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Determination of factors affecting the color and reducing sugar content of sugar cane panela (*Saccharum officinarum* L.)

Determinación de los factores que afectan el color y el contenido de azúcar de la panela de caña de azúcar (*Saccharum officinarum* L.)

Determinação dos factores que afectam a cor e a redução do teor de açúcar da panela de cana-de-açúcar (*Saccharum officinarum* L.)

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Rev. Fac. Agron. (LUZ). 2024, 41(3): e244111
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v41.n3.31

Food technology
Associate editor: Dra. Gretty R. Ettiene Rojas
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela.

Received: 06-05-2024
Accepted: 14-08-2024
Published: 02-09-2024

Keywords:
Sugar cane sugar
Controllable factors
Reducing sugars
ºBrix
Purity (%)
Processing

Abstract

The objective of this study was to determine the factors that affect the color and reducing sugar content of sugar cane (*Saccharum officinarum* L.), fundamental factors in the quality and marketing of product that must be evaluated and that will allow the improvement of the artisanal production of sugar cane panela. For this purpose, the MY5514 variety harvested at optimum maturity time was used and a 2^4 factorial design was applied to evaluate the incidence of the factors: ºBrix, purity (%), lime concentration ($g.L^{-1}$) and baking temperature (ºC), on the response variables: "color" and "reducing sugar content (%)", under a completely randomized design with three replications. It was found that the significant factors for the response variable "color" for the three coordinates evaluated were: lime concentration ($g.L^{-1}$), cooking temperature (ºC) and purity content (%) for the L* coordinate; ºBrix for the a* coordinate and purity content (%) for the b* coordinate. With respect to the response variable "reducing sugars (%)", the factors that significantly affected were cooking temperature (ºC) and purity content (%). It is recommended to use any of the combinations of these two factors, except the combination of 110 ºC and 95 % purity, because generates a final product with commercial characteristics not desired by the consumer.

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Resumen

El objetivo de este estudio fue determinar los factores que afectan el color y el contenido de azúcar reductor de la panela de caña de azúcar (*Saccharum officinarum* L.), factores fundamentales en la calidad y comercialización del producto que deben evaluarse y que permitirán el mejoramiento de la producción artesanal de panela de caña. Para ello se utilizó la variedad MY5514 cosechada en el momento óptimo de madurez y se aplicó un diseño factorial 2^4 para evaluar la incidencia de los factores: ºBrix, pureza (%), concentración de cal (g.L^{-1}) y temperatura de cocción (ºC), sobre las variables respuesta: "color" y "contenido de azúcar reductor (%)", bajo un diseño completamente aleatorizado con tres repeticiones. Se encontró que los factores significativos para la variable respuesta "color" para las tres coordenadas evaluadas fueron: concentración de cal (g.L^{-1}), temperatura de cocción (ºC) y contenido de pureza (%) para la coordenada L*; ºBrix para la coordenada a* y contenido de pureza (%) para la coordenada b*. Con respecto a la variable de respuesta "azúcares reductores (%)", los factores que afectaron significativamente fueron la temperatura de cocción (ºC) y el contenido de pureza (%). Se recomienda utilizar cualquiera de las combinaciones de estos dos factores, excepto la combinación de 110 ºC y 95 % de pureza, debido a que genera un producto final con características comerciales no deseadas por el consumidor.

Palabras clave: azúcar de caña, factores controlables, azúcares reductores, ºBrix, pureza (%), procesamiento.

Resumo

O objetivo deste estudo foi determinar os fatores que afetam a cor e o teor de açúcar redutor da cana-de-açúcar (*Saccharum officinarum* L.) processada de forma artesanal. Para isso, foi usada a variedade MY5514 colhida no momento ideal de maturação e foi aplicado um planejamento fatorial 2^4 fatores para avaliar a incidência dos fatores: ºBrix, pureza (%), concentração de cal (g.L^{-1}) e temperatura de cozimento (ºC), sobre as variáveis de resposta: "cor" e "teor de açúcar redutor (%)", em um delineamento inteiramente casualizado com três repetições. Verificou-se que os fatores significativos para a variável de resposta "cor" para as três coordenadas avaliadas foram: concentração de cal (g.L^{-1}), temperatura de cozimento (ºC) e teor de pureza (%) para a coordenada L*; ºBrix para a coordenada a* e teor de pureza (%) para a coordenada b*. Com relação à variável de resposta "açúcares redutores (%)", os fatores que afetaram significativamente foram a temperatura de cozimento (ºC) e o teor de pureza (%). Recomenda-se usar qualquer uma das combinações desses dois fatores, exceto a combinação de 110 ºC e 95 % de pureza, pois ela gera um produto final com características comerciais não desejadas pelo consumidor.

Palavras-chave: açúcar de cana-de-açúcar, fatores controláveis, açúcares redutores, ºBrix, pureza (%), processamento.

Introduction

Panela or "piloncillo", as it is called in some countries, is a product made from unrefined sugarcane juice (*Saccharum officinarum* L.) with a solid consistency molded into various shapes (García *et al*., 2017). Unlike white sugar that contains mainly sucrose, panela is considered a food product with high content of carbohydrates, sucrose, glucose, fructose, minerals, vitamins, fats, and protein compounds; being related to multiple benefits on health, compared to the consumption of common sugar, due to a lower amount of side effects linked in the development of diseases such as obesity and diabetes mellitus (Vargas-Valencia *et al.*, 2022).

Despite its benefits, technological advances in relation to sugarcane processing have been mainly focused on the refined sugar industry, while panela processing has remained a rural industry under rudimentary facilities with little degree of technification (Rodríguez-Campo, 2018). However, several studies have been developed focused on modernizing and standardizing the process of obtaining panela, motivated by the current trend in the consumption of high quality and healthy products (Vera-Gutiérrez *et al*., 2019).

Thus, some of these researches such as Prada Forero *et al.* (2015), García *et al.* (2017) and Velásquez *et al.* (2019) directed their efforts to evaluate a series of elements involved in the process, making reference that the quality of panela depends on certain operating conditions such as pH, temperature, pressure and caloric flow. Similarly, Prada Forero (2004), points out that the quality of panela is affected by factors such as the presence of insoluble solids (impurities) and hardness. Publications by Jaffé (2015) and Espitia *et al*. (2020) indicate that other factors that influence the deterioration of panela are related to humidity, composition and environmental conditions. They also suggest that as moisture absorption increases, panela softens, changes color, reducing sugars increase and sucrose content decreases, thus affecting the quality of the product.

In short, organoleptic traits are the best criteria used by consumers to define the quality of sugarcane panela and, in spite of being consumed as a beverage, it is mostly marketed in blocks. This is why consumers will normally look for a product with a slightly sweet taste, with typical color and aroma.

Based on the above and in order to evaluate the quality of sugar cane (*Saccharum officinarum*) panela during the elaboration process, a factorial design 2^4 was applied to evaluate the incidence of the following factors: ºBrix, Purity (%), lime concentration (g. L^{-1}) and cooking temperature (ºC); on the response variables "color" and "reducing sugar content (%)" in view of their relevance on the organoleptic characteristics and therefore on the quality of the final product.

Materials and methods

The research was carried out in an artisanal agroindustry dedicated to the production of panela from sugar cane, located in the "El Recreo" farm in the municipality of San Joaquín, Carabobo State, Venezuela. The sugar cane material used corresponded to the MY5514 variety, harvested at the optimum time of maturity for the production of panela. The factors evaluated were obtained through the application of the Pareto plot tool, with which it was possible to identify 80 % of the possible causes of variation in the quality of the panela. Table 1 shows the factors and levels used in this research.

Table 1. Factors and levels used in this research.

Factors	Levels	Units
Temperature (A)	100 y 110	ºC
Purity (B)	93 y 95	%
Lime concentration (C)	0.5 y 1	g.L^{-1}
ºBrix (D)	20 y 24	%

From the cane juice obtained from the selected material, the artisanal process was carried out under controlled conditions and at each stage measurements of temperature, pH and concentration of ºBrix in the raw material and in the final product were taken. Samples of panela were obtained for the analysis of the variables color responses and reducing sugars (%), as they were considered relevant during the elaboration process. The determination of reducing sugars ($g.L^{-1}$) was carried out using the Lane and Eynon technique of the manual "ICUMSA Methods of Sugar Analysis" (Whalley, 1971), and color was determined with a tristimulus spectro colorimeter (Hunterlab Miniscan XE 45/0), through readings based on the CIE-Lab chromatic model, which is represented tridimensionally in the positive coordinates L*, a* and b*; and which correspond to the colors white, red and yellow, respectively.

Experimental design and statistical analysis

A 2^4 factorial design was used to evaluate the effect of 4 factors, each at two levels (Montgomery, 2004) on the variables color and reducing sugars (%), under a completely randomized design with three replications. The randomization of the combination of each of the factors with its three replications was carried out in an unrestricted manner, therefore, it was ensured that the run of each of the combinations of the factors was totally randomized and the experimental unit was composed of panela of approximately 15x10x10.5 cm in dimension. To analyze the data from the experiment, the R Studio program was used. The first thing was to verify compliance with the normality assumption using the Shapiro-Wilk test since the sample size is less than 50. The second verified assumption was that of the homogeneity of the variances using the Bartlett test, with the assumptions verified, the analysis of variance was calculated for factorial experiment 24 and the Tukey post hoc test was calculated for the variables that presented significant differences.

Results and discussion

Regarding the color variable, three readings (L*, a* and b*) established by the method used for its measurement were analyzed, showing that the second and third order interactions were not significant (P≥0.05), so the effect of these interactions was added to the experimental error. In relation to the variable L*, the table 2 shows that the interaction between the factors cooking temperature (A) and lime concentration (C) presented statistically significant differences (P≤0.05), so it is inferred that both factors act jointly on the variable L*.

The figure 1 shows that when using a high firing temperature (A), the effect on color is insignificant, generating similar values of the L* variable. On the other hand, when using a low firing temperature value (A), a significant effect on L* is generated, decreasing as the concentration of lime (C) in the sample increases. It is important to point out that, in spite of the above, it should be noted that in none of the four combinations were the L* values outside the range considered optimal in a panela.

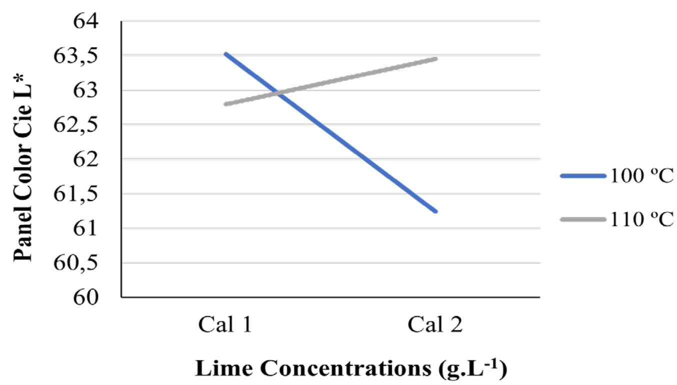

Figure 1. Interaction between the factors firing temperature (ºC) and lime concentration ($g.L^{-1}$) with the variable L*.

Regarding the effect of the individual factors, only purity showed statistically significant differences (P≤0.05). The figure 2 shows how, when going from a purity level of 93 to 95 %, the average L* values increased from 61.87 to 63.66. Despite this significant difference in the average L* values, from the commercial point of view there is no change in the final color of the panela, since the average value reported coincides with that reported by Galicia-Romero *et al*. (2017).

Regarding the variable a*, the table 3 shows that, between the first-order interactions and the individual factors, only the ºBrix (D) factor presented statistically significant differences (P<0.05). The figure 3 shows that when the raw material goes from 20 to 24 ºBrix, the average value of the variable a* decreased significantly. Despite this difference obtained, both average values are within the expected range for the value of a* in a panela.

Table 2. Analysis of variance for the variable L*.

Sources of variation	df	Ss	Ms	F	P
Cooking Temperature (A)	1	7.42	7.42	1.13	0.32 ns
Purity (B)	1	38.318	38.318	5.87	**0.028 ***
Lime concentration (C)	1	6.092	6.092	0.93	0.367 ns
ºBrix (D)	1	14.46	14.46	2.217	0.168 ns
Cooking Temperature* Pureza (A*B)	1	7.166	7.166	1.09	0.328 ns
Cooking Temperature*Lime concentration (A*C)	1	29.142	25.142	3.85	**0.047 ***
Cooking Temperature *º Brix (A*D)	1	15.268	15.268	2.34	0.157 ns
Purity * Cooking Temperature (B*C)	1	0.041	0.041	0.06	0.94 ns
Purity * ºBrix (B*D)	1	1.977	1.977	0.3	0.606 ns
Cooking Temperature * ºBrix (C*D)	1	5.786	5.786	0.89	0.379 ns
Experimental error	37	241.248	6.52		
Total	47				

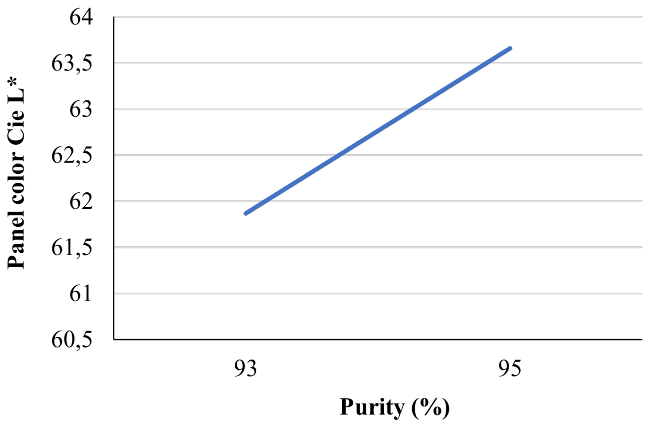

Figure 2. Effect of the factor Purity (%) on the variable L*.

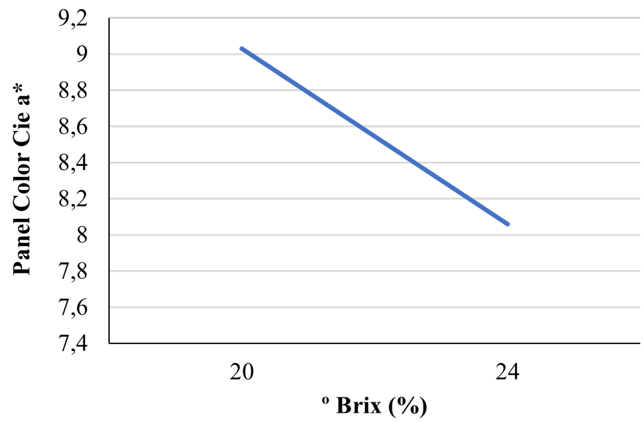

Figure 3. Effect of the ºBrix factor for the variable a*.

Table 3. Analysis of variance for the variable a*.

Sources of variation	df	Ss	Ms	F	P
Cooking Temperature (A)	1	0.594	0.594	0.35	0.555 ns
Purity (B)	1	0.068	0.068	0.04	0.841 ns
Lime concentration (C)	1	1.749	1.749	1.749	0.314 ns
ºBrix (D)	1	11.205	11.205	11.205	**0.014 ***
Cooking Temperature * Purity (A*B)	1	0.153	0.153	0.153	0.764 ns
Cooking Temperature * Lime concentration (A*C) (A*C)	1	0.815	0.815	0.815	0.49 ns
Cooking Temperature *º Brix (A*D)	1	0.063	0.063	0.063	0.847 ns
Purity * Lime concentration (B*C)	1	1.693	1.693	1.693	0.321 ns
Purity *ºBrix (B*D)	1	1.413	1.413	1.413	0.364 ns
Lime concentration * ºBrix (C*D)	1	0.02	0.02	0.02	0.975 ns
Experimental error	37	61.911	6.52	1.675	
Total	47				

Table 4. Analysis of variance for the variable b*.

Sources of variation	df	Ss	Ms	F	P
Cooking Temperature (A)	1	3.371	3.371	0.43	0.514 ns
Purity (B)	1	75.359	75.359	9.7	**0.004 ***
Lime concentration (C)	1	0.705	0.705	0.09	0.765 ns
ºBrix (D)	1	5.949	5.949	0.77	0.387 ns
Cooking Temperature * Purity (A*B)	1	18.792	18.792	2.42	0.128 ns
Cooking Temperature * Lime concentration (A*C) (A*C)	1	0.905	0.905	0.12	0.735 ns
Cooking Temperature *º Brix (A*D)	1	0.233	0.233	0.03	0.864 ns
Purity * Lime concentration (B*C)	1	1.2	1.2	0.15	0.697 ns
Purity *ºBrix (B*D)	1	1.582	1.582	0.2	0.654 ns
Lime concentration * ºBrix (C*D)	1	2.259	2.259	0.29	0.593 ns
Experimental error	37	287.371	7.767		
Total	47				

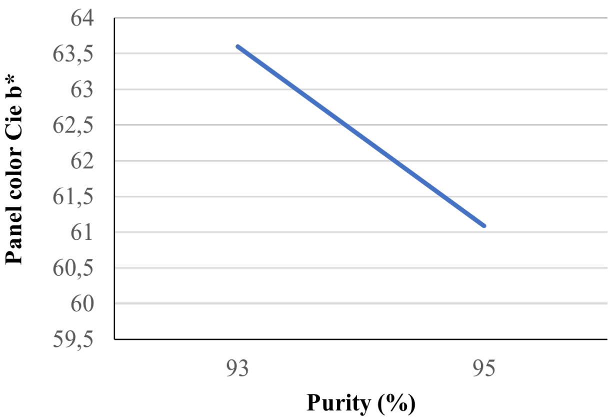

Figure 4. Interaction between purity factors (%) for the variable b*.

In relation to the color attribute b*, the analysis shown in the table 4, establishes that only the purity factor individually showed significant differences (P≤0.05). The remaining main effects, including the first order interactions, did not show significant differences.

The figure 4 shows that when going from a purity level of 93 % to a level of 95 %, there was a significant reduction in the average values of the color attribute b*.

Based on what was observed for the color variable with respect to the three coordinates (L, a* and b*) analyzed, it is found that the average values found in each of the main effects and significant interactions are considered within the expected range, establishing therefore that the different panela obtained in the artisanal process obtained a deep yellow color, which from the sensory point of view is convenient since it is possible to have a product with a commercial and acceptable color.

The above agrees with the studies conducted by Quezada-Moreno *et al.* (2016) and Galicia-Romero *et al.* (2017), who indicate that the deep yellow color present in sugarcane panela is characteristic of production under natural clarification conditions and is considered a determining factor in the quality of the product, in turn generating consumer acceptance. On the other hand, some authors point out that the heat generated during the elaboration process has an impact on the color of the final product producing the darkening of the juice (García *et al*., 2017). Likewise, Lee *et al.* (2018) and Prada Forero *et al.* (2015) mention that at temperatures above 100°C the development of color through sucrose caramelization, is not considered adequate compared to the color obtained at lower temperatures. Therefore, the thermal stage is the most relevant in the production process since it determines the quality of the final product.

Reducing-sugars Variable

Regarding the reducing sugars, the first and second order interactions were all non-significant, so these effects were added to the experimental error, leaving the final analysis of variance as shown in the table 5. Also, it is noted that only the interaction composed of the factors baking temperature and lime concentration presented significant differences (P≤0.05), which is why it is established that the combined action of these factors affects the content of reducing sugars (%) of processed panela.

The figure 5 shows that at a temperature of 100 ºC, regardless of the purity level of the raw material, a statistically similar average value of reducing sugars (%) was obtained; however, when the cooking temperature was increased by 10ºC, the purity level affected the final values of reducing sugars (%) obtained.

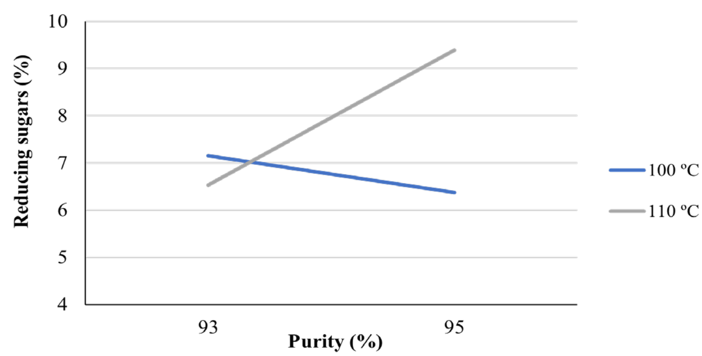

Figure 5. Interaction between the factor's purity (%) and cooking temperature (ºC), for the reducing sugars variable.

Table 5. Analysis of variance for the variable reducing sugars (%).

Sources of variation	df	Ss	Ms	F	P
Cooking Temperature (A)	1	13.033	13.033	2.46	0.125 ns
Purity (B)	1	17.449	17.449	3.31	0.077 ns
Lime concentration (C)	1	0.276	0.276	0.05	0.821 ns
ºBrix (D)	1	3.444	3.444	0.65	0.425 ns
Cooking Temperature * Purity (A*B)	1	39.802	39.802	7.53	**0.009 ***
Cooking Temperature * Lime concentration (A*C)	1	3.901	3.901	0.74	0.396 ns
Cooking Temperature *º Brix (A*D)	1	1.799	1.799	0.34	0.563ns
Purity * Lime concentration (B*C)	1	5.66	5.66	1.07	0.308 ns
Purity *ºBrix (B*D)	1	0.191	0.191	0.04	0.85 ns
Lime concentration * ºBrix (C*D)	1	0.126	0.126	0.02	0.878 ns
Experimental error	37	195.669	5.288		
Total	47				

Similarly, it was found that the combination of 110 ºC cooking temperature with a purity level of 95 % generated the highest average of reducing sugars (%), differentiating this value from the rest of the combinations evaluated. It is important to highlight that this average value obtained showed a fragile consistency of panela, coinciding with the results obtained by Cerda-Mejía *et al.* (2020) and Vargas-Valencia *et al.* (2022), who determined that as the content of reducing sugars (%) increases, the firmness of the panela becomes softer, requiring little force for its deformation.

Likewise, Cerda-Mejía *et al.* (2021) consider that sucrose hydrolysis is greater when temperatures higher than 100 ºC are applied, causing an increase in reducing sugars and in turn affecting the quality of the final product.

It is important to highlight that in the artisanal manufacturing process, knowing the exact doses of the factors that are involved is decisive, since they allow, first of all, a saving of resources and also not alter the necessary values in the final product, in the present investigation. For the color variable, a lime concentration value of 1 $g.L^{-1}$, a firing temperature of 110 ºC and a purity level of 95 % are needed. In relation to the reducing sugars variable, to achieve the recommended value, a purity level of 95 % and a temperature of 110 ºC must be used.

Conclusions

The quality of panela is given by a set of factors that intervene in the artisanal production process; however, for the purposes of this research it was found that the significant factors for the response variable “color” for the three coordinates evaluated were: lime concentration ($g.L^{-1}$), baking temperature (ºC) and purity content (%) for the L* coordinate; ºBrix for the a* coordinate and purity content (%) for the b* coordinate. With respect to the response variable “reducing sugars (%)”, the only factors that had a significant effect were cooking temperature (ºC) and purity content (%); where it is recommended to use any of the combinations of these two factors, except for the combination of 110 ºC and 95 % purity, since this generates a final product with commercial characteristics that are not desired by the consumer.

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