TEXTURAL PROPERTIES, COLOR, AND WATER ABSORPTION KINETICS IN NOODLES ENRICHED WITH PECAN NUT FLOUR

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Abstract
The incorporation of plant-based flours into bakery and cereal products represents a promising strategy to improve nutritional quality. This study evaluated how the substitution of wheat flour with pecan flour (0%, 5%, 25%, and 50%) affected the textural properties, color parameters, and water absorption kinetics of cooked noodles. Cutting force, texture profile analysis (TPA), color parameters (L*, a*, b*), and water absorption were determined and modeled using a kinetic equation. Results showed that formulations containing 25% pecan flour exhibited greater color stability during storage but lower mechanical resistance. Water absorption kinetics revealed a faster hydration rate in pecan flour formulations, likely due to their higher fiber content. All formulations maintained acceptable technological functionality, with cooking loss values below 9%. These findings demonstrate the technological feasibility of enriching noodles with pecan flour and support its use as an alternative ingredient for the development of value-added products.

Keywords: pecan flour; textural properties; color; water absorption kinetics; enriched noodles.

INTRODUCTION

The food industry continuously seeks to develop products with enhanced nutritional and functional value. Noodles and pasta are widely consumed staple foods, and their formulation with alternative ingredients offers an opportunity to improve nutritional composition without compromising consumer acceptability (Larrosa et al., 2015). Pecan stands out due to its high content of unsaturated fatty acids, proteins, dietary fiber, and antioxidant compounds (Alvarez-Parrilla, Urrea-López, & de la Rosa, 2018), making it a promising ingredient for the enrichment of bakery and cereal-based products.

However, the incorporation of oilseed-derived flours into cereal-based systems requires a detailed evaluation of their effects on the technological properties of the final product. Textural and color properties are critical quality attributes that directly influence sensory acceptability and shelf stability. In addition, water absorption kinetics during cooking determines important organoleptic characteristics, such as finals texture and optimum cooking time (Cunningham et al., 2007).

Previous studies have reported that lipids present in oilseed flours may form physical barriers around starch granules, delaying gelatinization and influencing water uptake behavior (Fennema, 2000). Nevertheless, few studies have simultaneously evaluated textural properties, color parameters, and water absorption kinetics in enriched noodle systems.

The aim of this study was to evaluate how partial replacement of wheat flour with pecan flour (5%, 25%, and 50%) affected textural properties, color parameters, and water absorption kinetics during cooking in fresh noodles.

MATERIAL AND METODOS

Preparation of Formulations

Four fresh dough formulations were prepared by progressively replacing wheat flour with commercial pecan flour: Control (0%), Noodle5 (5%), Noodle25 (25%), and Noodle50 (50%). The doughs were produced using a standardized protocol, maintaining a constant total amount of dry ingredients and hydration level. All formulations were sheeted to a

uniform thickness and cut into ribbon-shaped strands for subsequent analyses.

Evaluation of Textural Properties

An Instron 3342 texture analyzer was used to determine the mechanical properties of cooked noodles. Cutting force was measured using a Light Knife Blade probe (A/LKB), according to the methodology described by Chen et al. (2002). Texture Profile Analysis (TPA) was performed using two consecutive compression cycles simulating mastication, obtaining hardness, springiness, cohesiveness, adhesiveness, chewiness, and resilience parameters, according to Olivera and Salvadori (2008). At least three replicates were analyzed for each formulation. Measurements were conducted at 25°C using samples previously cooled in an ice-water bath to stop the cooking process.

Evaluation of Color Properties

Color parameters were determined using a Hunter Lab colorimeter. Both raw and cooked dough samples were evaluated after being cut into square pieces. Measurements were taken at three different points on the surface of each sample. The parameters assessed were L* (lightness, 0 = black, 100 = white), a* (red–green), and b* (yellow–blue). Three replicates were performed for all formulations at each storage time.

Water Absorption Kinetics During Cooking

Water absorption was determined using ribbon-shaped samples according to the AACC International 66-50 method (AACC, 2000). The strips were individually weighed using a Mettler Toledo analytical balance and placed in test tubes containing distilled water. The tubes were immersed in a stainless-steel vessel with boiling water. At one-minute intervals, the strips were removed and rapidly weighed to record mass increase due to water absorption. At least three replicates were performed for each formulation. The water absorption curves were fitted using the power model proposed by Cunningham et al. (2007), which relates the relative weight increase (AR) to cooking time through two empirical constants (K and n):

$$AR = K \cdot t^{n} \quad (1),$$

where K is the pre-exponential constant and n is the diffusion exponent.

Statistical Analysis

Data were analyzed by one-way ANOVA followed by a mean comparison test ($p \leq 0.05$). Statistical software with response surface analysis was used to evaluate the effects of pecan flour substitution. At least three analytical replicates were performed for each determination.

RESULTS AND DISCUSSION

Textural Properties of Cooked Noodles

Cutting force analysis showed statistically significant differences among formulations ($p < 0.05$). The Noodle5 formulation exhibited the highest cutting force (2.85 ± 0.39 N), significantly differing from all other samples, indicating greater mechanical resistance in cooked noodles containing 5% pecan flour (Figure 1). This suggests that at low substitution levels, pecan flour components such as fiber and proteins may reinforce the gluten matrix, increasing structural firmness.

The Noodle25 (1.44 ± 0.19 N) and Noodle50 (1.54 ± 0.25 N) formulations showed intermediate values and did not differ significantly from each other ($p > 0.05$). At higher substitution levels, the reduction in cutting force indicates a weaker matrix structure. This behavior may be associated with gluten dilution, since lower wheat flour content reduces the availability of gluten-forming proteins. In addition, the higher levels of lipids and insoluble fiber in pecan flour may disrupt matrix continuity and reduce structural integrity.

Overall, the results demonstrated that pecan flour significantly modified the mechanical resistance of cooked noodles, with the greatest firmness observed at low substitution levels and reduced resistance at higher replacement percentages.

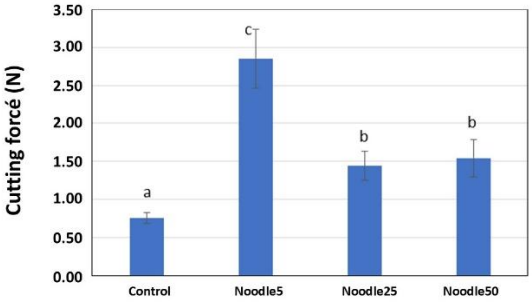


***Figure 1**. Cutting force of noodles cooked with different levels of wheat flour. Different letters in columns of the same color indicate significant differences ($p < 0.05$).*

Texture Profile Analysis (TPA) revealed that the incorporation of pecan flour significantly affected the structural properties of cooked noodles compared with the control formulation. The parameters are shown in Table 1. Overall, pecan flour reduced the mechanical strength of the product, producing softer and less cohesive noodles. Hardness, defined as the maximum force required to compress the sample, was highest in the control. All pecan flour formulations showed significantly lower values ($p < 0.05$), with Noodle5 exhibiting the lowest hardness. Noodle25 and Noodle50 showed no significant differences ($p > 0.05$). These results indicate that pecan flour incorporation reduced resistance to

compression. Adhesiveness, which represents the work required to separate the sample from the contact surface, showed similar values for the control, Noodle25, and Noodle50 ($p > 0.05$). In contrast, Noodle5 showed the lowest negative value, differing significantly from the other formulations. This suggests that higher pecan flour levels increased surface stickiness. Springiness remained similar in the control, Noodle5, and Noodle25 ($p > 0.05$), indicating comparable structural recovery after deformation. However, Noodle50 showed a significantly lower value ($p < 0.05$), suggesting reduced elasticity at high substitution levels. Cohesiveness, which reflects internal bonding strength, was highest in the control and Noodle5, with no significant differences between them. Noodle25 and Noodle50 showed significantly lower values ($p < 0.05$), indicating weaker internal structure as pecan flour increased. Chewiness and gumminess were significantly higher in the control ($p < 0.05$), while all pecan flour formulations showed lower values, with no significant differences among them. Resilience showed the highest values in the control and Noodle50. Overall, pecan flour produced noodles with a less resistant matrix, requiring less energy for chewing and disintegration.

Table 1. Texture parameters of noodles cooked with different walnut flour contents.

	Sample			
Parameters	Control	Noodle5	Noodle25	Noodle50
Hardness	165.6±6.93^{c}	65.5±0.77^{a}	97.6±5.6^{a}	97.9±10.1^{b}
Adhesiveness	-1.39±1.53^{a}	-0.25±0.01^{c}	-1.31±0.46^{a}	-2.16±0.14^{a}
Springiness	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.01^{b}
Cohesiveness	0.66±0.07^{b}	0.68±0.05^{b}	0.47±0.04^{a}	0.43±0.02^{a}
Chewiness	98.9±9.75^{b}	47.6±3.61^{a}	35.1±3.38^{a}	42.5±1.11^{a}
Resilience	1.80±0.06^{b}	0.38±0.06^{a}	0.18±0.01^{a}	1.16±1.06^{ab}
Gumminess	98.9±9.72^{b}	47.6±3.63^{a}	35.0±3.37^{a}	42.2±0.86^{a}

Means expressed as mean ± standard deviation (n=6) Columns: Means with a common letter are not significantly different (p > 0.05).

Color Properties

Color parameters (L*, a*, and b*) showed different responses during cooking depending on the formulation (Figure 2). Regarding lightness (L*), Noodle50 showed no significant changes after cooking, whereas Noodle5 and Noodle**25** exhibited a decrease, and the control sample showed an increase. These changes may be associated with modifications in starch gelatinization and the redistribution of lipids and phenolic compounds from pecan flour, affecting light reflectance. For the a* parameter (red–green), M5 showed no significant changes, whereas the control, Noodle25, and Noodle50 showed a decrease, particularly the Noodle50 formulation. This behavior reflects the thermal leaching of polyphenolic compounds present in pecan flour into the cooking medium. The b* parameter (yellow–blue) significantly decreased in all formulations. This reduction may be attributed to the solubilization and diffusion of yellow chromophores, as well as structural changes in gelatinized starch that altered color perception. The absence of salt in the cooking medium may have enhanced pigment migration.

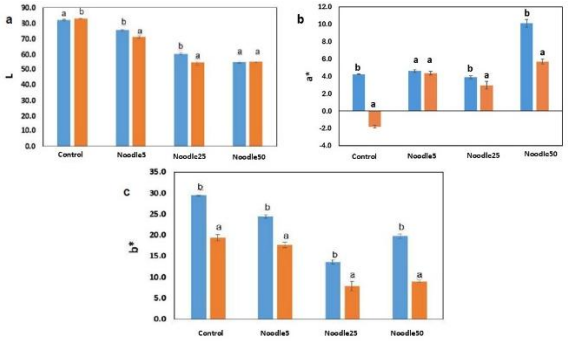


***Figure 2.** The parameters a)-L*, b)-a* and c)-b* of ■uncooked ■cooked noodles. Means with a common letter in the columns are not significantly different (p > 0.05).*

Water Absorption Kinetics During Cooking

Kinetic modeling of water absorption using the power equation ($Ar = K \cdot t^{n}$) allowed the characterization of hydration rate and magnitude. The parameters obtained were showed in the table 2. The exponent n is associated with the initial absorption rate: lower values indicate faster hydration during the early stages of cooking.

Table 2. Modeling of water absorption curves as a function of cooking time for the different formulations: coefficients K and n ± their standard deviations and R2.

	k	n	R2
Control	0.4033±0.0224	0.3591±0.0274	0.904
Noodle5	0.3255±0.0193	0.3294±0.0294	0.881
Noodle25	0.633±0.0303	0.2747±0.0240	0.878
Noodle50	0.6331±0.0298	0.3287±0.0259	0.896

The Noodle25 formulation showed the lowest n value, corresponding to a steeper initial slope in the absorption curve, indicating faster water uptake during the first minutes of cooking. This behavior contrasted with the control sample, which exhibited a gentler initial slope. The constant K is related to the initial magnitude of absorption: Noodle25 and Noodle50 showed the highest K values, indicating that these formulations absorbed more water at the beginning of the process.

Using the coincident curves test, Noodle25 and Noodle50 showed no significant differences between each other ($p > 0.05$), indicating a similar water absorption behavior during cooking. Figure 3 graphically shows the evolution of water absorption, where formulations containing pecan flour clearly reached higher total water uptake and faster kinetics compared with the control.

These findings suggest that the presence of fiber and proteins from pecan flour promoted faster hydration, likely due to their greater water-holding capacity compared with starch. However, the resulting matrix was less cohesive, as evidenced by the cutting force results.

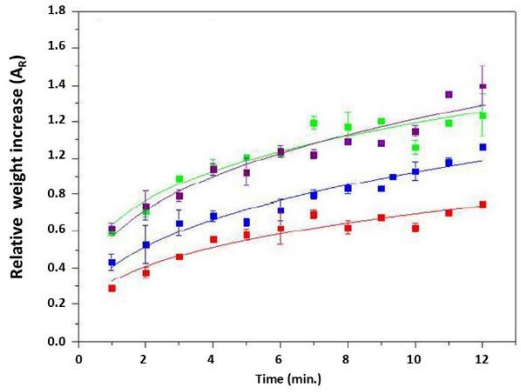


Figure 3. Water absorption curves of the different formulations (Control ■; Noodle5 ■; Noodle25 ■; Noodle50 ■), the solid line corresponds to the modeling with Equation $A_R=K*t^n$.

Relationship Between Composition and Properties

The integration of textural, color, and kinetic results allowed a comprehensive understanding of the complex interactions within the system. The incorporation of pecan flour generated matrices with greater water absorption capacity but lower mechanical resistance. This trade-off is typical of systems enriched with oilseed-based ingredients (Fennema, 2000). The improved stability of color parameters in formulations containing pecan flour suggests protective effects of its lipid and antioxidant components against browning during storage.

The faster absorption kinetics observed in formulations containing pecan flour has practical implications, as adjustments in the optimal cooking time may be required to achieve the desired texture. Nevertheless, all formulations-maintained cooking losses below 9%, indicating that the matrix remained sufficiently intact to retain components during thermal processing, thus meeting quality standards for noodles (D'Egidio et al., 1990).

CONCLUSION

This study demonstrated that the substitution of wheat flour with pecan flour significantly affected the textural properties, color parameters, and water absorption kinetics of cooked noodles. Although a reduction in mechanical resistance was observed with increasing pecan flour content, all evaluated formulations maintained acceptable technological functionality, with adequate cooking loss values.

The formulation containing 25% pecan flour emerged as the most balanced option, presenting: (1) greater stability of color parameters during storage, (2) favorable water absorption behavior during cooking, and (3) acceptable textural attributes. The faster absorption kinetics observed in formulations containing pecan flour reflected the distinct composition of this ingredient, particularly its higher fiber and protein content.

These results confirm the technological feasibility of enriching noodles with pecan flour and open new opportunities for the development of value-added products. Future studies should explore the incorporation of ingredients capable of reinforcing the matrix, such as hydrocolloids, as well as the evaluation of consumer sensory acceptability.

AGRADECIMENTOS

Escreva os agradecimentos aqui.

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