Wheat Bread with a Lower Glycemic Reaction Using Creole Maize and Turmeric: A Transdisciplinary Approach

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Abstract: *Adopting a transdisciplinary approach with the agricultural community of San Pedro Potla in the State of Mexico, where diseases such as diabetes are prevalent, it is necessary to propose foods that elicit a lower postprandial response to prevent this disease. This can be achieved by generating nutraceutical staple foods that elicit a lower postprandial response. Based on two agricultural products—Creole maize (CM) and turmeric—this research proposes producing value-added boxed bread with nixtamalized Creole maize and nixtamalized CM and turmeric. All added bread samples had a lower glycemic response, the best results were found for bread samples with maize and turmeric added, which significantly ($p \leq 0.05$) reduced the glycemic response by 14–19%. (2) Regarding phenolic compounds, breads with maize and turmeric showed trends to respect gallic acid reached its highest concentrations in breads prepared with hard yellow maize and turmeric (from 1.55 to 3.6 $\mu g\,mL^{-1}$). These results could be incorporated into nutrition education* *programs that promote the production and consumption of healthy foods in maize-producing communities to prevent diseases such as diabetes. Transdisciplinary research could lead to individual changes with global repercussions.*

Keywords: Transdisciplinary, bread, complexity, nutraceutical, creole maize, lower glycemic response.

1 Introduction

One relevant aspect of transdisciplinarity is its ability to bring us closer to society and diverse communities in rural areas. By working alongside these communities, we can integrate knowledge and methods from various disciplines, as well as people's own empirical knowledge, to address complex problems and develop innovative solutions that are adapted to their socio-cultural and economic context (Scholz, 2020; Hernández et al., 2020). Agricultural-producing communities are one type of community where transdisciplinary research is needed (Francis et al. 2008). Transdisciplinarity is essential for recognizing and valuing the traditional knowledge and ancestral wisdom that producers and their families possess regarding their crops, their region and their environment, as well as their use of natural remedies for the cure of certain diseases. These communities have developed production practices and techniques that have enabled them to survive and thrive in their environment for generations. Their knowledge of the land, climate, flora and fauna is invaluable and has been passed down through the generations.

However, despite this knowledge, agricultural communities still face significant health and nutrition challenges. Diabetes, cancer, obesity and other chronic diseases are becoming increasingly prevalent in these communities. It is important to recognize that education and interdisciplinary knowledge transfer can play a significant role in preventing these diseases, particularly in communities that produce one of the country's staple crops, corn. In the case of diabetes, reducing carbohydrate consumption is recommended, as is avoiding tortillas and bread. This has generated concern and resistance among corn producers and consumers, who work hard to grow the corn and are proud of their harvest and the colors they achieve. Maize is a culturally significant food, even considered sacred by some, and an integral part of daily life for many people in Mexico, particularly in regions where it is cultivated. Rather than eliminating maize from the diet, we should consider how to make use of its nutrients in food preparation and ensure they are suitable for consumption.

For many farmers and producers, tortillas and bread are an important source of energy, so eliminating them from the diet can be a major challenge. It is important to find ways to make these staple foods healthier, such as choosing the most suitable corn varieties, adding nutritious ingredients, or refrigerating them to retrograde the starch.

A transdisciplinary approach to research can help address this challenge by integrating knowledge and methods from different disciplines, such as agronomy, nutrition, health, technology, and ancestral and scientific knowledge. The transdisciplinary approach, based on systems thinking, looks at the whole, but also at the past and present, allowing us to consider the complexity of the system and find innovative and sustainable solutions. In this case, food options are needed that prevent degenerative diseases, which cause so many consequences and a decline in quality of life. Therefore, to consume maize in regions with a high risk of diabetes, it is important to develop consumption alternatives and promote the production of corn with healthier varieties. In this regard, it is important to recognize the importance of traditional medicine and ancestral wisdom that has been developed by corn-producing communities over the centuries, adding other ancestral knowledge from other countries and what science has advanced and today has demonstrated the therapeutic effects of various species is useful. For example, turmeric is a plant that has been used for centuries in traditional Indian medicine (Ayurveda) and traditional Chinese medicine, and its use has intensified in Mexico because of COVID-19. This root has been used to treat digestive (stomach upset, liver), inflammatory (arthritis, pain), respiratory (asthma, allergies), and liver conditions, as well as depression, using its anti-inflammatory and antioxidant properties for chronic degenerative, digestive, and cardiovascular diseases (Niranjan & Prakash, 2008). This research proposes the production of boxed wheat bread with added value by adding nixtamalized flour from Creole maize of various colors produced in the community of San Pedro Potla and the spice turmeric.

1.1 History of Research

Wheat bread, including rolls, baguettes, and other fine bread are of the most consumed bakery products at home (annual per capita consumption worldwide is about 70 kg), made from refined flour with low micronutrient and antioxidant content (Hernández-Aguilar et al., 2010). Wheat bread, including rolls, baguettes, and other fine bread are of the most consumed bakery products at home (annual per capita consumption worldwide is about 70 kg), made from refined flour with low micronutrient and antioxidant content. In addition, the current consumption of white wheat bread, baguettes, white pitta bread and sliced bread in some countries causes an elevated glycemic response and is therefore not suitable for populations with diabetes or at potential risk of developing it (Fardet et al. 2006). This is because they are made with refined flour and contain less fibre, causing the body to absorb sugar more quickly. Therefore, alternatives that enrich nutraceutical properties such as turmeric, or replacing wheat flour with a flour that has a lower glycemic index would be beneficial. Foods with a low or moderate postprandial response are considered favourable for health, especially for the prevention of diseases related to the metabolic syndrome: cardiovascular disease, obesity and type 2 diabetes (Manuzza et al., 2009). In addition, epidemiological studies have also reported that low postprandial response diets may be beneficial for certain cancers. Diets that induce postprandial hyperglycaemia, if followed regularly, could induce insulin resistance and irregularities in pancreatic beta function (Álvarez-Rodríguez et al., 2016).

The postprandial glycemic response to food is modified in several ways, including the speed of chewing food, the shorter the time, the slower the digestion speed, because starches are less exposed to digestive enzymes; shorter cooking time or insufficient cooking makes starches less available to digestive enzymes; cold storage in order to promoted retrogradation of starch, ingredients such as fat and protein to modifies the structure of the crumb, fibre to reduce gastric emptying and digestion, the type of starch in the flour used (Walsh et al., 2022). Research related to the development of new food products and the reformulation of traditional foods by adding bioactive compounds is on the rise and is recognized as a strategy for preventing metabolism-related diseases (Zhu, 2015). The objective of this research is to take advantage of the Creole maize grains of different colours produced in the State of Mexico and obtain nixtamalized flour, which is added and mixed with wheat flour to make box bread in two conditions: 1) box bread with nixtamalized corn flour and 2) box bread with nixtamalized corn flour and turmeric, evaluating the nutraceutical properties through the identification of phenolic acid concentrations, textural characteristics, and postprandial response. The flotation index, hardness and cooking time of the maize varieties and the mean particle diameter and proximal composition of the maize flour used in this research were also characterized.

Nixtamalization is a Mesoamerican culinary process of transforming maize grain into nixtamal and consists of cooking the corn with water and a lime solution (calcium hydroxide), which softens it and facilitates the removal of pericarp (Salinas Moreno et al., 2017). In maize-producing agricultural communities, it could be beneficial to consider strategies for using the nixtamalized Creole maize grain not only to make "tortillas" but also to make bread, thus reducing the postprandial response, since bread is sometimes consumed and is one of the foods with the highest postprandial response. Creole maize has been reported to have nutraceutical properties, such as phenolic acids, and consumption of foods with phenolic acids has been associated with reduced risk of diseases such as metabolic syndrome (Zhu, 2015). However, in Mexican agroecosystems, pigmented varieties with phenolic acids are still cultivated on a small scale (less than 10% of total production), as producers use Creole pigmented maize mainly for their own consumption and not for marketing (Rivera-Castro, 2020). It is important to take advantage of its qualities for consumption by adding it to different foods. In addition to the fact that the amylose in maize can become resistant starch due to storage conditions and reduce the postprandial response (Osorio-Díaz et al., 2011) this makes it a suitable option to be used in time to produce bread for own consumption and/or commercialization.

Furthermore, turmeric has been reported to contain bioactive compounds with antioxidant and anti-inflammatory properties. Some authors have reported a decrease in postprandial response when people with metabolic disorders consumed it before eating any other food (Uchio et al., 2024).

2 Methodology

TD methodology (Hernández, 2018) was used, focusing on the context of the application and based on the current situation of the study community and its problems. The phases applied were 1) Field research, 2) experimental research, 3), impact research, and 4) self-research by participants from the corn-producing community in the dimension of health: glucose response to the consumption of bread enriched with corn and turmeric (Figure 1).

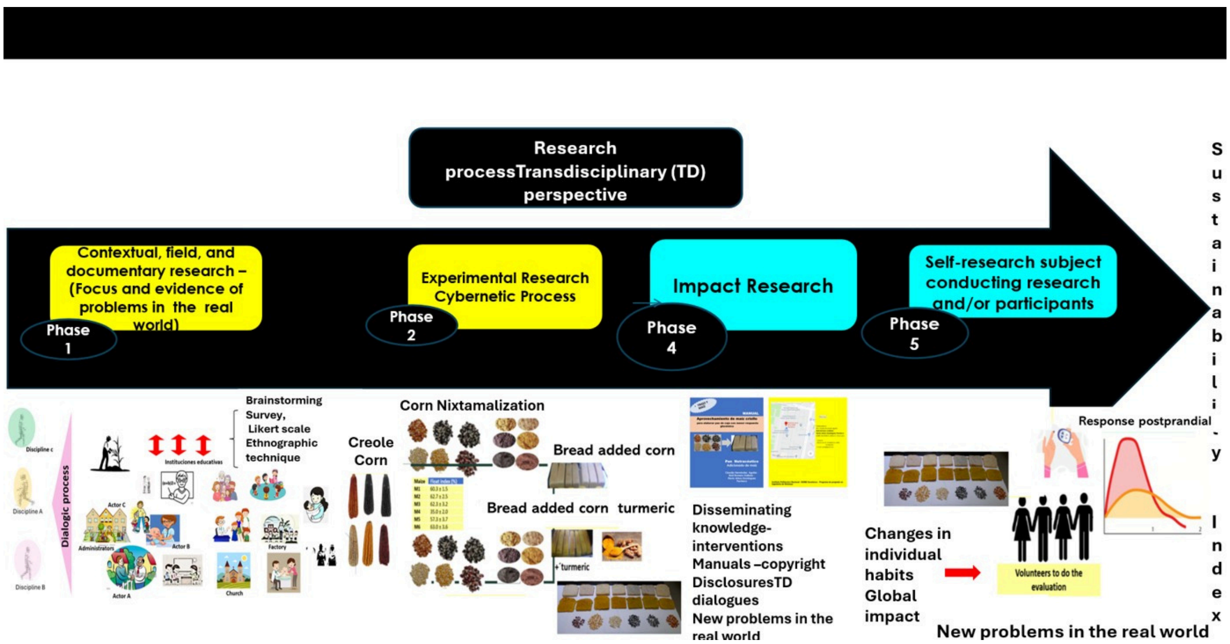


Figure 1: Transdisciplinary methodology used in research.

2.1 Field Research

Field research was based on a questionnaire created in Google Forms (`https://docs.google.com/forms/d/1tQU6Nqt6yjdw5bTMLZJZqybjmNp5e5IUd_1vHxMLWjc/edit`), field visits to encourage sustainable development in the community (group of teachers and students), and ethnographic techniques. Based on this data, an Iceberg Model was developed to represent the causes of problems of diabetes according to what is visible and invisible in the community.

Among the various causes of this disease, which is on the rise in the community and in the country, this research focused on the proposal aimed at the dimension of food for the health of the community. Maize producers in the area provided samples of harvested native corn to characterize its physical dimensions and transform it into nixtamal for use in the production of new food. The flotation index was determined, which is necessary to define the cooking time of corn to be used in the new food product.

2.1.1 Creole Maize and Characteristics

This study was carried out at ESIME-Zacatenco, Mexico City, at altitude of 2240 m.a.s.l., 19.42° North Latitude and 99.12° West Longitude and in the rainfed production system in the State of Mexico "San Pedro Potla", Primer Barrio Ejido, Temascalcingo, Coordenates: 19°50'40.4 "N 99°57'45.6 "W at 2660 m.a.s.l (Figure 2). The following landraces were used in the present investigation: "sweet conical", "conical", "conical", "vandeño", "conical", and "conical" (of different colors). The corn colors were M1 (red: L*a*b* (50, 12, 21), M2 (blue: 37, 2, 0.1), M3 (yellow: 62, 0.5, 5) and M4 (yellow: 63, 2, 23) and M5 (red: 40, 13, 5). The agro-ecosystem develops in a sub-humid climate with dry winters and is currently experiencing long periods of drought. The maize used belongs to the May-November 2020 production cycle.

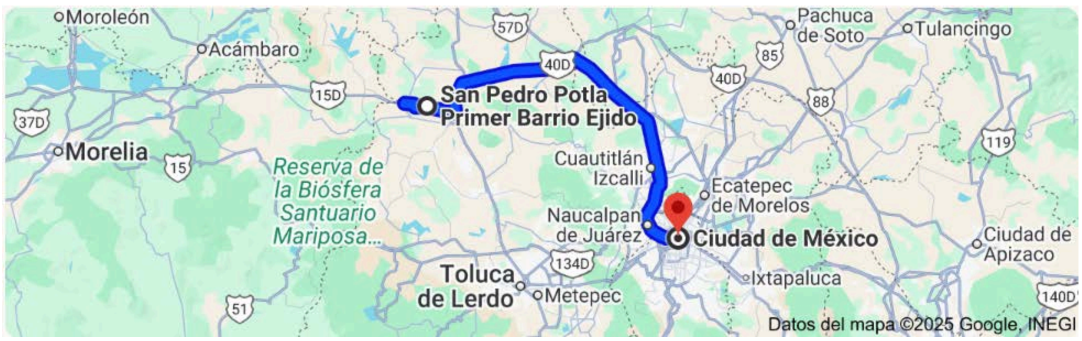


Figure 2: Location of the community of San Pedro Potla, almost 3 h from Mexico City.

2.1.1.1 Flotation Index Hardness and Cooking Time of Maize Grains

In the present investigation, nixtamalized maize used to be added in the preparation of bread, it was necessary to know the flotation index to know the cooking time of the maize, *e.g.* hard maize requires longer cooking time. Then, the maize kernels were cleaned to remove foreign materials, impurities, and broken kernels to evaluate the flotation index according to Abdala et al. (2018) , to establish the cooking time. The flotation index (FI) is one of the methods for measuring the hardness of maize. This method is since hard kernels (compacted starch granules with a higher vitreous endosperm/floury endosperm ratio) are of higher density, therefore, a lower percentage of kernels float in relation to kernels of lower density (NMX-FF034/2-SCFI, 2003) therefore, the number of floating grains is inversely proportional to the density of the kernel (Pérez et al., 2019). In nixtamalization processes, it is indicative of the cooking time; the lower the number of floating grains, the harder the grain, the longer the cooking time required and higher vitreous endosperm. According to the NMX-FF-034/1-SCFI-2002 Norm, the grain is classified as very hard (0-12), hard (13-37), intermediate (38-62), soft (63-87), very soft (87-100) and a cooking time of 35, 30, 40, 35, and 40 min, respectively, is associated with this classification. Thus, the study defined the cooking time of the creole maize grain in the nixtamalization.

2.1.1.2 Nixtamalized Maize Flour and Characteristics

For the process of obtaining the nixtamalized flour, the corn was cleaned to eliminate foreign materials, impurities and broken kernels to evaluate the flotation index according to Abdala et al. (2018), of this way to establish the cooking time. The nixtamalization process was carried out according to the methodology proposed by Valderrama-Bravo et al. (2021). In a 1500 ml solution of water, 5 g of food grade calcium hydroxide (Fermont, Monterrey, Mexico) was mixed. Subsequently, 500 g of maize grains were added and cooked at 90 °C during the cooking time (minutes) calculated M1 (35), M2 (30), M3 (40), M4 (35), and M5 (40); after, the grain allowed to stand for 12 h.

The nejayote was separated and the nixtamal was washed with 750 ml of water, to dry it in an air oven at 55 °C for 24 h. The dried samples were ground in a hammer mill (Pulvex 200, Mexico) with a mesh of 0.8 mm. The maize flour thus obtained were packed in airtight polyethylene bags and stored at 4 °C until use.

2.1.1.3 Nixtamalized Maize Flour and Characteristics

The maize flour was analysed by high vacuum scanning electron microscopy (SEM). The samples were mounted on bronze mounts with graphite tape. The mounted samples were coated with a thin gold film by sputtering to make them conductive and subjected to three rotation cycles of 4 minutes each. The specimens were then fixed and transferred to rail equipment and observed in an electron microscope JEOL JSM-GOGOLV (JEOL, Akishima, Tokyo, Japan) at 20 kV and 270 Pa of high vacuum. The analysis was performed in triplicate. To obtain the particle size, different zones were analysed considering several sizes, large, medium and small. Class intervals were made to consider the number of particles in each class. The arithmetic diameter was then calculated using eq. (1)

$$D_{ar} = \frac{\sum n\, D_{av}}{\sum n_t} \tag{1}$$

Where: D_{ar} = Arithmetic diameter (μm), n = Particles number in the interval, D_{av} = Average diameter in the interval (μm), n_t = Total particles Chemical analysis of maize flour.

Chemical analyses were carried out on maize flour used for the elaboration of bread. The moisture content, ash, protein (N 9 5.85), fat and fibre were evaluated according to AACC (2000) methods 44-15, 08-01, 46-13, 30-25 and 32-07. Total carbohydrate content was calculated by the differential method using the formula: total carbohydrate = 100 - (moisture + ash + fat + total protein + total fibre) according with Sebastian et al. (2023).

2.2 Experimental Research – Proposal for the Formulation of Bread with Added Turmeric and Native Corn

According to the survey conducted and interviews with the population, they showed openness to consuming new foods with a lower glycemic index and nutraceuticals for health care. Thus, the decision was made to develop a basic food product such as sliced bread.

2.2.1 Formulations of Bread with the Addition of Nixtamalized Maize and Turmeric

The bread-making process used in this research was as follows: Yeast and sugar were placed in warm water according to the quantities established in the formulation for fermentation. The yeast is fermented until it sporulates in warm water with 1 g of sugar, a process that involves the activation of the yeast, the breakdown of sugar into pyruvate, and the conversion of this into ethanol and carbon dioxide. Yeast fermentation is a catabolic process of incomplete oxidation that does not require oxygen, while the yeast is fermenting, the solid ingredients are incorporated according to the formulation in the mixer bowl (wheat flour, corn flour, salt), these ingredients are incorporated and then the liquids are added (water with fermented yeast, warm milk, egg and oil), in this way all the ingredients are mixed, once mixed with a large spoon, kneading begins with the mixer for 5 minutes. Once the flour was kneaded, the dough was placed in a previously greased box bread pan. The dough was placed and arranged giving the shape of the container; to cover it with non-stick plastic and let it ferment for an hour. Fifteen minutes before the time was turned on the oven, the non-stick plastic was removed and the pan was covered with its own lid, then it was baked for 50 minutes.

The wheat bread samples were fortified with NxCmF (nixtamalized Creole maize flour) at 10% without and with turmeric powder (TP) at 3% concentration in relation to the amount of flour used (600 g), as reported by Hernández et al. (2022a). Two cases were studied: Case I. Bread fortified with NxCmF. Wheat bread samples fortified with the 5 maize varieties including the control (no maize) (BM0, BM1, BM2, BM3, BM4 and BM5). The ingredients used to make the dough were in percentages (egg (7.21), salt (1.21), sugar (0.57), olive oil (3.46), yeast (0.95), wheat flour to make the wheat bread (control) and wheat and maize bread (85.58 and 77.92%), and finally the percentage of addition of the maize flour (8.95%).

Case II. Wheat bread fortified with NxCmF and turmeric (TP), including a control fortified with TP only (control (BM0-C)) and the others fortified with NxCmF and TP (BM1-C, BM2-C, BM3-C, BM4-C and BM6-C). For the bread formulations, the percentages of the basic ingredients egg, salt, yeast, olive oil and maize were the same as in case I. The formulations varied in relation to the percentage of wheat flour used for the control bread and the bread samples with maize and TP added (77.2 and 75.32); the turmeric added was at (2.6%). The bread samples were baked one after the other until 12 bread samples of a 33x12x10 cm mould were made.

The process consisted of fermenting the yeast (5 min) in 150 g of warm water (30˚C) with 1g of sugar and then incorporating it together with the other ingredients. Everything in the formulation was incorporated and beaten using a spiral hook for 10 min to form the dough; 150 g of milk (30 ˚C) was also added. It was then placed in a mold (box bread) which was greased (with olive oil) and left to rise for about 1 h, covered with a moistened cotton cloth. The 12 bread samples made followed the same process only adjusting the ingredients according to the formulation. Subsequently, the mold was covered with its lid and baked at 180˚C for 50 min, after heating the electric oven (Black & Decker). After baking, the bread was left to cool at room temperature for 2 h and then cut into slices (1.5 cm thick) using an electric knife (Hamilton Beach, type EK08, 121 V, 11 Hz).

Turmeric powder (TP). Turmeric powder was purchased in Mexico City with kosher certification and nutritional information according to the manufacturer's specifications for protein, fiber, carbohydrate, sugar, sodium of 10, 23, 67, 3 and 0 g and energy = 335 Kcal, per 100 g. According to Hernández et al. (2020a), turmeric powder contains 0.002 μg mL^{-1} of synaptic acid and 0.004 μg mL^{-1} of β-resorcylic acid. The concentration of curcumin was calculated to be 2.85 μg mL^{-1} at a wavelength of 430 nm, with a molar extinction coefficient of 55,000 L mol^{-1} cm^{-1} and an optical cell length of 1 cm. The dough was prepared at a concentration of 3% (15 g turmeric) based on the weight of wheat flour (600 g).

2.2.2 Analysis of Phenolic Acids by HPLC of Added Bread (NxCmF and NxCmF and TP)

Extracts were obtained with 50 mg of dry and pulverized material in 1 mL of HPLC grade methanol (Sigma-Aldrich number 36860) at 80%, incubated for 20 min in an ultrasonic bath (BRANSON at Smithkline company 50/60 Hz, mod. B-220, USA) at room temperature (25 ˚C). Crude extracts were centrifuged at 731 g (Eppendorf, centrifuge model 5804) for 10 min according to Meneses et al. (2008) and Irakli et al. (2018). The supernatants were filtered with 25 mm diameter acrodiscs with nylon membrane and 0.45 mm pore size (Titan). These, extracts were immediately injected for HPLC analysis of phenolic acids. The samples were analyzed on a Hewlett Packard® chromatograph mod. 1100 chromatograph equipped with a diode array detector and an Agilent Technologies mod.1200.

The column was a Hypersil ODS HP column with a length of 125 mm and an internal diameter of 4 mm, with a particle size of 5 μm. The mobile phase was distilled water adjusted to pH 2.5 with trifluoroacetic acid (A) and acetonitrile (B) (Bilia et al., 2001). The analysis was performed by gradient: T1 0.10 min (85% A) (15% B); T2 20 min (65% A) (35% B) and T3 25 min (65% A), (35% B), $\lambda = 254$, 280, 330 and 365 nm, column temperature 30 ˚C and flow rate 1 mL min^{-1}. Calibration curves were generated for standards of phenolic acids: sinapinic, β-resorcylic, syringic, chlorogenic, ferulic, rosmarinic, p-hydroxybenzoic and gallic (Sigma-Aldrich®). Interpolations of all extracts were calculated using ChemStation software © Agilent Technologies, Inc. 2004.

2.3 Impact Investigation

2.3.1 Texture Analysis of Bread and Sensory Acceptability

Texture analysis of the 12 maize enriched bread formulations without turmeric (6) and with turmeric (6) including controls (no maize wheat bread samples) was performed using the texture analyser (Brookfield Model CT3 25 K, USA) in a 25 kg load cell. After cutting the bread, 5 slices were taken from the center of the loaf and placed in polyethylene bags for preservation prior to measurement. The analysis was performed for two 20% compression cycles using a generic TA TA25/1000 test kit with a cylinder diameter and length of 50.8 and 20 mm, at a speed of 2 mm/s and 1 g preload. The parameters obtained were hardness, elasticity index, cohesiveness and chewiness for days 1, 2 and 3. Day 1 corresponded to 12 h after baking (at ambient temperature, average 25 °C). Day 2 and 3 bread samples were refrigerated for 24 and 48 h at a temperature of 5 °C.

2.3.2 Sensory Acceptability

Sensory acceptability was conducted using the 9-point hedonic scale (where 1 = Dislike Extremely, 2 = Dislike Very Much, 3 = Dislike Moderately, 4 = Dislike Slightly, 5 = Neither Like nor Dislike, 6 = Like Slightly, 7 = Like Moderately, 8 = Like Very Much and 9 = Like Extremely) (Hernández et al., 2020b). In this study, the participants from the maize-producing community sensorially evaluated the bread according to the given indications. For the evaluation of the bread, each participant was given a questionnaire to fill in the evaluation of each bread they tasted once they had neutralised flavour and aroma (using water and coffee). The attributes to be evaluated were colour, porosity, sponginess, cohesiveness, aroma, chewiness, flavour, and healthy and nutritional preferences and attributes in general. The bread was allowed to cool, then sliced to a slice thickness of 1.5 cm, and placed in hermetically sealed bags (low-density polyethylene) and stored in a refrigerator at room temperature.

2.4 Self-assessment in the dimension of health: glycemic response of participants from the corn-producing community to the consumption of a food product: bread with added maize and turmeric

2.4.1 Postprandial Response

2.4.1.1 Subjects

Ten individual family members of maize growers participated in the study. These included 3 males (1 obese, 1 overweight, 1 normal weight) and 7 females (5 obese, 2 overweight), according to established body mass index ranges (BMI<18.5, underweight; 18.5 <BMI<24.9, normal weight; 25.0 <BMI<29.9, overweight, BMI >30.0; obese) according to Godoy et al. (2020). The average age of the participants was 44 years, and 8 of the 10 participants had a family history of diabetes and were potentially at risk of developing diabetes due to insulin resistance.

2.4.1.2 Glucose Evaluation

Bread was prepared according to the formulations of the 12 types in its two bread cases: 1) added with nixtamalized maize flour and case 2) added with nixtamalized maize flour and turmeric. The glucose test was then performed. Rapid tests were performed by finger prick using a capillary glucose meter, Glucometer /Accu-chek instant (model 963, is a trademark of Roche), a reliable glucometer for patient use according to Oñate and Martínez (2012). It should be noted that people were advised not to eat heavy meals the night before the test. Basal glucose (before eating the bread) and postprandial glucose were obtained from each participant, fasting or with at least 4 hours without food (with prior informed consent), every 30 minutes until 2 hours had elapsed. In this way, postprandial response curves were constructed from the participants' blood glucose data. All participants received the same amount of bread, which was weighed and bagged.

Institutional Review Board Statement: The research did not involve the collection of biological samples or any medical interventions. The glucose test was carried out following training provided by a health specialist, enabling each person to perform the test themselves. Rather than involving sample collection, it involved data collection. Each person was given a glucometer and took their own measurement under the supervision of the medical specialist. No medical or invasive intervention was performed on the individuals. The glucose test did not pose any risk to participants, the amount of food consumed does not put the person at risk of a possible increase in glucose response, but the presence of a health specialist ensured that the test was carried out properly. All tests conducted in this study adhered to rigorous data protection procedures and ethical guidelines in accordance with international standards for sensory testing with human subjects, including ISO 11136:2014 guidelines. The evaluation panel followed pre-established protocols to ensure compliance with ethical standards and data protection regulations.

Informed Consent Statement: All the panellists who participated in the sensory analysis and glucose test gave their consent by filling in the consent form. This consent also certifies that the analysed products do not contain ingredients that are not allowed by national/European legislation. The research belongs to the research project Registration assigned by the SIP: 20254142, endorsed by the SIP (Secretariat for Research and Postgraduate Studies-IPN).

2.5 Statistical and Principal Component Analysis

Once the data were recorded, they were arranged according to the SAS program for statistical analysis, corresponding to the analysis of variance and comparison of means by means of the least significant difference test and the Tukey test for the variables evaluated in this research. The program used was SAS software (SAS Institute, 2008) and Origin (version 2017) and the level of probability used was 5% error. Two principal component analyses were performed. The first principal component analysis was developed on the phenolic acids identified in this research in each of the 12 wheat bread samples added with nixtamalized maize and with nixtamalized maize and turmeric studied. The second principal component analysis was performed on the glucose responses evaluated at 30, 60, 90, and 120 minutes after consumption of the twelve pieces of bread. The analysis was carried out using Project R and Origin (version 2017).

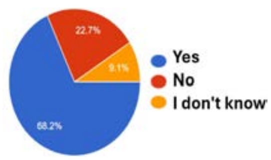
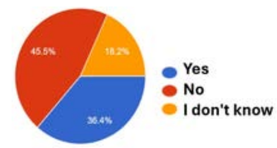
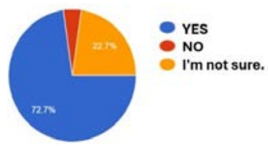
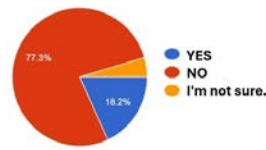
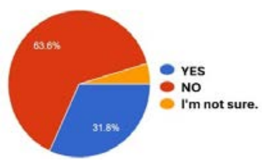
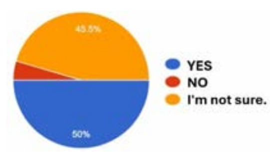
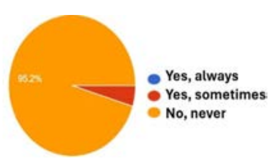
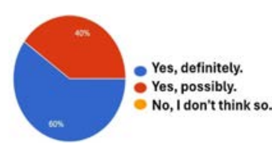
3 Results and Discussions

3.1 Phase 1. Field Research

Based on field research in the community of San Pedro Potla, a tendency to suffer from certain diseases related to diabetes, insulin resistance, cancer, depression, and anxiety was found. When asked if they had relatives with diabetes, insulin resistance, or prediabetes, 68.2% said they had relatives with diabetes, and 36.4% said they had relatives who were at risk of developing it (prediabetes). It is therefore important to take action to halt the increase in diabetes cases and prevent people who already have prediabetes from developing it. One aspect of interest is self-monitoring glucose and knowing the glycemic index of foods. In terms of accepting self-monitoring of glucose and whether they would like to know the glycemic index of bread, corn, rice, and tortillas, more than 70% were interested, as their response was "yes." Similarly, it is important to note that the population is aware of the importance of self-monitoring glucose in people with or without diabetes as a preventive strategy. For both questions, 100% of participants answered that it is important for the population to self-monitor glucose.

It should be noted that the participants evaluated are not aware of the characteristics of their corn in relation to the postprandial response to personal consumption, nor that of others, nor from manuals or nutritionists, nor have they used it as a strategy for choosing corn varieties to plant. However, they are open to learning about and consuming foods with added nutraceuticals, with turmeric being more acceptable to them than spirulina or moringa (Table 1).

Table 1: *Field research results*

Do you have any family members who have been diagnosed with diabetes?		Do you have any family members who have been diagnosed with prediabetes or insulin resistance?	
Would you like to self-monitor your glucose response?		Do you know the glycemic index of bread, corn, tortillas, and rice?	
Do you know which corn colors have the lowest glycemic index or glycemic response?		Do you consider it important to know the glycemic index of foods for diabetics?	
Do you consider it important to know the glycemic index of foods for healthy people as a preventive strategy?		Would you like to eat tortillas, bread, or rice with turmeric added?	
Do you use the glycemic index (GI) to choose the varieties of corn you produce and consume?		Would you like to participate in a workshop on Low GI foods?	

GI: Glycemic index

3.1.1 Iceberg Model

In this regard, based on the survey, community visits, and ethnographic techniques, it is possible to represent the Iceberg Model, which differentiates between the visible (the tip of the iceberg) and the invisible (the submerged mass) to understand the reason for the increase in diabetes, since there are elements that are not visible but are part of the causes of the identified problem, such as i) behavior patterns, ii) structures and systems, iii) mental models and culture, and iv) the vision and purpose of the corn-producing community.

In relation to what is at the tip of the iceberg, *i.e.*, "what people see," the following must be done: 1). Most people in the community do not measure their glucose levels, 2. Consumption of corn is a cultural practice, with white corn being the most popular, followed by blue and red corn, 3. Most people grow white corn for them own consumption, 4. Diabetes is often diagnosed late, 5. Increased incidence of diabetes, more in men than in women, 6. Openness to consuming new staple foods such as bread, enriched with nutraceuticals and corn sprouts. 7. Population mostly open to having their glucose levels measured, 8. Increased insulin resistance, 9. Openness to learning how to make bread enriched with turmeric. So, what we see, then, is that although there is a problem with rising diabetes rates, this is a community that is open to improvement and willing to adopt new foods and habits to improve their health and prevent diseases such as diabetes.

In relation to what people do not see or are not aware of, the following generally occurs in the corn-producing community: I. behavior patterns: 1. lack of awareness about the importance of prevention, 2. Fear of the results, 3. Lack of time or resources to get tested, 4. They do not feel at risk of developing diabetes , 5. They have no symptoms, so they are not concerned, 6. They do not have access to a glucose meter, 7. Test strips are expensive.

On a second level of what "cannot be seen," there are what are known as structures and systems. In relation to this, the following aspects were identified in the community: 1. Lack of access to preventive health services, 2. No education programs on diabetes and prevention, 3. Health systems do not prioritize prevention, 4. No incentives for prevention, 5. Medical care focuses on treating the disease rather than, preventing it, 6. No subsidies or support for the purchase of meters and test strips, 7. No personnel to provide the service free of charge in locations close to the community, 8. No materials purchased for health support by community leadership groups.

Other aspects such as mindset, culture, vision, and purpose are among the factors that may contribute to diabetes and are not immediately apparent, but are part of what needs to be addressed in order to bring about change (Figure 3). In this research, we have chosen to propose to the community a food such as sliced bread with the addition of one of the most representative crops they produce: corn, as well as a nutraceutical ingredient: turmeric. This proposal is based on the hypothesis that it could reduce the glycemic response of wheat bread when consumed. To this end, the next stage of transdisciplinary research is being carried out, which includes the characterization of the corn produced by the community, in order to develop the formulation of nutraceutical bread that is being developed in this research.

3.1.2 Characteristics of Criollo Maize Produced in the Community

Table 1 shows some characteristics of the maize (flotation index, maize hardness and cooking time, proximate composition and mean diameter of maize flour particles) used for the addition to the fortified bread proposed in this study. The statistical analysis shows significant statistical differences ($p \leq 0.05$) between the different maize varieties used in this study. It can be observed that blue (M2) and red (M1 and M5) maize had the highest flotation index (FI) value, with M5 having the highest value (63). Yellow maize (M3) had the lowest value (35). These values allow a classification of the hardness of the maize, since in this agroecosystem the production of hard (M3), intermediate (M4 and M1) and soft (M2 and M5) maize is possible. This parameter is used to determine the cooking time required for nixtamalization of maize. It has been reported that the hardness of maize kernels is a function of kernel structure, specifically the proportion of floury and crystalline endosperm, which is between 83-85% (Salinas Moreno et al., 2010). Hard maize tends to have a higher proportion of crystalline endosperm and a lower content of floury endosperm. Conversely, soft maize has less crystalline endosperm (CE) and morefloury endosperm. Therefore, the higher the percentage of FE

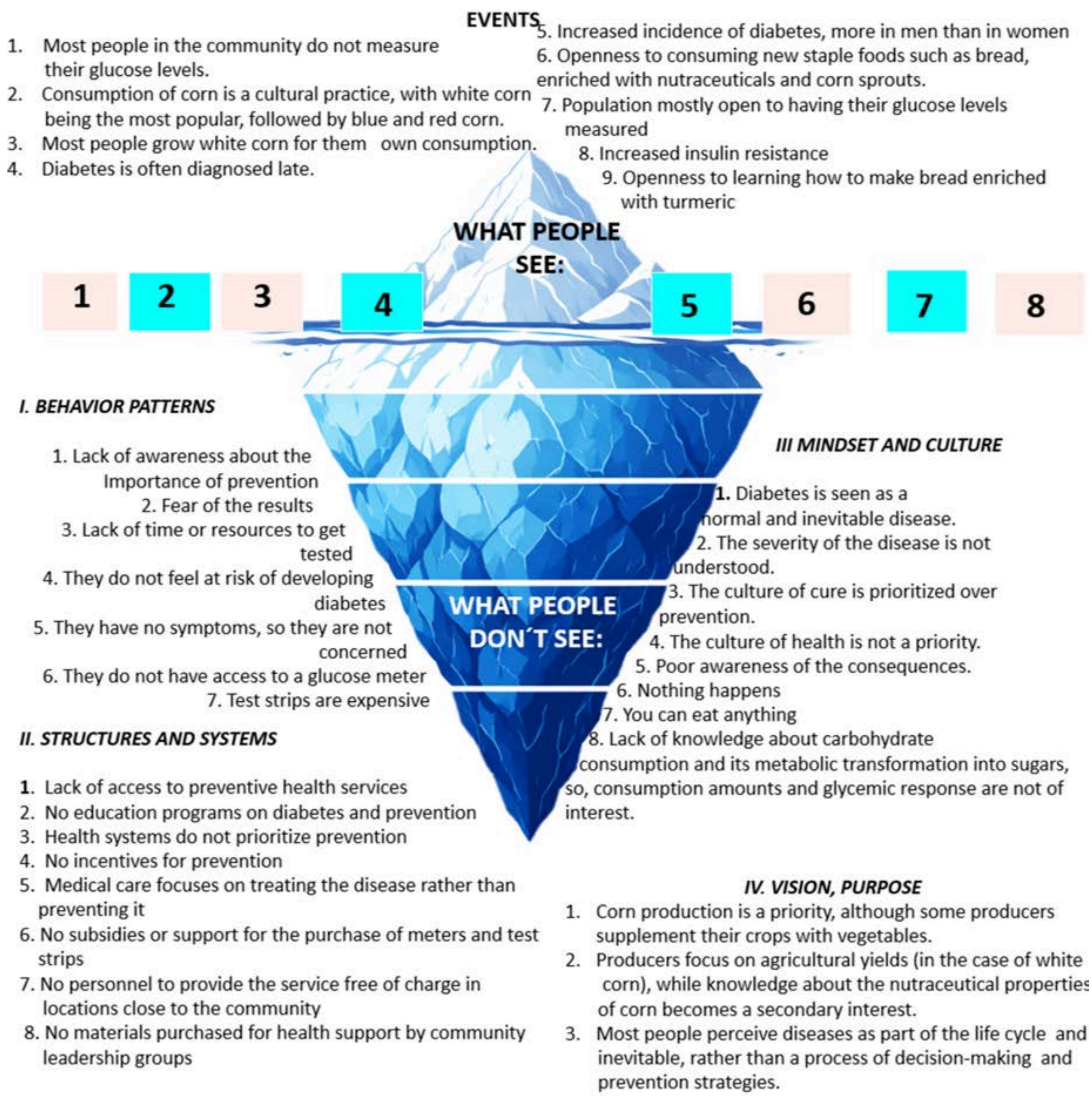


Figure 3: Iceberg Model about the diabetes in community agricultural " San Pedro Potla".

(floury endosperm), the less hard the grain and vice versa (Watson et al., 2003). It has been reported that the FI variable is the most suitable for determining grain hardness; it allows a good distinction between soft, medium and hard maize, soft being more floury and hard being more crystalline or vitreous endosperm (Salinas-Moreno et al., 1992).

The blue race "Tepecintle" was defined by other authors with a flotation index of 35 and was therefore classified as having a hard endosperm. In our case, the agroecosystem of the State of Mexico presented maize with hard endosperm in yellow maize (M4), "raza vendaño" with a similar value. However, in the subtropical regions of the state of Oaxaca, maize varieties with FI (8), classified as very hard endosperm, were found. Hardness is also associated with higher or lower protein and starch content. This is attributed to a higher presence of protein bodies surrounding the starch granules in hard maize compared to soft maize (Carvalho et al., 2010). Starch content is lower in hard maize grains compared to soft maize grains. It has been reported that hard and intermediate maize behave similarly, but not soft maize as mentioned Salinas Moreno et al. (1997). Similarly, hard maize has a higher amylopectin content than soft maize.

This is interesting because, for the preparation of products with a lower glycaemic response (in the case of non-refrigerated products), cereals with a higher amylopectin content are more suitable, i.e. with a higher hardness and lower flotation index, which, according to some authors, is also associated with a higher protein content. Although the cooking time would be longer than the one used in this study, the cooking time for hard maize M3 corresponded to the longest cooking time used in the preparation of nixtamal, which was 40 minutes.

The average particle size of the flour obtained from maize showed a similar behaviour, ranging from 86 to 96.34 μm. The flour obtained from maize M3 was the one with the highest significantly different value of particle diameter, with a difference of 12% with respect to the one with the smallest size (M2). In relation to what is reported in the literature, they are within the values of particle size to be able to elaborate box bread (Table 1). Some authors report that smaller particle sizes cause damage. Particle sizes smaller than 50 µm to have been studied, reporting alterations in the structure of bread and damage to starch (Guan et al., 2020). In our study, all maize samples had a particle diameter greater than 86 μm, with M3 maize (96.34 μm) having the largest particle size.

The quality of flour depends on several factors, including its particle size. Some authors have shown that better baking quality is obtained with medium or fine particles. The effects of particle size have been studied. Flour of different particle size show changes in bread properties, even when the amount of protein is the same (Gracza et al., 1961). It has been reported that maize flour, used in the production of pet food and other products, changes feed texture as a function of particle size (Carvalho et al., 2010). The texture of bread is one of the most important characteristics and has been shown to depend, among other factors, on the particle size, which is also a function of the type of maize added in the production of bread (Carbas et al., 2016). In the present study, the particle size is within the range of sizes that have been shown to have adequate sensory acceptance by consumers. Figure 4 shows different micrographs in columns (a), (b) and (c) at 500, 100 and 50 μm of the maize flour used to make the bread (M1, M2, M3, M4 and M5).

Of this mode, the size of flour particles and differences in distribution can significantly alter the rheology of the dough, gluten development, and bread quality (Biduski et al. 2024). Finer particles tend to increase water absorption and gluten development, while coarser particles can limit these processes, resulting in denser bread with lower volume (Sarkar, 2022). It has been reported that as particle size decreases (43.07 μm to 25.81 μm), damaged starch content increases significantly, as do maximum viscosity, trough viscosity, break viscosity and final viscosity. There is a significant negative correlation between flour particle size and damaged starch content and pastiness temperature, and a significant positive correlation with falling number values (Guan et al., 2020).

Therefore, particle size has an impact on the structure of bread. Some authors have reported that elevated glucose and insulin responses after eating starchy foods (associated with an increased risk of developing various metabolic diseases) could be improved by changing the structure of the food. Eelderink et al. (2015) studied glucose kinetics after consuming two types of bread, 1) compact bread structure and 2) porous bread structure. Consumption of bread with a more compact structure resulted in lower maximum glucose and insulin responses when compared to responses to porous bread. Thus, the structure of wheat bread, which among other factors depends on the particle size of the flour, can influence the postprandial metabolic response, with bread made with a more compact structure being more beneficial to health.

Table 2 shows the parameters obtained from the proximate composition, i.e. dry matter, total moisture, ethereal extract, ash, crude protein, crude fibre, nitrogen-free extract (total carbohydrates). The parameters obtained show a similar pattern of behaviour for the nixtamalized maize flour from each of the maize varieties studied in terms of the variables dry matter (97.02 to 97.65%), total moisture (2.35 to 2.98%), ash (1.07 to 1.73%) and crude fibre (1.32 to 1.91%), since no significant statistical differences were found when

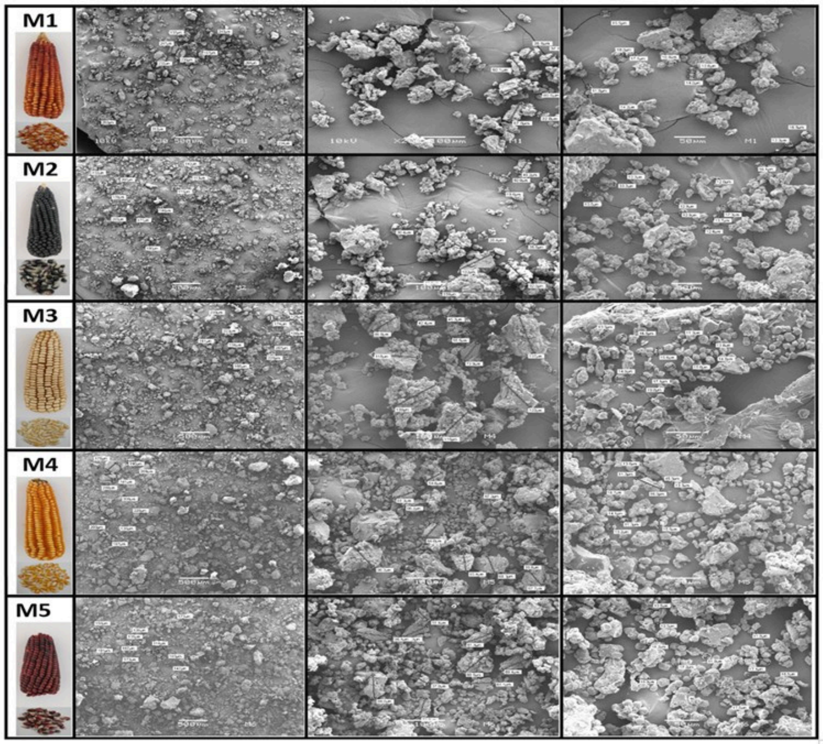


Figure 4: Scanning electron microscopy (SEM) of maize M1 (Conic/dulce), M2 (Conic), M3 (Vandeño), M4 (Conic), M5 (Conic).

they were compared.

On the other hand, there were significant statistical differences for the crude protein and total carbohydrate variables. The maize flour with the lowest amount of crude protein were M2 (8.75%) and M3 (7.47%), and the highest were M4 (10.56%) and M1 (10.51%), with a range of 21% between the highest and lowest values. For total carbohydrates, the values ranged from (74.49 to 80.30%), with maize flour from M3 having the highest amount of total carbohydrates (80.3%), followed by M2 (78.65%). In the case of protein, other authors such as Rivera-Castro et al. (2020) have reported similar ranges in a study carried out in another region of Mexico, where the values obtained for blue and yellow maize ranged from 9.02 to 10.39%. However, for carbohydrates they have reported lower values than those found in this study, up to 62.54 and 65.86% in samples of yellow corn "olotillo" and "dos puntas".

The highest values for carbohydrates (74.47%) and protein (10.61%) were reported for a type of yellow maize called "Toro". In this sense, the authors recommend this type of maize for food processing because of its high carbohydrate, protein and low-fat content. Maize could be consumed with certain recommendations for addition to food, since the high carbohydrate content leads to a higher postprandial response (Ludwig & Jenkins, 2004). However, it should be noted that the carbohydrate values are lower than those reported for wheat used in bread making. Therefore, in the preparation of wheat-based foods, they could be added with native maize to reduce the postprandial response (Carbas et al., 2016). It has been reported in the preparation of bread samples such as "broa" in Portugal. In Mexico, it could be a strategy to take advantage of the Creole maize produced in rural agricultural areas of the country and reduce the postprandial response of bread consumed by the community, where there is a potential risk of developing diabetes (Sansores et al., 2020). However, in the case of maize with a high flotation index, which is associated with a higher amylose content, it can undergo a process of retro-degradation and change its starch into starch resistant.

Table 2: *Flotation index, Hardness, and cooking time of maize and proximal composition of maize flour and mean diameter of maize flour particles.*

Maize breeds	Maize 1 (red)	Maize 2 (blue)	Maize 3 (yellow)	Maize 4 (yellow)	Maize 5 (red)
	Sweet	Conical	Vandeño	Conical	Conical
Flotation index, Hardness, and cooking time of maize					
L^*a^*b	50, 12, 21	37, 2, 0.1	62, 0.5, 5	63, 2, 23	40, 13, 5
Flotation index (%)	$60.3 \pm 1.5ab$	$62.7 \pm 2.5a$	$35.0 \pm 2.0c$	$57.3 \pm 3.7ab$	$63.0 \pm 3.6a$
Hardness classification	Intermediate	Soft	Hard	Intermediate	Soft
Cooking time	35	30	40	35	30
Proximal composition (%)					
Dry matter	97.05	97.65	97.21	97.02	97.06
Total humidity	2.95	2.35	2.79	2.98	2.94
Ethereal extract	7.09	7.14	6.04	9.17	9.17
Ash	1.73	1.44	1.47	1.07	1.51
Crude Protein	10.51	8.75	7.47	9.69	10.56
Crude fiber	1.6	1.66	1.91	1.44	1.32
Nitrogen free extract (Total carbohydrates)	76.12	78.65	80.30	75.65	74.49
Mean diameter of maize flour particles by SEM					
Diameter (μm)	$86.5 \pm 1.6bc$	$86.0 \pm 1.5b$	96.34 ± 1.01^a	$87.44 \pm 1.41b$	$89.75 \pm 1.31b$

Means with different letter in column "flotation index" are statistically different ($p \leq 0.05$). NMX-FF-034/1-SCFI-2002: Grain is classified as very hard (0-12), hard (13-37), intermediate (38-62), soft (63-87), very soft (87-100) and a cooking time of 35, 30, 40, 35 and 30 min.

3.2 Phase 2. Experimental Research: Characteristics of a New Food Product for the Community Based on Locally Grown Maize

Table 3 shows the comparison of the mean values of the phenolic compounds (sinapic acid, beta-resorcylic acid, syringic acid, chlorogenic acid, ferulic acid, rosmarinic acid, p-hydroxybenzoic acid, gallic acid) identified in 12 formulations of bread made with nixtamalized maize and nixtamalized maize and turmeric powder. It can be observed that there were significant differences ($p \leq 0.05$) in the concentration of phenolic acids (gallic acid, beta-resorcylic acid, syringic acid, rosmarinic acid, p-hydroxybenzoic acid) of the bread samples. Among these phenolic compounds, gallic acid and syringic acid were the most abundant. About gallic acid, BM3-C bread was found to have the highest concentration of this phenolic compound (3.639 μg mL^{-1}), with an increase of about 28% compared to BM3 (2.607 μg mL^{-1}) and 58% compared to BM0 (control wheat bread). BM3-C and BM3 are the bread samples with the highest concentrations of gallic acid. Among the bread samples treated with NxCmF, BM5 had the lowest concentration of this phenolic compound.

Thus, wheat bread with the addition of M3 maize, which corresponds to hard maize, increases its concentration of this type of phenolic compound (gallic acid). In general, the bread samples with maize added (BM1, BM2, BM3) tended to increase the phenolic compounds, although without statistical difference ($p \leq 0.05$) compared to BM0 (control). This could be a proof of these phenolic compounds and therefore of the nutraceutical power of the bread with NxCmF added. Although in this study it was found that the bread with NxCmF and TP for the bread samples (BM1-C, BM2-C, BM4-C and BM5-C) there was no significant difference ($p \leq 0.05$) when compared to the bread samples BM0-C and BM0. It is worth noting that these results are in the range reported by Hernández-Aguilar et al. (2022b) who reported a concentration in the range of 1.7 μg mL^{-1} in turmeric bread added at 10%, but the changes were not significant when compared to wheat bread. As can be seen, the addition of TP did not show any tendency to improve the gallic acid content of the bread samples, except in the BM3-C bread. This may be since its molecule becomes unstable during the bread-making process and when it enters synergy with the different characteristics of the maize, in the case of M3 maize, it has the characteristics of a hard, yellow maize, i.e. it is related to carotenoid compounds, the most stable molecules. Among the phenolic compounds measured in the bread samples, gallic acid and syringic acid were the most abundant. Gallic acid reached its highest concentration in BM3-C, followed by BM3, suggesting that the combination of hard yellow maize (M3) and turmeric may favors the retention or formation of this compound during baking. In general, bread samples with added nixtamalized maize (BM1, BM2, BM3) tended to have higher levels of gallic acid than the control bread, while the addition of turmeric showed no consistent effect, except in BM3-C. Syringic acid increased in all bread samples with maize and maize-turmeric combinations, with BM3 showing the highest levels among the maize bread samples. The addition of turmeric slightly enhanced syringic acid concentrations in some formulations (BM1-C, BM2-C).

Although the bread samples baked showed similar concentrations of gallic and syringic acids across different formulations, literature indicates that the original raw materials differ in their phenolic profiles. Several studies indicate that maize generally contains higher total phenolic content than wheat, which often translates into higher concentrations of certain hydroxybenzoic acids, such as gallic acid and syringic acid, in maize flour compared to wheat flour. For example, gallic acid has been reported in maize flour in the range of approximately 1,100–1,268 $\mu g \cdot g^{-1}$, compared to approximately 706 $\mu g \cdot g^{-1}$ in wheat flour in comparative HPLC analyses; syringic acid is also detected in maize but only in minor amounts in wheat (Nikolić et al., 2019). Turmeric (*Curcuma longa*) contains various phenolic compounds (including gallic acid and other hydroxybenzoic acids) and high total phenolic content reported in extracts (Wu et al., 2024). However, when turmeric powder is incorporated at low percentages (3% w/w relative to flour in our formula), its contribution to minor phenolic acids (gallic, syringic) in the final bread is diluted and may be lower than the natural variability among flour and analytical errors. Moreover, the thermal process that accompanies baking and the interactions with the dough matrix can modify the extraction and quantified profiles of phenolic acids, both in free and glycosylated forms, reducing detectable differences between bread types (Chen et al., 2021). The phenolic compound beta-resorcylic acid was not present in the control wheat bread (BM0) and BM1. It was identified in the other maize bread samples (BM2, BM3, BM4, BM5) and in the maize and turmeric bread samples (BM0-C, BM1-C, BM2-C, BM3-C, BM4-C, BM5-C). Interestingly, when turmeric was added to BM0-C and BM1-C bread samples, the presence of this compound was detected, indicating that turmeric contributes to its presence. The highest concentrations of beta-resorcylic acid were found in BM3 (0.215 $\mu g\ mL^{-1}$) and BM3-C (0.209 $\mu g\ mL^{-1}$). Other studies have shown that this compound is absent from wheat bread but can appear when turmeric is added at different concentrations (1.25, 2.5, 5, 10%), though at higher percentages it may decrease, as in bread samples with 10% turmeric (37).

For p-hydroxybenzoic acid, wheat bread showed the highest BM0 value (0.158 $\mu g\ mL^{-1}$) compared to all other bread samples, while bread samples with nixtamalized maize flour (BM4, BM5) and maize with turmeric (BM1-C, BM4-C) also showed relatively high levels. Rosmarinic acid was higher in wheat bread (BM0, 0.121 $\mu g\ mL^{-1}$) than in most maize bread samples (BM1, BM2) and maize-turmeric bread samples (BM0-C, BM1-C, BM2-C). Chlorogenic and ferulic acids were present at lower concentrations across all bread samples.

Figure 5a shows the principal component analysis of phenolic compounds, grouping bread samples into four clusters based on phenolic acid concentrations: I) BM0; II) BM3; III) BM1, BM2, BM4, BM5, BM4-C; IV) BM0-C, BM1-C, BM2-C, BM3-C, BM5-C. Clusters I and II similarities are due to sinapic, hydroxybenzoic, and gallic acids; cluster III shows similarities in beta-resorcylic and syringic acids; cluster IV shows similarities in p-hydroxybenzoic, rosmarinic, chlorogenic, and ferulic acids. BM3 and BM3-C bread samples had the highest gallic acid content. Overall, gallic and syringic acids were the most abundant compounds in the bread samples analyzed, and their levels are influenced by the type of maize and the inclusion of turmeric. Overall, gallic and syringic acids were the most abundant compounds in the bread samples analyzed, and their levels are influenced by the type of maize and the inclusion of turmeric, highlighting the potential for designing functional bread samples with enhanced nutraceutical properties.

It is also possible to observe positive correlations between the phenolic acids: p-hydroxybenzoic acid, sinapic acid, rosmarinic acid, chlorogenic acid and ferulic acid (they form between them angles of less than 90°), there is a negative correlation between -gallic acid and ferulic acid and also between p-hydroxybenzoic acid, sinapic acid and syringic, beta-resorcylic (they form between them angles of more than 90°).

The strongest correlations exist between syringic acid and beta resorcylic acid; and between p-hydroxybenzoic acid, sinapic acid (between the vectors representing the respective phenolic compounds have almost 0°). This makes it possible to visualise the changes in the nutraceutical components (phenolic compounds in the bread with nixtamalized maize flour, corn and turmeric added). It can be said that the bread samples of groups II and III correspond to the bread samples with more gallic acid and syringic acid beta resorcyclic compared to groups I and IV. Bread with maize and maize and turmeric improves the nutraceutical properties of wheat bread.

Among the varieties used, the maize with the best characteristics for the production of nutraceutical bread is M3 maize (yellow), followed by M5 (red) and M4 (yellow), considering only some phenolic compounds. The maize bread with the lowest nutraceutical content was BM1, followed by BM2. However, it can be said that, in general, nixtamalized maize enriches the bread due to the bioactive phenolic compounds it incorporates. Group 4 consists of bread samples enriched with maize and turmeric (BM0-C, BM1-C, BM2-3, BM3-C, BM5-C) and corresponds to those with the highest concentration of p-hydroxybenzoic, rosmarinic, chlorogenic and ferulic acids. Therefore, if the presence of p-hydroxybenzoic, rosmarinic, chlorogenic and ferulic acids is desired, it is advisable to add turmeric. If the presence of gallic, beta-resorcylic and syringic acids is required, only maize can be added.

Table 3: *Phenolic compounds in box bread a) Bread added with maize and b) Bread added with maize and turmeric.*

Treatment	Bread	Sinapic acid	Beta resorcylic acid	Syringic acid	Chlorogenic acid	Ferulic acid	Rosmarinic acid	p-hydroxybenzoic acid	Gallic acid
a) Bread added with maize									
1	BM0	0.707 a	NP b	0.594 b	0.025 a	0.059 a	0.121 a	0.158 a	1.558 b
2	BM1	0.130 a	NP b	0.627 ab	0.026 a	0.060 a	0.114 a	0.114 b	2.133 b
3	BM2	0.068 a	0.108 a	0.642 ab	0.021 a	0.068 a	0.054 a	0.114 b	2.060 b
4	BM3	0.067 a	0.215 a	1.283 a	0.021 a	0.031 a	NP	0.114 b	2.607 b
5	BM4	0.125 a	0.193 a	1.228 ab	0.022 a	0.057 a	NP	0.115 b	1.263 b
6	BM5	0.131 a	0.194 a	1.225 ab	0.019 a	0.061 a	NP	0.117 b	1.123 b
b) Bread added with maize and turmeric									
7	BM0-C	0.133 a	0.195 a	1.227 ab	0.024 a	0.062 a	0.055 a	0.114 b	1.274 b
8	BM1-C	0.129 a	0.195 a	1.232 ab	0.023 a	0.059 a	0.061 a	0.115 b	1.306 b
9	BM2-C	0.148 a	0.207 a	1.253 ab	0.023 a	0.071 a	0.056 a	0.114 b	1.399 b
10	BM3-C	0.127 a	0.209 a	1.270 ab	0.017 a	0.033 a	NP	0.112 b	3.639 a
11	BM4-C	0.125 a	0.195 a	1.228 ab	0.024 a	0.057 a	NP	0.116 b	0.886 b
12	BM5-C	0.131 a	0.196 a	1.228 ab	0.021 a	0.063 a	NP	0.115 b	0.809 b
	R^2	0.48	0.86	0.60	0.32	0.47	0.64	0.77	0.55
	LSD	0.768	0.1555	0.6853	0.2452	0.4045	0.1674	0.0339	1.539

LSD is the least significant difference, and the same letters are statistically equal (Tukey, $p \leq 0.05$). NP is not present. R2 is coefficient of determination, NP is non-presence.

These bioactive compounds have health benefits. The results of epidemiological studies suggest that consumption of foods containing these polyphenols is associated with a reduction in the risk of developing various chronic diseases. The specific health mechanism is related to the reduction of oxidative stress and anti-inflammatory effects (Liang et al. 2015).

Ferulic acid has been reported to have antioxidant and anti-inflammatory properties that protect against external aggressions, such as pollution and UV rays, and internal aggressions, such as stress. Rosmarinic acid with antiviral, antibiotic, anti-inflammatory and antioxidant properties (Petersen et al. 2013). The effects on the postprandial response have also been reported by some authors, in its pure form or with parts of other plants or species. Yanagimoto et al. (2023) reported that chlorogenic acid alters postprandial secretion of gastrointestinal hormones and improves insulin sensitivity. Nutraceutical foods composed of a

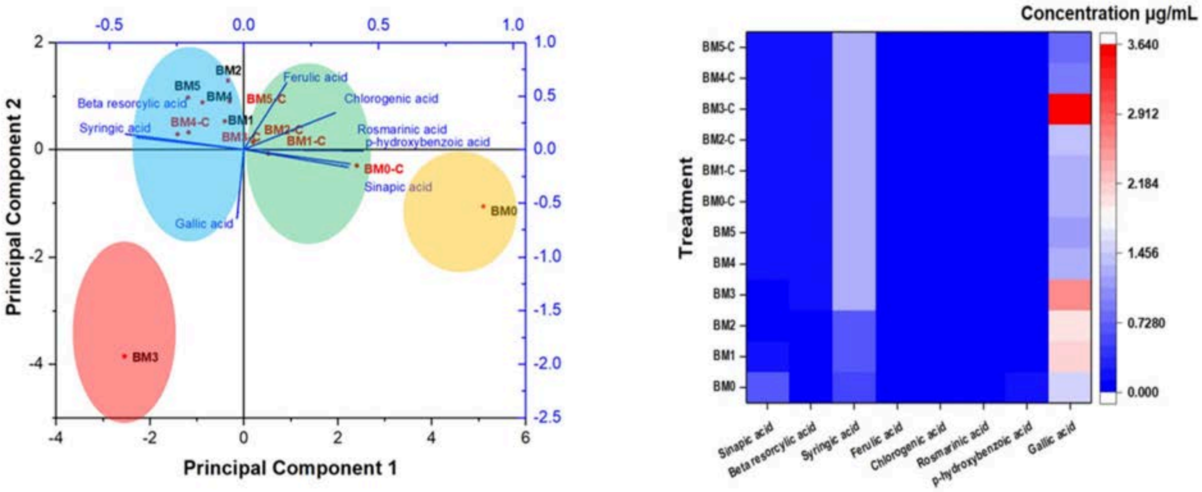


Figure 5: Phenolic acids in 12 types of bread formulations. a) Principal component analysis of phenolic acids in the bread i) added with maize and ii) added with maize and turmeric b) Heat map of magnitudes of phenolic acids (sinapic acid, beta resorcylic acid, syringic acid, chlorogenic acid, ferulic acid, rosmarinic acid, p-hydroxybenzoic acid, gallic acid) in bread a) added with maize and b) added with maize and turmeric.

variety of bioactive compounds have also been used to develop foods with a reduced postprandial response. An additional strategy proposed in this research is the addition of maize and turmeric. It has been reported to contain an active compound that has been attributed with various properties, including antioxidant, anti-inflammatory, antibacterial, antiviral and anticarcinogenic properties (Niranjan, 2008).

In experiments with obese, diabetic and pre-diabetic people, a reduction in postprandial response was reported when consumed before a meal. In addition, after twelve weeks of turmeric consumption, the postprandial response to food was measured and the glucose response was reduced (Uchio et al., 2024).

Mixtures of pepper and turmeric have also been studied; an experiment was carried out in which healthy people consumed turmeric and pepper (1 g each) before eating, and a reduction in postprandial response was found (Khan et al., 2024). In this study, maize and maize and turmeric are incorporated into bread. Adding them to corn to make bread would have a potentiating effect. Many other flours have been used in bread making to reduce the postprandial response (Shakib et al., 2010). Maize is one of the options, although it should be complemented with other elements to achieve a lower postprandial response and reduce the risk of developing diabetes in maize-consuming areas. The most appropriate type of maize, as well as cooking and storage methods, need to be defined. There are reports of a higher postprandial response when compared with wheat bread, which is related to the type of corn used and its processing, preparation and cooking characteristics, as well as the process of retrogradation to which it is subjected. Fibre from maize has been used to reduce the postprandial response when added to beverages, finding that it can reduce the glycaemic response, thus helping to control diabetes, heart disease and body weight.

Figure 5b shows the changes in bread with the addition of maize and maize and turmeric. 1) syringic acid, which has a higher concentration in bread samples BM3, BM4 and BM5 and all of them with turmeric added (BM0-C, BM1-C, BM2-C, BM3-C, BM4-C, BM5-C), 3) gallic acid, which varies according to the type of maize used, with the highest values in BM3 and BM3-C and generally in maize bread samples without turmeric, with the highest values in BM3 and BM3-C and, in general, in maize bread samples without turmeric. 4) In general, synaptic acid, beta-resorcyclic acid, ferulic acid, chlorogenic acid, rosmarinic acid and p-hydroxybenzoic acid have lower concentrations in bread samples. 5) Phenolic acid: synaptic acid decreases in the bread samples fortified with both maize and maize and turmeric.

In this work, the different phenolic compounds of the maize used for bread design are observed. Other authors have considered maize as one of the cereals with the highest content of phenolic compounds according to its colour, which gives maize nutraceutical properties (Salinas-Moreno et al., 2010). Among the possible mechanisms of action that allow the design of foods with a lower postprandial response is the ratio of carbohydrates to polyphenols. Camelo-Méndez et al. (2017) reported that binding interactions between polyphenols and starch influence starch gelatinisation by increasing resistant starch. Lijun and Ming (2019) suggest that bound polyphenols can inhibit digestive enzymes, which contributes to the delayed effect of starch digestion and thus reduced postprandial response. Therefore, maize and turmeric, which are high in these compounds, may be useful in the design of foods for the prevention of diseases such as diabetes.

3.3 Phase 3. Impact Research

The bread was evaluated after 12 hours (day 1) and then refrigerated for 48 hours, with texture measurements taken every 24 hours (days 2 and 3). It was found that the bread changes its textural properties depending on the type of maize added and the length of time it has been refrigerated. Figure 6 shows the textural variables a) hardness, b) elastic index, c) cohesiveness and d) elasticity of wheat bread without (BM0) and with turmeric (BM0-C) and wheat bread with maize (BM1, BM2, BM3, BM4, BM5) and with maize and turmeric (BM1-C, BM2-C, BM3-C, BM4-C, BM5-C). Figure 5a shows the hardness of the bread with maize and with maize and turmeric on days 1 (12 h without refrigeration), 2 (refrigerated after 24 h) and 3 (refrigerated for 48 h). The hardness values (N) of the bread vary according to the ingredients added (maize and turmeric), but also according to the storage conditions applied over the days. In the first measurement (at 12 h), the bread with M1, M2 and M3 maize added showed statistically significant changes compared to the control. The bread with the highest decrease in hardness was the bread with M3 maize (60%). Bread samples added with M4 and M5 maize did not show statistically significant changes compared to BM0. Thus, M1, M2 and M3 maize modify the hardness of bread. In the case of the addition of maize and turmeric, it is possible to observe an increase in the hardness of bread added with M2 (36%) and M3 (55.8%) maize. However, the BM0-C (16.63 N), BM4-C (18.84 N) and BM5-C (20.03 N) bread samples tended to be less hard than the bread samples without turmeric.

The results are consistent with those reported by Hernández et al. (2022a), who added turmeric to bread at different concentrations and reported increases in hardness at different concentrations of turmeric. Hardness changes have also been reported with the addition of maize (Hernández-Aguilar et al., 2022b). This research found that this textural property can be increased or decreased depending on the type of maize. Hardness increased over time for all the bread samples studied, with the greatest increases for corn bread and the smallest increases for corn and turmeric bread.

Reports of hardness reduction with maize range from 24 to 65% according to some authors. It is important to note the importance of the hardness reduction for the shelf life of the product, as some bioactive compounds have been associated with the shelf life of the product and with an adequate hygienic state of the bread. However, on days 2 and 3, when the bread was refrigerated, the increase in the hardness of the bread is noticeable. The percentages of increase in hardness with respect to the first day reach up to 94% increase in the case of the highest increase in hardness, which was the BM1 bread.

Other authors have reported a smaller increase in hardness at room temperature depending on the type of maize added, ranging from 24.5 to a maximum of 63%. In this study, the hardness increased significantly when the bread was refrigerated at 5°C for 12 hours. As regards the change in hardness 24 hours after chilling, the bread with the highest increase in hardness, i.e. the BM1 bread, was modified to more than 200% of its initial hardness on the first day. Thus, refrigeration of bread modifies its hardness. It was exposed to a temperature of 5°C because we wanted to subject the maize added starch to a retrogradation process that would allow us to add aspects for the design of maize added bread samples with a lower postprandial response, as it has been reported that maize starch transforms into a resistant starch type. It is important to note that the bread with the least change in hardness was the BM5 bread, but when M4 (yellow) and M5 (red) maize and turmeric were added, the highest values of hardness change were found, reaching values up to 44 N in the BM4-C and BM5-C bread samples. Bread samples BM4-C and BM5-C with yellow and red maize added. This suggests that the presence of carotenoids from yellow and

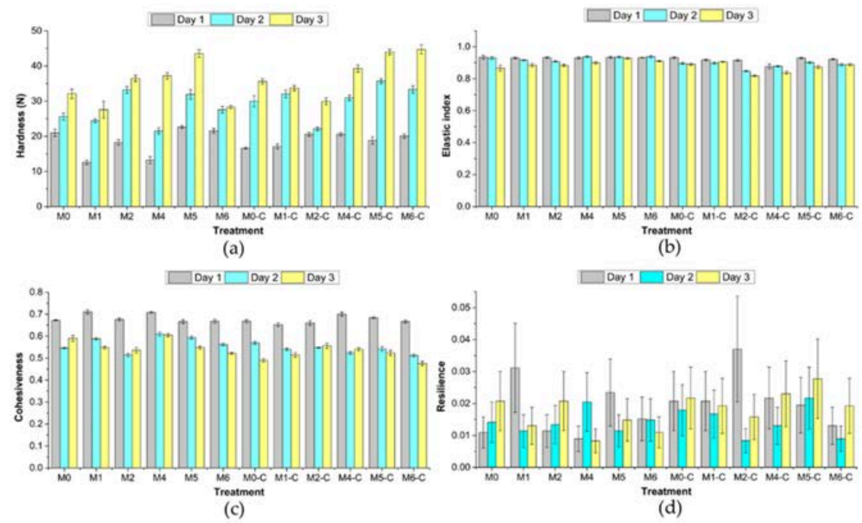


Figure 6: Textural variables a) hardness, b) elastic index, c) cohesiveness and d) elasticity of wheat bread without (BM0) and with turmeric (BM0-C) and wheat bread with maize (BM1, BM2, BM3, BM4, BM5) and with maize and turmeric (BM1-C, BM2-C, BM3-C, BM4-C, BM5-C) on the days 1 (unrefrigerated), 2 (refrigerated by 24 h) and 3 (refrigerated 48 h) of evaluation.

red maize in combination with turmeric increases the hardness of the bread, which is consistent with other reports where the bread was not refrigerated. However, it should be noted that other authors mention that the hardness of wheat bread with added corn increases over time, possibly due to starch retrogradation. In this process, the starch granules react with water, allowing the amylose and amylopectin bonds to become more rigid and retain less available water, which leads to the bread hardening. Maize flour, being rich in starch, can accentuate this effect, especially if its starch suffers significant damage during processing, leading to greater water absorption but with a firmer final texture due to structural disorganization.

The BM2-C bread with M2 (blue) maize and turmeric showed the smallest change in hardness between day 1 (20.5 N) and day 3 (29.9 N). Blue maize has been reported to have anthocyanin content and shelf life extending properties. Regarding elasticity, the data show no significant difference between the maize and turmeric maize bread samples and between the days of refrigeration. The elasticity index obtained is between 0.84 and 0.92, with no significant statistical differences (Figure 6b). These values are among those reported by other authors, who agree that the elasticity is the most stable variable in the added bread. For the cohesiveness, there is a significant statistical difference between the days evaluated, mainly between the first day and days 2 and 3. The highest value of cohesiveness was found on the first day, with a range of values between 0.65-0.71. On the second and third days, the cohesiveness decreased by between 9 and 29% compared to the values obtained on the first day. The maize bread samples with the highest cohesion value on day 1 were BM1 (0.71) and BM3 (0.70), while the lowest value was BM4 (0.66). For the maize and turmeric bread samples, the highest value was BM3 (0.70) and the lowest BM1 (0.65) (Figure 6c). Finally, the resilience, that is the ability of the materials to recover, only BM2-C showed significant statistical differences when comparing its behaviour between the evaluation days, decreasing by 22% (Figure 6d).

The texture variable most affected was hardness. Texture variables, which can be related to potential consumer acceptance, are important to have sensory preferences about what is suitable to eat and help prevent diabetes. It has also been reported by other authors that bread samples with low postprandial response are often not accepted by consumers due to changes in texture, taste, smell, etc. To this end, educational interventions are needed to raise awareness among the population of agricultural communities and to encourage them to choose foods that help prevent disease.

3.4 Phase 4. Auto-Research: Self-Assessment by Community Participants. Glycemic Response to Consumption of Bread Enriched with Corn and Turmeric

Figure 7 shows normalised data of the average blood glucose levels of the subjects before and after consumption of the bread boxes at 30, 60, 90 and 120 min. Each of the bread cases a) wheat bread (control - BM0) and added with NxCmF (BM1, BM2, BM3, BM4, BM5) and b) wheat bread added with turmeric (BM0-C) and, NxCmF and TP (BM1-C, BM2-C, BM3-C, BM4-C, BM5-C) was evaluated. The mean glucose values evaluated at 30 and 60 minutes showed significant statistical differences ($p \leq 0.05$). At 30 min (Figure 6a), the control bread (BM0) is the one that reaches the highest glucose level, while all the other bread samples added with NxCmF and those added with NxCmF and TP tend to reach lower values.

The bread samples with maize added that had the lowest glucose levels when compared to BM0 were BM1, BM2, BM3 and BM5, with a decrease of 9.5, 10.3, 12.5 and 15.8% respectively. The bread samples with maize and turmeric produced lower glucose levels than the bread samples with maize alone. They produced glucose reductions of 16.2, 14.4 and 19.1% respectively, corresponding to bread samples BM1-C (106 mg/dL), BM2-C (108 mg/dL) and BM4-C (102 mg/dL). It is worth noting that the glucose level produced by the turmeric bread (117 mg/dL) was lower compared to BM0 (control - no TP, 126 mg/dL) with a 7% reduction.

Ideally, we would like to achieve a low glycaemic index bread based on corn and other culturally acceptable ingredients that are affordable for low-income populations. This would be a bread like almond bread, which raises glucose levels by 5 to 10 points 15 to 30 minutes after consumption. This is in healthy people, because as we know, in diabetics it can increase. Figure 7b shows the GR at 60 min after bread consumption. The values obtained with BM5, and BMC-1 bread show significant statistical differences when compared with the value obtained with wheat bread (control). There is a tendency towards lower mean glucose values in the bread samples with NxCmF and turmeric powder.

Figure 7c shows the behaviour of the GR at 90 min after consumption of the bread. It is observed that some wheat bread samples fortified with NxCmF (BM1) and fortified with NxCmF, and turmeric (BM-2-C, and BM4-C) have values lower than those of the control samples. Finally, after 120 minutes (Figure 7d), it was observed that BM1-BM3 and BM2-C produced lower values (100 mg/dL or less) than the control bread (110 mg/dL). In this way, it can be said that wheat bread with maize and maize and turmeric can be useful for the agricultural production community to consume bread with a lower postprandial response. As could be observed, wheat bread (without maize or maize and turmeric) caused the highest values of glycaemic response during the duration of the test (two hours). The addition of maize in combination with turmeric powder in the preparation of bread is also suitable for improving (lowering) the glycaemic response.

Previous studies reported by other authors have shown that turmeric reduces plasma glucose and postprandial serum insulin elevation. However, other studies have found no postprandial effects of turmeric use, but working memory was improved in pre-diabetics and diabetics by consuming as little as 1g of turmeric. This study has shown that nixtamalized Creole maize, without turmeric or in combination with turmeric, may therefore be a promising approach for inclusion in staple foods and the development of functional foods designed with the aim of preventing diabetes; because it could reduce the postprandial response and could be consumed in moderation, taking advantage of its properties to make bread and store it refrigerated. Include it in a conscious diet and lifestyle aimed at reducing the postprandial response of the foods consumed. this means reducing wheat flour and adding maize flour, which has a lower overall glycaemic index than wheat flour. The results of this research showed changes in the postprandial response in this study. In other studies, wheat fibre and insulin were added to bread and reduced the postprandial response of participants (15 healthy non-diabetic volunteers) who consumed them.

Figure 7e shows the correlation between the glucose responses obtained at 30, 60, 90 and 120 minutes. These response values are highly correlated, with the highest correlation between the vectors representing the glucose responses at 30 and 90 minutes. It should be noted a classification of 4 clusters, corresponding to similarities in the glycaemic response behaviour of bread after consumption: 1) BM0, 2) BM4, BM0-C, BM3-C and BM5-C, 3) BM1, BM2, BM1-C and 4) BM5, BM2-C and BM4-C. Thus, the control bread

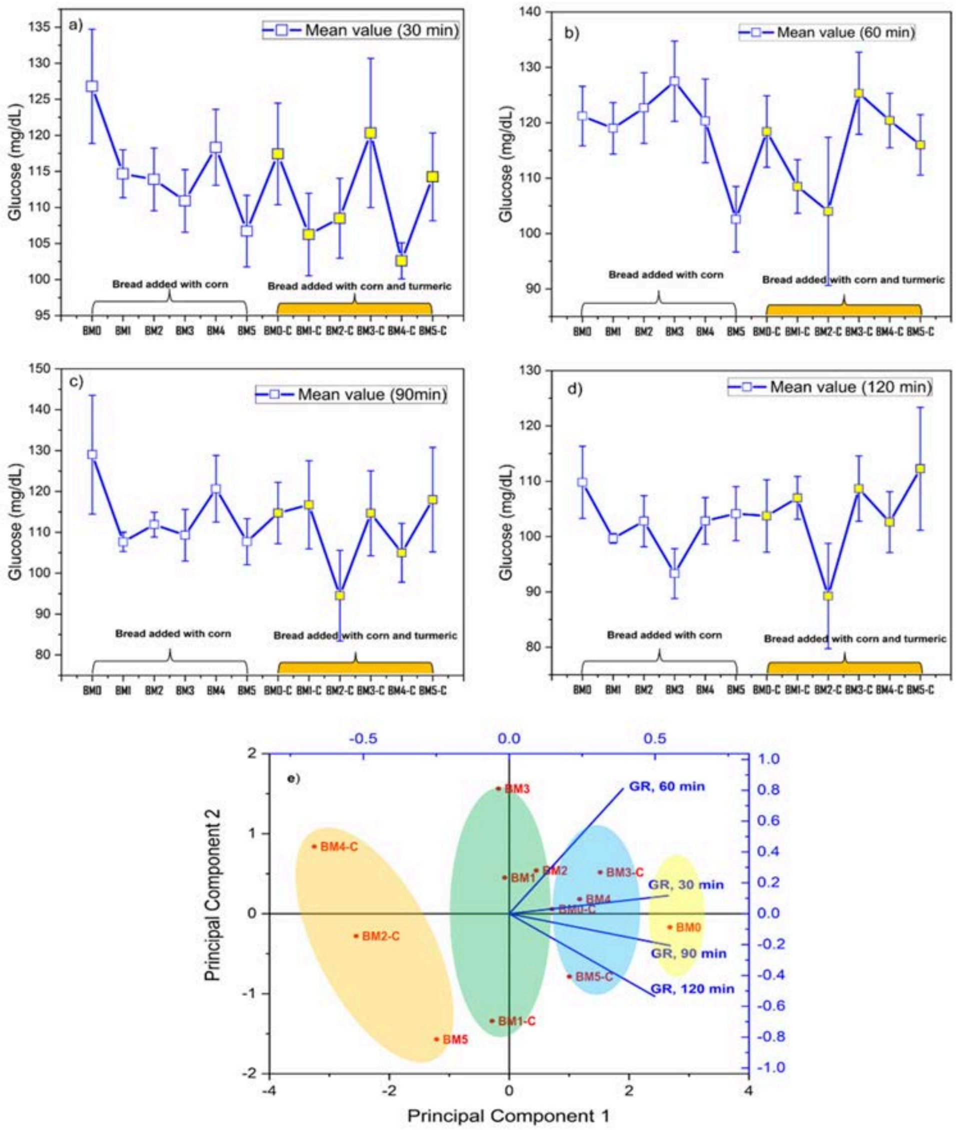


Figure 7: Glycaemic response (mg/dL) after consumption of wheat bread with added maize (a) and maize and turmeric (b) at a) 30, b) 60, c) 90 and d) 120 minutes and e) principal component analysis of the glycaemic response at the different times evaluated in the 12 bread samples formulated.

(without maize and without turmeric) is the least suitable for consumption in a diet that considers the postprandial food response. According to this research, the most suitable formulations for bread design would be using maize type M5 and maize types M2 and M4 in combination with turmeric.

Other authors have demonstrated benefits in terms of improved bread shelf life and quality, as well as nutraceutical enhancement of bread with turmeric (Hernández-Aguilar et al., 2020). This research has shown that Creole maize, grown in the "San Pedro Potla" region of the State of Mexico, could be an ingredient in bread with nutraceutical properties and reduce the postprandial glycaemic response, i.e. without or in combination with turmeric. The postprandial response GR of blood glucose caused by the ingestion of a carbohydrate-containing food or meal is a very important issue considering the diabetes problem and potential risk in the world and in a focused way in different agricultural production agroecosystems in Mexico. These are low-income populations; therefore, it would be difficult for them to acquire low glycaemic index flour, such as almond flour, to produce their staple foods. Eating foods with a lower postprandial response may help prevent metabolic syndrome diseases. GR is a metabolic response of the body to available carbohydrates, i.e. carbohydrates from food that are digested, absorbed and metabolised, resulting in an increase in blood glucose. The trend in the pandemic of diabetes and obesity is to consume foods with additives to reduce this postprandial response. Many authors suggest adding fiber, protein, different flour types, storage, refrigeration, dehydration, etc. In maize-producing populations, educational interventions could be used to teach people how to make better use of their harvests and how to store them. In the case of maize, its ability to be consumed after 24 hours of refrigeration could be used to retrograde the starch and make it resistant starch.

Other authors have prepared tortillas made with floury endosperm maize with a higher flotation index, which was found to increase the amount of resistant starch (Osorio-Díaz et al., 2011). In this study, the bread samples that produced a lower postprandial response were those with a higher flotation index, related to those with a higher amylose content. Storing bread in the refrigerator before testing can cause starch to change into resistant starch (Salinas-Moreno et al., 1992;1997), which could have led to a lower glycaemic response at 30 and 60 minutes. Retrogradation makes starch resistant to breakdown by digestive enzymes and consequently lowers the glycaemic index. According to the literature, these are the times when the maximum glucose levels are expected to occur. Therefore, the maize added to bread and then refrigerated after processing is an appropriate strategy for the use of creole corn in maize-producing agroecosystems.

In our research, bread samples made with high flotation maize, followed by refrigeration of the bread, reduced the postprandial response because of the possibility of starch retrogradation to resistant starch. However, a low flotation maize additive is also suitable for addition to bread as it also reduces the postprandial response by reducing the amylase content. A low-income farmer can use other flour, both maize and other low-cost, high-protein flour such as lentils. They can also add fibre from their vegetable crops to their maize, or even some organic kitchen waste. But if they have maize as part of their agroecosystem, they can use it to make their own bread. However, a bread distributor could buy native maize from Mexican producers and refrigerate the maize-added products designed to before selling them to improve the characteristics to a population with a high incidence of type 2 diabetes mellitus.

Given the increase in diabetes in Mexico and the projections for the year 2040 in countries such as the United States, China and India, it is important to make proposals using native crops from different regions, but with the aim of reducing the postprandial response in different basic consumption products. It is important to make proposals using native crops from different regions, but with the aim of reducing the postprandial response in different basic consumption products. In rural communities, where they often do not have access to the information available in large cities, it is necessary to carry out educational interventions to raise awareness of the importance of knowing the glucose response in foods and, in addition, to provide alternatives to improve them, either nutraceutical or by reducing the postprandial response. This research proposes the use of native maize for this purpose. This does not mean that they should be consumed in excess, but in moderation, as they are still foods with a medium glycaemic index.

The results of the sensory preference evaluation can be seen in Figure 8. In relation to sensory preferences in bread without turmeric, the following results were obtained: the participants in this study showed a preference for BM0 bread in terms of colour, porosity, flavour and general attributes compared to bread without turmeric (Figure 8a). However, in terms of porosity, BM0, BM2, and BM4 bread samples obtained a similar score (5), and the same occurred with aroma, where BM0, BM1, BM2, and BM3 bread samples obtained a similar score. In the variable called general attributes, the most preferred bread samples were BM2 and BM3, followed by BM3, BM4 and BM5. The bread samples with the lowest ratings in the variables of colour, aroma, cohesiveness, chewiness and flavour, and in the use of preservatives, were BM4 and BM5.

When comparing BM0-C and BM0 bread samples, it can be seen that BM0-C bread scored lower on the variables of colour and fluffiness, and higher on the variables of cohesiveness, chewiness, absence of preservatives and nutritional attributes. In this case, the bread samples with the lowest evaluation were

BM4-C and BM5, and the best were BM1-C, BM2-C, and BM3-C. BM3-C bread obtained the best score in fluffiness (7), while BM2-C and BM0-C bread samples obtained the best score in cohesiveness (7). In terms of taste preference, the BM1-C, BM2-C and BM3-C bread samples obtained the same score (5). In terms of general attributes, the corn-added bread samples with the best evaluation in general attributes were the BM1-C and BM2-C bread samples (Figure 8b).

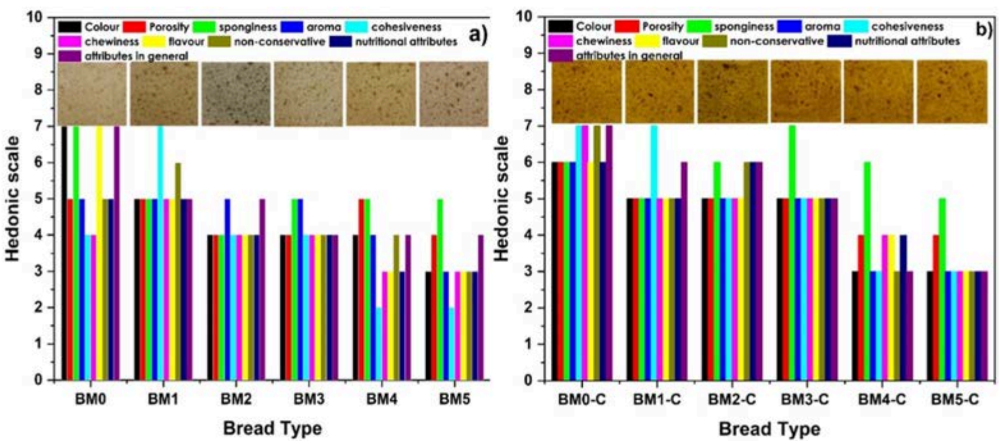


Figure 8: Sensory acceptability of corn and maize bread and turmeric based on indicators of colour, porosity, smoothness, odour, adhesion, chewiness and flavour evaluated on a hedonic scale (1-9).

Prevention of metabolic syndrome-related diseases requires reducing the glycaemic response 'e.g. by: a) reducing carbohydrate intake, b) increasing intake of nutrients that slow gastric emptying (e.g. fats, proteins, viscous fibre and acidity), and c) increasing intake of low postprandial response foods by designing foods that decrease it using bioactive compounds and/or fibre. In this regard, according to the literature, turmeric has been reported to promote insulin secretion and maize has a lower glycaemic index than wheat, as well as secondary metabolites when maize is of different colours. Maize products have a lower glycaemic index (GI) than white rice and bread made from wheat flour and bread made from wheat flour, but even with some processing of the product and addition of various bioactive compounds and fibre, the glycemic response could be lowered as demonstrated in this research in the design of staple foods.

This research proposes, as a relevant fact, to increase the nutraceutical properties of wheat bread added with maize flour and maize flour and turmeric for populations of agro-ecosystems in Mexico, where they can take advantage of their post-harvest maize by adding it as a beneficial product for daily consumption and even be a plus for the sustainable development of their communities, promoting its commercialization and improving their quality of life through their own consumption. Without losing sight of the fact that consumption is moderate, because although it is true that the postprandial response is reduced, it is still a food that should be consumed in moderation.

Consumption of foods with a low postprandial response may be a preventive model for diabetes in developing countries. Post meal hyperglycemia is associated with the development of diabetes, heart disease and all-cause mortality. Therefore, diets that limit glycemic response is beneficial. In this research, we propose to make bread with added maize and maize and turmeric to reduce the postprandial response. Using strategies to add corn, which is a culturally sacred element for the Mexican people, but which, when added and refrigerated, improves properties to be consumed in a staple food such as bread. The design of foods with a low postprandial response is important for countries such as Mexico and others that have a problem of an acute increase in type 2 diabetes mellitus related to dietary habits and a potential opportunity to prevent it. The consumption of foods with a low postprandial response will be important in the coming years for some populations with diabetes and obesity problems.

In this study, the glucose response was assessed every 30 minutes for two hours. However, future research may involve either measuring over a longer period or reducing the time intervals between assessments.

Transdisciplinary methodology, which involves the researcher or participants from the target population conducting self-research, is necessary to address the problem of diabetes. People must realise that making healthy lifestyle choices, such as opting for foods with lower carbohydrate content, will not only improve their own quality of life, but also contribute to achieving sustainable development goals (SDGs 1, 2, 3, 8 and 13), thus increasing the country's sustainability index.

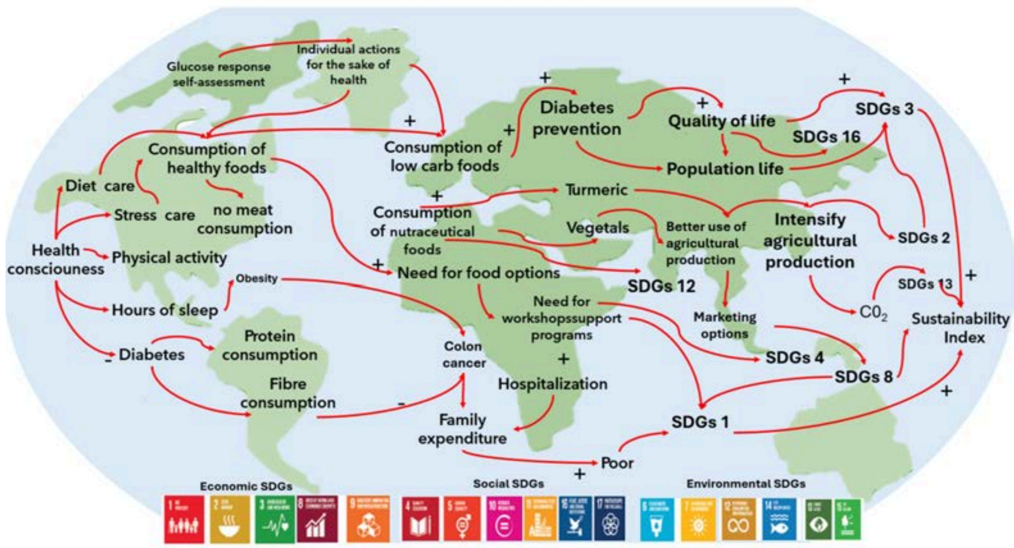


Figure 9: Causal diagram, individual awareness, global impact.

Approaching producer communities requires transdisciplinary work (Hernández-Aguilar et al., 2020a) in which academia comes forward to propose solutions to this sector, which is often technologically neglected, and to carry out educational interventions that improve their quality of life. The maize-producing community has a tradition of consuming it mainly in the form of tortillas; with this proposal, they may have the opportunity to use it in another staple food product. In addition, it is important for them to become familiar with turmeric, as it is used to make products with a medium to high glycaemic index. One of the most significant limitations of the research is that people with prediabetes, diabetes and healthy individuals have different metabolisms.

Therefore, it is not only necessary to promote proposals for new food products or ways of using them, but also to promote a culture of prevention. Prevention should not only be carried out as is customary in some diabetes prevention programmes with metformin, but also by taking care of one's diet and incorporating low glycaemic index products and nutraceuticals, taking advantage of the benefits of their own crops in their respective regions. This would be a trend for future research directions with a transdisciplinary perspective. On the other hand, in future research, bread will need to be stored for longer periods of time to analyse its texture and functional characteristics.

Future work could focus in three directions. The first is the design of low glycemic index bread samples with maize and lentil sprouts, added with turmeric and spirulina or other ingredients rich in fiber and protein. The second direction is aimed at transdisciplinary research, an approach with the community with whom new combinations of ingredients can be co-created with products according to their cultural context to be more easily adopted for consumption, so that ultimately the population consumes nutritious foods of high quality and low postprandial response, making new proposals for bread in accordance with the idiosyncrasies of agricultural populations u others. A third direction would be related to the technology used to make bread to create healthy foods that prevent metabolic diseases, since the structure of bread also modifies the postprandial response. Finally, it is, of course, to develop more transdisciplinary research in agricultural communities that produce corn or other crops. Support, education, awareness and choice and consumption programmes for food of lower glycemic response should be implemented as a strategy for preventing diseases that diminish the joy of living.

It is important to note that transdisciplinary work is required both from researchers and from the target population. Something else that will continue to be required in the future is the training of transdisciplinary researchers and the training and transformation of transdisciplinary trainers. Proposals cannot be incorporated, much less transform quality of life, unless they are part of a set of transformations.

Kurt Lewin said that you cannot change the system if the system does not turn around to look at you. The problem of non-transformation in social systems is due to a need for widespread change. To achieve this, institutions must work hard to encourage systemic thinking and transdisciplinary work (Hernández-Aguilar et al., 2024), providing support throughout the research process and beyond to ensure sustained change. In this way, the co-production of knowledge is essential. However, monitoring by academia and the target population is constant, even after the proposed solutions have been implemented. What could be done to ensure continuity? Research should be oriented toward permanently addressing real-world problems. Each research group and collaborators should focus on a priority sector, but also train new generations to follow up and consolidate changes in study systems.

Some theoretical and practical forms of transdisciplinary research on healing seek to integrate different methodologies through a holistic perspective that encompasses various areas of knowledge, including medicine, philosophy, social sciences, and the humanities (Versluis and Nicolescu, 2018; Martins et al., 2025).

In this research, we see the importance of transdisciplinarity as a way to raise awareness, to have a global impact through individual actions that are necessary for the prevention of diseases such as diabetes, and to enable future generations to improve the quality of life that has deteriorated for many people, causing suffering for both them and their families. Transdisciplinary research could be a process for the sustainability of life and the preservation of joy through preventive actions. In this proposal, choosing and incorporating foods that may be beneficial in your diet, as Hippocrates said, "Let your food be your medicine."

4 Conclusion

Maize bread and maize with turmeric produced a glycaemic response that tended to decrease compared to wheat bread. The percentage reduction in glycaemic response is greater in bread with added maize and turmeric, varying between 14% and 19% depending on the type of maize, 30 minutes after consumption according to the evaluations obtained with the focus group of participants. Future research will need to increase the study population.

The study demonstrates that the type of maize and the addition of turmeric influence both the nutraceutical and functional properties of bread. Incorporating nixtamalized maize and turmeric into wheat bread enhances its phenolic content, particularly certain bioactive compounds, and contributes to potential health benefits such as reduced postprandial glycaemic response. Bread quality, including texture, is generally maintained after baking and short-term storage, with hardness showing the most variation while elasticity remains stable. Among the tested formulations, bread samples made with specific maize types presented the most promising combination of phenolic enrichment and functional properties. These findings suggest that maize and turmeric can be strategically used in bread design to improve its nutritional and functional profile, supporting the development of healthier, value-added bakery products with a lower glycemic response.

Authors' Contribution: Conceptualization and methodology, C. Hernandez-Aguilar; Validation, C. Hernandez-Aguilar, M. Palma-Tenango and M. Soto-Hernández; formal analysis, M. Palma-Tenango; investigation, M. Franco-Colin and R. San Miguel-Chavez, M. Soto-Hernández; data curation, A. Dominguez-Pacheco; writing—original draft preparation, C. Hernandez-Aguilar; writing—review and editing, C. Hernandez-Aguilar; visualization and glucose test, R. Romero Galindo; data analysis, O. Igno-Rosario;

supervision "All authors have read and agreed to the published version of the manuscript. All authors critically revised and edited the text and results, and finally approved the manuscript.

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