined that the water-coffee ratio was the factor that had a significant influence on all the response variables, while time and stirring were significant for the extraction rate and titratable acidity. The optimal conditions of soluble solids, extraction yield, extraction rate, titratable acidity, and chlorogenic content were a water temperature of 85°C, a water-coffee ratio (w/w) of 4:1, and a stirring speed of 66 rpm for 10 min. At these conditions, an extract of 5.85% Total Dissolved Solids, 14.54% as yield, an extraction rate of 654.8 g/h, and a content of 5.62 mg of CGA/mL was obtained. Hence, this study presents an alternative process to obtain coffee extract in producing soluble coffee at a low industrial scale.

Key words: Chlorogenic acid; Extraction yield; Foods; Optimization; Soluble coffee.

1 INTRODUCTION

Coffee is one of the most important food commodities worldwide. Its economic significance is mainly due to the beverage or extract obtained from roasted and ground coffee beans, used to produce soluble coffee (Ocampo; Alvarez, 2017) Instant coffee, a growing preference, recorded consumption surpassing 1.6 million tonnes in 2017. (Sulewska et al., 2021), whose popularity is attributed to the convenience of its preparation and the shelf life of the product (Capek et al., 2014). The industrial production of this coffee is carried out using roasted and ground beans. Initially, the compounds present in the coffee are extracted, followed by the concentration stage of the extract through evaporation or technologies such as freeze concentration. Finally, the extract is sent to a spray dryer or a freeze dryer before packaging the product (Sulewska et al., 2021).

In general, at industrial scale, the extraction of coffee extract is carried out in large percolators, where roasted and ground coffee beans are in contact with water at 200 °C and 1500 kPa to extract volatile and non-volatile compounds present in them (Benincá et al., 2016). At this stage, three main processes are identified: the solubilization of solutes from the food matrix, the diffusion of these solutes through the coffee bean pores, and finally, the solubilization of solutes in the extract (Fuller; Rao, 2017). The objective of extraction to produce soluble coffee is to remove the highest amount of soluble solids (TDS) since they influence the operational yield and represent the proportion of dissolved material in the extract over the total mass of coffee. This result can vary depending on the quality of the bean, the roasting process, particle size after grinding, and the extraction method, where conditions, parameters, and variables in the process can affect the sensory and chemical characteristics of coffee. (Cordoba et al., 2021a).

The extraction time is a key factor, as soluble compounds such as organic acids, sugars, and caffeine are extracted quickly, while less soluble compounds require more time to be removed from the food matrix (Mestdagh; Glabasnia; Giuliano, 2017). Likewise, the water-to-coffee ratio used for extraction greatly affects the extract, as an unsuitable selection will result in underdeveloped flavors and reduced extraction yield of the coffee extract (Angeloni et al., 2019). Temperature favors the solubility of many compounds in the coffee bean. However, very high temperatures can lead to the extraction of undesired compounds in the extract, affecting its sensory perception (Mestdagh; Glabasnia; Giuliano, 2017). Finally, agitation and particle size of the coffee beans determine the extraction rate of the process and consequently the total solid content achieved in a specific time. Those variables promote the transfer of compounds to the extract by increasing the extraction surface area and the interface between water and coffee (Cordoba et al., 2020).

In recent years, interest in coffee extraction has increased. Nevertheless, due to the complexity of the process to obtain a high-quality product, the studies conducted so far have been small-scale and focused on obtaining coffee extract for immediate consumption, where the concentration of soluble solids in the extract reaches only between 1.3% and 3.2% (Angeloni et al., 2019); while at an industrial scale, fixed-bed percolation systems are employed at high pressure, which can yield around 30% (Benincá et al., 2016). However, in our best knowledge, there are no reported studies of non-pressured pilot-scale equipment. An alternative for industrial coffee extract production is the ribbon blender solid mixer, whose purpose is promoting coffee ground-water mixing and enhance convective mass transfer. The study of extraction in pilot-scale units allows identifying alternatives to industrial production with simpler and more economical equipment than traditional percolation equipment. The term "pilot-scale" refers to a scaled-down version of the equipment used in preliminary testing before potential upscale to larger production. The use of a pilot-scale setup is crucial at this stage as it allows for controlled experimentation in a smaller, more manageable setting. This approach enables meticulous parameter adjustments, facilitating a detailed understanding of their impact on the extraction process. The insights gained from this pilot-scale exploration lay the foundation for optimizing conditions before considering large-scale industrial production. The aim of this study the effect of different water-to-coffee ratios, extraction times, and stirring in a pilot-scale ribbon blender on the percentage of TDS, yield, extraction rate, titratable acidity, and pH.

2 MATERIAL AND METHODS

2.1 Materials

Medium-high roast and ground non-rated coffee (*Coffea arabica*) (Aro, Colombia), purchased from a local store in Bogotá, Colombia.. NaOH CAS 1310-73-2 (Sigma Aldrich, USA) and 0.15% potassium bitartrate CAS 868-14-4 (Sigma-Aldrich) were used for titratable acidity.

2.2 Methods

2.2.1 Particle size distribution

The average particle size of the coffee was calculated according to the NTC 2441 standard for particle size distribution (Instituto Colombiano de Normas Técnicas - ICONTEC, 2011). The sieves were stacked on top of each other in decreasing mesh order in the AS 200-Retsch analytical sieve shaker, and 65 g of roasted and ground coffee was placed on the top sieve, covered with a lid. The equipment was run for 5 mins, and the accumulated fractions of coffee in each sieve were collected and weighed, and the percentage of each fraction relative to the initial sample was calculated, analyzing the results in CurveExpert Pro Version 2.2.3 software (Hyams Development). The information of sieve diameter and cumulative percentage was analyzed in CurveExpert Pro Version 2.2.3 software (Hyams Development) using a Gaussian model fit, as shown in Equation 1 and 2.

$$y = ae\frac{-\left(x-b\right)^2}{2c^2} \tag{1}$$

The average particle size was calculated using Equation 2.

$$X = c\sqrt{\frac{Ln\left(\frac{a}{Tm}\right)}{0.5}}+b \tag{2}$$

Where a, b, and c are the model parameters, and Tm is the sample size used.

2.2.2 Experimental design

A d-optimal response surface model to obtain 21 experimental combinations was obtained by the software Design Expert® Version 11.0 (Stat-Ease Inc, Minneapolis, MN). The water temperature was set at 85 °C, and 3 L of water per trial, medium-high roast of coffee. The design factors corresponding to agitation speed (between 30 and 95 RPM), time (between 10 and 60 min), and water-to-coffee ratio (between 4:1 to 10:1 w/w) that would maximize the total soluble solids, extraction rate, and acidity.

Statistical techniques, such as Analysis of Variance (ANOVA) and regression analysis, were applied using the same software to examine the relationships between independent factors and dependent response variables. In addition, the software facilitated the determination of the most favorable conditions, conducting a desirable analysis to identify those that enhance the response variables.

2.2.3 Extraction process

For coffee extraction, the ribbon blender equipment depicted in Figure 1, designed by University of La Sabana, was employed. The unit operates in batch mode. The unit consists of a chamber with a ribbon blender type agitator that promotes contact between water and coffee. The chamber is cylindrical with dimensions 18 cm in diameter by 80 cm in length. It has a 20 L capacity water storage tank, with electrical resistances that heat the water used in extraction. After mixing the coffee and water, there is a filter with a pressure frame that allows the coffee to be pressed and the extract separated, which is collected in a final tank. Before connecting the equipment to the electrical source, the water tank (2) was filled, and then it was connected, the temperature was established at 85°C on the equipment controller (6). While the water in the tank reached the required temperature, roasted and ground coffee was placed in the coffee hopper (1), ensuring it is closed to prevent its passage to the extraction tank (3). When the water reached 85°C, the agitation for the extraction tank was turned on at the set speed using the equipment controller, and the passage valve (7) to the extraction tank was opened. Subsequently, the coffee hopper was opened to let the coffee fall to the extraction tank. The mixing operated at the set speed until the operational time. After the mixing time was achieved, the extract pass to a press filter (4) where the remaining solids of the process were collected. The filter is a 20 cm squared frame with a filter clothe and a press system. Ultimately, the coffee extract was stored in the product tank (5).

2.2.4 Statistical Analysis

A D-optimal response surface design was used. The obtained results were analyzed using Design-Expert V11 software, and the significance of the factors in the extraction process was determined using a p-value of 0.05. Likewise, a desirability analysis was performed to obtain the factor configuration that would fit a replicable prediction model at an industrial level, maximizing the total dissolved solids (TDS), extraction rate, operation yield, and titratable acidity of the coffee extract.

2.2.5 Total dissolved solids

The total dissolved solids (TDS) were determined using the PAL-COFFEE BX-SST refractometer (Atago, Japan).

2.2.6 Yield

The extraction yield is determined as the ratio of the extracted solids to the total amount of roasted ground coffee, it was determined using Equation 3 (Zhang et al., 2022).

$$Yield = \frac{TDS * W_{extr}}{W_{coffee}} \quad (3)$$

Where TDS represents the extracted soluble solids, W_{extr} is the weight of coffee extract (g), and W_{coffee} is the weight of roasted and ground coffee used in the trial (g).

2.2.7 Extraction Rate

The extraction rate was reported in g/h and calculated using Equation 4 (Moroney et al., 2016).

$$Extration\ rate = \frac{\left(W_{extr} * \left(\frac{TDS}{100}\right)\right)}{\left(\frac{t}{60}\right)} \quad (4)$$

Where W_{extr} is the weight of coffee extract (g), TDS represents the extracted soluble solids, and t represents the stirring time in minutes.

2.2.8 pH and Titratable Acidity

The pH of the coffee extract was measured using a Mettler Toledo FiveEasyTM F20 benchtop pH meter. The determination of titratable acidity in the sample was carried out using the A.O.A.C 920.92 reference method. A 0.1 M NaOH solution was prepared and then standardized using a 0.15% potassium bitartrate solution to determine the equivalence point. The coffee extract samples were then titrated potentiometrically with the standardized NaOH solution until they reached pH 7. The results are expressed in mg of CGA/mL coffee (mg CGA/mL coffee) (Vezzulli et al., 2021).

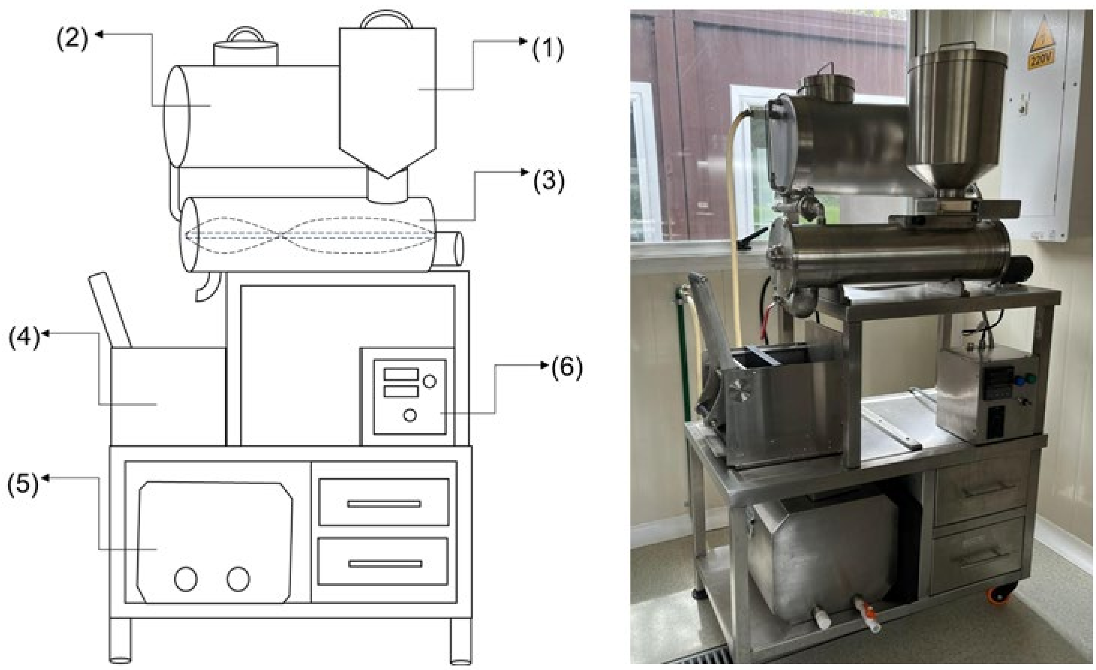

Figure 1: Diagram of the pilot coffee extractor.

3 RESULTS

3.1 Particle Size Distribution

The average particle size of the roasted and ground coffee beans is presented in Table 1.

Table 1: Coffee recovered in the sieving process.

Sieve N°	Sieve Diameter (µm)	% m/m
16	1180	1.2
18	1000	2.5
20	850	4.3
35	500	34.9
45	355	25.9
60	250	16.2
70	212	12.1
Bottom	0	2.9
Total		100.0

Table 2 presents the obtained parameters for a, b, and c, as well as the correlation coefficient and the standard error of the model of Equation 1.

Table 2: Parameters of the Gaussian model for the particle size distribution.

a	102.54
b	63.42
c	332.76
EE	0.0026
R^2	0.99

Using the above information and Equation 2. the average particle size for the roasted and ground coffee used was calculated to be 383.67 µm.

3.2 Characterization of the obtained extracts

The relationship between the evaluated parameters (water-to-coffee ratio, stirring speed, and extraction time) as well as the response variables are presented in Table 3. Each treatment 1 to 21 correspond to the combination of the studied factors (water to coffee ration, stirring speed and extraction time) shown on each line. The effect of operational parameters on each response variable is explained in the following sections.

Table 3: Experimental Design, Extraction Yield, and Characterization of the Obtained Extracts.

	Water to coffee ratio	Stirring speed (rpm)	Extraction time (min)	TDS (%)	Extraction yield (%)	pH	Titratable acidity (mg CGA/mL coffee)	Extraction rate (g/h)
1	4.0	57.6	60.0	6.57	10.42	5.66	10.38	78.17
2	7.0	62.5	35.0	3.65	11.87	5.63	4.63	87.24
3	6.9	77.8	60.0	4.37	14.91	5.78	5.42	64.72
4	10.0	95.0	60.0	2.80	20.03	5.84	3.08	60.11
5	10.0	30.0	10.0	1.87	17.74	5.89	1.29	321.48
6	4.0	95.0	10.0	5.12	12.61	5.8	4.97	567.26
7	6.6	30.0	60.0	2.74	15.00	5.53	3.40	68.69
8	10.0	95.0	10.0	2.52	14.35	5.94	2.37	258.26
9	10.0	95.0	60.0	2.29	22.22	5.63	2.75	66.67
10	10.0	95.0	10.0	2.05	18.03	5.9	2.64	324.92
11	5.3	93.1	35.0	3.66	15.87	5.68	3.48	153.54
12	4.0	30.0	10.0	5.90	7.79	5.98	5.19	350.23
13	10.0	30.0	60.0	2.16	19.10	5.66	2.85	57.82
14	8.6	95.0	35.0	2.72	17.32	5.66	3.08	103.35
15	4.0	95.0	60.0	5.92	12.50	5.67	7.28	93.74
16	4.0	95.0	10.0	4.19	13.82	5.96	2.35	621.87
17	10.0	62.5	22.5	2.85	14.82	5.69	4.57	118.71
18	10.0	30.0	60.0	2.26	16.92	5.61	3.16	50.76
19	10.0	30.0	10.0	1.92	15.48	5.9	1.32	278.75
20	5.5	62.5	10.0	3.89	14.50	5.64	4.44	474.02
21	4.0	30.0	38.8	4.23	13.60	5.69	3.80	157.95

3.2.1 Total Soluble Solids

The results of TDS obtained in the experimentation follow a normal distribution and range from 1.87 to 6.57 %. The collected data was analyzed in Design-Expert V11 software using a quadratic model. Table 4 presents the significance of the factors.

Table 4: ANOVA of the Quadratic Model of TDS.

	p-Valor	
Model	< 0.0001	*
A (Water-to-coffee ratio)	< 0.0001	*
B (Stirring speed)	0.4432	
AB	0.5053	
A^2	0.0249	*
B^2	0.0168	*
Lack of Fit	0.1008	

*Significant influence, p-value < 0.05.

According to the Table 4, it can be observed that the obtained model for the process is significant. Similarly, it can be observed that the only significant factor on its own is the water-to-coffee ratio while stirring speed is significant in the quadratic factor.

Furthermore, the lack of fit result is non-significant, indicating that the proposed model will fit well and, therefore, its replicates will be satisfactory. Additionally, a determination coefficient of 0.87amd and adjusted R^2 value of 0.83 were obtained, indicating that despite the variations that may arise from the non-significant factors excluded from the model, it mostly fits the experimental values.

These results reinforce the observed impact of the water-to-coffee ratio, as detailed in Figure 2, where it is confirmed that this parameter significantly influences Total Soluble Solids (TDS) attainment, with a 4:1 ratio proving optimal for maximizing solids extraction during the coffee extraction process.

Based on the above, Equation 5 proposes a formula in terms of the significant factors present in the model. This equation can be used to make predictions about the TDS response obtained from different operating conditions.

$$TDS = 8.73708 - 1.95285(A) + 0.107263(B) + 0.100286(A^2) - \\ - 0.000893(B^2) \quad (5)$$

3.2.2 Extraction Yield

Concerning the coffee extracts, extraction yields ranged from 7.79 to 22.22%. As seen in Table 5, the water-to-coffee ratio significantly influences the extraction yield, while stirring speed and extraction time does not have a significant effect on this variable. Additionally, Equation 6 describes the extraction yield as a linear model, with a coefficient of determination R^2 of 61.97%, which is influenced by the factors B and C.

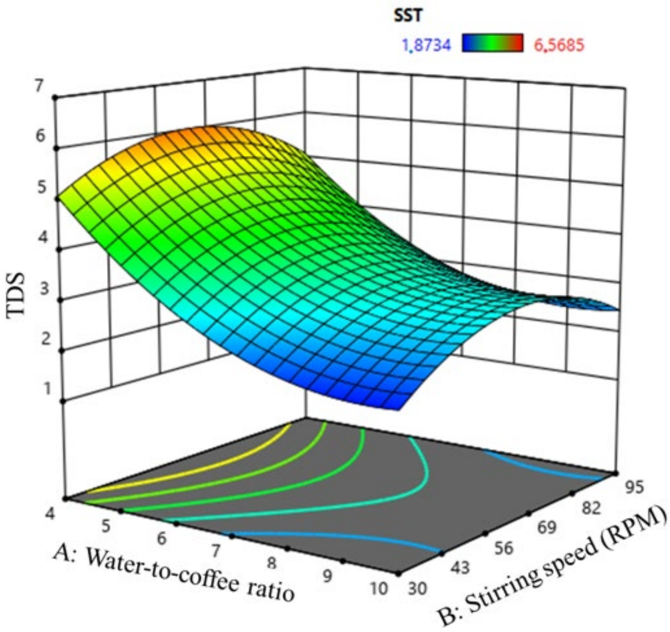

Figure 2: Response surface of extracted TDS. Water-to-coffee ratio vs. Stirring speed.

Table 5: ANOVA of the linear model of yield extracts.

	p-Valor	
Model	0.0002	*
A (Water-to-coffee ratio)	< 0.0001	*
B (Stirring speed)	0.0892	
C (Extraction time)	0.0780	
Lack of Fit	0.3247	

*Significant influence, p-value < 0.05.

$$Yield = 5.15206 - 0933063(A) \quad (6)$$

A determination coefficient of 0.68 and an adjusted coefficient of 0.62 were obtained.

As observed in Figure 3, when lower water-to-coffee ratios are used, extraction yields are lower.

3.2.3 Extraction Rate

In the 21 samples, extraction rates ranged from 50.76 to 621.87 g/h. Table 6 clearly shows that the extraction rate is significantly affected by the water-to-coffee ratio, stirring speed, extraction time, and their interaction.

The determination coefficient was 0.96 and the adjusted correlation coefficient was 0.93, indicating a good fit of the model (Equation 7) and suggesting that it can be used for accurate predictions of the extraction rate.

$$Extration\ rate = 675.5696 - 27.9562(A) + 2.4523(B) - 22.3734(C) - \\ +0.59598(AC) + 0.18617(C^2) \quad (7)$$

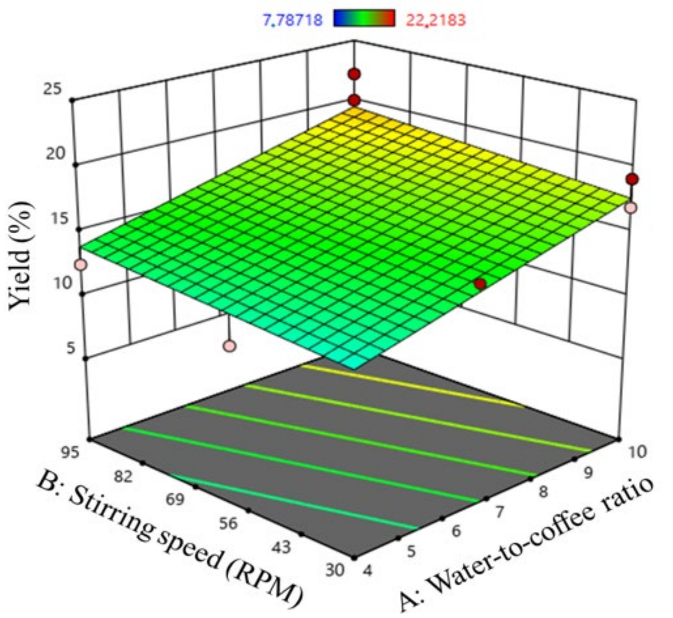

Figure 3: Response surface of extraction yield. Water-to-coffee ratio vs. Stirring speed.

Table 6: ANOVA of the quadratic model of extraction rate.

	p-Valor	
Model	< 0.0001	*
A (Water-to-coffee ratio)	0.0005	*
B (Stirring speed)	0.0466	*
C (Extraction time)	< 0.0001	*
AB	0.0618	
AC	0.0065	*
BC	0.2120	
A^2	0.9191	
B^2	0.7495	
C^2	0.0015	*
Lack of Fit	0.3247	

*Significant influence, p-value < 0.05.

Figures 4A and 4B demonstrate that a 4:1 water-to-coffee ratio and a shorter 10-minute extraction time lead to elevated extraction rates. Furthermore, higher stirring speeds are linked to increased extraction rates.

3.2.4 Titratable Acidity (TA) and pH

The obtained extracts exhibited titratable acidity values ranging from 1.29 to 10.38 mg CGA/mL coffee. As shown in Table 7, the water-to-coffee ratio and extraction time have a significant effect on the model. Similarly to the total soluble solids model, the quadratic term for stirring speed shows a significant influence on titratable acidity.

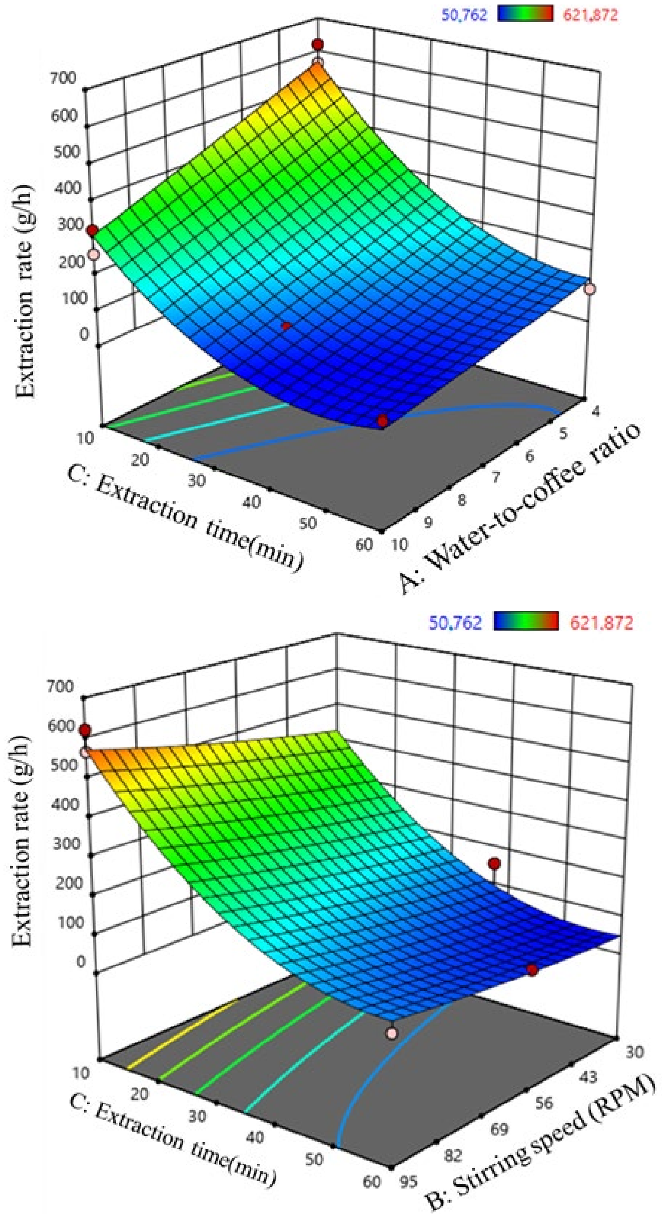

Figure 4: Response surface of extraction rate (A) Water-to-Coffee Ratio vs. Time (min) (B) Stirring Speed (RPM) vs. Time (min).

Table 7: ANOVA of the Quadratic Model for TA.

	p-Valor	
Model	< 0.0001	*
A (Water-to-coffee ratio)	< 0.0001	*
C (Extraction time)	0.0005	*
B^2	0.0003	*
Lack of Fit	0.4118	

*Significant influence, p-value < 0.05.

Equation 8 presents the non-hierarchical model for determining titratable acidity (mg CGA/mL coffee) in the obtained extracts. The determination coefficient was 0.84 and the adjusted coefficient for the model was 0.79, indicating that it can be used for accurate predictions.

$$TA = 4.91665 - 2.82898(A) + 0.02864(C) + 0.175409(A^2) + 0.002575(B^2) \quad (8)$$

Figure 5 illustrates that extracting at lower water-to-coffee ratios and operating for one-hour results in higher acidity values.

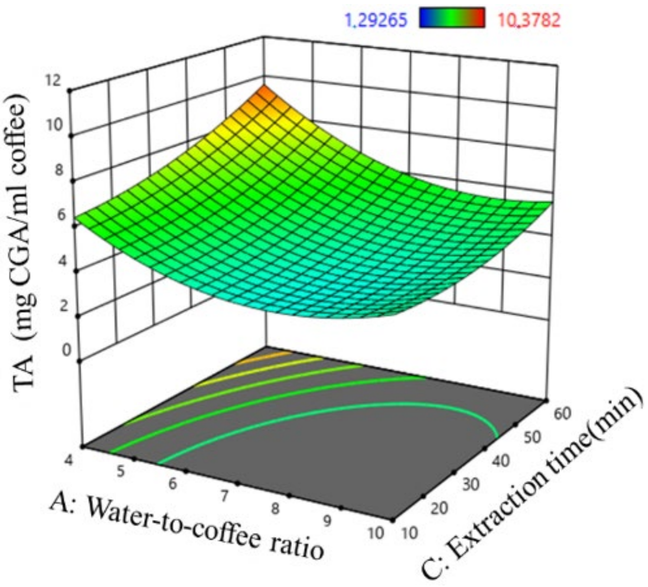

Figure 5: Response Surface of Titratable Acidity. Water-to-Coffee Ratio vs. Extraction Time (min).

The coffee extracts had a pH range of 5.53 to 5.98 consistent with findings reported by Muzykiewicz-Szymanska et al. (2021) for Colombian coffee extracts obtained under similar time and temperature conditions. Their study indicated pH values ranging from 5.03 to 6.28. Furthermore, an analysis of variance was performed to assess the factors influencing pH in relation to the studied variables. Table 8 reveals that the water-to-coffee ratio and stirring speed have no significant impact on the pH of the extracts, while extraction time stands out as the sole factor with a notable influence on pH, demonstrating an inversely proportional relationship (Equation 9).

Table 8: ANOVA of the Linear pH Model.

	p-Valor	
Model	0.0126	*
A (Water-to-coffee ratio)	0.6165	
B (Stirring speed)	0.5093	
C (Extraction time)	0.0017	*
Lack of Fit	0.2743	

*Significant influence, p-value < 0.05.

$$ph = 5.81542 - 0.003946(C) \quad (9)$$

Figure 6 shows a clear linear correlation between titratable acidity and the content of soluble solids present in the extract, while no relationship is evident between pH and the extracted solids.

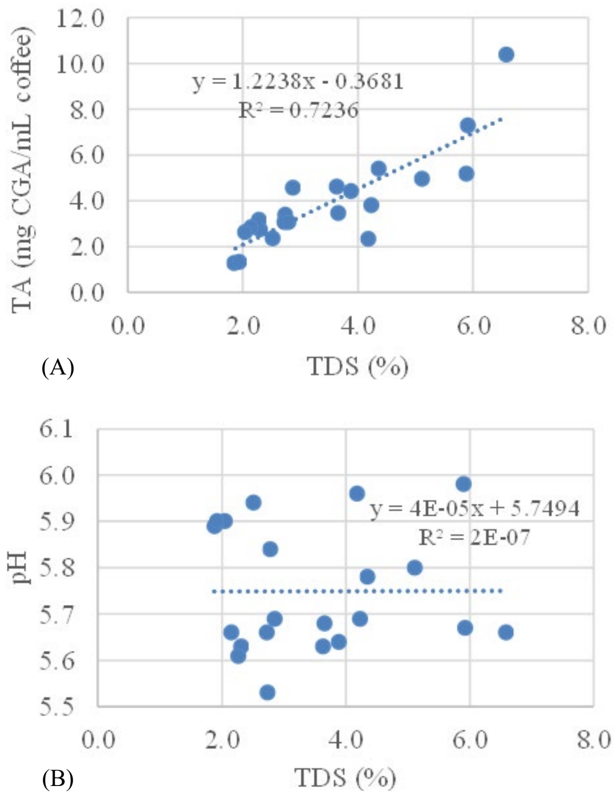

Figure 6: (A) Linear Regression of Titratable Acidity vs TDS. (B) Linear Regression of pH vs. TDS.

Therefore, the relationship between titratable acidity and pH of the extracts was studied. Similar to the results obtained by Gloess et al. (2013), Figure 7 shows no correlation between pH and titratable acidity, as the Pearson coefficient (r) was less than 0.5, and the correlation between them was not statistically significant (Rao; Fuller, 2018).

3.3 Operating Conditions and Desirability Analysis

Based on the obtained results, a desirability analysis was conducted to determine the operating conditions that would maximize the percentage of soluble solids, extraction yield, extraction rate, and titratable acidity in the coffee extracts with desirability of 74%, which were found to be a ratio of 4:1, 66 RPM, and 10 minutes. The expected values for the response variables as well as the experimental values are presented in Table 9.

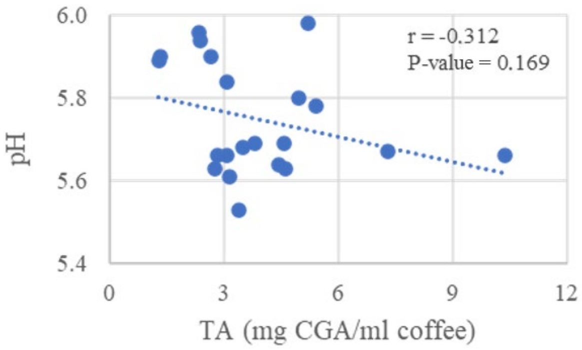

Figure 7: Correlation between pH and Titratable Acidity.

Table 9: Predicted and experimental operational conditions at the optimal point.

	Predicted values	Experimental values
TDS (%)	6.02 ±1.06	5.85 ± 0.05
Yield (%)	11.15 ± 3.08	14.53 ± 1.48
Titratable acidity (mgCGA/mL coffee)	6.57 ± 2.65	5.62 ±0.19
Extraction rate (g/h)	499.99 ± 138.68	654.8 ± 66.8

With the most favorable extraction conditions determined under the studied variables, three confirmation trials were conducted. The average results obtained from these trials were 5.85% TDS content, an extraction yield of 14.53%, an extraction rate of 654.8 g/h, and a TA value of 5.617 mg CGA/mL coffee. The TDS value is above the 1.5% value obtained in an extraction for coffee drinks. It is suitable for an instant coffee production process for subsequent concentration or freeze-drying operations. The acidity value of 5.7 is comparable to those reported by Cordoba et al. (2020) for Colombian coffee. The extraction yields are slightly lower than those reported for coffee drinks in drip brewers (Batali; Ristenpart; Guinard, 2020). These results confirm that the chosen operating conditions, based on the desirability analysis and optimization, reached the desired outcomes for the response variables.

4 DISCUSSION

The results obtained in this study provide valuable insights of new coffee extraction process made in a ribbon blender unit. By examining various factors and their interactions, we can better understand the nuances involved in optimizing coffee process.

The water-to-coffee ratio had significance for all the response variables. A ratio of 4:1 is shown to be particularly effective in maximizing solids extraction, because of the higher amount of coffee solid that can be extracted. Although the concentration gradient is lower with a smaller amount of water, the amount of solids to be extracted will be greater and therefore the TDS will be higher. The higher the solute gradient, the faster the mass transfer (Cordoba et al., 2020). This ratio not only promotes increased diffusion but also elevates the concentration of soluble solids, playing a significant role in flavor development (Lingle, 2011). A high TDS content and high extraction yield promotes a strong bitter coffee. The balance between the water-to-coffee ratio and the concentration of soluble solids is critical for achieving the desired taste profile of coffee. In practice, a 4:1 ratio enhances the extraction of flavors and aromatic compounds while ensuring a substantial concentration of these elements in the final extract. The highest water -coffee ratio, such as 10:1, may result in low brew strength. The highest TDS is desirable for an instant coffee production process. The influence of the water-to-coffee ratio is further evident in the extraction yield, as lower ratios lead to reduced yields. Despite a low ratio can increase a solvent retention within the food matrix, it results in higher levels of soluble solids (Wankat, 2022; Guinard et al., 2023). Figure 3. Shows that the highest extraction yield was obtained at the highest water to coffee ration and the highest stirring speeds. This result is consistent with the mass transfer theory. The higher the concentration gradient and missing increase the mass transfer rate. However. Only, the water to coffee ratio had a significant difference. Extraction rates values were between 15 and 20%, which correspond to under-developed and ideal extraction yield respectively reported to coffee beverage (Batali; Ristenpart; Guinard, 2020).

Stirring is a common practice in coffee extraction, known for its role in enhancing compound diffusion and maintain concentration gradients to increase the mass transfer rate. However, our study suggests that stirring has a low influence in the solid's extraction within the studied range of agitation speeds, as reported by Dueñas-Rivadeneira et al. (2016).

Furthermore, it is evident in Table 5 that the water-to-coffee ratio, stirring speed, and extraction time significantly influence the extraction rate, as well as the interaction between the water-to-coffee ratio and extraction time. This can be explained by the fact that the extraction technique in a belt-based system involves complete immersion, ensuring thorough mixing of the roasted and ground coffee with water. Additionally, the operating temperature helps facilitate the extraction of a greater amount of compounds from the food matrix in a shorter time compared to extraction techniques at lower temperatures agreeing with the data obtained by Cordoba et al. (2021b).

A closer look at Figures 4A and 4B demonstrates that a 4:1 water-to-coffee ratio and a short extraction time, like 10 minutes, lead to higher extraction rates. This result is explained because the shorter the time the higher the rate at a constant

TDS. Furthermore, the data corroborates with Zhang et al. (2022) in which higher stirring speeds contribute to increased extraction rates by improving mass transfer between coffee grounds and water.

Figure 5 shows the total acidity of the extract. Values ranged from 4 to 10 mg CGA/mL coffee. Values are similar to those reported by Cordoba et al. (2020) for Colombian coffee and greater than those reported by Rao and Fuller (2018) for Colombian coffee cold brewed. This result shows that the extraction process in a ribbon blender allows to obtain high acidity from the coffee. In the scope of Titratable Acidity (TA) and pH, our findings in Figure 5 reveal a direct correlation between lower water-to-coffee ratios and higher acidity values. This relationship can be explained by the preference for the elution of acidic coffee components due to their high solubility in water, particularly at higher temperatures (Cordoba et al., 2020; Schwarzmann; Washington; Rao, 2022). Furthermore, Figure 6 sheds light on a discernible linear correlation between titratable acidity and the content of soluble solids within the extract, reaffirming the viability of extracted soluble solids as an effective metric for approximating titratable acidity in the context of coffee (Batali et al., 2021).

Figure 7 shows no correlation between pH and TA as reported by Cordoba et al. (2020). Analyzing the pH range of coffee extracts, we find consistency with the results reported by Muzykiewicz-Szymanska et al. (2021). The pH values of the extracts fall within a range of 5.53 to 5.98, corresponding to similar conditions. Our study also investigates the factors influencing pH, revealing the absence of a significant relationship between pH and extracted solids. While both acidity measures offer insights into coffee's acidity, titratable acidity proves to be a more precise measure, accounting for acidic protons even when they aren't fully dissociated. In contrast, pH measurement is related to dissociated hydrogen ions, offering a more limited perspective on the coffee's acidity profile, as discussed by Muzykiewicz-Szymanska et al. (2021) and Schwarzmann, Washington and Rao (2022).

The investigation of the relationship between pH and titratable acidity, reaffirms the lack of a meaningful correlation, consistent with earlier research findings. This outcome can be attributed to the likelihood that many acids in coffee extracts may not be completely deprotonated, minimally influencing pH measurements.

Nevertheless, a more comprehensive assessment of their impact can be achieved through the measurement of titratable acidity using an alkaline compound, as suggested by Gloess et al. (2013).

The utilization of a pressure-free ribbon blender, while not matching the performance of industrial high-pressure and high-temperature equipment, presents an efficient alternative for coffee extract production, outperforming immediate consumption extracts by at least 81%, and although its performance is approximately half of what is achieved with industrial equipment using high pressures and temperatures, it remains a valuable alternative for efficient coffee extract production for the obtainment of soluble coffee.

5 CONCLUSIONS

The investigation delved into the effect of operational parameters of the extraction with a ribbon blender on the physicochemical properties of coffee. By varying the water-to-coffee ratio, stirring speed, and extraction time, we scrutinized their influence on key response variables. The outcomes revealed a substantial effect of the water-to-coffee ratio on all response variables, except pH, while stirring speed impacted the extraction rate and titratable acidity. Additionally, extraction time influenced both pH and extraction rate. Notably, the analysis of pH and titratable acidity unveiled their lack of correlation, emphasizing the distinct nature of the measurements. Employing a desirability analysis based on the obtained results, we identified optimal conditions—85°C water, a 4:1 water-to-coffee ratio for 10 minutes, and a stirring speed of 66 rpm—yielding a coffee extract with 5.85% soluble solids, an extraction yield of 14.53%, an extraction rate of 654.8 g/h, and titratable acidity of 5.617 mg chlorogenic acid/mL coffee. In conclusion, the operating conditions selected, optimized through desirability analysis, successfully achieve the desired outcomes for TDS, extraction yield, extraction rate, and titratable acidity. The ribbon blender equipment studied can be used for coffee extraction on small scales, with a possible use for the production of soluble coffee. It provides extraction levels suitable for a further concentration or lyophilization operation. This simple and economical equipment that operates in batch mode can be an alternative to traditional percolation systems, useful at high production scales.

These findings offer valuable insights into optimal operating conditions for coffee extraction at a in a ribbon blender unit, aligning with the specified objectives. Furthermore, they underscore the potential of ribbon mixer equipment for producing concentrated coffee extracts, holding promise for small-scale industrial production of soluble coffees. A further comparison with a standard commercial unit is recommended.

6 AUTHOR CONTRIBUTIONS

Conceptual Idea: F.L. Moreno; RY Ruiz; Methodology design: F.L. Moreno, Data collection: P.A. Mayorga, Data analysis and interpretation: F.L. Moreno; RY Ruiz; P.A. Mayorga, and Writing and editing: P.A. Mayorga, F.L. Moreno; RY Ruiz.

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