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Effect Of The Partial Substitution Of Chocolate With Yacon (*Smallanthus Sonchifolius*) Flour On The Physicochemical, Rheological, Mechanical And Sensory Properties Of Dark Chocolate.

Efecto De La Sustitución Parcial Del Chocolate Por Harina De Yacón (*Smallanthus Sonchifolius*) Sobre Las Propiedades Fisicoquímicas, Reológicas, Mecánicas Y Sensoriales Del Chocolate Negro.

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RESUMEN

El objetivo de esta investigación fue estudiar el efecto de la sustitución parcial de la harina de yacón en el chocolate sobre sus propiedades fisicoquímicas, reológicas y mecánicas. Se evaluaron los contenidos de carbohidratos, lípidos, proteínas, humedad, cenizas, fibra, pH, índice de acidez, índice de yodo e índice de peróxido de la harina de yacón y de los chocolates con harina de yacón añadida. Se determinaron las propiedades reológicas y mecánicas de compresión de los chocolates con harina de yacón añadida. El contenido de proteínas, cenizas, índice de acidez e índice de yodo del chocolate aumentó significativamente (p < 0,05) al aumentar las concentraciones de harina de yacón. Todas las muestras presentaron un comportamiento fluido no newtoniano de tipo plástico. Las viscosidades plásticas de Casson η_C aumentaron (p < 0,05) al aumentar el contenido de harina de yacón en el chocolate, mientras que la tensión de fluencia de Casson τ_o disminuyó (p < 0,05). Un aumento de la temperatura disminuyó (p < 0,05) las propiedades reológicas de los chocolates (τ_o y η_C). La resistencia máxima a la compresión aumentó al aumentar la concentración de harina de yacón. Las muestras de control y la muestra con un 10 % de harina de yacón mostraron una mayor aceptabilidad entre los catadores que la muestra con un 20 % de harina de yacón. Estos resultados demuestran la importancia de utilizar harinas de tubérculos como sustitutos parciales en la formulación de nuevos productos alimenticios.

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Palabras clave: Harina de yacón; Reología; Chocolate; Red neuronal artificial; Predicción de propiedades reológicas.

ABSTRACT

This research aimed to study the effect of the partial substitution of yacon flour to chocolates on its physicochemical, rheological, and mechanical properties. The carbohydrate, lipid, protein, moisture, ash, fiber, pH, acid value, iodine, and peroxide content of yacon flour and chocolates with added yacon flour were evaluated. The rheological and mechanical compressive properties of chocolates with added yacon flour were determined. The protein, ash, acid value, and iodine value of chocolate increased significantly $(p < 0.05)$ with increasing of yacon flour concentrations. All samples presented plastic-type non-

Newtonian fluid behavior. The Casson plastic viscosities η_C increased ($p < 0.05$) with increasing yacon flour content in the chocolate, while the Casson yield stress τ_o decreased ($p < 0.05$). An increase in temperature decreased ($p < 0.05$) the rheological properties of chocolates (τ_o and η_C). The maximum compressive strength increased with increasing concentration of yacon flour. The control samples and the sample with 10% yacon flour showed greater acceptability among panelists than the sample with 20% yacon flour. These results demonstrate the importance of using tuber flours as partial substitutes in the formulation of new food products.

Keywords*:* Flour yacon; Rheology; Chocolate; Artificial neural network; Prediction of rheological properties.

INTRODUCTION

Yacon (*Smallanthus Sonchifolius*) is a sweet-tasting Andean tuber, belonging to the Asteraceae botanical family, originally cultivated at altitudes from 1800 to 3500 meters above sea level (Reis et al., 2021; Orellana, et al.,2020). One of the main characteristics of the yacon crop is its adaptability to different climatic conditions, if it can tolerate minimum temperatures between 4-5°C, and its optimal range for its release is between 18 to 25°C, where these characteristics of templates and subtropical regions, y its consumption is very extensive in the South American region (R. A. de Sales et al., 2021). This tuber is characterized by its content of bioactive compounds, such as fructooligosaccharides (FOS), which provide prebiotic properties that positively affect consumer health, particularly by supporting gut health (Bayona Buitrago, et al., 2022; Lancetti et al., 2020). Due to these properties, the yacon has generated increasing interest in the food industry as a source of functional ingredients, not only stands out for its prebiotic properties but has also been shown to improve the physicochemical and sensory properties of foods when incorporated, making it an innovative and healthy alternative (S. da S. Sales et al., 2023; M. de F. G. da Silva et al., 2018), being reported by various studies, the incorporation of yacon flour into various food products such as sweet biscuits (Simanca-Sotelo et al., 2021), conventional cake (Rocha et al., 2015), gluten-free breads (Pelinson Tridapalli et al., 2023), chocolate cake (Moscatto et al., 2004) and gluten-free muffins (Lancetti et al., 2020). Chocolate is a cocoa-based emulsion and is considered one of the most popular confectionery products worldwide. Its main varieties are dark chocolate, milk chocolate, and white chocolate, which are primarily distinguished by their content of cocoa solids, milk fat, and cocoa butter (Cheragheshahi et al., 2025; Barišić et al., 2021; Sánchez y Caballero, 2019.). The demand for chocolate operates in a highly competitive market, where factors such as food safety, production efficiency, affordability, taste, and quality play key roles in meeting consumer expectations (Cheragheshahi et al., 2025; Tarón Dunoyer et al., 2022; Del Prete & Samoggia, 2020). The addition of yacon flour in chocolate production helps improve its prebiotic properties and blood glucose control due to the presence of fructooligosaccharides (FOS), in addition to enhancing the properties of the chocolate and reducing its caloric content (Montarroyos Padilha et al., 2010; Moscatto et al., 2004).

The rheological properties of chocolate are crucial in the manufacturing process, as they directly impact the production of high-quality products. For instance, when chocolate has high viscosity, it creates a pasty sensation that lingers in the mouth (Selvasekaran & Chidambaram, 2024; Púa et al., 2022). Therefore, prediction of rheological properties such as viscosity is crucial in terms of the quality of the final product, which, depending on the non-linear relationships between the variables studied, the use of a traditional adjustment method for its prediction may be inaccurate (Chen et al., 2021). Therefore, the objectives of this research were to analyze the partial substitution of yacon (*Smallanthus Sonchifolius*) flour on the physicochemical, rheological mechanical and sensory properties of dark chocolates.

MATERIALS AND METHODS.

Raw material.

Yacon tubers, chocolate and commercial flour were purchased from a supermarket in the department of Atlántico, Colombia. Sodium hypochlorite, citric acid and calcium chloride were acquired from Panreac.

Preparation of yacon (*Smallanthus Sonchifolius*) tuber flour.

Yacon tuber flour was prepared following the methodology reported by Coronado & Salazar (Coronado & Salazar, 2017) with slight modifications. Briefly, the yacon tubers were selected, washed with a sodium hypochlorite solution, and then dried at room temperature. Subsequently, it was manually peeled, and the pulp was washed with a citric acid solution (0.4% *w/v*), chopped and blanched in water at 98°C for 6 min. Then conditioned pulp was then dried at 60°C for 24 h, ground and sifted (ASTM N60). The resulting flour was vacuum-packed for subsequent analysis

Preparation of chocolates with partial substitution yacon (*Smallanthus Sonchifolius*) flour.

Chocolates samples with partial substitution yacon flour were prepared according to the formulations shown in Table 1, following the process described by the production process control standard for bonbons and solid tablets - NEIAL 6737 (NEIAL – 6737, 2006). Initially the chocolate, previously weighed, was melted in a water bath at a temperature between 50 - 55°C. Then, the yacon flour was added to the melted chocolate and stirred constantly until the mixture reached a temperature of 29°C. Subsequently, the mixture was heated to a temperature between 30 - 32°C, then placed into molds with agitation to eliminate air bubbles. The samples were then cooled for 45 min at a temperature between 13 - 15°C and removed from the molds. The chocolate samples were stored in amber glass containers at room temperature for later analysis.

Table 1. Chocolate formulation with partial substitution yacon *(Smallanthus Sonchifolius)* flour.

Code Sample	Chocolate (%)	Yacon flour (%)
C_FYa0	100	0
C_FYa10	90	10
C_FYa20	80	20

Physicochemical characterization of yacon (Smallanthus Sonchifolius) flour and chocolates with partial substitution yacon (Smallanthus Sonchifolius) flour.

The moisture, ash, ether extract, protein contents of yacon (*Smallanthus Sonchifolius*) and commercial flour, and Chocolates samples with partial substitution yacon (*Smallanthus Sonchifolius*) flour were determined using standard methods of Association of Official Analytical Chemists – A.O.A.C No. 926.08, 935.42, 972.28, 926.123 respectively (AOAC, 2000). The carbohydrate content was determined by differences with the contents of ash, ether extract, moisture, and proteins (Marsiglia-Fuentes et al., 2022). The pH was determined using a Boeco potentiometer previously calibrated, following the method 981.12 described by Association of Official Analytical Chemists – A.O.A.C (AOAC, 2000). The fiber content of the yacon (*Smallanthus Sonchifolius*) flour and the commercial flour was determined by the Weende method (A.O.A.C. No. 978.10). The acidity and iodine indices of the chocolates with the addition of yacon (*Smallanthus Sonchifolius*) flour were determined using standard methods of Association of Official Analytical Chemists – A.O.A.C No 942.15 and 993.20 respectively (AOAC, 2000). The peroxide index was measured using the standard method of the Colombian Technical Standard NTC 236:2011 (INCONTEC, 2008).

Microbiological count yacon (Smallanthus Sonchifolius) flour and chocolates with partial substitution yacon (Smallanthus Sonchifolius) flour.

The count of mesophilic aerobes, *Escherichia coli*, *Salmonella spp*, molds and yeasts present in yacon flour and chocolates with partial substitution yacon (*Smallanthus Sonchifolius*) flour were measured using the standard methods reported by the International Organization for Standardization (ISO) and Colombian Technical Standards (NTC) as follows: ISO 4833-1, NTC 4458, NTC 4574 and ISO 21257-1, respectively (INCONTEC, 2008; ISO, 2008, 2014) . The count of *Staphylococcus aureus* coagulase-positive present in yacon flour and the coliforms on plate in chocolate with the addition of yacon (*Smallanthus Sonchifolius*) flour were measured using the methods reported in the Colombian Technical Standards - NTC 4779 and 4458, respectively (INCONTEC, 2008).

Rheological properties.

The rheological characterization of chocolate with partial substitution yacon flour was carried out using a Brookfield DV-I PRIME viscometer (Brookfield Engineering Laboratories, Massachusetts, USA) following the methodology proposed by Brewer et al

(Brewer et al., 2024). The flow behavior was evaluated at rotation speeds between 20 and 100 rpm using a SC4-27 spindle at different temperatures (37°C and 50°C). The Casson model was used to fit the results of the flow behavior of the chocolate with added yacon flour (Equation 1):

$$\sqrt{\tau} = \sqrt{\tau_o} + \sqrt{\eta_C \dot{\gamma}} \qquad (1)$$

where η_C is the plastic viscosity of Casson $(Pa\ s)$ and τ_o is yield stress (Pa).

Mechanical properties.

The mechanical properties of chocolate samples with partial substitution yacon flour were determined using a Texturometer EZ-S (SHIMADZU) following the methodology proposed by Hosseini et al (Hosseini et al., 2021). The test was carried out applying a unidirectional compression up to 50% to evaluate the hardness or maximum deformation force of penetration with a speed of 0.5 mm/s at a room temperature of 33°C.

Sensory evaluation.

The sensory evaluation of the chocolates was conducted to determine consumer preference for chocolates with added yacon flour and to compare them with the control sample. A total of 50 untrained panelists were selected to carry out the sensory test. The chocolate samples were kept at room temperature (30 °C) for 30 min beforte tests. The samples were presented to the panelists with the following coding: C110 (100% chocolate and 0% yacon flour - C_FYa0), C128 (90% chocolate and 10% yacon flour - C_FYa10) and C193 (80% chocolate and 20% yacon flour - C_FYa20). Each panelist completed a questionnaire indicating their level of liking (“like” or “dislike”) for the chocolate samples.

Data and statistical analysis.

Matlab R2021a and *R* software were used for modeling and statistical analysis of the data. All tests were performed in triplicate. ANOVA analysis and Fisher's LSD test were used to determine significant differences and comparison of means respectively with $p < 0.05$. The coefficient of variation (C.V) was used to analyze the relationship between the standard deviation and the means of measurements.

RESULTS AND DISCUSSION.

Physicochemical and microbiological characterization.

The results of the physicochemical characterization of yacon flour and chocolates elaborated with partial substitution yacon flour are presented in Table 2. The carbohydrate content of yacon flour ($80.92 \pm 3.84\,\%$) was similar to that reported by Chessum et al (Chessum et al., 2022) and Simanca-Sotelo et al (Simanca-Sotelo et al., 2021) (80.354 ± 0.544 and 80.354 ± 0.544, respectively) and lower than that reported by Gonzales et al (Gonzales et al., 2023) ($95.19 \pm 0.012\%$) and Sousa et al (Sousa et al., 2015) (89.01%). The lipid content of yacon flour ($0.97 \pm 0.11\,\%$) was similar to that reported by Coronado & Salazar (Coronado & Salazar, 2017) (0.93%), and higher than that reported by Simanca-Sotelo et al (Simanca-Sotelo et al., 2021) ($0.67 \pm 0.11\%$) and Gonzales et al (Gonzales et al., 2023) ($0.13 \pm 0.00\,\%$). Regarding the protein content of yacon flour ($6.02 \pm 0.61\,\%$), the results obtained in this study were similar to those reported by Chessum et al (Chessum et al., 2022) ($6.634 \pm 0.158\%$), but lower than those reported by Simanca-Sotelo et al (Simanca-Sotelo et al., 2021) ($8.50 \pm 0.03\%$), while the total fiber content ($13.43 \pm 0.10\%$) was higher than that reported by Coronado & Salazar (Coronado & Salazar, 2017) and Simanca-Sotelo et al (Simanca-Sotelo et al., 2021) (0.85% and 0.76%, respectively). These variations in the composition of yacon flour could be due to the cultivation methods, varieties of yacon, soil type, planting season and environmental factors. Regarding the moisture content ($2.93 \pm 0.32\%$) of the yacon flour in this study, the results obtained were lower than those reported by Simanca-Sotelo et al (Simanca-Sotelo et al., 2021) ($5.77 \pm 0.20\%$) and Rodrigues et al (Rodrigues et al., 2011) (6.9%), while the ash content ($9.16 \pm 2.80\%$) was higher than that reported by Coronado & Salazar (Coronado & Salazar, 2017) (0.93%) and Rodrigues et al (Rodrigues et al., 2011) (2.72%). This may be due to the drying processes applied to obtain yacon flour (Simanca-Sotelo et al., 2021). Compared to commercial flours (Table 2), we can observe that yacon flour has a significantly higher ($p < 0.05$) carbohydrate content ($80.98\% > 66.81\%$), the protein content of yacon flour was significantly lower ($p < 0.05$) than that of commercial flour ($6.02\,\% < 17.88\%$), while there were no significant differences ($p > 0.05$) in terms of lipid content, indicating that yacon flour is a good source of carbohydrates (I. F. da Silva et al., 2024).

Chocolates with partial substitution yacon flour do not show significant differences ($p > 0.05$) in carbohydrate content, which indicates that the increase in the concentration of yacon flour did not have a significant influence on the carbohydrate content. Similar results were reported by Simanca-Sotelo et al (Simanca-Sotelo et al., 2021) in sweet biscuits prepared with yacon flour, where the control treatment did not present significant differences with the formulation with 40% yacon flour. For the lipid content the sample C_FYa0 (control) obtained the highest values, showing significant differences $(p < 0.05)$ with the samples C_FYa10 and C_FYa20, however, the lipid content of samples C_FYa10 and C_FYa20 did not show significant differences $(p > 0.05)$, indicating that an increase in the concentration of yacon flour from 10 to 20% did not significantly influence the lipid content of the samples. These results are consistent with those reported by Moscatto et al (Moscatto et al., 2004) in chocolate cakes added with yacon flour, where the control treatment showed a higher percentage of lipids than the formulations with 20 and 40% replacement with yacon flour. Regarding the protein content, the sample C_FYa0 (control) obtained the lowest of yacon flour decreased the protein content of the formulations.

The ash content of the samples increased with the concentration of yacon flour, with the sample C_FYa20 showing the highest value. This could be related to the ash content of the yacon flour $(9.16 \pm 2.80\%)$, which, when its content increases in chocolates, leads to a rise in the ash content. These results are consistent with those reported by R. da Silva et al (R. da Silva et al., 2000), which showed that yacon flour increases the ash content of biscuits. Regarding the moisture content, significant differences are observed between the C_FYa0 (control) sample and the C_FYa10 and C_FYa20 samples, whereas the concentration of yacon flour increases, the moisture content decreases significantly $(p < 0.05)$. According to R. da Silva et al (R. da Silva et al., 2000), moisture content is a very important component in new products because it establishes a microbiological parameter on the quality control of food, giving the product greater physical, chemical and microbiological stability if formulated and stored properly. The acidity index of chocolates with the addition of yacon flour increases with the concentration of yacon flour, showing significant differences between the C_FYa20 sample and the C_FYa0 and C_FYa10 samples. This can be explained by the pH of the yacon flour, which has a value of 5.67 ± 0.05, indicating an acidic pH, which can be related to the increase in the acidity index (Akoja & Coker, 2018). Regarding the iodine index, we observe that the increase in the concentration of the yacon flour increases its value, with the C_FYa20 sample having the highest value. This result indicates that the greater the quantity of yacon flour, the higher the degree of unsaturation in the fatty acids, which is beneficial for human health (Przybylski & Eskin, 2011). The results of the peroxide index are negative, which indicates that the addition of yacon flour does not contribute to the oxidation of fats or rancidity in the samples (Charles Bai et al., 2022).

Table 2. Physicochemical characterization of flour yacon and chocolates with partial substitution yacon (*Smallanthus Sonchifolius*) flour.

	Flour yacon	Flour commercial	C_FYa0	C_FYa10	C_FYa20
Carbohydrates (%)	80.92 ± 3.84^a	66.81 ± 0.86^b	56.04 ± 1.48^c	57.83 ± 0.97^c	58.19 ± 1.05^c
Lipids (%)	0.97 ± 0.11^a	1.15 ± 0.28^a	38.45 ± 1.01^b	35.12 ± 0.77^c	33.62 ± 0.15^c
Proteins (%)	6.02 ± 0.61^a	17.88 ± 0.16^b	2.97 ± 0.18^c	5.06 ± 0.10^d	6.04 ± 0.67^{ad}
Moisture (%)	2.93 ± 0.32^a	13.08 ± 0.14^b	1.51 ± 0.25^c	0.81 ± 0.06^d	0.46 ± 0.16^e
Ash (%)	9.16 ± 2.8^a	1.88 ± 0.28^b	1.03 ± 0.04^c	1.18 ± 0.04^c	1.69 ± 0.07^b
Fiber (%)	13.43 ± 0.10^a	19.93^{b*}	N.D	N.D	N.D
pH	5.67 ± 0.05^a	6.0^{b*}	N.D	N.D	N.D
Acidity index (%)	N.D	N.D	4.58 ± 0.55^a	6.23 ± 0.56^b	8.02 ± 0.47^c
Iodine index	N.D	N.D	36.04 ± 0.27^a	38.74 ± 0.71^b	42.27 ± 0.96^c
Peroxide index	N.D	N.D	---	---	---

Data were expressed as mean ± standard deviation. Different letters in the same row express statistically significant differences ($p < 0.05$). * Data with C.V < 0.05. N.D. Not determined.

The results of the microbiological analysis are shown in Table 3. These results show that the values of the *Escherichia coli*, *Staphylococcus aureus*, *Salmonella spp*, mold and yeast and mesophilic aerobic counts for yacon flour are lower than those required by ICONTEC in the Colombian Technical Standard (NTC) 267 of 2007 for flours (Table S1, supplementary material). Likewise, the values of the *Escherichia coli*, *Salmonella spp*, mold and yeast, mesophilic aerobic and coliform on plate counts are within the parameters required by ICONTEC in the Colombian Technical Standard (NTC) 792 of 2008 for chocolate (Table S2, supplementary material). These indicate that the processes and the final product comply with the provisions of the standard in terms of

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hygiene and sanitary quality, and compliance with good manufacturing practices (GMP).

Table 3. Microbiological count of flour yacon and chocolates with partial substitution yacon (*Smallanthus Sonchifolius*) flour.

	Flour yacon	**C_FYa0**	**C_FYa10**	**C_FYa20**
Escherichia coli (UFC/g)	< 10	< 10	< 10	< 10
Staphylococcus aureus coagulasa positiva (UFC/g)	< 100	N.D	N.D	N.D
Salmonella spp. (UFC/g)	Absence	Absence	Absence	Absence
Molds and Yeasts (UFC/g)	< 10	< 10	< 10	< 10
Mesophilic aerobes (UFC/g)	< 10	< 10	< 10	< 10
Coliforms on plate (UFC)	N.D.	< 3	< 3	< 3

N.D. Not determined.

Rheological properties.

Figure 1 shows the shear stress vs. strain gradient curves for chocolates with partial yacon flour substitution at different temperatures (37°C and 50°C). All samples exhibit non-Newtonian fluid behavior of a plastic type. The parameters obtained from the Casson model are presented in Table 4. The Casson model showed $R^2 > 0.99$, indicating an optimal fit to the experimental data for all samples. According to Table 4, the Casson yield strength is between 0.098 and 0.601 Pa at 37°C and between 0.0263 and 0.477 Pa at 50°C. It is observed that as the yacon flour content increases, the Casson yield strength decreases ($p < 0.05$), being higher for the control sample (C_FaY0).

These results are consistent with those reported by Akdeniz et al., (Akdeniz et al., 2021) who observed that an increase in carob flour led to a decrease in the Casson elastic limit. Regarding the plastic viscosity of Casson, its values range from 1.511 to 2.052 Pa·s at 37°C and from 1.262 to 1.591 Pa·s at 50°C. The results showed that an increase in the yacon flour content increased ($p < 0.05$) the Casson plastic viscosity values, which may be due to increased particle-to-particle friction resulting from the increased particle

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content and the decreased lipid content of the chocolates (Table 2) (Feichtinger et al., 2020).

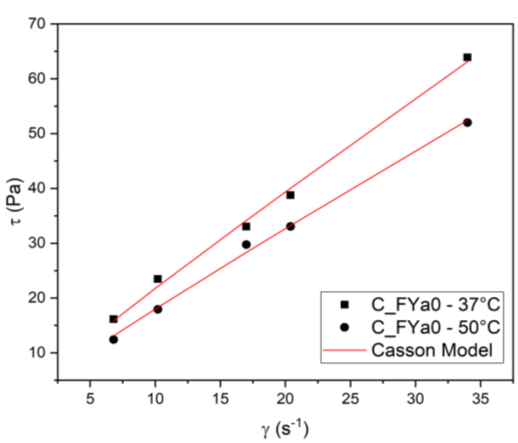
Furthermore, with an increase in temperature for the same yacon flour concentration value, the rheological properties decreases. This result is consistent with that reported in the literature (Khushbu & Sunil, 2020; Nastaj et al., 2022, 2024; Vásquez et al., 2019), where an increase in temperature causes a decrease in rheological properties, due to an increase in the thermal energy of the molecules, which increases the inter-molecular space and improves the mobility of the molecules (Deshmukh et al., 2015).

Table 4. Parameter of the Casson model of chocolates with partial substitution yacon (*Smallanthus Sonchifolius*) flour.

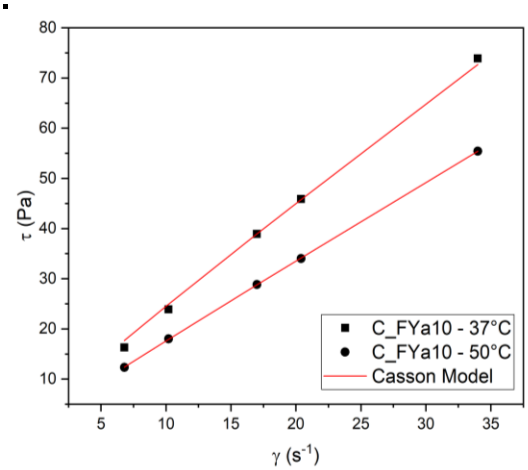
Sample	T (°C)	τ_0 (Pa)	η_C (Pa s)	R^2
C_FYa0	37	0.601^a	1.511^a	0.996
	50	0.477^b	1.262^b	0.997
C_FYa10	37	0.512^c	1.794^c	0.996
	50	0.120^d	1.481^d	0.999
C_FYa20	37	0.098^e	2.052^e	0.999
	50	0.0263^f	1.591^f	0.998

Data with C.V < 0.05
Different letters in the same column express statistically significant differences ($p < 0.05$).

a.



b.



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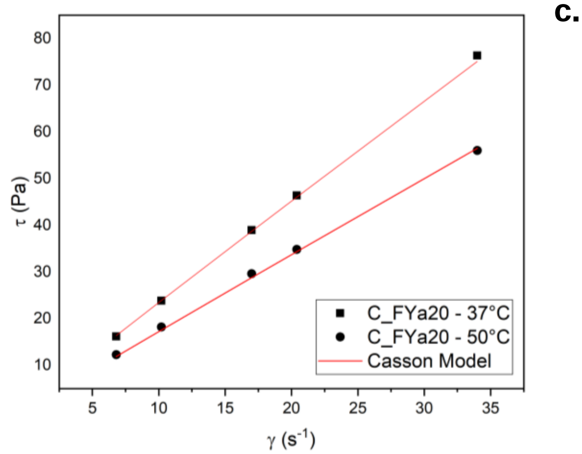

Figure 1. Stress curves of chocolates with partial substitution yacon (*Smallanthus Sonchifolius*) flour.

Mechanical Properties.

Table 5 shows the results of the compression test of chocolate samples with the addition of yacon flour. It is observed that the deformation experienced by the chocolate samples does not present significant differences $(p > 0.05)$ with the addition of yacon flour. Regarding the compressive strength values, sample C_FYa0 $(163.88 \pm 6.07\,N)$ presented the lowest value and sample C_FYa20 $(260.88 \pm 5.55\,N)$ the highest value, which indicates that an increase in the concentration of yacon flour significantly increases $(p < 0.05)$ the maximum compressive strength values. This could be explained by an increase in particle-particle interaction due to a higher amount of yacon flour in the chocolates, which increases the maximum force required to compress the product (Biswas et al., 2017). In addition, Nastaj et al (Nastaj et al., 2024) reported that an increase in protein

content increases the maximum compression force in chocolate samples, which may be due to the fact that proteins can act as coating agents, generating a larger particle size, resulting in an increase in the mechanical properties of the chocolates, therefore, an increase in the concentration of yacon increases the protein content of the chocolate simples (Table 2), with sample C_FYa20 being the one that required the greatest force for compression. Similar results were reported by Selvasekaran & Chidambaram (Selvasekaran & Chidambaram, 2024) for dark chocolates with substitutes of pea protein isolate-kappa-carrageenan complex coacervate.

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Table 5. Values of the mechanical properties of chocolate with partial substitution yacon (*Smallanthus Sonchifolius*) flour.

Sample	Force max (*N*)	Deformation max (%)
C_FYa0	165.30 ± 6.07^{a}	2.23 ± 0.05^{a}
C_FYa10	218.78 ± 8.13^{b}	2.08 ± 0.26^{a}
C_FYa20	260.88 ± 5.55^{c}	2.45 ± 0.74^{a}

Different letters in the same row express statistically significant differences ($p < 0.05$). Data were expressed as mean ± standard deviation

Sensory Evaluation.

Figure 4 presents the results of the sensory evaluation of chocolates with added yacon flour. It can be observed that sample C110 (100% chocolate and 0% yacon flour) and sample C128 (90% chocolate and 10% yacon flour) exhibited higher acceptability compared to sample C193 (80% chocolate and 20% yacon flour). This difference may be attributed to the fact that increasing the yacon flour content raises the acidity of the chocolate samples and the compression force required to deform the product, as shown in Tables 2 and 5 respectively. These changes were reflected in both flavor and texture (hardness during mastication), which ultimately influenced the overall acceptability of the product. These findings are consistent with those reported by Quispe-Sanchez et al (Quispe-Sanchez et al., 2022)who observed that the incorporation of flours into dark chocolate formulations affects their sensory acceptability.

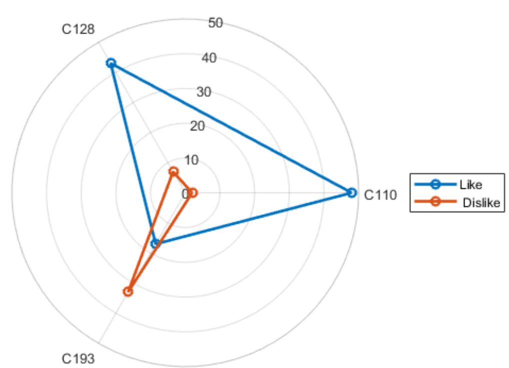

Figure 4. Polar plot for the results of the panelists' affective test.

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CONCLUSIONS.

In this study, In this study, the partial substitution with yacon flour in dark chocolate samples on the physicochemical, rheological and mechanical properties was investigated. The addition of yacon flour significantly influenced the lipid, protein, moisture, ash, acid value and iodine value of chocolates. An increase in yacon flour from 10 to 20% in chocolates significantly increased $(p < 0.05)$ the protein, ash, acid value and iodine value content, and significantly decreased $(p < 0.05)$ the moisture content, while the lipid content did not show significant changes $(p > 0.05)$. The results of the microbiological analysis of the chocolate samples met the standards established by the Colombian Technical Norms, guaranteeing their microbiological quality. Chocolates with added yacon flour showed a plastic-type non-Newtonian fluid behavior and were optimally adjusted to the Casson model. Regarding the mechanical behavior, an increase in the concentration of yacon flour increased the compressive force applied to chocolate samples, which is related to an increase in particle-particle interactions due to an increase in the amounts of yacon flour in the chocolates. The control samples (C_FYa0) and those with 10% substitution with yacon flour (C_FYa10) showed a higher degree of acceptance than the samples with 20% substitution with yacon flour (C_FYa20). These results are of great importance for the development of new products with partial flour substitutions.

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