Rooting for pasta: Unleashing the rheological potential of tannia (*Xanthosoma sagittifolium*)

Enraizamiento de la pasta: liberando el potencial reológico de la malanga (*Xanthosoma sagittifolium*)

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ABSTRACT

The quest for technological advancements in food products has led to the exploration of unconventional raw materials and innovative formulations. This study investigated the feasibility of incorporating tannia (*Xanthosoma sagittifolium*) starch as a partial substitute for wheat flour in pasta formulations. Tannia tubers were sourced, and native starch was extracted following a wet method. Four pasta formulations were prepared with varying percentages of tannia starch substitution (5%, 10%, 15%, and 20%), alongside a control sample. Physicochemical analyses applied for moisture content, ash content, acidity, and pH revealed 11.97% moisture, 0.4% ash, 0.007% acidity, and 4.6 pH in tannia starch. The rheological analysis denoted as the parameters in the Mixolab showed alterations in hydration, moisture, and stability with increasing tannia starch substitution. Cooking tests demonstrated a reduction in optimal cooking time with higher levels of tannia starch substitution, attributed to lower gelatinization temperatures of the tannia starch. Weight loss increased with greater substitution of tannia starch, while water absorption varied, showing a non-linear trend. Quality indices reflected changes in dough characteristics and gluten strength with tannia starch substitution. Further optimization of formulations is recommended to balance technological enhancement with pasta quality attributes, paving the way for the development of novel pasta products.

Key words: starch, starchy raw material, sustainable agriculture, physicochemical properties, wheat, new cocoyam.

RESUMEN

La búsqueda de mejoras tecnológicas en productos alimenticios ha llevado a la exploración de materias primas no convencionales y formulaciones innovadoras. Este estudio investigó la viabilidad de incorporar almidón de malanga (*Xanthosoma sagittifolium*) como un sustituto parcial de la harina de trigo en formulaciones de pasta. Se extrajo el almidón nativo de tubérculos de malanga siguiendo el método húmedo. Se prepararon 4 formulaciones de pasta con diferentes porcentajes de sustitución de almidón de malanga (5%, 10%, 15% y 20%), junto con una muestra de control. Los análisis fisicoquímicos ejecutados, humedad, cenizas, acidez y pH, revelaron 11,97% de humedad, 0,4% de cenizas, 0,007% de acidez y 4,6 de pH en el almidón de malanga. El análisis reológico denotado como los parámetros de Mixolab mostró alteraciones en la hidratación, humedad y estabilidad con el aumento de la sustitución de almidón de malanga. Las pruebas de cocción demostraron una reducción en el tiempo de cocción óptimo con niveles más altos de sustitución de almidón de malanga, atribuido a las temperaturas de gelatinización más bajas del almidón de malanga. La pérdida de peso aumentó con una mayor sustitución de almidón de malanga, mientras que la capacidad de hinchamiento varió, mostrando una tendencia no lineal. Los índices de calidad reflejaron cambios en las características de la masa y la fuerza del gluten con la sustitución de almidón de malanga. Se recomienda una mayor optimización de las formulaciones para equilibrar la mejora tecnológica con atributos de calidad de la pasta, allanando el camino para el desarrollo de productos de pasta novedosos.

Palabras clave: almidón, materia prima amilácea, agricultura sostenible, propiedades fisicoquímicas, trigo, quequesque.

Introduction

The escalating demand for food products with enhanced technological properties has spurred a continuous quest for unconventional raw materials and innovative formulations (De & Goswami, 2021). Due to its versatility, wheat has become an indispensable component of the human diet (Mefleh *et al*., 2019). Globally, it stands as a mainstay crop, serving as the primary livelihood for countless farmers across the planet. In terms of contribution of nutrients,

Received for publication: February 4, 2024. Accepted for publication: April 7, 2024.

Doi: 10.15446/agron.colomb.v42n1.113836

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wheat outshines many agricultural commodities, offering the global populace a rich source of both calories and proteins (Boland & Hill, 2020). One of the remarkable attributes of wheat lies in its unique viscoelastic properties, which are primarily manifested in its dough. Unlike many other grains, wheat dough exhibits a distinctive combination of viscosity and elasticity, allowing it to stretch and hold its shape during the kneading and shaping processes (Van Rooyen *et al*., 2023). This inherent characteristic of wheat dough is essential to produce a wide array of wheat-based products, including pasta (Uthayakumaran & Wrigley, 2010). In the context of pasta production, the viscoelastic nature of wheat dough plays a salient role as it enables the dough to be molded into various shapes, such as *spaghetti*, *penne*, or *lasagna*, while retaining its structural integrity during cooking. The elasticity of the dough ensures that the pasta maintains its shape and texture, even when subjected to boiling water (Gasparre & Rosell, 2022). Therefore, the viscoelastic properties of wheat dough are significant in the manufacturing process of pasta, facilitating the creation of diverse pasta shapes and ensuring the desired texture and consistency of the final product (Shang *et al*., 2023). In this context, pasta, conventionally crafted from durum wheat has undergone a notable evolution through the integration of novel constituents (Sarkar & Fu, 2022). These include rice, corn, pseudocereals, legumes, and fiber-enriched variants, contributing to the diverse landscape of dry pasta offerings in the market (Schmidt & Raczyk, 2023). The ubiquity of pasta across retail shelves owes to its economic accessibility, prolonged shelf life, and user-friendly preparation protocols (Shirhatti *et al*., 2023). Traditionally, pasta formulations predominantly feature starch-rich grains, complemented by proteins, bioactive compounds, vitamins, and minerals (Gull *et al*., 2018). In 1964, the Food and Agriculture Organization (FAO) introduced the concept of composite flours as a solution for nations devoid of wheat cultivation (Noorfarahzilah *et al*., 2014). These composite flours, incorporating wheat alongside up to 40% of alternative cereals or supplementary ingredients, have been extensively studied for their implications in pasta production (Baiano *et al*., 2011; Chillo *et al*., 2007). The adoption of composite flours has played a role in yielding pasta endowed with commendable attributes, catering to the dietary exigencies of demographics constrained by limited access to nutrient-rich sustenance (Nilusha *et al*., 2019). With the global agro-industrial panorama witnessing a surge in demand, there arises an imperative for economically viable products endowed with superior technological attributes (Podio *et al*., 2019). Pasta, as a dietary staple embraced worldwide, offers myriad benefits but also exerts a significant calorific load attributable to its elevated carbohydrate content *vis-à-vis* modest nutrient density (Yadav & Gupta, 2015). To redress this asymmetry, the food industry has endeavored to fortify pasta formulations with nutrient-rich adjuncts, envisaging a diminution in dependence on wheat imports (Nkwonta *et al*., 2023). The partial replacement of wheat with starch derived from alternative botanical sources has engendered the inception of technological-modified food commodities, wielding substantial influence over consumer dietary patterns (Sharif *et al*., 2022). This emphasis underscores the importance of carefully selecting ingredients, refining cooking techniques, and optimizing processing methods (Podio *et al*., 2019). Starches derived from tubers and roots offer a promising alternative, promoting the use and cultivation of local resources (Pacheco de Delahaye & Techeira, 2009). This shift goes beyond traditional sources of starch such as wheat, potatoes, and rice, reflecting a landscape with starches of different structural characteristics that can impact product manufacturing (Bertoft, 2017). The potential benefits of using non-conventional roots such as yam, cassava, and sweet potato in pasta production have been already reported. The integration of these roots can improve cooking qualities and introduce new functional properties. Moreover, these alternative raw materials can contribute to food diversity, sustainability, and meet the demands of health-conscious consumers (Alvis *et al*., 2008; Djeukeu *et al*., 2017; Meaño Correa *et al*., 2014; Odey & Lee, 2020; Singh *et al*., 2004). The aim of this research was to investigate the impact of substituting wheat flour with tannia starch (derived from *Xanthosoma sagittifolium*) and varying cooking and cooling temperatures on the rheological properties and overall quality attributes of pasta.

Materials and methods

Starch source

Tannia (*Xanthosoma sagittifolium*) tubers were sourced from Pucará (Ecuador) during the rainy season. *Triticum durum* semolina and other ingredients for pasta production were procured from local stores.

Extraction of native tannia *(Xanthosoma sagittifolium)* starch

The extraction of native tannia starch followed the wet method (Quezada-Correa *et al*., 2021) at pilot scale. Fifty kg of tannia tubers were disinfected, peeled, sliced into 1-cm-thick slices, and immediately immersed in a 2% (w/v) citric acid solution. Wet blending was conducted using a semi-industrial blender for 3 min at low speed. Subsequently, the blend was filtered through a sieve cloth, and the residue obtained was washed until no apparent traces of starch remained. The filtrate was allowed to settle for 24 h to facilitate solid precipitation. The sediment obtained, corresponding to starch, was dried in trays at 55°C for 24 h in a laboratory oven (INB 500, Memmert GmbH + Co. KG, Schwabach, Germany), then crushed and sieved through a 0.25 mm (ASTM No. 60) mesh sieve.

Physicochemical analysis of *Xanthosoma sagittifolium* starch

Moisture analysis

Moisture content was determined using a MB90/120 halogen analyzer (Ohaus Corporation, Parsippany, USA) at a temperature range of 40-160°C. A 0.5 g sample of tannia starch was placed in the analyzer pan, initiating the drying process (Calero-Jiménez *et al*., 2021). The equipment registered consecutive weight loss, and drying was considered complete once the weight stabilized. The moisture content present in the starch was automatically obtained by the difference in weight. Each analysis was performed in triplicate.

Ash determination

Ash content was determined following the procedure outlined by Mitchell (1990). Five grams of the sample were weighed into crucibles, then placed in a muffle furnace and calcined at temperatures of 550 ± 3°C for 3 h until reaching a constant weight. The sample was subsequently allowed to cool in a desiccator to 25°C. The ash percentage was calculated using Equation 1:

$$\text{Ash content (\%)} = \frac{A - B}{C} \times 100 \qquad \text{Eq. (1)}$$

where

A = weight of crucible with sample (g);

B = weight of crucible with ashes (g);

C = weight of the sample (g).

Titratable acidity

To determine the acidity in starch samples, the AOAC method (AOAC, 2005) standardized protocol was applied. Ten grams of starch were weighed and added to 100 ml of distilled water in a beaker. The mixture was stirred for 30 min to ensure the formation of a homogeneous slurry. Fifteen ml of the starch slurry were pipetted into another beaker. A few drops of phenolphthalein were added to the sample slurry. Titration was then initiated by adding a standardized solution of NaOH, 0.1 N, from a burette while stirring the mixture. The endpoint of the titration was determined by monitoring the color change of the indicator solution up to a permanent color change. The volume of NaOH 0.1 N required to reach the endpoint was recorded and Equation 2 was applied:

$$\%\ \text{Acidity} = \frac{V_{NaOH} \times N_{NaOH} \times P_{meq\ acetic\ acid}}{P_{sample}} \times 100 \qquad \text{Eq. (2)}$$

where

V_{NaOH} = volume of NaOH used (ml);

N_{NaOH} = NaOH normality (0.1 N);

$P_{meq\ acetic\ acid}$ = milliequivalent weight of acetic acid (0.06);

P_{sample} = sample weight (g).

Determination of pH

To determine the pH value in starch, the methodology indicated by Medina and Catarí (2022) was used with adaptations. Five grams of starch were weighed and dispersed in 100 ml of deionized water in a flask. The mixture was heated in a water bath at 50°C for 15 min. Subsequently, the mixture was cooled to room temperature to stabilize the gelatinized starch slurry. A Bante900P pH meter (Bante Instruments, Shanghai, China) was used to read the values in the samples. The electrode of the pH meter was immersed in the cooled starch slurry. The pH value of the starch sample was recorded.

Blends formulation

Four formulations were prepared, each incorporating varying percentages of starch (5%, 10%, 15%, and 20%) into wheat flour. These were compared against a standard sample consisting of 100% wheat flour. The total mixture weight for each formulation was standardized to 250 g.

Rheological analysis of the blends

The rheological analyses were conducted using the Mixolab Chopin instrument (KPM Analytics, Westborough, USA) in accordance with ICC-173 standards and the methodologies outlined by Contreras Dioses *et al*. (2017). These tests were carried out in the laboratories facilities of the Ambato University of Technology (UTA). Each analysis utilized 75 g of the respective blend and evaluated 5 key parameters (Švec & Hrušková, 2015) detailed in Table 1.

Additionally, the analysis included the determination of water absorption necessary for dough development (%) and dough stability (min), as per the methodology described by Acurio *et al*. (2018). Quality indices such as water absorption index, kneading index, gluten strength, viscosity, amylase resistance, and retrogradation index were also evaluated.

TABLE 1: Description of parameters assessed in the rheological analysis.

Parameter	Description	Usage
C1	Maximum torque during mixing.	To assess the initial mixing phase for information regarding water absorption capacity and development during kneading of the dough.
C2	Protein quality, represents the weakening of the protein based on the mechanical work and the increasing temperature.	To measure the stability of dough proteins during mixing. It is indicative of the quality of the gluten network, which affects its elasticity and extensibility, essential for bread-making quality.
C3	Starch gelatinization, expresses the rate of starch gelatinization.	To evaluate the temperature at which starch granules begin to gelatinize and swell; relevant for the viscosity and gas-holding capacity of doughs during baking.
C4	Amylase activity, indicates the stability of the hot-formed gel.	To measure the activity of enzymes that break down starches into sugars, influencing the fermentation process of the dough and the crumb structure and sweetness in final products.
C5	Starch retrogradation, represents starch retrogradation during the cooling period.	To assess the recrystallization of gelatinized starch during cooling, which affects the shelf life and staling rate in bread.

Source: Švec and Hrušková (2015).

Manufacturing of pasta

Pasta formulations were prepared following the procedures indicated by Alamprese *et al*. (2007) with adaptations using an HR2375/06 extruder (Koninklijke Philips N. V., Amsterdam, The Netherlands). The percentages of water, egg, and salt remained unchanged for all formulations. The established formulations are presented in Table 2.

TABLE 2. Formulations for pasta manufacturing.

Ingredients	Formulations				
	F0	F1	F2	F3	F4
Wheat flour (%)	69.3	64.3	59.3	54.3	49.3
Tannia starch (%)	0	5	10	15	20
Egg (%)	4	4	4	4	4
Water (%)	26	26	26	26	26
Salt (%)	0.7	0.7	0.7	0.7	0.7

The ingredients of the pasta formulations were weighed in accordance with predetermined formulations. Subsequently, a preliminary blending of flour and starch was conducted before combining all ingredients. The resultant mixture was then cold-extruded in the HR2375/06 extruder with all the ingredients to form the pasta shapes, which were subsequently dried in an oven set to 65-70°C for 4 h to achieve a moisture content of 13%. The pasta was then allowed to cool at room temperature for 60 min before packaging.

Cooking trials in pasta

Determination of optimal cooking time

Fifty grams of pasta from the control sample and those prepared with varying substitution percentages were individually immersed in 400 ml of boiling water. After 9 min, a piece of pasta was extracted, placed between two glass slides, and subjected to compression. The ideal cooking time was established as the point at which the pasta exhibited no whitening upon compression (Granito *et al*., 2014).

Assessment of pasta weight loss

To assess the weight loss of the pasta, the water used for boiling was collected and evaporated at 100°C until a constant weight was achieved. The percentage of solids remaining in the cooking water for each pasta formulation was subsequently determined (Granito *et al*., 2014).

Determination of water absorption

An adapted methodology, based on the approach outlined by Granito *et al*. (2014), was employed for the determination of water absorption. Fifty grams of dry pasta from each formulation were cooked to their respective optimal times, drained, and cooled to 25°C. The cooked and dry pasta weights were then measured using an analytical balance. The water absorption in the pasta was calculated using Equation 3:

$$\text{Water absorption (\%)} = \frac{W_{cooked} - W_{dry}}{W_{dry}} \times 100 \qquad \text{Eq. (3)}$$

where

W_{cooked} = weight of cooked pasta;

W_{dry} = weight of dry pasta.

Statistical analysis

Statistical analyses were conducted to investigate the effect of varying levels of tannia starch substitution (5%, 10%, 15%, and 20%) for wheat flour in pasta manufacturing using a completely randomized design (CRD). The evaluated variables included cooking tests (cooking time, weight loss, and water absorption percentage) and rheological analyses.

Each parameter was assessed in triplicate, and the results were reported as mean ± standard deviation. Analysis of variance (ANOVA) and Tukey's multiple comparison test were employed to assess statistical significance, with a significance level set at $P<0.05$. Data analysis was performed using IBM SPSS Statistics version 20 (International Business Machines Corporation, Armonk, USA).

Results and discussion

Moisture content

The moisture content found in this study for tannia starch was 11.97%. Palomino *et al*. (2010) reported lower moisture content in tannia starch (10.82%). Madrigal-Ambriz *et al*. (2018) found lower values for *X. sagittifolium* flour (6.87%). However, Torres Rapelo *et al*. (2013) recorded values higher than those obtained in this study (14.49--14.29%).

Ash content

The ash content found in tannia was 0.4%, higher than that reported by Palomino *et al*. (2010) for Criollo tannia starch (0.09%). Torres Rapelo *et al*. (2013) reported lower values for taro (*Colocasia esculenta* L. Schott) starch of around 0.27%.

Acidity and pH values

The acidity and pH values obtained were 0.007% and 4.6, respectively, both lower than those reported by Madrigal-Ambriz *et al*. (2018), who reported acidity values of 0.47% and pH of 5.91. Rodríguez- Miranda *et al*. (2011) also reported a pH of 6.78, both values derived from taro starch analysis. Palomino *et al*. (2010), however, reported higher acidity (0.04%) and pH (6.0) values for *Xanthosoma sagittifolium* starch. Differences in acidity and pH values can be attributed to the methods of extraction and processing, the inherent properties of the starch source, and storage conditions (Ashogbon & Akintayo, 2014). Environmental factors such as soil composition, climate, and cultivation practices can also influence the chemical composition of the starch (Patindol *et al*., 2015). Lower acidity and pH values can affect the functional properties of the starch, including its gelatinization temperature, pasting properties, and shelf life (Awuchi *et al*., 2019). A lower pH can enhance the solubility of the starch and affect its interaction with other ingredients in food formulations (Zhu, 2017). Table 3 details the results for physicochemical parameters found for tannia starch in the present study.

TABLE 3. Physicochemical parameters found for tannia starch.

Parameters	Percentage (%)
Ash	0.4 ± 0.001
Acidity	0.007 ± 0.003
pH	4.6 ± 0.002
Moisture	11.97 ± 0.002

Values reported are the means of 3 replicates ± standard deviation.

Cooking test of pasta

The results obtained from this analysis, as presented in Figure 1, confirmed that as the percentage of tannia starch increases, the optimal cooking time for pasta decreases.

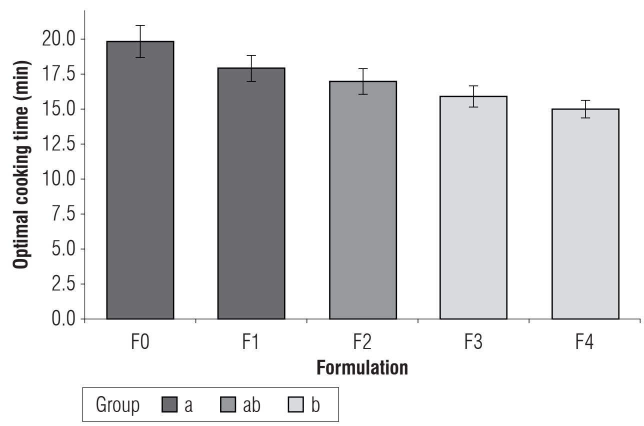

FIGURE 1. Optimal cooking time (min) by formulation. Error bars in the columns represent the standard errors (n= 3) of the mean. F0, F1, F2, F3, and F4 correspond to the formulations described in Table 2, where the percentages of wheat flour, tannia starch, egg, water, and salt are specified. The groups (a, ab, b) represent statistical differences in optimal cooking times among the formulations. Group "a" indicates significantly longer cooking times, group "b" represents shorter cooking times, and group "ab" includes formulations with intermediate cooking times that are not significantly different from either "a" or "b." Tukey's multiple comparison tests were employed ($P<0.05$).

The reduction in cooking time (Fig. 1) is attributed to the lower gelatinization temperatures exhibited by tannia starch. Consequently, as the substitution of tannia starch increases, less energy is required for complete cooking (Torres Rapelo *et al*., 2013). Supporting this, Littardi *et al*. (2020) suggest that the optimal cooking time for pasta increases with gluten content. Li *et al*. (2017) affirm that the addition of non-wheat starches prolongs the time required for noodles to reach readiness. This finding is consistent with observations by Criollo Feijoo *et al*. (2017), who noted an increase in cooking times with increased banana starch content, attributable to its higher gelatinization temperatures.

Weight loss

The recorded weight losses ranged from 5.39% (F0) to 11.12% (F4), as depicted in Table 4. Notably, with each incremental substitution of tannia starch, weight loss increased accordingly as shown in Figure 2. This phenomenon shows the impact of partially replacing durum wheat with an alternative starch source on pasta properties (García-Valle *et al*., 2021). The incorporation of starch from a different nature into pasta formulations can significantly impact the weight loss observed during cooking (Giuberti *et al*., 2015). Tannia starch may have higher hydration capacity compared to durum wheat (Suparthana & Putu Timur Ina, 2020), meaning it can absorb more water during cooking, leading to increased weight loss when the pasta is drained after cooking. On the other hand, durum wheat is high in gluten, which helps form a strong protein network that traps starch granules and retains water during cooking (Sissons, 2008). Replacing durum wheat with tannia starch reduces the gluten content, weakening the pasta's structural integrity. This weaker network allows more water to escape, contributing to higher weight loss. Additionally, tannia starch might interact differently with gluten compared to wheat starch, potentially leading to a less cohesive matrix that releases more water during cooking. Tannia starch could also have a higher swelling power than wheat starch (Krisbianto & Minantyo, 2024), causing it to expand more during cooking. This higher expansion may lead the pasta produced to break apart more easily, leading to greater weight loss.

This pattern mirrors findings reported by Gianibelli *et al*. (2005), who noted that reducing the percentage of wheat starch and substituting it with other starch sources leads to increased cooking losses. Similarly, Granito *et al*. (2014) observed results consistent with those described in this study in formulations consisting in 100% wheat (3.00±0.15), 90% wheat:10% *Vigna sinensis* (5.35±0.15), 88% wheat:12% *Phaseolus vulgaris* (15.13±0.12), and 88% wheat:12% *Cajanus cajan* (19.7±0.08).

TABLE 4. Weight loss in pasta formulations with varied levels of tannia starch substitution.

Formulation	Weight loss
F0	5.39 ± 0.12^{a}
F1	5.75 ± 0.14^{a}
F2	6.16 ± 0.35^{a}
F3	9.68 ± 0.27^{b}
F4	11.12 ± 0.52^{b}

Values reported are the mean of 3 replicates ± standard deviation. Values containing a, b differ significantly according to the Tukey's test (P<0.05).

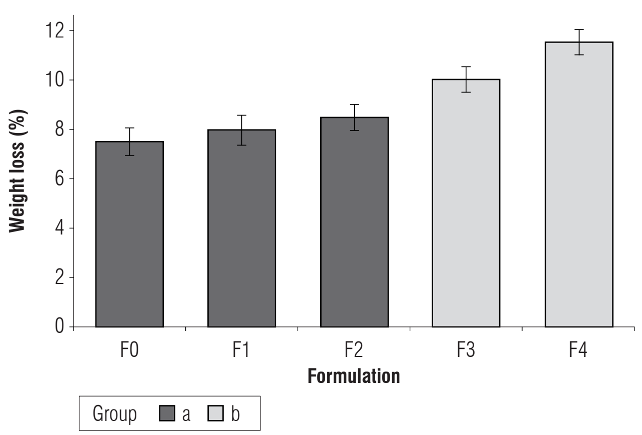

FIGURE 2. Weight loss in pasta formulations with varying levels of starch substitution. Error bars in the columns represent the standard errors (n= 3) of the mean. F0, F1, F2, F3, and F4 correspond to the formulations described in Table 2, where the percentages of wheat flour, tannia starch, egg, water, and salt are specified. The groups (a, b) represent statistical differences in weight loss among the formulations. Group "a" indicates significantly lower weight loss, and group "b" represents higher weight loss. Tukey's multiple comparison tests were employed (P<0.05).

Water absorption in pasta

Water absorption in pasta relates to the amount of water the starch retains during cooking, causing an enlargement in its volume. The cooking test analysis is linked to the size of the pasta, as boiling water hydrates the gluten network, leading to an increase in volume. Consequently, as less

TABLE 5. Water absorption in the pasta formulations proposed.

Formulation	Water absorption (%)
F0	152.20 ± 1.42^{a}
F1	149.07 ± 2.87^{a}
F2	181.71 ± 2.28^{b}
F3	185.43 ± 4.13^{b}
F4	252.57 ± 5.61^{c}

Values reported are the mean of 3 replicates ± standard deviation. Values containing a and b differ significantly according to the Tukey's test (P<0.05).

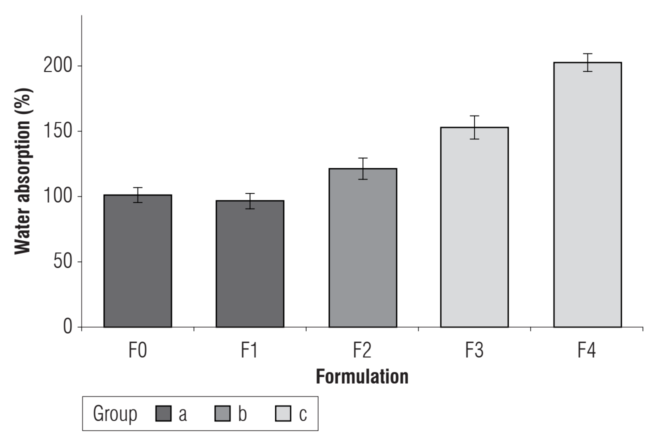

FIGURE 3. Water absorption in pasta formulations with varying levels of starch substitution. Error bars in the columns represent the standard errors (n = 3) of the mean. F0, F1, F2, F3, and F4 correspond to the formulations described in Table 2, where the percentages of wheat flour, tannia starch, egg, water, and salt are specified. The groups (a, b, c) represent statistical differences in water absorption among the formulations. Group "a" indicates significantly lower water absorption, group "b" indicates intermediate levels, and group "c" represents the highest water absorption. Tukey's multiple comparison tests were employed (P<0.05).

wheat flour is used, the water absorption capacity increases, as observed in Figure 3; this behavior has been observed by Akanbi *et al*. (2011). Interestingly, in this study, a different trend is observed; substituting 5% of tannia starch decreases the water absorption, whereas increasing quantities of 10%, 15%, and 20% result in an increment in the water absorption. Table 5 depicts the water absorption in the pasta formulations evaluated. The described phenomenon is due to the high values of water absorption in the starch (Akanbi *et al*., 2009). Similar findings were reported by Adepeju *et al*. (2011) when increasing the percentage of breadfruit starch by 20% and 30% resulted in an increase in the water absorption capacity.

Rheological characterization of the blends

Hydration refers to the percentage of water needed to be added to the flour to form a dough with suitable properties for manipulation. As mentioned by Witczak *et al* (2016), absorption is linked to the endosperm of the grain and the gluten present therein. As observed in the results, mixtures with different substitution percentages, as well as the standard mixture, exhibited inversely proportional outcomes; as the amount of tannia starch increased, the moisture percentage decreased. This behavior aligns with findings reported by Sacón-Vera *et al*. (2016), primarily due to the varying quantity of proteins present in the different formulations. The stability percentage obtained for F1, F2, and F3 treatments were similar to that in the control treatment (F0), corresponding to a strong dough. The stability percentage for F4 was significantly different (P<0.05) from the others, showing lower stability as the substitution percentage increased. Table 6 indicates the values found for the parameters related to the rheological characterization in the formulations. The results of this analysis ranged between 8.1 and 10.6 min. This is associated with the formation of a weak dough, which would not withstand thorough kneading or fermentation without breaking apart.

TABLE 6. Parameters for the rheological characterization in the formulations evaluated.

Formulation	Hydration (%)	Moisture (%)	Stability (min)
F0	62.5 ± 0.04[a]	14.1 ± 0.2[a]	10.2 ± 0.6[a]
F1	62.2 ± 0.02[a]	13.6 ± 0.6[a]	10.6 ± 0.4[a]
F2	62.1 ± 0.01[a]	13.7 ± 0.5[a]	9.9 ± 0.1[a]
F3	62.4 ± 0.07[a]	13.5 ± 0.7[a]	9.4 ± 0.5[a]
F4	60.2 ± 0.03[b]	13.2 ± 0.2[a]	8.1 ± 0.3[b]

Values reported are the mean of 3 replicates ± standard deviation. Values containing a and b differ significantly according to the Tukey's test (P<0.05).

Rheological analysis of doughs

When doughs are placed in the equipment to determine rheological parameters and reach the highest point, which is 1.1 N×m at 30°C, they are considered stable in their transformations; therefore, at that moment and classified as a solid mass (Sandoval *et al*., 2012). The values of the analyzed properties ranged from C1, with values between 1.05 to 1.12 N×m, Typical C1 values for wheat dough range from 1.1 to 1.5 N×m (Sandoval *et al*., 2012). The study values are slightly lower but still within an acceptable range, indicating that the dough develops well, albeit slightly weaker when more tannia starch is added. For the C2 parameter, which reflects the water content retained by the starch granules, inversely proportional values were obtained in relation to the addition of tannia starch, ranging from 0.48 to 0.33 N×m; the higher the C2 value, the higher the water content retained by the starch granules. C2 values often range from 0.3 to 0.6 N×m depending on the type of starch and protein content (Dubat, 2013). The values in the study fall within this range, but a decrease in C2 with increased tannia starch indicates less swelling power, likely due to reduced gluten content. The values obtained in parameter C3, which correspond to starch gelatinization, ranged from 1.46 to 1.25 N×m, with the first value belonging to the control sample. These results indicate that higher values correspond to masses composed of high-quality starches, with a tendency to achieve good volume during the production. C3 values for wheat dough typically range from 1.3 to 1.8 N×m (Koksel *et al*., 2009). The study values are slightly lower but still indicate good gelatinization, with higher values for formulations with less tannia starch, signifying better starch quality and volume during product production; the higher the value, the higher the increase in the viscosity of the dough under heat. F1 showed starch gelatinization similar to F0, whereas the rest were significantly different (P<0.05). The results obtained for C4, representing amylase activity, ranged from 0.89 to 0.70. F0 and F1 showed similar amylase activity, while the remaining treatments were significantly different (P<0.05). Values in the range of 0.7 to 1.0 N×m are common for doughs with moderate to low amylase activity (Arcangelis *et al*., 2020). The study results aligned well, showing lower amylase activity, which increases water absorption and makes the dough easier to handle. Lastly, C5, corresponding to retrogradation, is directly related to the values of C4. The results should not vary much between them, as this will determine the shelf life for the product (Coțovanu *et al*., 2020). The values observed in C5 ranged from 1.19 to 0.98 N×m. Typical C5 values range from 1.0 to 1.3 N×m (Coțovanu *et al.*, 2020). The values in the study are consistent with these ranges, with higher tannia starch content indicating better retrogradation characteristics and potentially longer shelf life. Comparing the results for C5 with the parameters of C4 indicate that the more tannia starch is added in pasta production, the longer the shelf life of the product. Table 7 presents the results obtained from Mixolab analysis.

Quality indices of the blends

The water absorption index (WAI) remained unchanged across formulations with substitution percentages of 5%, 10%, and 15%, as well as the control sample. However, when substituting 20% of tannia starch with wheat starch, WAI decreased. This decrease is attributed to the reduction in protein content in the mixture with higher substitution levels. Wheat doughs typically have WAIs between 8.0 and 9.0 (Ma *et al*., 2021). The study shows a slight decrease with higher tannia starch, indicating that lower protein content affects water absorption. The kneading index (KI) values show differences starting from a 10% substitution compared to the control sample, which consists of 100% wheat starch. These differences arise due to the gluten percentage present in the various mixtures; higher substitution leads to lower protein content, resulting in a dough that lacks proper stretching during fermentation (Sandoval *et al*., 2012). The KI is an indicator of the resistance of dough to this stretching process. As the water and flour combination undergoes this process, its texture changes, becoming soft, viscoelastic, and easily extendable. KI values vary based on gluten content, typically between 3.0 to 6.0 for doughs (Marchenkov *et al*., 2021). The study values decrease significantly with higher tannia starch, reflecting reduced dough resistance and stretching ability due to lower gluten. The gluten strength index (GSI) results were inversely proportional to the percentages of tannia starch substitution. This parameter relates to the quality of proteins in the dough rather than their quantity. Glutenins and gliadins, found in wheat, contribute to forming a good dough by providing elasticity, strength, extensibility, and viscosity (Quezada Correa *et al*., 2019). GSI for good quality wheat doughs are usually around 4.0 to 8.0 (Marchenkov *et al*., 2021). The decrease in the study indicates a loss in protein quality and gluten strength with higher tannia starch content. The starch viscosity index (SVI) and amylase resistance index (ARI) analyses yielded consistent results across all formulations, indicating no significant differences. This highlights the importance of considering the amylase percentages in the mixtures to maintain food properties; higher amylase content results in a very soft paste, making it difficult to handle (Dubat & Rosell, 2013). The consistent values indicate that amylase activity is balanced across formulations, maintaining similar starch viscosity and resistance to enzyme activity. The retrogradation index (RI) is associated with the shelf life of the product. Results for this parameter were consistent across all mixtures, including the control sample. Lower retrogradation values correspond to longer product shelf life, and the consistent values suggest that despite variations in starch content, the retrogradation properties remain stable, indicating good shelf life potential (Bárcenas & Rosell, 2007). During this stage, starch molecules that have been gelatinized reassociate to form a crystalline double-helix structure, transferring some of the water and reducing elasticity due to instability (De Arcangelis *et al*., 2020). Table 8 features the quality indices in the doughs analyzed.

TABLE 7. Results of Mixolab analysis.

Formulations	C1 (N×m)	C2 (N×m)	C3 (N×m)	C4 (N×m)	C5 (N×m)
F0	1.12 ± 0.03^{a}	0.48 ± 0.02^{a}	1.42 ± 0.005^{a}	0.89 ± 0.006^{a}	1.19 ± 0.04^{a}
F1	1.10 ± 0.05^{b}	0.45 ± 0.04^{a}	1.43 ± 0.003^{a}	0.86 ± 0.002^{a}	1.12 ± 0.06^{b}
F2	1.08 ± 0.01^{a}	0.42 ± 0.01^{a}	1.37 ± 0.02^{b}	0.81 ± 0.004^{b}	1.10 ± 0.01^{b}
F3	1.06 ± 0.03^{b}	0.37 ± 0.06^{b}	1.27 ± 0.04^{c}	0.71 ± 0.001^{c}	1.02 ± 0.02^{c}
F4	1.05 ± 0.07^{ab}	0.33 ± 0.04^{b}	1.25 ± 0.06^{c}	0.70 ± 0.007^{c}	0.98 ± 0.02^{a}

Development of dough (C1), protein quality (C2), starch gelatinization (C3), amylase activity (C4), and retrogradation (C5). Values reported are the mean of 3 replicates ± standard deviation. Values containing a, b, c differ significantly according to the Tukey's test (P<0.05).

TABLE 8. Quality indices in doughs analyzed.

Parameter	F0	F1	F2	F3	F4
WAI	8.0 ± 0.03^{a}	8.0 ± 0.01^{a}	8.0 ± 0.06^{a}	8.0 ± 0.05^{a}	7.0 ± 0.38^{a}
KI	7.0 ± 1.02^{a}	6.0 ± 0.92^{a}	4.5 ± 0.43^{b}	3.0 ± 0.67^{b}	2.0 ± 0.26^{c}
GSI	4.0 ± 1.13^{a}	3.0 ± 1.02^{a}	1.5 ± 0.97^{b}	2.0 ± 0.42^{b}	0.5 ± 0.89^{c}
SVI	2.0 ± 0.04^{a}	2.0 ± 0.83^{a}	2.0 ± 0.27^{a}	2.0 ± 0.09^{a}	2.0 ± 0.05^{a}
ARI	1.0 ± 1.08^{a}	2.0 ± 0.76^{a}	2.0 ± 0.93^{a}	2.0 ± 1.24^{a}	2.0 ± 1.14^{a}
RI	2.0 ± 0.87^{a}	2.0 ± 0.36^{a}	2.0 ± 0.68^{a}	2.0 ± 0.08^{a}	2.0 ± 0.53^{a}

WAI: water absorption index; KI: kneading index; GSI: gluten strength index; SVI: starch viscosity index; ARI: amylase resistance index; RI: retrogradation index. Values reported are the mean of 3 replicates ± standard deviation. Values containing a, b, and c differ significantly according to the Tukey's test (P<0.05).

Conclusions

This study explored the feasibility of using tannia starch as a partial substitute for wheat flour in pasta formulations. The results demonstrated that substituting up to 20% of the wheat flour with tannia starch yielded pasta with acceptable cooking properties and quality indices. Rheological analysis revealed significant alterations in hydration, moisture, and stability as the proportion of tannia starch increased, highlighting the need for careful formulation adjustments. Despite these challenges, the potential of tannia starch to enhance the technological advancements of pasta warrants further exploration and optimization. Based on these findings, pasta manufacturers could consider incorporating tannia starch into their formulations to improve technological properties of their products. Furthermore, optimizing the formulation to maintain desirable cooking properties and pasta quality could open new market opportunities for innovative pasta products.

Acknowledgments

We would like to express our sincere gratitude and appreciation to the authorities at the Faculty of Food Science, Engineering and Biotechnology (Ambato University of Technology - UTA) for their unwavering support and openness in facilitating the development of the rheological experiments essential to this research.

Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

HMGV and FPCM set research goals. SECM and FPCM annotated and maintained scrub data. HMGV, MLPE, SECM, and FPCM analyzed data. HMGV, MLPE, and SECM conducted experiments and developed methodology. FPCM managed research planning. MLPE, SECM, and FPCM provided resources. MLPE and FPCM led planning and execution. SECM and FPCM ensured reproducibility. All authors prepared and presented work. HMGV and FPCM drafted, revised, and translated the manuscript. All authors revised the final version of the manuscript.

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