Techno-functional and physicochemical properties of corn flours as potential food ingredients

Adriana Mejía-Terán¹², Carla María Blanco-Lizarazo³*, Eduardo Leiva Mateus⁴, Indira Sotelo-Díaz⁵

¹ Doctorado en Ciencias Naturales para el Desarrollo (DOCINADE), Instituto Tecnológico de Costa Rica, Universidad Nacional, Universidad Estatal a Distancia, Costa Rica
² Grupo Interinstitucional de Investigación en Ciencias Agropecuarias, Forestales y Agroindustriales del Trópico, Universidad Nacional Abierta y a Distancia (UNAD), Bogotá, Colombia
³ Centro de investigación y desarrollo cárnico CI+D, Industria de Alimentos Zenú, Medellín, Colombia
⁴ Instituto de Investigaciones en Materiales (IIM), Universidad Nacional Autónoma de México (UNAM), México, CDMX 4510
⁵ Grupo de Alimentación, Gestión de Procesos y Servicio, Universidad de La Sabana, Chía, Colombia

*Corresponding author: cmblanco@zenu.com.co

Authors ORCID:
Mejía-Terán, Adriana: 0000-0002-9044-7548
Blanco-Lizarazo, Carla Maria: 0000-0002-6463-3056
Sotelo-Díaz, L.I 0000-0002-6594-2539
Leiva, E: 000-0001-7839-2233

This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4737960
Abstract

Corn plays a crucial role in food security and nutrition. This study aimed to assess the impact of three corn cultivars (Advanta, Lepra, and Porva) and varying particle sizes of flours on estimated glycemic index (eGI), techno-functional properties, and rheological behaviors, crucial in defining their technological properties. WAI and WSI presented differences among particle sizes for Advanta and Lepra corn flours, whereas Porva flour displayed consistent results regardless of particle sizes. Notably, while Advanta and Lepra did not showed differences in eGI and its fractions, Advanta (174.4 µm) demonstrated the lowest eGI at 32.21, alongside higher WHC compared to wheat flours. Further findings included an initial Emulsification Activity Index (EAI) of 40.55 m²/g and a minimum gelation concentration of 12%. Additionally, rheological characterization indicated a non-Newtonian and pseudoplastic behavior. This study presented a corn flour with high resistant starch content and low glycemic index with functional properties that could be applied to manufacture healthy food requiring high water solubility, greater emulsification capacity, and water retention capacity greater than conventional flours. This exploration holds the potential to design healthy commercially viable products.

Keywords: techno-functional assessment, in vitro digestion, gluten-free flours, Rheological properties
1. Introduction

Corn is the cereal with the most significant worldwide production and is widely used in supplementary food. Corn, wheat, and rice provide 42.5% of humans' energy intake (Dongmo et al., 2020). Corn endosperm has emerged as a promising alternative to gluten-free foods (Hassan et al., 2020). The technological and nutritional properties of corn depend on intrinsic traits, such as kernel hardness, size, shape, molecular composition (amylose/amylopectin), the presence of proteins and lipids, crop variety, and extrinsic properties such as milling method and unit processing operations (An et al., 2023; Caballero-Rothar et al., 2022).

In addition, corn is characterized by its availability, accessibility, ease of use, and transformation (Dongmo et al., 2020). Accordingly, a primary method of large-scale consumption is in the form of whole or fractionated flour (Gwirtz & Garcia-Casal, 2014). However, there is currently a dichotomy regarding the use of corn in the design of functional food due to its high starch content and its classification as a high glycemic index (GI) food (≥ 70%). This is significant considering that its ingestion can lead to adverse health effects, particularly in overweight, obese, or diabetic individuals (Caballero-Rothar et al., 2022). Nevertheless, some studies have demonstrated that corn contains resistant starches and fiber, which lower the starch hydrolysis rate. Therefore, assessing the factors influencing the digestibility of its fractions and their impact on GI presents a noteworthy opportunity to advance knowledge regarding its properties for food design. Furthermore, Bello-Pérez et al., (2021) have suggested considering processes that control starch gelatinization to inhibit enzymatic starch hydrolysis in the development of corn products with a low glycemic index and to improve their nutritional value.

The analysis of corn flour's technological, rheological, and functional properties from different cultivars could contribute to predicting their behavior during processing. This analysis includes identifying the integrity of the molecular components in the food system, further understanding
their storage stability and food acceptability, and defining practical applications for product development (Al-Attar et al., 2022; Hettiarachchi & Gunathilake, 2023). Furthermore, food security implies that the study of indigenous food products can promote the conservation of culinary traditions, guarantee the availability of food, and encourage the use of crops that can better adapt to local environmental and agroecological conditions, becoming more resilient to climatic changes and possibly more tolerant to pests and diseases (Erenstein et al., 2022; Nhamo L et al., 2022). In this study, maize cultivars were selected based on their distinctive traits and specific contributions of commercial interest in Colombia. The Advanta hybrid material has high yield potential, evidenced by cob uniformity, optimal grains, a more significant number of rows, structural resistance, and light efficiency. The Leptra hybrid material was selected for its adaptability to varying moisture conditions, high yield, harvest precocity, outstanding grain-specific gravity, and effective pest control. Both hybrids promise significant contributions, bringing particular strengths in crop management, adaptability, and productivity. The Porva commercial maize variety in Colombia was selected for its market relevance, adaptability to cold and temperate climates, and higher proline content, which may provide a mechanism for strengthening cell integrity. Therefore, the objective of this study was to determine the functional properties, starch fractions, glycemic index, and rheological properties of corn flour obtained with different particle sizes from three cultivars of productive relevance in Colombia to predict their technological behavior and determine their suitability for use in the food industry.

2. Materials and methods

2.1. Experiment design

The study was conducted in three phases. A completely randomized two-factor design (cultivar and particle size) was employed in the first phase. Each analysis was performed in triplicate using three different batches of corn.
Phase 1. The water absorption index (WAI) and water solubility index (WSI) of corn flour were evaluated using a completely randomized design (3x4). Two corn cultivars (Leutra and Advanta), processed raw, were studied, and a commercial raw flour (Porva) served as control. The flours were sequentially fractionated, defining four levels corresponding to the particle diameter factor use of mesh no. 40 (425 μm), 50 (300 μm), 70 (212 μm), and 100 (150 μm). In each analysis, the dependent variables were the WAI and WSI.

Phase 2. Based on the statistical results of phase 1, the flour fractions were grouped by particle size. Thus, the digestibility rate, estimated glycemic index (eGI), and amylose percentage were evaluated for the three corn cultivars, and the fractions were grouped by particle size.

Phase 3. Based on the results of Phases 1 and 2, the corn cultivar and the fraction with the lowest (eGI) were selected for a techno-functional evaluation based on their water-holding capacity (WHC), emulsifying activity index (EAI), gelation capacity, and rheological behavior.

2.2. Materials

Two hard endosperm hybrid yellow corn cultivars, Advanta 9339 and Leutra 30F35, were supplied by the National Federation of Cereal, Legume, and Soybean Growers (Fenalce), were harvested in 2021 from three different geographical areas in Tolima, Colombia [4°03’N 75°15’W, average altitude: 1285 m], and a commercial raw Porva yellow corn flour purchased from a local store in Bogotá, Colombia [4°36’35”N 74°04’54”W] were studied. Corn kernels were selected and manually cleaned of foreign material, then stored in a dry place at room temperature (18 °C). All analytical testing was randomly performed on three independent corn batches.

The enzymes used (pepsin, pancreatic amylase, amyloglucosidase, and invertase) were purchased from Sigma-Aldrich (St. Louis, USA). The D-Glucose Assay kit, the K-AMYL 06/18
amylose/amylopectin kit, and the high amylose corn starch standard (68%) were purchased from Megazyme International (Wicklow, Ireland).

2.3. Obtaining the flour

The raw corn was dry-milled using a 5.29 oz electric grain grinder mill (Cgoldenwall, China). The flours were sequentially fractionated using a series of four ASTM (USA) sieves for 6 min with a Vibratory Sieve Shaker, Analysette 3 Spartan (Fritsch, Germany). All flours and their fractions were packed in low-density polyethylene bags and stored at 4±2°C until analysis for a maximum period of 4 months.

2.4. Determining the WAI and WSI

The WAI and WSI were determined by the method described by Igual et al., (2021) with minor modifications. One gram of each flour fraction was dispersed in distilled water at a 1:10 w/v ratio. The suspension was heated in a water bath at 30 °C while stirring for 30 min at 400 rpm using a Velp AREC magnetic stirrer (VELP Scientifica, Italy). Subsequently, the dispersions were adjusted to 13 ml with water and centrifuged at 1,700 g for 10 min using a Power Spin DX centrifuge (UNICO, New Jersey, USA). The WAI was calculated as the weight of the sediment per unit weight of the original sample. The WSI was determined as the weight of dissolved solids in the supernatant measured with a digital refractometer, with a Brix range of 0-85% (Milwaukee Instruments, Wisconsin, USA), and expressed as a percentage of the original sample’s weight.

2.5. Determining the amylose/amylopectin content

The amylose content of the corn flours was analyzed using a K-AMYL 06/18 amylose/amylopectin kit as per the manufacturer’s instructions. The amylose was hydrolyzed to D-glucose and measured using the D-Glucose Assay kit.

2.6. In vitro starch digestion
The *in vitro* starch digestion of corn flour was determined using the two-phase digestion method: gastric and pancreatic, as described in Englyst et al., (1992). For this, 2 g of flour was suspended in a buffer solution of 5 ml of HCl (0.05 M, pH 1.5), mixed with pepsin (7 mg), and incubated for 60 min at 37 °C.

The pH was adjusted to 5.2 with 0.5 M sodium acetate buffer (3.5 ml), and the sample was hydrolyzed by adding a mixed enzyme solution (10 mg of pancreatic amylase, 0.06 ml of amylglucosidase, and 0.086 mg of invertase) to simulate pancreatic phase. Digestion was continued at 37 °C, and aliquots (0.1 ml) were taken at 0, 20, 60, 120, and 180 min. The D-Glucose Assay kit was used to determine the glucose released from the sample. Based on the hydrolysis rate, the hydrolyzed rapidly digestible starch (RDS) fractions were determined during the first 20 min, the hydrolyzed slowly digestible starch (SDS) fractions were determined between 20 and 120 min, and the non-digestible, resistant starch (RS) fractions were determined after 120 min of digestion. The content of each starch fraction is expressed as a percentage (%) and was calculated using the equations 1 – 3, where G20 and G120 are the glucose content (mg) after 20 and 120 min of hydrolysis, respectively; FG is the free glucose content (mg) of the starch samples before hydrolysis; and TS is the total starch content (mg) of the samples.

\[
\text{RDS} \% = \frac{G_{20} - FG}{TS} \quad (\text{Eq. 1})
\]
\[
\text{SDS} \% = \frac{G_{120} - G_{20}}{TS} \quad (\text{Eq. 2})
\]
\[
\text{RS} \% = \frac{[TS - (\text{RDS} + \text{SDS})]}{TS} \quad (\text{Eq. 3})
\]

### 2.7. Determining the estimated glycemic index

The eGI was determined by starch hydrolysis kinetics based on the data obtained from the in vitro digestion of starch, following the proposed method (Granfeldt et al., 1992). The HI was calculated as the ratio between the area under the hydrolysis curve of the sample at different digestion times (0, 20, 60, 120, and 180 min) and the area under the curve of the corn starch standard.
2.8. Techno-functional properties

2.8.1. Water holding capacity

The WHC was determined using the method described in Lin & Fernández-Fraguas, (2020). 0.10 g of flour was mixed with 15 ml of distilled water. The suspension was vortexed for 10 sec at 5-min intervals over 20 min. Then, the suspension was centrifuged at 5,000 g for 15 min. The decanted supernatant was removed completely, and the hydrated dough was weighed. The WHC was calculated as the weight of retained water (g) by sample weight (g).

2.8.2. Emulsifying properties

The turbidimetric technique described in Lin & Fernández-Fraguas, (2020) was used and expressed as the EAI (m^2/g). For this, emulsions were prepared with 3 ml of vegetable oil and mixed with 9 ml of 0.5% (w/v) flour dispersion in 10 mM phosphate buffer (pH 7). The emulsions were homogenized by stirring for 3 min; then, 5-μL aliquots were taken from the emulsion’s bottom at 0 min and after 10 min at rest. These were diluted in 5 ml of a 0.1% sodium dodecyl sulfate solution and stirred for 15 sec. The absorbance was measured at 500 nm.

2.8.3. Gelation capacity

This property was evaluated using the method described by Shen & Li, (2021). Ten flour suspensions in distilled water (10 ml) were prepared at 2 to 20% (w/v) concentrations. The suspensions were then heated at 100 °C for 1 h with subsequent cooling in water at 4°C for 120 min. The least gelation concentration (LGC) was determined when the sample in the inverted test tube did not drop or slide.

2.9. Rheological characterization

An ARES-G2 controlled-stress rheometer (TA Instruments, New Castle, DE, USA) equipped with a disk-disk meter (25 mm diameter, 2 mm separation) was used to analyze the rheological behavior

This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4737960
of the sample doughs. The dough was prepared with distilled water at 25 °C in a 1:0.8 flour/water ratio and allowed to stand for 30 min. Subsequently, a sample of approximately 982 mm³ was loaded onto the disks; the excess sample was removed and allowed to stand for 5 min. A shear rate of 0.1 to 10 s⁻¹. The strain sweep test was evaluated at a strain swing stress in a range of 0.01–10% at 25 °C, and the sample's linear viscoelastic region (LVR) was determined. Frequency sweeps were performed at an angular frequency range of 0.1 to 100 rad.s⁻¹ with a voltage of 1%. Temperature ramp tests were conducted at a temperature range of 25 °C - 90 °C - 25 °C at a rate of 2 °C min⁻¹ (heating and cooling) and a constant frequency of (ω) 6.28 rad.s⁻¹ and 0.05% strain. From the rheological tests, the values of the storage modulus (G′), loss modulus (G″), and the tanδ value (G″/G′) were determined. The texture map of the corn dough and the classification of the sample were constructed as per Schreuders et al. (2021).

2.10. Statistical analysis

For the dependent variables in phases 1 and 2, the effect of the three flours, particle diameters, and their interactions were analyzed by two-way analysis of variance (α = 0.05) with subsequent application of Duncan’s multiple-range test (α = 0.05). Based on the statistical results of phase 1, grouping was carried out by testing orthogonal contrasts to evaluate significant differences between the particle sizes studied, and the corn flours were classified into whole, coarse, and fine. Subsequently, a main components analysis was carried out. The statistical software SAS ODA (SAS Institute, Inc., Cary, NC) was used for all statistical procedures. All tests were performed in triplicate, and the reported values represent means with their respective standard deviations (means ± SD).

3. Results and discussion

3.1. WAI and WSI
Figure 1 shows the WAI and WSI values for the corn flours. For the WAI, there were statistically significant differences between cultivars and particle sizes \((p < 0.0001)\), as well as significant interactions between both factors \((p < 0.05)\). Average WAI values ranged from 1.91 to 2.44, with the highest values for Advanta, Leptra, and Porva, respectively (Figure 1A). Porva showed statistically significant differences \((p < 0.05)\) compared to Advanta and Leptra. The Advanta 256 \(\mu m\) and 363 \(\mu m\) fractions had the highest WAI with no significant differences \((p>0.05)\) between them. In contrast, the Porva 125 \(\mu m\) and 135 \(\mu m\) fractions had the lowest WAI values with no significant differences \((p>0.05)\) between them.

Regarding the WSI technological variable, there were significant differences between cultivars and particle diameters \((p < 0.0001)\). The interactions between both factors were also highly significant \((p < 0.05)\). The average WSI values of the corn flours fluctuated between 5.65 and 12.65% (Figure 1B). The Advanta and Lepta 35 \(\mu m\) fractions and the Lepta 181 \(\mu m\) fraction had the highest WSI values, showing no statistically significant differences among them. However, there were significant differences when compared to the coarse fractions (256 \(\mu m\) and 363 \(\mu m\)) \((p < 0.05)\). Conversely, the 256 \(\mu m\) and 363 \(\mu m\) fractions did not exhibit statistically significant differences between them. The Porva flour also had the lowest WSI value without statistically significant differences \((p > 0.05)\) between the particle sizes studied.

Overall, corn flours exhibited low water absorption \((WAI < 2.5)\), which is a distinctive trait of native corn starches. The data were consistent with Beech et al. (2022), who reported a WAI of 2.31. However, the corn flours of the Lepta \((8.1\%\) protein) and Advanta \((7.3\%\) protein) cultivars showed higher WAI than the Porva variety \((6.7\%\) protein). These results could be related to the protein content, which has an affinity with and can retain water through weak forces such as hydrogen bonds, increasing its absorption (Bravo-Núñez & Gómez, 2019). The decreasing trend of WAI as the particle sizes of the fractions decrease could be attributed to the fact that the finer
particles may have a more significant impact on the integrity of the structure, with possible breakage of the polysaccharide chains affecting the hydration and absorption properties (Feng et al., 2022).

The WSI percentages of the three flours evaluated were consistent with the values reported by Guo et al., (2021) for purple corn flour (9.63%) and higher than the values reported for native corn starch, which fluctuated between 0.44 and 0.89% (Beech et al., 2022). The increase in WSI may be related to the release of soluble solids and the disintegration of starch granules, which may be an effect of milling and interactions of amylose with water (An et al., 2023). A higher WSI increases the adhesiveness and stickiness of the final product (Lapcíkov et al., 2021).

Based on the statistical results of the WAI and WSI, the Advanta and Leptra corn flours were grouped into coarse (363 + 256 μm) and fine (181 + 135 μm) fractions. The Porva flour did not show statistically significant differences between its fractions; therefore, the whole flour was evaluated without fractionation. Based on these groups, the average particle diameter studied in phase two was 174.4 μm (whole flour), 299.8 μm (coarse fraction), and 151.5 μm (fine fraction) for Advanta; 190.3 μm (whole flour), 293.2 μm (coarse fraction), and 166.1 μm (fine fraction) for Leptra; and 141.1 μm (whole flour) for Porva.

3.2. Determining the amylose content

Regarding the amylose content (Table 1), there were statistically significant differences between maize cultivars (p < 0.05). For Advanta, there were no significant differences in amylose content between particles of different sizes (p > 0.05), unlike Leptra, which had significant differences between its fractions (p < 0.05). The Leptra fraction showed the highest amylose content (56.42%) and had significant differences with respect to the other flours (p > 0.05).

The average amylose content in the corn flours was similar to that reported by Giuberti et al. (2012) (i.e., 31.1%) and was higher than that reported for wheat (26.4%), tapioca (17.7%), potato
(24.16%), and sweet potato (18.82%) (Zhang et al., 2017). Thus, the amylose content would represent greater shear strength compared to the other referenced cereals, which could be more susceptible to starch retrogradation, have less swelling, and have higher resistance to enzymatic digestion due to their compact linear structure (Kunyanee & Luangsakul, 2022).

3.3. **In vitro starch digestibility and estimated glycemic index.**

The values of the starch fractions, including RDS, SDS, and RS; the HI calculated from the starch hydrolysis curves; and the eGI corresponding to each sample are shown in Table 1. Regarding the RDS fraction, the average values fluctuated between 7.2% and 11.14% without significant differences between the cultivars and particle diameters evaluated. For SDS, the values fluctuated between 8.61% and 13.53% without significant differences between the assessed samples (p > 0.05). Additionally, the whole flours (Advanta, Leptra, Porva) and the Advanta fine fraction had the highest RS values (47.74%–50.19%).

There were no statistically significant differences between the Advanta and Leptra maize cultivars for HI and eGI, and no statistically significant differences between the particle sizes evaluated (p < 0.05). After 180 min, the Advanta (174.4 μm) whole flour had the lowest HI value (27.86%); consequently, it had the lowest eGI (32.21), with statistically significant differences (p < 0.05) compared to the Leptra fine flour (166 μm) and the Porva flour (141.1 μm). The average RS content of the flour samples in this study was comparable to that reported by Barretti et al. (2022) for corn starch, that is, 62.6%. Therefore, they could have a potential nutritional functionality by increasing the hydrolysis rate at the end of digestion, with an inverse effect on the eGI. On the other hand, cooking can significantly impact the eGI because the results in precooked corn flours amount to between 77.3 and 80.7 (Caballero-Rothar et al., 2022). This phenomenon could be associated with the fact that cooking causes the hydration of the starch granules that subsequently swell due to the
effect of temperature and gelatinize, increasing availability to enzymatic hydrolysis and, therefore, its bioaccessibility (Lal et al., 2021; Singh et al., 2020).

On the other hand, particle size had no effect on eGI. This result is consistent with the results presented by Mete et al., (2021) on the glycemic response of adults with whole wheat flour bread. However, further studies are required to understand the synergy of the components of the corn flour and the underlying mechanisms that have an effect on this index because previous studies show significant effects of flour particle size on enzyme sensitivity, regardless of its source (Dong et al., 2021).

3.4. Principal component analysis

As shown in Figure 2, the principal component analysis revealed that the first three components (FC) account for 81.03% of the total variance (FC1: 37.82%, FC2: 23.14%, and FC3: 20.07%). Thus, the FC1-FC2 plane (Figure 2A) indicates that SDS has a high relative contribution to both FCs, while the amylose content shows a low contribution to the variance of the experimental data. Furthermore, common patterns representing co-variation between amylose content and WSI were identified. The FC1-FC3 plane shown in Figure 2B highlights the high contribution of amylose content and WSI in FC3, while in FC1, the higher contribution is related to RS, HI, and eGI. On the other hand, WAI and particle diameter (PD) contributed significantly to FC2 (Figure 2C).

3.5. Functional properties, WHC, EAI and LGC

Based on the above results, Advanta whole flour (174.4 µm) was selected because it exhibited the best eIG (32.21). Functional properties, such as WHC, EAI, and least gelation capacity (LGC), were evaluated for this sample, and its rheological behavior was analyzed. The WHC of Advanta whole corn flour was approximately 1.93 g/g ± 0.12, comparable to the value reported by An et al., (2023) for raw corn flours (1.04g/g) and similar to the data for amaranth flours reported by Rahimi et al., (2020) (1.09 g/g). However, it was higher than the WHC for wheat
flour (0.51g/g). The increase in WHC may depend on the protein structure and the presence of hydrophilic carbohydrates. Consequently, flours with high WHC may form hydrogen bonds between hydroxyl groups or other non-covalent bonds, allowing them to form protein aggregates that trap water. This effect can influence the texture of products, creating higher softness, retention of flavors, and yields (Aguilera et al., 2009; An et al., 2023; Shen & Li, 2021).

Advanta flour showed an initial EAI of 40.55 ± 1.45 m²/g, decreasing to ~32.52 ± 0.24 m²/g after 10 min. Raw corn flours exhibited an emulsifying capacity comparable to that reported by Lin & Fernández-Fraguas, (2020) for raw bean flours (~42 m²/g) and higher than that was reported by Aguilera et al., (2009) for chickpea flours (~22.9 m²/g). The ability to form an emulsion in Advanta flour can be influenced by the fiber content and the balance of hydrophilic/hydrophobic groups, contributing to the stability of the emulsion by increasing the system’s viscosity.

Furthermore, the LGC of Advanta flour was 12% ± 0.57, lower than that reported in (Hettiarachchi & Gunathilake, 2023) for legume flours (16%–20%). This difference is related to the relative proportion of the macro components of the flour and the physical competition for water that could occur between protein and gelatinized starch.

3.6. Rheological properties

3.6.1. Flow measurement

Figure 3 shows the flow measurement of the Advanta whole-flour dough. The viscosity (η) was found to decrease as the shearing speed (γ) increased within the studied range (10 s⁻¹ to 10). The dough exhibited shear-thinning behavior and a flow behavior index (n) less than 1, classifying the Advanta flour dough among non-Newtonian foods with pseudoplastic characteristics. This behavior could be attributed to the material's molecular structure breaking down, reducing internal resistance in the form of friction and making the material more fluid. Zhang et al., (2017) concluded that gluten-free doughs, such as those made from corn, tapioca, or potato, are more
likely to exhibit shear-thinning compared to gluten doughs, presenting a technological challenge for the production of gluten-free foods.

### 3.6.2. Strain sweep

Figure 4 shows the strain sweep measurements. The Advanta dough had an LVE limit of ~0.16%; from applying this strain, the $G'$ modulus began to decrease, indicating that a critical deformation of the dough occurred beyond this level (Figure 4A). Likewise, the data showed that at low oscillatory stress, $G'$ was greater than $G''$, indicating that the samples are in an elastic regime more similar to that of a solid. With the increase in oscillatory stress, the samples exhibited confluence at an oscillation stress of 2.3% ($G' = G''$) and at a high oscillatory stress ($G'' > G'$), indicating that the material becomes more fluid or viscous, forming a complex network structure through interactions. This behavior was consistent with the results presented by An et al., (2023). The dynamic functions $G'$ and $G''$ of the Advanta dough are independent of the deformation, reflecting a viscoelastic behavior where there is an alteration and reorganization of the gel network with a transitory and fragile structure, allowing the inference of weak gel formation. Figure 4B shows the texture map based on the stress values with the strain at the end of the LVE regime and the stress at the crossing points ($G' = G''$). The corn dough fell into the brittle region in quadrant 4 (top left), and as the tension increased, it approached the rubbery region (bottom right).

### 3.6.3. Frequency sweep test

Figure 5A shows the frequency sweep measurements, indicating the response of $G'$, $G''$, and tan (δ) against the angular frequency of the Advanta dough measured at 25°C. The sample exhibited magnitudes of $G' > G''$ (tan δ < 1) throughout the studied frequency range. The values showed a slight decrease at low frequencies (0.01–1 ω), followed by a slight increase at higher frequencies (1–100 ω), indicating an improvement in viscoelasticity with differences in the modules' frequency dependence. At the studied frequencies, no observable crossing was present ($G' ≠ G''$), suggesting...
that the corn dough displayed a dominant elastic behavior. The graph illustrated that at low frequencies, the deformation rate is slow, and at higher angular frequencies, there was a decrease in tan δ, possibly associated with a transition from viscous to more elastic behavior of the material (Figure 5B). This observation aligns with the findings presented by An et al., (2023) in corn flours, demonstrating a weak gel structure with minimal fluidity due to crosslinked polymers (Sadat & Joye, 2022).

3.6.4. Temperature ramp

Figure 5C shows the dynamic viscoelasticity of the Advanta dough at constant stress (2%) and constant frequency (6.28 rad/s) as a function of temperature (heating and cooling cycle). During the initial heating stage (from 25 to 60°C), G′ and G″ gradually increased as the temperature increased, suggesting that the material is becoming more rigid and less deformable. It presented a crossing of G′ and G″ in the heating cycle around 60°C along with a peak G′ around 75°C, which may reflect that the starch granules swell at that temperature (Brishti et al., 2020). Likewise, the sample showed peaks in tan(δ) around 65°C and 80°C (Figure 5D). According to Jekle et al., (2016), the maximum tan(δ) can be used as a tool to identify the onset of gelatinization. However, as the temperature increased, the loss modulus (G″) and the tan(δ) value reached maximum values, consistent with Zhang, (2023), who studied corn starch doughs with 2% hydroxypropyl methylcellulose and reported that as the temperature increased, tan(δ) reached its maximum point and then decreased, changing to a relaxation behavior. This results that the polymer chains become less mobile, and the dough becomes more fragile in the last heating stage than other doughs, resulting in a relatively loose structure in the final product.

4. Conclusions

The physicochemical and rheological properties of corn flour obtained from three cultivars, Advanta, Lepra and Porva, were studied. Findings show that the particle size of the flour had an
effect on the increase in WAI, although it did not influence the eGI. The selected raw corn varieties were classified into low glycemic index foods, relevant to the food industry considering the desirability of regulating blood glucose levels. The rheological behavior revealed that Advanta corn flour is more likely to present shear-thinning behavior compared to doughs containing gluten, posing a technological challenge.

The outcomes of this study reveal corn flour as a promising food ingredient, characterized by a high content of resistant starch and low glycemic index. These functional properties make it an ideal candidate for applications in the food industry, particularly in the manufacture of health-conscious products requiring high water solubility and greater emulsification capacity. Examples include soups and instant drinks. Moreover, the corn flours exhibit superior water retention capacity compared to conventional flours, contributing to the softness and flavor retention essential for bakery products like cookies. Consequently, the findings from this study may inform future research focused on the design of gluten-free food.

**Author contributions**

**Adriana Mejía-Terán:** experimental execution, data analysis, wrote the manuscript and conceptualized the study. **Carla Blanco-Lizarazo:** analyzed data, statistical analysis, wrote the manuscript, reviewed and conceptualized the study. **Eduardo Leiva-Mateus:** experimental execution and reviewed the manuscript. **Indira Sotelo-Díaz:** reviewed the manuscript.

**Data availability**

Data will be made available on request.

**Acknowledgments**

This work was supported by the National Open and Distance University of Colombia-UNAD under [Grant ECAPMAPIE092022]. Fenalce especially to Henry Vargas for his guidelines and sample supply.
References


This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4737960


**Figure captions**

**Table 1.** Starch fractions, rapidly digested starch (RDS), slowly digested starch (SDS), resistant starch (RS), amylose contents, hydrolysis index (HI), glycemic index (eGI) of corn flours.

**Figure 1.** Water absorption index (WAI) (A) and water solubility index (WSI) (B) for corn flours Advanta (■), Leptra (■), and Porva (■) with different particle diameters.

**Figure 2.** Loading plots in PC1-PC2 plane (A), PC1-PC3 plane (B), and PC2-PC3 plane (C). Water absorption index (WAI), water solubility index (WSI), particle diameter (PD), rapidly digested starch (RDS), slowly digested starch (SDS), resistant starch (RS), Hydrolysis Index (HI), Glycemic Index and (GI).

**Figure 3.** Flow behavior of Advanta corn dough (▲), influence of shear rate on the viscosity curve at 25°C.

**Figure 4.** Dynamic strain sweep for Advanta corn. A): Storage modulus [G'(▲ blue)] and loss modulus [G''(▲ green)] versus Oscillation strain to define the end of the linear viscoelastic regime and the crossover point (G' = G''). B): Texture map and the classification of materials in four quadrants using the stress rates with the oscillation strain at the limit of the linear viscoelastic [LVE: R(●)] region and the crossover point [(G'= G''): ●)].

**Figure 5.** Frequency sweep and Dynamic viscoelasticity of Advanta corn sample. A) response of storage modulus [G'(▲ blue)] - loss modulus [G''(▲ green)] versus the angular frequency; B) tan(δ)=G''/G' versus the angular frequency of the samples at 25°C. C) Doughs during the heating cycle (25 °C-95) at constant strain of 2% and frequency of 1 Hz. D) Values of tan (δ) versus temperature.