Comparative analysis of four corn (*Zea mays* L.) varieties, transformed from grain corn into tortilla

Maimone-Celorio, José A.[1]; Regalado-López, José[1*]; Gallego-Moreno, Francisco J.[2]; Pérez-Ramírez, Nicolás[1]; Méndez-Espinoza, José A.[1]

[1] Colegio de Postgraduados, Campus Puebla, Programa en Gestión del Desarrollo Social., Puebla, México.
[2] Universidad de Castilla-La Mancha, Facultad de Trabajo Social, Cuenca, Castilla-La Mancha, España.
* Correspondence: josere@colpos.mx

ABSTRACT

Objective To identify the corn variety with the best yield, nutrients, flavor, and profitability to use as main input for a future *tortillería* (tortilla store) operated by the Sociedad de Producción Rural Campo Lima (SCL). A mixed research **methodology** was used to compare key values of the transformation chain of corn grains into nixtamalized tortilla. In addition, interviews with key players and participant observation were used as information tools and included weights, properties, and yields of the *tortillerías*. The **findings** allowed a comparative evaluation of the four corn varieties (Niebla, HS-2, native corn, and Sinaloa) and included the following yield indicators: nixtamalization-to-dough-to-tortilla, nutrient content, sensory perception, and benefit/cost analysis. The hybrid HS-2 (developed by the Colegio de Postgraduados) stood out with the highest average value. A **limitation** was the scarce literature about this type of research carried out in semi-mechanized *tortillerías*. In **conclusion**, the identification and selection of the most efficient and balanced corn input will help the small producers of the Sociedad de Producción Rural Campo-Lima to carry out a better decision-making process and responsibly invest in the creation of a *tortillería*. This step will get them closer to a fair market inclusion, consequently, generating a fair income. This process will add value to the corn they grow and will motivate new generations to continue sowing corn.

Keywords: yield, nutrients, profitability, *tortillería*.

Citation: Maimone-Celorio, J. A., Regalado-López, J., Gallego-Moreno, F. J., Pérez-Ramírez, N., & Méndez-Espinoza, J. A. (2024). Comparative analysis of four corn (*Zea mays* L.) varieties, transformed from grain corn into tortilla. *Agro Productividad*. https://doi.org/10.32854/agrop.v17i12.3174

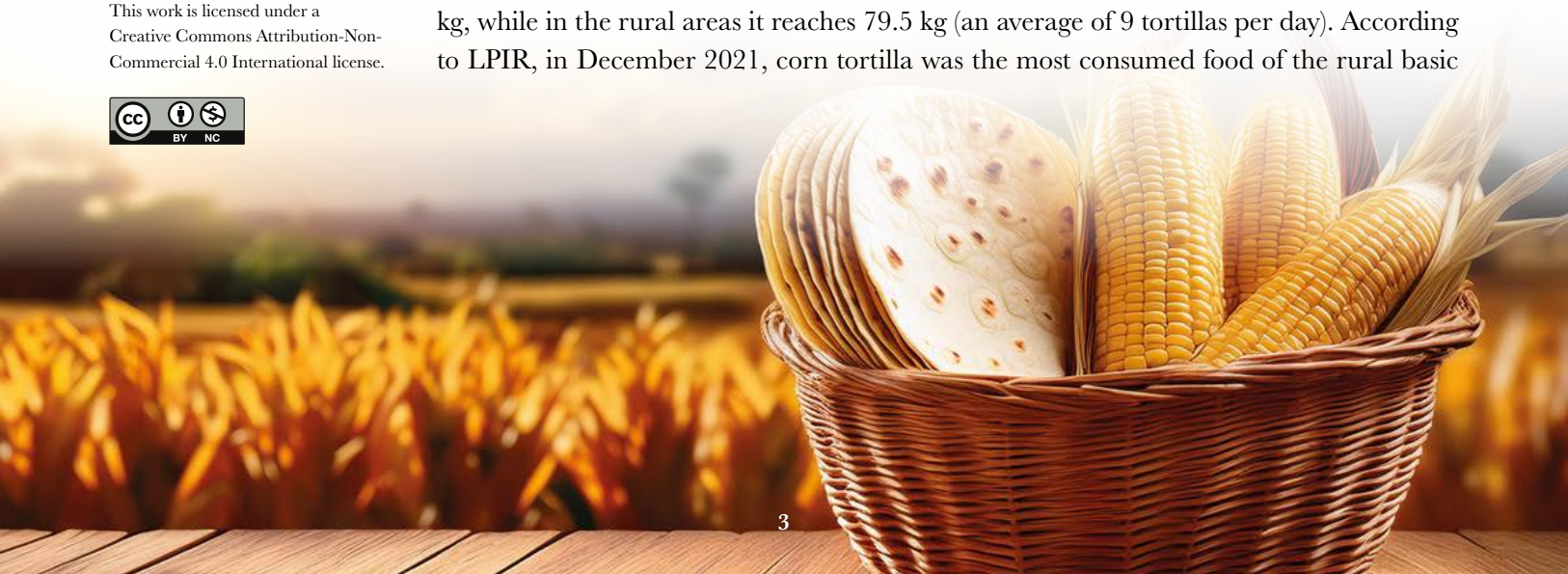
Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: June 11, 2024.
Accepted: November 29, 2024.
Published on-line: December XX, 2024.

Agro Productividad, 17(12). December. 2024. pp: 3-13.

INTRODUCTION

Despite the public policy regarding guaranteed fixed prices for food, the economic situation of most small producers in Mexico has not improved (CONEVAL, 2023). Approximately 94% of the population eats tortillas and —according to the estimations of the CONEVAL database regarding the cost of the basic food basket in the Poverty Line for Rural Income (LPIR)— the average consumption of tortilla per capita in urban areas is 56.7 kg, while in the rural areas it reaches 79.5 kg (an average of 9 tortillas per day). According to LPIR, in December 2021, corn tortilla was the most consumed food of the rural basic



food basket (217.9 grams per day), reaching a monthly cost of MXN$129.78. Regarding the daily nutrient requirements of Mexicans, tortilla provides about 45% carbohydrates, 39% proteins, and 49% calcium. In rural areas, these values are higher, because tortillas are prepared with fresh nixtamalized dough (Rivera Chavira *et al.*, 2021; Colín-Chávez *et al.*, 2020). Flores *et al.* (2007) pointed out that ≈33.6% of the corn produced in Mexico is used to prepare tortillas (8,775,000 t). According to the Directorio Estadístico Nacional de Unidades Económicas (INEGI, 2022), 121,445 establishments are part of the corn grain-to-tortillas transformation chain (*i.e.*, *tortillerías* and mills). Based on the Grupo Minsa (2021) credit ratings developed by HR Ratings, 30% of Mexican *tortillerías* use fresh nixtamalized corn, 20% use enriched flour, and 50% use a mixture of fresh nixtamalized dough and corn flour. In Puebla, Mexico, most consumers (≈65%) chose fresh nixtamalized *tortillas*, produced in nearby mechanized *tortillerías* or buy them in retailer stores (Escobedo and Jaramillo, 2019).

The study area is located in the municipality of Tlaltenango, in the central-western area of Puebla. It borders with the municipality of Huejotzingo (north and west), the state of Tlaxcala (north), San Miguel Xoxtla (east), and Juan C. Bonilla (south). The area is located at 2,200 m.a.s.l. and covers 37 km^2. In 2020, it had 7,425 inhabitants (population density: 355 per km^2). According to the Secretariat of Social Development, the high marginalization and social backwardness of this municipality places it in 38th place out of the 217 municipalities of the state (H. Ayuntamiento de Tlaltenango, 2022). In Tlaltenango, farmers use several corn varieties —such as the native white, blue, red, and yellow corn— and hybrids —such as Niebla, produced by the Ceres company, and HS-2, developed by the Colegio de Postgraduados. HS-2 was created from a cross of several corn types with desirable characteristics. This hybrid has an improved yield and is more resistant to weather and pests (Núñez and Sempere, 2016). The *tortillerías* of Tlaltenango use a mixture of hybrids and corn flour. These hybrids come from Sinaloa and are bought at a very cheap price. Sinaloa corn is grown using a large volume of agrochemicals and a wide variety of pesticides (Cruz and Leos, 2019). According to the interviews with members of the Sociedad de Producción Rural Campo Lima in 2023, only a small percentage of *tortillerías* use the Niebla, native corn, or HS-2 varieties. In addition, most of the regional *tortillerías* and intermediaries pay farmers between MXN$5 and MXN$8 per kilogram of white corn. According to the Anuario de Granos del Sistema Nacional de Información e Integración de Mercados (SNIIM, 2022), the consolidated price of white corn (Sinaloa) in the Central Market of Puebla reached a minimum price of MXN$8.75 and a maximum price of MXN$24 (average: MXN$16.37), while a kg of tortilla cost between MXN$15.72 and MXN$17.67 (SNIIM, 2023). The guaranteed price fixed by the Ministry of Agriculture of Mexico (2022) was MXN$6.8 per kg of corn grain; however, the small corn producers of Tlaltenango believe that MXN$9.50 per kg is a fair minimum purchase price.

In 2023, the situation of the Sociedad de Productores Rurales Campo Lima (SCL) was diagnosed. The results indicated a lag in the income of its members, as a consequence of the low price of corn in the market. Therefore, a responsible investment was suggested to the SCL. The investment should be equally divided among all the members and it should be used to develop, install, manage, and operate a tortillería in Tlaltenango. The

aim of this proposal was not just to promote local consumption, but also to help the SCL to transform their corn grains into a fair price tortilla. In order to achieve a responsible investment (FAO-CSA, 2014) the following five strategies were proposed: a) to analyze the yield and the nutritional properties of corn varieties; b) to conduct a marketing study about the small tortillerías in the region; c) to develop a business and investment plan for a *tortillería*; d) to improve the input for sustainable corn production; and e) to develop an organizational-management plan for the SCL. Consequently, this study contributed to three (a, b, and c) of the five strategies. Subsections 3.1 and 3.2 describe how this research meets strategy a. In addition, subsection 3.3 includes a sensorial analysis and interviews conducted with owners and employees of local *tortillerías*. Meanwhile, subsection 3.4 consists of a benefit/cost analysis that advances strategy c. Finally, subsection 3.5 describes a comparative evaluation that will help the SCL to make management decisions, such as the selection of the most suitable corn variety for the production, transformation, and commercialization of the corn-to-nixtamalization-to-dough-to-tortilla chain. In addition, the results will help the SCL to establish a new *tortillería* in Tlaltenango, promoting the rural, local, and sustainable development of the region.

MATERIALS AND METHODS

Inductive and exploratory-descriptive methodologies were used in the analysis. They included qualitative methods, such as the study case and situational participation. In addition, quantitative methods —such as experimental design and comparative analysis— were used (Hernández Sampieri and Mendoza Torres, 2018). The diagnosis and research problem of this study were developed based on 8 interviews conducted with key rural producers of the SCL in Tlaltenango. In addition, the Mexican context was subjected to a documentary review. The corn comparative evaluation methodology used in the study (Table 1) is described from subsection 3.1 to subsection 3.5. The materials and methods used in this research are included in these subsections. This research was carried out from February to July 2023.

Subsection 3.1 of Table 1 shows the mechanized methods used for nixtamalization and the preparation of dough and tortillas, as well as their yields. Twelve employees and 3 owners of *tortillerías* from the rural areas of the valley of Puebla were interviewed. Out of all the *tortillerías* visited for the study, the tortillería that had the most traditional transformation (grain-to-tortilla) method was selected. Its transformation method included nixtamalization, milling, kneading, and cutting. In addition, this *tortillería* uses the type of tortilla machine that is most popular in the Valley of Puebla. In this *tortillería* (a.k.a., "*tortillería* 1"), the transformation process from grain corn into tortilla was carried out thrice, using the 4 corn varieties most used in Tlaltenango (Niebla, HS-2, native corn, and Sinaloa). These three samples were subjected to a comparative analysis between their means and variances (descriptive and inferential statistics), in order to determine the corn grain-to-tortilla process of the four corn varieties. A randomized complete block design with three replicates was used to analyze corn weight at every stage of the transformation process (nixtamalization, dough, and tortilla), to determine significant differences in weight yield (kg). The R software was used to conduct an analysis

of variance, in order to compare the mean values resulting from the three transformation processes and to determine if the statistical significance of p-value < is less than 0.05 for the recorded treatments. In addition, statistically significant yield differences between corn varieties were identified, during the nixtamalization, dough, and tortilla stages of the process. Tukey's mean comparison test was used to find differences between means. Meanwhile, in subsection 3.1, additional tortilla samples were used for a sensory perception study: 30 inhabitants of the region participated in a convenient sampling. Cronbach's Alpha was used to determine the reliability of the survey (subsection 3.2). In addition, the samples included in subsection 3.1 were used for a bromatological nutrient analysis (subsection 3.3). Therefore, the study included the benefit/cost analysis of the corn grain-to-tortilla process (subsection 3.4). Finally, the results included in subsections 3.1 to 3.4 were used to compare the indicators (%). These results are included in the tables and graphs (subsection 3.5).

RESULTS AND DISCUSSION

Nixtamalization, dough, and tortilla yields

According to the yield responses of nixtamalization, the highest results (nixtamalization kg/ grain kg) were recorded by Sinaloa (1.878), followed by Niebla (1.837), HS-2 (1.801), and native corn (1.793). Regarding fresh dough, the highest result (nixtamalization kg/ grain kg) was recorded by Sinaloa (1.989), followed by Niebla, HS-2, and native corn. However, the yield varied in tortilla production: the highest result (nixtamalization kg/ grain kg) was recorded by HS-2 (1.486), followed by Niebla, native corn, and Sinaloa (Table 2). These results are similar to the yield rates recorded by Salinas and Aguilar (2010) and Ramírez-Muñoz (2021). However, no references were found about dough-to-tortilla yield calculations made directly in a *tortillería* in Tlaltenango.

Regarding weight increase and loss, Niebla and Sinaloa recorded higher weight increases (84 and 88%, respectively) than HS-2 and native corn (80 and 79%, respectively), during the corn grain-to-nixtamalization transformation. This phenomenon is the result of the medium hardness of Niebla and Sinaloa grains, which produces a flourier endosperm, while HS-2 and native corn have a more vitreous endosperm. Sinaloa recorded the highest loss weight percentage (24%) during the dough-to-tortilla transformation stage, followed by Niebla (21%), native corn (20%), and HS-2 (17%). According to Salinas and Aguilar (2010), this behavior is the result of the capacity of each corn variety to preserve moisture and the high cooking temperature (285 to 300 °C) inside the tortilla machine, where evaporation causes a great moisture loss. Sinaloa recorded the highest moisture absorption during the nixtamalization and dough stages. However, this variety lost the greatest water volume during the tortilla preparation stage and, consequently, it obtained the lowest yield. These results match the findings of Gaytán-Martínez *et al.* (2013).

Nutritional value of white corn tortillas prepared in tortillerías

The tortillas prepared with HS-2 and native corn varieties recorded a lower wet weight in the bromatological analysis (47 and 46%, respectively) (Table 3). In addition, these varieties absorbed less water during the nixtamalization process and lost less water

Table 1. Materials and methods: four corn varieties, from crop to tortilla.

No.	Steps	Description
3.1	Yields of nixtamal, masa and tortilla in a convenience tortilla factory, 3 replications.	
3.1.1	Nixtamalization process	The corn kernels used had a moisture content between 12.9 and 13.1 percent and a weight of 5 kg per corn variety. All grains were harvested in the 3rd quarter of 2022. For cooking, 12 liters of potable water from a municipal well and 50 grams of food-grade lime were used at a temperature of 91° in accordance with NMX-FF-034/1-SCFI-2020.
3.1.2	Milling and kneading process	The nixtamal was transported to the "tortillería 1" mill to be ground into nixtamal flour. Before grinding each variety of corn, it was verified that the stones and the mill were perfectly washed to avoid adding to the weight of the fresh dough. Subsequently, a kneading machine was used for 4 minutes to achieve a homogeneous consistency in the texture of the dough (Serna-Saldivar, 2021).
3.1.3	Die-cutting, cutting and cooking process in tortilla machine	In "*tortilleria* 1", the fresh nixtamal dough was placed in the feeder of the tortilla machine rollers, which flatten the dough and then it is cut into 2 discs of 15 cm in diameter for transport on a belt and baking in an oven at 285 to 300 °C for a time of 30 s (±5). Upon leaving the oven, they are stacked in a container for packaging and refrigeration in hermetically sealed polypropylene vacuum bags for shipment for bromatological analysis (Espinosa-Ramírez *et al.*, 2021). Tortilla samples were separated for the perception surveys.
3.1.4	Measurement of nixtamal, dough and tortilla yields.	Subsequently, the incoming corn product and the outgoing corn product were weighed on an analytical balance for each corn variety. It is clarified that the weight of the tortillas was obtained 5 minutes after processing (Salinas & Aguilar, 2010). The basic hygienic practices of the official Mexican standard were used, NOM-187-SSA1/SCFI-2002 & NOM-120-SSA1-1994.
3.2	Bromatological analysis and nutritional declaration of tortillas	The methods and materials of analysis and the nutritional declaration are described in the Mexican standards: NOM-116-SSA1-1994, "NOM-F-68-S-1980, NMX-F-089-S-1978, NMX-F-066-S-1978, NOM-F-90-S-1978, NMX-F-496-SCFI-2011 and NOM-051-SCFI/SSA1-2010. These analyses were performed at the food laboratory of the Universidad Tecnológica de Huejotzingo (UTH), Puebla, Mexico. Tortilla samples were taken for analysis.
3.3	Tortilla sensory evaluation	A 15-item Likert-scale questionnaire to evaluate the perception of flavor (sweet, bitter, salty, sour), texture (consistency, hardness, viscosity), odor (pleasant whimsical aroma), freshness (recent processing), flexibility (elasticity, softness and rollability) and reheatability in freshly made and unrefrigerated nixtamal tortilla (Escobedo & Jaramillo, 2019).
3.4	Benefit/cost evaluation	Semi-structured interviews of 10 items to the 8 producers of the "Campo Lima"(Ortiz Pech *et al.*, 2020), and to 15 convenience tortilla factories (Boué *et al.*, 2018). As well as sources of information from the National Tortilla Council, FIRA and SNIIM. Some of the items are: a) Minimum price MXN of 1 kg of corn grain; b) Price MXN of 60 thousand corn seeds; c) Cost MXN of sowing, fertilizers, pest control, tillage and harvest in 1 ha; d) Price 1 kg of tortilla in rural areas; e) Cost of production of 1 kg tortilla in rural areas.
3.5	Comparative Evaluation	A table compares the results of steps 3.1, 3.2, 3.3 and 3.4, with percentages of the values obtained, as well as a presentation in a Hexa-radial graph.

Table 2. Grain-to-tortilla yields of the three transformation processes.

Maize Varieties	(3 replicates), 5 kg shelled corn base					
	Mean* nixtamal	Mean* dough	Mean* tortilla	Yield** nixtamal	Yield** dough	Yield** tortilla
Niebla	9.214	9.910	7.269	1.837 [b]	1.976 [b]	1.449 [b]
HS-2	9.059	9.678	7.475	1.801 [c]	1.924 [c]	1.486 [a]
Criollo	9.007	9.599	7.222	1.793 [d]	1.911 [d]	1.438 [c]
Sinaloa	9.437	9.995	7.175	1.878 [a]	1.989 [a]	1.428 [d]

*Mean values are shown in kilograms. **Yield=kg of the result product/kg corn grain. Different letters in superscript indicate significant differences between corn varieties (one-way ANOVA, Tukey's mean comparison test, $p<0.05$).

due to evaporation during their transformation into tortillas. Vázquez-Carrillo (2020) pointed out that this phenomenon is mainly a consequence of their vitreous consistency and harder grain.

According to the proximate composition included in Table 3, tortillas prepared with freshly nixtamalized dough mainly provide carbohydrates, crude protein, crude fat, sodium, and, in a lower proportion, fiber. Consequently, the tortillas with the highest protein content were those prepared with native corn, followed by those prepared with HS-2, Niebla, and Sinaloa. Meanwhile, HS-2 and native corn are the varieties that provide more energy (carbohydrates), followed by Sinaloa and Niebla. Following the proposal of Figueroa *et al.* (2001), the highest ash content and the lowest sodium content were recorded by HS-2. None of the four corn varieties recorded any sugar content. Regarding the total energy content in 100 g of tortilla, native corn recorded the highest results, followed by HS-2, Sinaloa, and Niebla. The results of this bromatological analysis match the findings of Michael Latham (2002), who recorded that corn mainly provides energy as carbohydrates; however, it also has significant amounts of proteins and lower fat/oil, fiber, and micronutrient content (vitamins A, B1, B2, and B3 and

Table 3. Results of the bromatological and physico-chemical analyses.

Parameter Chemical Component	Niebla	HS-2	Criollo	Sinaloa	Unit	Mean
Moisture [1]	51.53	47.00	46.06	50.10	g/100g	48.67
Crude protein [2]	4.40	4.50	4.80	4.20	g/100g	4.48
Ethereal extract (fat) [3]	1.30	1.70	1.60	1.80	g/100g	1.60
Ashes [4]	0.73	0.98	0.89	0.95	g/100g	0.89
Crude fiber [5]	0.20	0.30	1.20	2.00	g/100g	0.93
Sodium chloride (Salt) [6]	11.00	7.30	11.50	10.60	g/100g	10.10
Reducing sugar [7]	0.00	0.00	0.00	0.00	g/100g	0.00

[1]Moisture level determination (NOM-116-SSA1-1994 Mexican Official Standard). [2]Crude protein determination (NOM-F-68-S-1980 Mexican Official Standard). [3]Ether extract determination (fat) (NMX-F-089-S-l978). [4]Ash content determination (NMX-F-066-S-l978). [5]Crude fiber determination (NOM-F-90-S-1978 Mexican Official Standard). [6]Sodium chloride determination (Morh's method) (975.20, AOAC). [7]Reducing sugars determination (NMX-F-496-SCFl-2011).

Ca, P, Fe, Cu, and Zn). The ether extractor or crude fat contains triglycerides, fatty acids, wax, sterols, pigments, and fat-soluble vitamins. Unlike saturated fat and trans-fat, crude fat does not cause health problems. All the tortillas prepared with the four corn varieties under study recorded a low-fat content. Overall, the four corn varieties showed basic micronutrients values conductive to a healthy diet: 50.7 kcal per 25 g of tortilla (INCMNSZ, 2016).

Tortilla sensory perception analysis

The sensory perception for the grain-to-tortilla transformation and commercialization stages was surveyed. The surveys included the following elements of the four tortilla varieties: flavor, texture, color, freshness, flexibility, and reheated. The surveys had a Cronbach's Alpha of 0.842, indicating a good reliability. The sample consisted of n=30 interviewees. Out of this total, 57% were women and 43% were men and their age ranged from 19 to 55 years old, with a mean age of 39. During the first part of the survey, 73% of the interviewees responded with an overall liking to the flavor, texture, aroma, freshness, and flexibility of the tortillas. This stage recorded the following liking percentages: 41% Niebla, 31% HS-2, 18% native corn, and 10% Sinaloa. The remaining 27% of the sample obtained the following results: 35% Niebla, 30% native corn, 23% HS-2, and 12% Sinaloa. Freshly made tortillas were compared with reheated tortillas; in addition, the average of both tortillas was used to determine which was the best. In average, all the evaluated characteristics of tortillas recorded a 95% congruency, which reinforces the reliability of the tool. Consequently, the average results of the two-day surveys indicate that Niebla was the best qualified variety regarding flavor (92%), aroma (74%), and freshness (78%), while HS-2 recorded the best texture (74%), flexibility (70%), and reheated (68%). The tortilla control sample was prepared with corn flour bought in a supermarket and recorded the lowest percentages in all the surveyed characteristics, both for freshly made tortillas and reheated tortillas. These results were expected, as a consequence of the chemical differences in the preparation process between the freshly nixtamalized dough and the corn flour dough.

Benefit/cost analysis of the corn chain, from crop to tortilla

The highest benefit/cost (B/C) was recorded in the production, transformation, and commercialization of tortillas made with HS-2 (1.7 in 5 years). This result shows the feasibility of the proposal made to the SCL about the *tortillería*. A *tortillería* partnership should include at least 8 producers. Each producer should make an initial investment of MXN$37,000 to obtain a net profit of MXN$319,648.99 in 60 months. The *tortillería* should sell 25 kg per partner and per day and the producers should sow an annual total of 6,250 m^2 of HS-2 white corn. The economic benefit would be 8.6 times higher than the initial investment. A larger cultivation would enable the increase of the business, whether the additional tortillas were sold in same *tortillería* or if the producers invested in a new *tortillería*. The partners could focus on the production of corn grains, because the *tortillería* would be managed by employees. If each member of the SCL produced 1.25 ha of HS-2 corn in a year and sold 50 kg of tortillas per day, the 5-year

net profit would be MXN$639,297.99 per partner, which would result in a 3.41 B/C ratio (MXN$10,654.97 per month). Minimum estimated values were used in this B/C calculation; therefore, the profit could increase if the market price of tortilla increases. Regarding the abovementioned projection (1.25 ha/5years/50 kg per day, per partner), the B/C ratio of HS-2 would be 23, 43, and 32% higher than Niebla, native corn, and Sinaloa respectively, which makes it the best mid-term sustainable economic choice. Mexicans consume an average of 7 to 8 white corn tortillas per day. According to the *Guía Alimentaria y de Actividad Física en Contexto de Sobrepeso y Obesidad en la Población Mexicana* (Bonvecchio and Fernández, 2015) 19-59 years old persons who exercise lightly should consume 7.5 portion of cereals per day. The Plan de Desarrollo Municipal of Tlaltenango established that this municipality has 7,425 inhabitants and, consequently, a *tortillería* could sell a minimum of 200 kg of tortillas per day. In addition, Tlaltenango is not the only area in which a *tortillería* could sell its product: other selling points could be established in nearby localities of the Izta-Popo valley area.

Comparative evaluation of four corn varieties, from crop to tortilla

The analysis of variance showed statistical differences ($p<0.05$) in the grain-to-tortilla transformation process, using the usual tools and machinery of the tortillerías located in the rural and peri-urban area of Tlaltenango. Out of the four corn varieties, HS-2 recorded the highest yield during the tortilla stage. Taking into account all the nutrient and sensory values, costs of the value and production chain, and the yield of the four corn varieties (Table 4), HS-2 is the most comprehensive, balanced, and complete variety.

Figure 1 shows a comparison between the main value indicators of the production, transformation, and commercialization chain of nixtamalized tortillas in a *tortillería*. The values of the parameters in Table 4 were transformed into equivalent percentages to develop this figure, establishing 100% as the maximum value of corn variety for each indicator. This figure shows that the HS-2 variety recorded the most balanced indicators. However, Niebla recorded the best sensory parameter. Consequently, tortillas should be prepared with a combination of both varieties, because they complement each other.

Table 4. Main indicators of the corn grain-to-nixtamalized tortilla chain.

Parameter	Niebla	HS-2	Criollo	Sinaloa
Tortilla Yield	1.449	1.486	1.438	1.428
Dough Yield	1.976	1.924	1.911	1.989
Protein * (g)	4.4	4.5	4.8	4.2
Carbohydrates * (g)	38.8	45.5	45.5	40.9
Sensory P. %	38	27	24	11
Benefit/Cost**	3.18	3.41	2.98	3.09

Tortilla Yield (tortilla kg/grain kg). Dough Yield (dough kg/grain kg). *=in a 100-g tortilla sample. P=average perception. **=growing 10 ha of corn per year and selling 400 kg of tortilla per day, in a 5-year period.

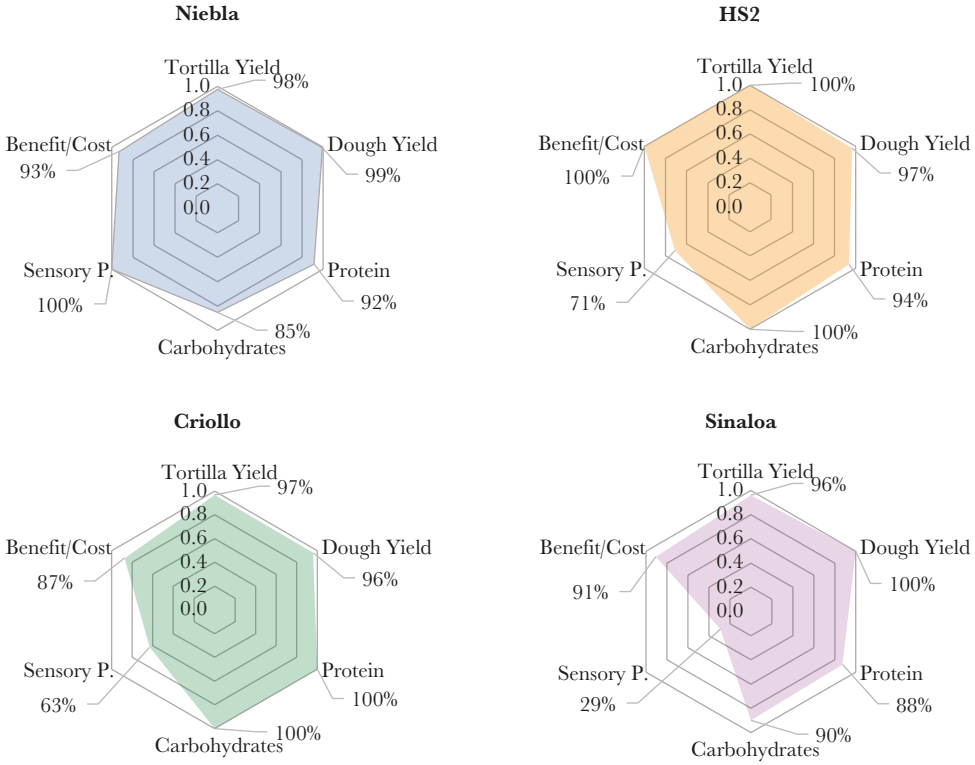


Figure 1. Comparison of the value indicators between the four corn varieties studied.

CONCLUSIONS

This study focused on the generation, analysis, and systematic comparison process of the yield, nutrition, sensory perception, and benefit/cost of tortilla dough prepared with four white corn varieties in Tlaltenango. The results identified HS-2 and Niebla as the two best corn varieties. These findings would help the SCL in the decision-making process and in a responsible investment aimed at the creation of a small company for the transformation of nixtamalized corn into tortillas or the establishment of a *tortillería*. The ultimate aim is to improve the socio-economic conditions of the SCL families. In addition, the balanced nutrients of freshly nixtamalized dough prepared with the HS-2 and Niebla varieties, without commercial corn flour, promotes a healthy diet. Meanwhile, Niebla recorded the best flavor, aroma, and freshness qualifications. However, HS-2 recorded better results regarding texture, flexibility, and reheated. In addition, HS-2 recorded better yield and B/C than Niebla and the other corn varieties. The purpose of this study was to help the SCL to take concrete actions in its consolidation process and to create a company that manufactures and commercializes tortillas. Consequently, the SCL would obtain a better price for its corn grains, avoiding intermediaries and generating a sustainable income with the transformation of corn grains into tortillas. The HS-2 variety is locally produced by the Colegio de Postgraduados and favors endogenous development.

Finally, a 60% HS-2 and 40% Niebla mixture should be evaluated for the preparation of tortillas, because, according to the results of the indicators of this study, they could complement each other in flavor and yield.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Manuel Pastor Bañuelos, Mr. Pepe H., and Mr. Juan Carlos (Tortillón), who opened up the doors of their establishments where they transform corn grains into tortillas.

REFERENCES

Bonvecchio, A., & Fernández, A. C. (2015). Guías alimentarias y de actividad física en contexto sobrepeso y obesidad en la población mexicana. https://www.insp.mx/epppo/blog/3878-guias-alimentarias.html

Boué, C., López Ridaura, S., Rodríguez Sánchez, L. M., Hellin, J., & Fuentes Ponce, M. (2018). Local dynamics of native maize value chains in a peri-urban zone in Mexico: The case of San Juan Atzacualoya in the state of Mexico. *Journal of Rural Studies*, 64, 28–38. https://doi.org/10.1016/j.jrurstud.2018.09.014

Carballo-Carballo, & Regalado-López. (2016). Maíz Híbrido HS-2. *Agro Productividad, 9*(11-b), 54-55. https://revista-agroproductividad.org/index.php/agroproductividad/article/view/894

Colín-Chávez, C., Virgen-Ortiz, J. J., Serrano-Rubio, L. E., Martínez-Téllez, M. A., & Astier, M. (2020). Comparison of nutritional properties and bioactive compounds between industrial and artisan fresh tortillas from maize landraces. *Current Research in Food Science*, 3, 189-194. https://doi.org/10.1016/j.crfs.2020.05.004

Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL). (2023). Informe de Evaluación de la Política de Desarrollo Social en México, 2022. https://www.coneval.org.mx/Evaluacion/IEPSM/IEPSM/Paginas/IEPDS-2022.aspx

Cruz Delgado, D., & Leos Rodríguez, J. A. (2019). La producción de maíz en Sinaloa, México, y sus implicaciones para el medio ambiente/ The Production of Corn in Sinaloa, Mexico and its Implications for the Environment. *Letras Verdes. Revista Latinoamericana de Estudios Socioambientales, 1*(25), 100-118. https://doi.org/10.17141/letrasverdes.25.2019.3705

Escobedo-Garrido, J. S., & Jaramillo-Villanueva, J. L. (2019). Las preferencias de los consumidores por tortillas de maíz. El caso de Puebla, México. *Estudios Sociales. Revista de Alimentación Contemporánea y Desarrollo Regional, 29*(53). https://doi.org/10.24836/es.v29i53.627

Espinosa-Ramírez, J., De la Rosa-Millan, J., Pérez-Carrillo, E., & Serna-Saldívar, S. O. (2021). Assessment of the quality of fresh nixtamalized maize doughs with different degrees of cooking and milling: A comparison of Mixolab and RVA analyses. *Journal of Cereal Science, 102*(103321), 1–8. https://doi.org/10.1016/j.jcs.2021.103321

FAO, Comité de Seguridad Alimentaria Mundial (CSA). (2014). Principios para la inversión responsable en la agricultura y los sistemas alimentarios. www.fao.org/cfs

Figueroa Cárdenas, J. de D., Acero Godinez, M., Vasco Méndez, N., Lozano Guzmán, A., Flores Acosta, L., & González-Hernández, J. (2001). Fortificación y evaluación de tortillas de nixtamal. *Archivos Latinoamericanos de Nutrición, 51*(3), 293-302. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0004-06222001000300013&lng=es

Flores, C., Ponce, P., & Ramírez, P. (2007). Reporte de Investigación 80: Situación del maíz y la tortilla. https://ciestaam.edu.mx/reporte_investigacion/situacion-del-maiz-la-tortilla/

Gaytán-Martínez, M., Figueroa-Cárdenas, J. D. D., De La, M., Reyes-Vega, L., Morales-Sánchez, E., & Rincón-Sánchez, F. (2013). Maize landraces selection for industrial end-use based on their added value. *Revista Fitotecnia Mexicana, 36*(Supl. 3-A), 339-346. https://revistafitotecniamexicana.org/documentos/36-supl-3-A/7a.pdf

H. Ayuntamiento de Tlaltenango, (2022). Plan Municipal de Desarrollo del municipio de Tlaltenango, Puebla, del periodo 2021 – 2024. https://tlaltenango.puebla.gob.mx/docus/docus_nor/DOCUMENTO_NORMATIVO_PLAN_DE_DESARROLLO_MUNICIPAL-1718321917.pdfHernández Sampieri, R., & Mendoza Torres, C. P. (2018). Metodología de la investigación : las rutas cuantitativa, cualitativa y mixta (M. Rocha Martínez, Ed.; 1a ed.). McGRAW-HILL. http://repositorio.uasb.edu.bo:8080/handle/54000/1292

HR Ratings de México (2021). Reporte de Calificación Crediticia del Grupo Minsa, S.A.B. de C.V. Proceso productivo / Industria de Harina de Maíz. https://www.hrratings.com/pdf/Reporte%20Grupo%20Minsa%20Inicial%202021%20sl.pdf

INCMNSZ. (2016). Cuadros de composición de y productos alimenticios alimentos (Versión condensada 2015). Tables of composition of food and food products (Condensed version 2015). (2016a ed.). Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán.

Instituto Nacional de Estadística y Geografía INEGI. (2022). Directorio Estadístico Nacional de Unidades Económicas DENUE. https://www.inegi.org.mx/rnm/index.php/catalog/764/study-description

Latham, M. C. (2002). Nutrición humana en el mundo en desarrollo (Vol. 29). FAO. https://www.fao.org/3/w0073s/w0073s00.htm

Núñez Melgoza, F. J., & Sempere Campello, J. (2016). Estudio de mercado de producción, procesamiento, distribución y comercialización de la cadena de maíz-harina/nixtamal-tortilla en México. En Secretaría de Economía. https://www.economia.gob.mx/files/sipot/318/XLI/2016%20Maiz%20Tortilla.pdf

Ortiz Pech, R., Castillo Caamal, J. B., & García Ceh, G. G. (2020). Análisis de costos para las tortillas de maíz destinadas al autoconsumo y venta en Yaxcabá, Yucatán. Cost analysis for corn tortillas destined for auto-consumption and sale in Yaxcabá, Yucatán. *Agricultura Sociedad y Desarrollo, 17*(2), 233-252. https://doi.org/10.22231/asyd.v17i2.1344

Ramírez-Muñoz, E., Jiménez-Vera, R., & González-Cortés, N. (2021). Rendimiento de nixtamal, masa y tortilla de maíces criollos pigmentados de Perote, Veracruz. *CIENCIA UANL, 24*(107), 22–27. https://hemerotecadigital.uanl.mx/files/original/250/13318/Ciencia_UANL._2021._Ano_24._No_107._Mayo-Junio.OCR.pdf

Rivera Chavira, B., Morales Corral, D., Gómez Méndez, M., & Nevárez Moorillón, G. (2021). Consumo responsable de la tortilla de maíz, una herencia que debemos cuidar. *Temas de Ciencia y Tecnología, UTM, 25*(73), 9-14. http://repositorio.utm.mx:8080/handle/123456789/371

Salinas-Moreno, Y., & Aguilar-Modesto, L. (2010). Effect of maize (*Zea Mays* L.) grain hardness on yield and quality of tortilla. Efecto de la dureza del grano de maíz (*Zea Mays* L.) sobre el rendimiento y calidad de la tortilla. *Ingeniería Agrícola y Biosistemas, 2*(1), 5-11. https://doi.org/10.5154/r.inagbi.2010.08.009

Secretaría de Agricultura y Desarrollo Rural. (2022). Todo lo que debes conocer sobre el Programa Precios de Garantía. https://www.gob.mx/agricultura/es/articulos/todo-lo-que-debes-conocer-sobre-el-programa-precios-de-garantia

Serna-Saldivar, S. O. (2021). Understanding the functionality and manufacturing of nixtamalized maize products. *Journal of Cereal Science*, 99, 103205. https://doi.org/10.1016/j.jcs.2021.103205

Sistema Nacional de Información e Integración de Mercados SNIIM. (2022). Anuario Estadístico, Comportamiento para el Maíz blanco Puebla: Central de Abasto de Puebla. http://www.economia-sniim.gob.mx/SNIIM-AN/estadisticas/e_anuariosgran1.asp?cent=210&prod=OMABLAN&ACCION=Aceptar

Sistema Nacional de Información e Integración de Mercados SNIIM. (2023). Información de Precios de Tortilla en Tortillerías y Autoservicios de México. http://www.economia-sniim.gob.mx/TortillaPorFecha.asp?Cons=D&dest=21&preEdo=Edo&dqDia=1&dqMes=1&dqAnio=2023&aqDia=31&aqMes=12&aqAnio=2023&Formato=Nor&submit=Ver+Resultados

Vázquez-Carrillo, M. G., Martínez-Gutiérrez, A., Zamudio González, B., Espinosa-Calderón, A., Tadeo-Robledo, M., & Turrent Fernández, A. (2020). Estabilidad de rendimiento y características fisicoquímicas de grano de híbridos de maíz en Valles Altos de México. *Revista Mexicana de Ciencias Agrícolas, 11*(8), 1803-1814. https://doi.org/10.29312/remexca.v11i8.1990