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Effect of Roasting Time and Temperature on the Aroma and Flavor Descriptors of Criollo and Hybrid Cocoas. Preliminary Sensorial Approach

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Abstract: It is generally agreed that roasting conditions; time, and temperature largely determine the cocoa's flavor profile and the resulting sensory quality of the chocolate. On the other hand, there is no universal standard for roasting cocoa beans; every chocolate maker develops a roast profile suited to the specific bean origin and the flavor profile they decide, without consumer expectations. That's why it is commercially important to develop a wide portfolio of flavors that can satisfy consumer demands and tendencies. Consequently, desired flavors can be designed in the chocolate by working with different roasting protocols on the cocoa beans. The design of this research focused on applying different roasting temperatures and times to fermented and dried cocoa beans from two different cocoa types, Criollo and Forastero, from different Venezuelan regions and evaluating, in a sensory way, the flavor developed in them. The goal of the work was to show an approximation of the development of specific flavor notes that can satisfy consumers' demands using temperature and time on Criollo and Forastero cocoa beans.

Keywords: Aroma profile, Criollo cocoa, Cocoa bean roasting, Hybrid cocoa, Quantitative Descriptive Analysis (QDA), Roasting profiles, Sensory evaluation.

INTRODUCTION

Venezuelan cacao is classified as fine and extra-fine due to its aromatic qualities. One of its types is the Criollo cocoa, which is considered among the best in the world. Criollo cacao is a type of cacao with a unique flavor characteristic associated with its region of origin, which sets it apart from cacaos from other latitudes. This cacao is highly valued by chocolatiers worldwide because of its flavor and aroma characteristics, which give the chocolate an unsurpassed quality associated with specific regions of the country (Pérez and Silva, 2017).

Furthermore, the term "Fine Aroma Cacao" defines the unique and incomparable types of cacaos; that includes, besides those Criollos, the Trinitarios or Deltanos growing in Venezuela, which also develop intense and distinct flavors (Baker, 1780-1886). This fine aroma of Criollos, Trinitarios, or Deltanos cacaos is due not only to genetic factors but also to the ecological conditions and microclimate where the cacao trees grow, as well as to post-harvest handling and processing into their derivatives (Pérez and Silva, 2017).

On the other hand, it is a consensus that the quantity and quality of chocolate flavor is determined by multiple post-harvest processing stages, including fermentation, drying, and roasting, which collectively contribute to the development of key flavor precursors and characteristic aromatic compounds (Santander et al., 2025).

During post-harvest process the cocoa beans start after the pods selection to remove the beans from cocoa fruit (shelling) selected and naturally fermented in wooden containers; that are usually sealed with banana leaves for a period of 3-7 days, depending of its genetic origins; if it is a criollo cocoa must be fermented for 3 days, trinitarian or Deltans for 5-6 days and forastero 5-8 days.

Throughout the fermentation, the activity of microbial successions, such as yeast, lactic acid bacteria (LAB), and acetic acid bacteria (AAB), produces acids (lactic and acetic) that diffuse into the seeds. This diffusion, plus the heat generated on the cocoa mass resulting in embryo death. The embryo death drives several enzymatic reactions with go to the formation of flavor compounds, aromas, and color changes (Apriyanto et al. 2026).

Apriyanto et al. (2026) have pointed out the influence of yeast, LAB, and AAB in fermentation. The authors have indicated that yeast and LAB had a the most significant effect on the fermentation process. Yeasts drive the first 24-48 hours of cocoa fermentation, metabolizing pulp sugars into ethanol and secondary metabolites. This activity generates crucial volatile flavor precursors (like esters, higher alcohols, and acetyl-CoA) to make acetate-esters, compounds that produce floral and fruity notes, and to create an optimal environment that ultimately allows enzymes within the seed to produce the amino acids needed for chocolate flavor (Pérez et al., 2017, Gutierrez-Ríos et al., 2022).

LAB are thought to conduct three major activities during bean fermentation: (i) they ferment pulp sugars, principally glucose and fructose, to mainly lactic acid and lesser amounts of ethanol and acetic acid, (ii) they utilize citric acid within the pulp to produce mainly lactic acid, acetic acid, acetaldehyde, diacetyl, acetoin and 2,3-butanediol and (iii) some species may reduce pulp fructose to mannitol and they are considered to be significant in modulating the pH of the beans (Ho et al., 2015, Pérez et al., 2017).

Acetic acid production in cocoa bean fermentation is largely due to acetic acid bacteria (AAB), which oxidize the ethanol produced by yeasts (Ho et al., 2015; Pérez et al., 2017).

All of these flavor formations are the named flavor precursors. Therefore, it is important to note that most of the development of the precursors of aroma and taste through the physiological, biochemical, and chemical actions of the microbiological succession occurs during the fermentation process. Therefore, it is important to apply the good fermentation practices, represented in the standardized fermentation protocol associated with the cocoa genetic origin and the local procedure.

These microbiological populations are also inherent to the region of origin where the cocoa is grown and processed. During this stage of the process, there is a significant increase in volatile compounds (alcohols, organic acids, and aldehydes) and also other aroma precursors (free amino acids, short-chain peptides, and reducing sugars). It is important to note that cocoa protein fractions have been implicated in influencing both the bioactive potential and sensory properties of cocoa and its products (Rawel et al., 2019).

Cocoa protein constitutes 11-13% based on dry weight and may vary depending on geographical origin between 11.8% and 15.7% (Timbie and Keeney 1977, Bertazzo et al., 2011).

The average amino acid-based protein content of cocoa bean cotyledons from different varieties was also investigated and was found to be approximately 10.4%; for Criollo, it lies at 10%, for Trinitario it is between 8.8% and 10.7% and that for Forastero lies at 10.2-11.4% (Timbie and Keeney 1980).

The 1993 study "The major seed proteins of *Theobroma cacao* L." by Voigt, Biehl, and Wazir established that mature cocoa seeds contain no prolamin. Instead, the seed proteins consist almost entirely of albumin (~52%) and a single class of vicilin-like globulin (~43%). The study was foundational in determining that, during fermentation, these storage proteins (particularly the vicilin-like globulin) are degraded by enzymes into peptides and amino acids. These breakdown products are critical cocoa aroma and flavor precursor.

Several authors have pointed out that during fermentation, the action of aspartic endoproteinase and carboxypeptidase on vicilin-type globulins generates oligopeptides (a nonapeptide and a hexapeptide) and free amino acids—compounds considered precursors to the specific aroma of fermented cocoa (Biehl et al., 1982; Voigt et al., 1994; Amin et al., 1997, 1998)

Once the fermentation has proceeded, the cocoa beans must be set in the "secaderos" and sundried. The cocoa beans must be dried until they reach 7-7.5 of moisture by sun drying. During this process, the Maillard reaction does not begin to any significant extent, as it requires high temperatures to be activated. This stage is characterized primarily by dehydration, polyphenol oxidation, and the evaporation of acetic acid, thereby preparing the beans.

The sundried cocoa beans with controlled parameters (mainly moisture content of 7-7.5%) are stored under good storage conditions in storage centers for their use in the future.

To obtain its derivatives, such as liquor (paste) and fat, to produce the chocolate, the fermented and sundried cocoa beans must be roasted. The roasting conditions, time, and temperature essentially command the sensory profile of cocoa and the resulting chocolate through the reactions of the different flavor precursors formed during the fermentation process. Roasting reduces the content of undesirable components, produces chocolate-specific aroma and flavor, and decontaminates the cocoa beans. In this phase, all precursors formed in the previous phases react and form numerous compounds (Barišić, et al., 2019)

Roasting is one of the most important technological operations in cocoa bean processing; the properties of roasted beans, such as the formation of a characteristic brown color, texture of roasted beans, concentration of volatile flavor compounds, total acidity, and fat content, depend mainly on roasting conditions, such as temperature and processing time (Afoakwa, et al., 2008, Rocha et al., 2017, Barišić, et al., 2019).

Therefore, in the unit operation of roasting, these two important parameters drive the sensorial profile; while roasting temperature drives the flavor-altering Maillard reactions, among others, the roasting time primarily adjusts moisture levels, acidity and add some flavors notes.

As reported by Cocoa Supply North America, (2026), there is no universal standard for roasting cocoa beans. Every chocolate maker develops a roast profile suited to the specific bean origin and the flavor outcome they decide.

However, as a summary, Cocoa Supply North America (2026) points out that the most professional and craft roasts fall within these general ranges:

Table 1: Professional crafts roast ranges

Roasting Style	Range Temperature	Range Time	Typical Result
Low-temperature roast	80-100°C (176-212°F)	25-35 minutes	Preserves delicate fruity and floral notes; common for fine flavor cacao
Moderate roast	120-140°C (250-284°F)	15-25 minutes	Balanced flavor development; the most common range for craft chocolate
Higher-temperature roast	150-190°C (300-375°F)	5-10 minutes (often followed by a lower-temperature finish)	Used to kill bacteria quickly, release moisture, and loosen the husk for easier winnowing

A common professional approach combines both ends of this range: an initial high-temperature blast for the first 5 minutes to release moisture and loosen the shell, followed by a longer roast at a lower temperature to develop flavor without scorching the bean's interior.

It's worth noting that the temperature your oven or roaster displays is not the same as the bean's internal temperature. Professional roasters must monitor internal bean temperature directly, tasting samples at an internal temperature of 110–115 °C (230–240°F), since flavor can shift dramatically within a difference of just a few degrees.

It has been pointed out that low temperatures (80°C-110°C) yield a milder, sweet flavor, preserving the natural, delicate notes like fruity (citrus), floral, and nutty tones, with lower bitterness and astringency. Being the optimal range for maximum consumer acceptability, from 90°C to 110°C. The study by Chen and Robbins in 2000, which analyzed three cocoa-flavored samples, identified 5-methyl-2-phenyl-2-hexenal and 4-methyl-2-phenyl-2-pentenal as Maillard reaction products, both exhibiting penetrating chocolate notes.

Later, the BenchChem Technical Support Team in 2006 pointed out that 4-Methyl-2-phenylpent-2-enal, or cocoa pentenal, is an α, β-unsaturated aldehyde widely recognized for its potent and characteristic cocoa-like aroma. Despite the authors indicating concerns about its genotoxicity, they detail its chemical properties, sensory profile, and likely formation pathways during cocoa processing.

In contrast, a high temperature (120°C-160°C) accelerates Maillard reactions and carbohydrate/protein degradation, which produces a deep brown to reddish-brown color. Moreover, have been reported that emphasizes heavy chocolate, roasted, and bitter notes, but crossing 130°C quickly introduces undesirable astringency and burnt off-flavors (acrid, rubbery).

On the other hand, the time mostly acts as an accelerant for heat penetration, moisture loss, and acid reduction. It has been reported that a short time (10-20 mins) facilitates a sharp decrease in total acidity and volatile acetic acid (especially during the first 15-20 minutes), while a long time (40-60 mins) drives continued moisture removal and deep cellular/structural rearrangement. Prolonged times at higher temperatures will amplify bitterness and destroy valuable bioactive compounds (such as polyphenols and antioxidant activity).

Studies by Ramli et al., (2006) on cocoa beans roasting established that flavor precursors—such as pyrazines and aldehydes—are optimized at 150°C for 30 minutes. Their research showed that higher temperatures (e.g., 160°C to 170°C) cause undesirable burnt flavors and bitterness, while lower conditions (e.g., 120°C for 40 minutes) minimize astringency and sour tastes

As an assumption, since both roasting temperature and time dictate the chemical transformations and sensorial non-volatiles and volatile compounds that will be developed in the resulting products, together, time and temperature could shift the profile from acidic and fruity to bitter and burnt, or by using adequate roasting practices, could produce a wide exceptional range of sensorial profiles in the resulting chocolates that could be welcomed by the consumers. Therefore, the goal of the study was to produce a range of sensorial descriptors by roasting two different types of cocoa from different genetics at different times and temperatures, and to evaluate them in their sensorial descriptors using an 8-member trained panel and 20 semi-trained judges.

MATERIALS AND METHODS

Material and Experimental Design

The Criollo cocoa bean samples with a moisture content of 6.4% were obtained from a commercial farm, Hacienda La Porcelana, located in sector Caño Amarillo, Táchira state, the south-central end of Maracaibo Lake, Venezuela, growing under a tropical climate during the fruiting and harvest period of January to May 2026.

The Forastero cocoa bean samples with a moisture content of 7.2% were obtained from a farm located in an indigenous community setting belonging to the Piaroa ethnic group, located in Bolívar State, Venezuela of the parish Guaniamo of Cedeño Municipality, within the Alto Suapure Circuit growing during the period of January to May 2026.

The cocoa beans from the two different places were preselected, transported at ambient temperature, and fermentation was carried out in standard wooden boxes under controlled conditions (fermentation good practices), followed by the drying process in sun-roof surfaces (drying good practices) until 6.4 and 7.2% of moisture respectively.

Roasting Protocol

The fermented and sun-dried beans of each cocoa type (about 0.5 kg) were roasted in a forced-airflow-drying horizontal rotating drum roaster, where the heat is transferred primarily through conduction (contact with the drum walls) and convection (hot airflow passing through the drum), with a temperature control device (precision ± 0.1 °C). At the beginning of each process, the toaster heating cover temperature was stabilized at different working temperatures (100, 115, 125, or 140 °C). The studied process parameters (roasting temperature and time) were based on the work of Ramli et al. (2006) and Rocha et al. (2017), with adaptations.

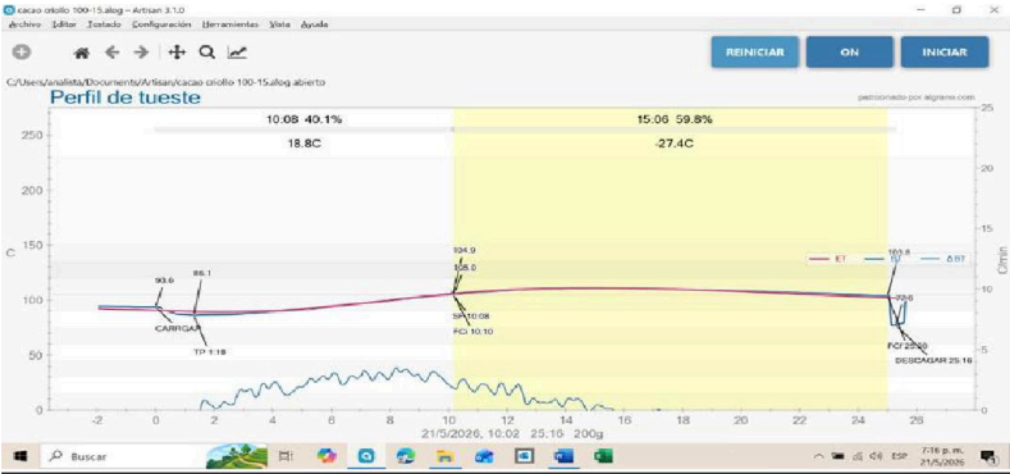
As can be seen in Table 2, three separate batches of approximately 500 g samples of Criollo cocoa were roasted in a forced airflow-drying oven at 100°C (212°F) during 10, 15, and 25 minutes. A second batches of 500g of Criollo cocoa were roasted at 115°C (239°F) during 10, 15, and 25 minutes. A third batches of Criollo cocoa of the same quantity were roasted in an oven at 125°C (257°F) during 10, 15, and 25 minutes.

The Forastero cocoa was processed similarly, but changing some temperature and oven type, (maintaining the form of the heat application as in the previous batch). Therefore, the first 3 batches of approximately 500 g samples of Forastero cocoa were roasted in a forced airflow-drying oven at 115°C (239°F) during 10, 15, and 25 minutes. A second 3 A third batches at 125°C (257°F) during 10, 15, and 25 minutes. Then the last batches were roasted at 140°C (284°F) during 10, 15, and 25 minutes (see codification in Table 2). The samples of cocoa roasted were evaluated for flavor compounds by sensory evaluation as cocoa nibs (Table 3).

Table 2: Roasting temperature and time protocols for the two cocoa types

Cocoa Type	Roasting Temperature (°C/°F)	Roasting Time minutes	Code	Cocoa Type	Roasting Temperature (°C/°F)	Roasting Time min	Code
Criollo, Sur del Lago	100°C (212°F)	10	C/100/10	Forastero, Bolivar state	115°C (239°F)	10	F/115/10
		15	C/100/15			15	F/115/15
		25	C/100/25			25	F/115/25
	115°C (239°F)	10	C/115/10		125°C (257°F)	10	F/125/10
		15	C/115/15			15	F/125/15
		25	C/115/25			25	F/125/25
	125°C (257°F)	10	C/125/10		140°C (284°F)	10	F/140/10
		15	C/125/15			15	F/140/15
		25	C/125/25			25	F/140/25

Nine temperature curves were registered for each cocoa type, as can be seen, the Criollo cocoa was processed at 100 °C for 25 minutes (Graphic A, as example).



Graphic A: **Sample of one of the eighteen curves (100 ˚C for 25 minutes) obtained during the roasting process.**

Sensorial Evaluation

The sensorial study protocol was as follows: Eight trained assessors consensually defined twelve descriptors showing similarities and differences among a 10g cocoa nibs at room temperature, using the methodology based on Quantitative Descriptive Analysis (QDA as follows: Table 2. Protocol of the evaluation sensorial procedure,

Table 3: Protocol of the assay of the descriptors by sensory evaluation of cocoa nibs

Descriptors used		Assay Procedure
Odor	Taste	• It was selected eight judges trained with good olfactory and gustatory capabilities. The previous training was not necessary because all the judges are "Chocolatiers" who can recognize, differentiate, and measure the intensity of the product's attributes. Besides, they are students of the Cocoa and Chocolate Diplomate of the Central University of Venezuela, and they had received the cocoa and chocolate sensorial theories. • The judges were also informed (Informed Consent Form) of the sample composition (roasted cocoa nibs), allergy risks, the composition and type of processing of the samples, and alternatives to the analysis procedure, and they consented to conduct the evaluation. • The judges conducted the tastings in isolation, in individual places under controlled conditions (lighting, temperature, and standardized vessels). • The judges were asked to test using the instructions and the list of odor and taste descriptors to perform the assay on a defined measurement • scale (ranging from 1 to 5) to measure the magnitude of each attribute.
Cocoa	Cocoa	
Chocolate	Acid	
Acid	Bitter	
Fruity	Astringent	
Nut	Sweet	
Floral	Nut	
Wood	Floral	
Spicy	Fruity	
Smoked	Wood	
Metal	Smoked	
Putrid	Metal	
Moldy	Putrid	

RESULTS AND DISCUSSION

The results obtained, expressed in a radial presentation for the description test of the nib samples, are shown in Figures 1-12. where the impact of roasting temperature and roasting time (at the studied levels) on previously described descriptors of aroma and taste of the two cocoa types than that of the cocoa type.

Figures 1 through 3 show the odor profile of the roasted Criollo cocoa. As can be seen, roasting at 100˚C for 10 min (Figure 1) resulted in the slight development of odor descriptors such as cocoa, chocolate, fruity, and woody. Extending the roasting time to 15 min at the same temperature slightly reduced the cocoa, fruity, woody, and acidic aromas, while the chocolate odor intensified and floral and nutty notes emerged. Roasting at 100˚C for 25 min diminished all the previously developed descriptors. It is concluded that, for this type of Criollo cocoa at 100˚C, the optimal roasting time at this temperature is 15 min.

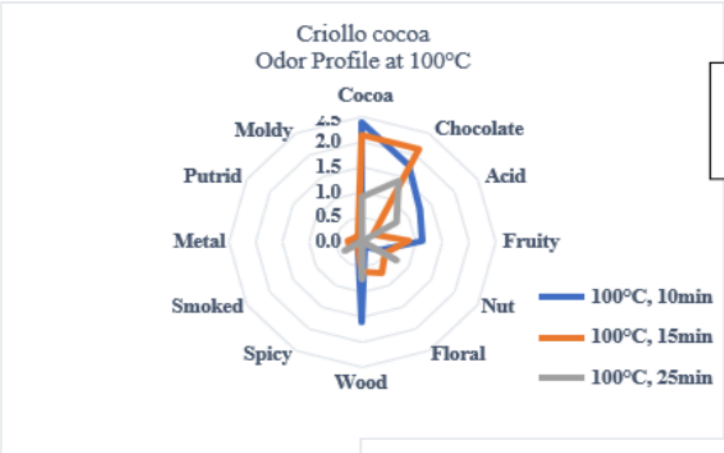


Figure 1. Radial representation of the odor profile of Criollo cacao beans roasted at 100°C at 10, 15, 25min.

Figure 2. Radial representation of the odor profile of Criollo cocoa beans roasted at 115°C, 10, 15, 25min

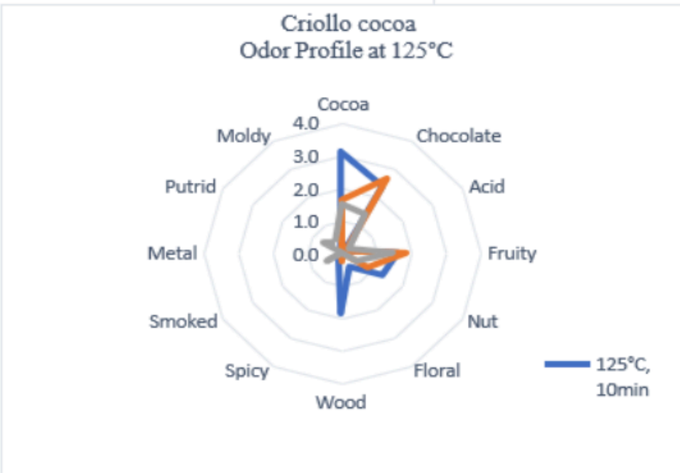


Figure 3. Radial representation of the odor profile of Criollo cocoa means roasted at 125°C, 10, 15, 5min

Figure 2 shows that, at 115˚C for 15 min of roasting, the same pattern of odor note formation was maintained, with a slight increase in their concentrations; the rise in woody and nutty notes was particularly notable. All descriptor tends to diminish with increment of the time to 25minutes. At 125˚C, the pattern of note formation remains similar to that observed at lower temperatures, with a slight increase in its concentration. After 15 minutes, the woody and nutty notes disappear, and fruity notes become prominent. After 25 minutes, all the previously mentioned notes are lost, and a smoky odor emerges (Figure 3).

Figure 4 shows the pattern of taste profile at a roasting temperature of 100˚C for 10, 15 and 25min. As can be seen at 100˚C, the pattern is similar at the different roasting times, with slight differences by the appearance of bitter notes at 15 and 25 minutes. While at 115˚C, it is observed that increasing the time, bitter notes are dismissed, and the nut a woods notes are increased (Figure 5). At 125˚C it is relevant the effect of the time showing that a time of 25 min decreases all pleasant notes and appears smoked, metal and putrid notes (Figure 6).

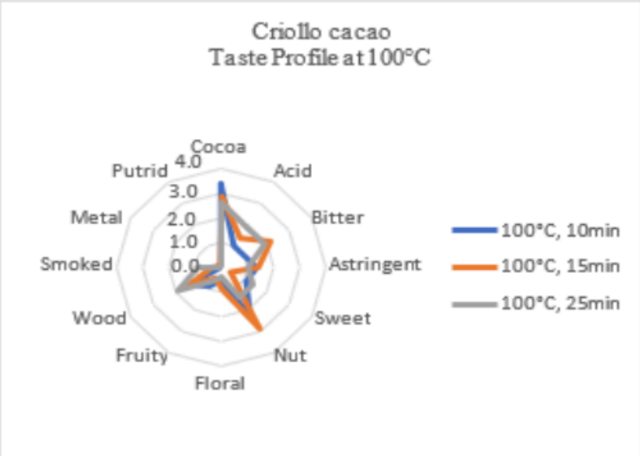


Figure 4. Radial representation of the taste profile of Criollo cacao beans roasted at 100°C, 10, 15, 25min

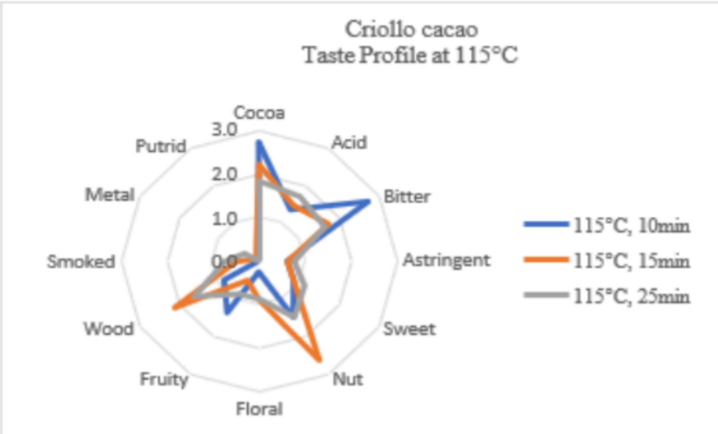


Figure 5. Radial representation of the taste profile of Criollo cocoa beans roasted at 115°C, 10, 15, 25min

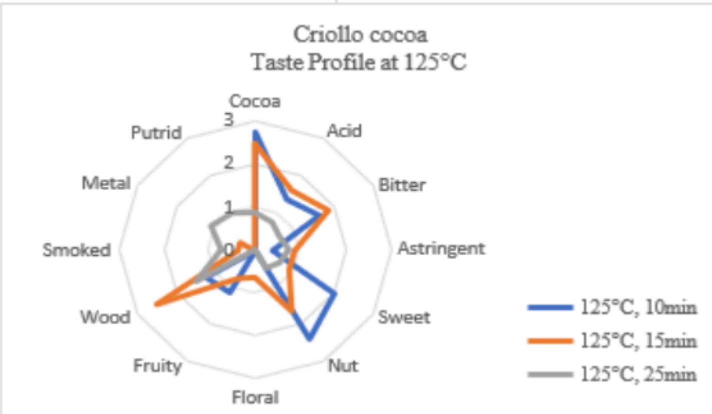


Figure 6. Radial representation of the taste profile of Criollo cocoa beans roasted at 100°C, 10, 15,

Figures 7 to 12 show the pattern of aroma and taste of Forastero cocoa roasted at different temperatures and times.

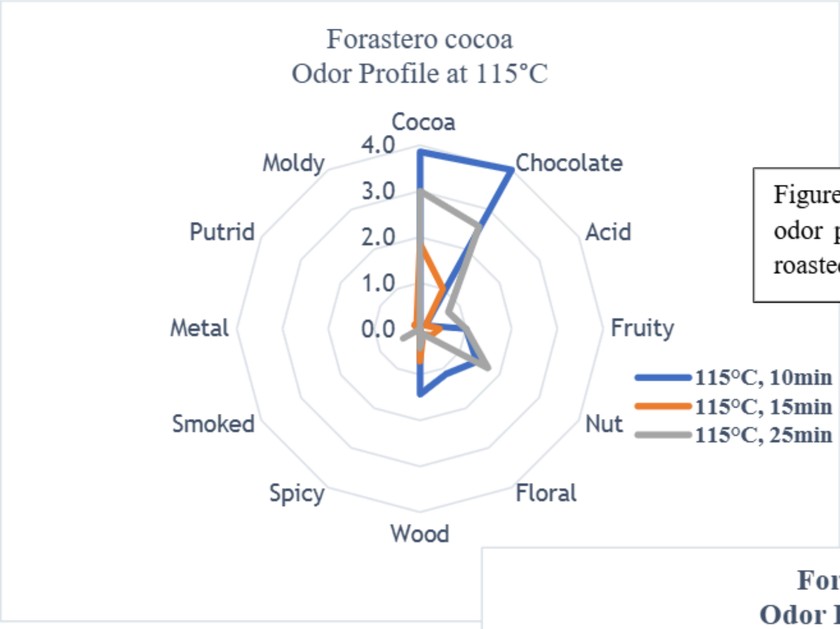


Figure 7. Radial representation of the odor profile of Forastero cacao beans roasted at 115°C at 10, 15, and 25min.

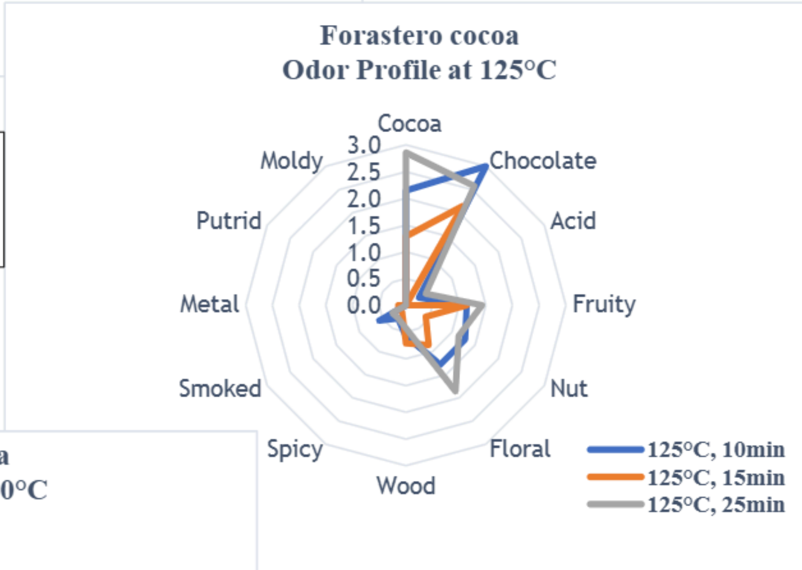


Figure 8. Radial representation of the odor profile of Forastero cacao beans roasted at 125°C at 10, 15, and 25min.

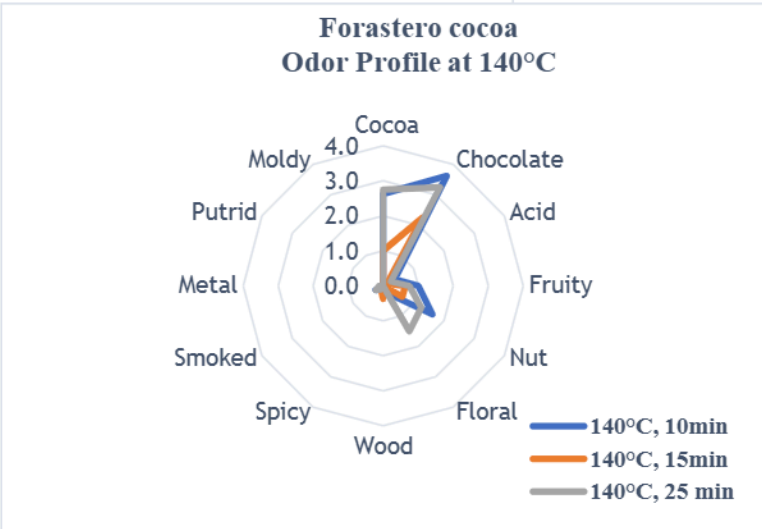


Figure 9. Radial representation of the odor profile of Forastero cacao beans roasted at 140°C at 10, 15, and 25min.

As can be seen in Figure 7, Forastero cocoa notes of cocoa, chocolate, nut, floral, and wood developed at 10 minutes of roasting and diminished as the roasting time increased. At 125˚C (see Figure 8), the odor generally presents a profile similar to that of the roast at

115°C; however, as the roasting time at this temperature is increased, the development of floral and fruity notes is observed, and at 15 minutes, cocoa, floral, and nutty notes are high as compared to the same notes at 10 minutes. While at 140°C it is reduced the notes detected at the other temperatures, except for the chocolate odor (Figure 9).

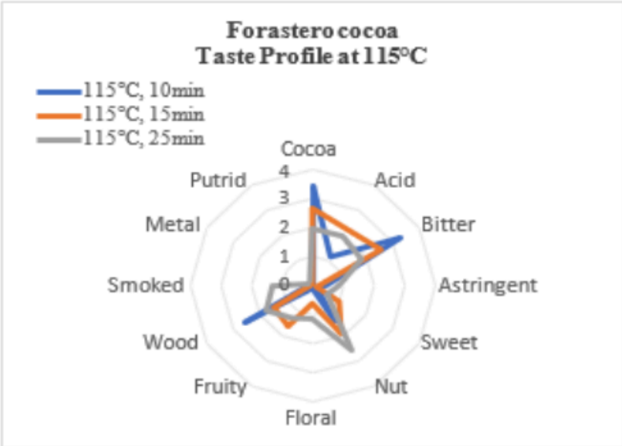


Figure 10. Radial representation of the taste profile of Forastero cacao beans roasted at 115°C at 10, 15, 25min.

Figure 11. Radial representation of the taste profile of Forastero cacao beans roasted at 125°C at 10, 15, 25min.

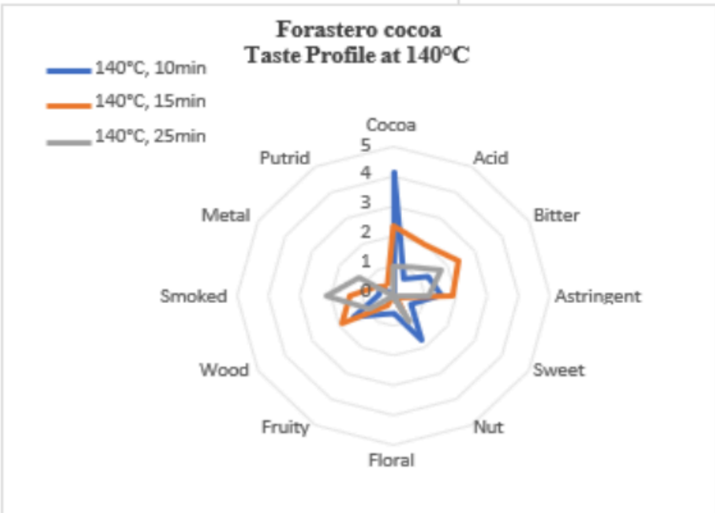


Figure 12. Radial representation of the taste profile of Forastero cacao beans roasted at 140°C at 10, 15, 25min.

Roasting at 115°C for 10 minutes developed cocoa, woody, and nutty taste; as the roasting time increased, bitter, astringent, and smoky notes were detected (Figure 10). However, when the temperature was increased to 125°C (Figure 11), chocolate and nutty tastes were detected; with an increase in time to 15 and 25 minutes, at the same temperature, slight notes of cocoa, acidity, nuttiness, and floral characteristics were perceived. Roasting at 140°C for the first 10 minutes developed a cocoa taste; however, extending the roasting time significantly diminished the notes detected at the previous temperatures, while bitter, astringent, and smoky tastes emerged (Figure 12).

CONCLUSIONS

In Criollo cacao, the odor notes of cocoa, wood, and nut are more developed at 115°C for 10-15 minutes. At the same temperature, extending the roasting time diminishes the cocoa and bitter taste. While taste develops the most notes at 100°C during a roasting time of 10 to 15 minutes where the cocoa, nut and wood and notes are more representative. Forastero cocoa odor also have cocoa, chocolate and wood notes development at 115°C during the 10 minutes, temperatures of 100 and 115°C in both cocoas are the most relevant for development of notes of cocoa, chocolate, nut and wood. Given that this work is an initial approach, further research is required to evaluate the same descriptors as well as others not included in this framework.

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