Nixtamalization, a Mesoamerican technology to process maize at small-scale with great potential for improving the nutritional quality of maize based foods

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- Abstract -

"Nixtamalization" is the process of cooking maize grains in a lime solution, soaking and washing them, to obtain "nixtamal". Then it is stone-ground to obtain nixtamal dough or *masa*. A variety of products are obtained from it and *tortilla* (flat pancakes cooked in a griddle) is the most popular one. Although maize became a staple crop in numerous African countries, this process has not been commonly adopted in Africa. This paper reviews the technology of nixtamalization and highlights its benefits for possible adoption in African countries.

This technology improves the quality of maize in different ways. From the technological point of view, lime-cooking improves the rheological properties of the dough (elasticity, resistance to tearing and cracking), conferring desired organoleptic characteristics. It significantly increases its calcium content, releases bound niacin and makes it available. Insoluble dietary fibre decreases from raw to nixtamalized maize; however the relatively high levels that remain in the dough are of nutritional significance. Total fat content decreases, but the lime cooking process does not cause changes in fatty acid distributions. Protein quality, as shown by higher protein efficiency ratios (PER) of nixtamal, compared to maize increases. In addition to these nutritional benefits, lime-cooking has also been found to reduce significantly the amount of mycotoxins that are present in maize. Fermentation of nixtamal further enhances its nutritional properties. Being simple and inexpensive, conditions to transfer this ancient technology to Africa could be assessed to contribute to improve the nutritional quality of maize based foods.

Key words: Maize – Nixtamal.

- Résumé -

La nixtamalisation: un procédé mésoaméricain de transformation du maïs à petite échelle présentant un grand potentiel pour l'amélioration de la qualité nutritionnelle d'aliments à base de maïs

La Méso-Amérique est fort probablement le berceau du maïs où il fut domestiqué et devint un aliment de base. Au Mexique, le maïs représente la moitié des aliments consommés et contribue à environ 50% des ingérés énergétiques, cette proportion étant supérieure pour les populations à bas revenus.

La nixtamalisation est le procédé qui consiste à cuire les grains de maïs dans une solution de chaux, à les tremper et à les laver pour obtenir le «nixtamal». Il est ensuite broyé pour obtenir une pâte de «nixtamal» ou *masa*. De nombreux produits peuvent en être dérivés dont la *tortilla* (fine galette cuite sur une plaque chauffée) qui est le plus populaire. Bien que le maïs soit aussi devenu un aliment de base dans de nombreux pays africains, ce procédé n'a pas été communément adopté en Afrique.

Cette technologie améliore la qualité du maïs de différentes façons. D'un point de vue technologique, la cuisson à la chaux facilite l'élimination du péricarpe et l'hydrolyse alcaline libère des gommes du péricarpe et saponifie les lipides du germe, ce qui améliore les propriétés rhéologiques de la pâte (élasticité, résistance au déchirement et au craquelage). La cuisson altère la structure cristalline de l'amidon, et la réassociation des molécules constitutives de l'amidon durant le trempage est importante pour développer les propriétés rhéologiques de la pâte de nixtamal. L'intensité de la couleur, l'odeur et la flaveur sont affectées par la chaux, conférant ainsi des propriétés organoleptiques désirées. La teneur en calcium est significativement augmentée, ce qui est important car les apports de calcium par les produits laitiers sont limités dans les pays en développement en raison de leurs coûts et des problèmes liés à l'intolérance au lactose. Le traitement alcalin libère la niacine et la rend disponible, c'est la raison pour laquelle les civilisations pré-colombiennes ne souffraient pas de pellagre. La teneur en fibres insolubles diminue du maïs brut au maïs nixtamalisé; toutefois les niveaux relativement élevés encore présents dans la pâte sont encore d'intérêt nutritionnel. La teneur totale en lipides diminue, mais la cuisson alcaline n'altère pas la distribution en acides gras. Les protéines du maïs sont de mauvaise qualité à cause de leur concentration limitée en lysine et tryptophane. La nixtamalisation améliore la qualité des protéines, comme l'indique la valeur plus élevée du coefficient d'efficacité protéique (CEP) dans le nixtamal que dans le maïs. Outre ces bénéfices nutritionnels, il a été aussi montré que la cuisson à la chaux réduit significativement la quantité de mycotoxines présentes dans le maïs.

La fermentation du nixtamal améliore ses propriétés nutritionnelles. La fermentation naturelle d'une pâte de nixtamal pour obtenir du *pozol* (une boisson préparée par suspension de la pâte fermentée dans de l'eau) entraîne une amélioration de la qualité des protéines. Dans la mesure où elle est simple et peu coûteuse, il semble intéressant d'étudier les conditions du transfert de cette ancienne technologie en vue d'améliorer la qualité nutritionnelle des aliments à base de maïs.

Mots-clés: Maïs – Nixtamal.

INTRODUCTION

Mesoamerica (a region from Northern Mexico to Honduras and Nicaragua) is very likely the origin of maize[1]. It was cultivated throughout the American continent, but it was only consumed as the main food by the Mesoamerican cultures and at the Southeast of the United States[2]. Maize is capable of adapting to the most diverse ecological conditions, but is not capable of self-reproduction, so it depends on man to perpetuate. It is Mesoamerica where it was domesticated and consumed as a staple food[1]. Maize was also consumed in South America; however its role was never as important as in Mesoamerica[2]. In Mexico, half of the total volume of food that is consumed is maize, which provides approximately 50 percent of the energy intake and this proportion is even greater for lower income groups. A great culinary tradition includes about 605 different foods made with maize[3].

Maize has several nutritional limitations, especially the quantity and quality of its essential amino acids and niacin[4]. It is thought[2] that unless it is prepared by specific techniques, its nutritional value is marginal and any human population that depends on it as a major staple would suffer some degree of malnutrition. Alkali cooking was the main technique used to improve its nutritional value.

Presently, alkaline cooking or “nixtamalization” is widely used in Mexico and Central America to process maize. The traditional process, which is still widely used, consists of cooking maize grains in a lime solution, soaking for 8 to 16 hours and washing them by hand to remove the pericarp. This nixtamal is then stone-ground to obtain nixtamal dough or *masa*. A variety of products (*tortilla* chips, *tamales*, *tostadas*, *tacos*, *enchiladas*, *panuchos*, *sopes*, *atoles*, etc.) are obtained from it and *tortilla* (flat pancakes cooked in a griddle) is the most popular one (figure 1). According to Paredes-López and Saharópulos[5], in rural areas t*ortillas* provide 50% of the proteins and 70% of de calories consumed daily.

Figure 1: *Tortilla* baking at San Cristóbal de las Casas, Chiapas, Mexico.

In the American continent, the societies that cultivate and consume large amounts of maize, use the alkali treatment as a way of softening the outer kernel[2]. The alkali used for cooking can include lime ($Ca(OH)_2$), wood ashes (KOH) and lye (NaOH). Lime use is restricted to Mesoamerica; North American producers use wood ashes and it is not used in South America, except for one community in Venezuela[2]. Although maize became a staple crop in numerous African countries, this process has not been commonly adopted in Africa.

Nixtamalization improves the quality of maize in different ways:

CHANGES IN THE MICROSTRUCTURE OF MAIZE DURING NIXTAMALIZATION

From the technological point of view, lime-cooking alters the microstructure of the outermost layers of maize pericarp, which shows a corrugated-like structure[5]. Surface materials dissolve partially and this facilitates pericarp removal during washing. The aleurone layer remains attached to the endosperm; it behaves as a semi-permeable envelope and might contribute to reduce protein losses. Most of the germ is retained during nixtamal and *tortilla* making process and contributes to the overall nutritional properties of the product. Boiling in lime causes removal of starch granules, so that the soft (inner) endosperm is greatly altered: starch arrangement becomes irregular and some fibrils connect the dispersed starch granules[5]. Important structural alterations, caused by heat denaturation of proteins, cross-linkages produced by unusual aminoacids and disruption of the tertiary structure of proteins occur. The endosperm proteins remain attached to the starch granules; lime cooking changes the physical appearance of protein bodies[6]. Improved digestibility of nixtamal proteins may be due to a better accessibility to them caused by starch gelatinization and changes in the protein matrix[5].

LIME COOKING ALTERATIONS THAT RESULT IN TECHNOLOGICAL IMPROVEMENTS

Alkaline cooking and the steeping step cause water and calcium to be taken up by the grain[7]. The role of lime is important, as it allows faster water absorption and distribution throughout the grain components and it modifies the outer layers, so that the pericarp fraction becomes gummy and sticky[7]. The alkaline treatment degrades and solubilizes cell wall components and this facilitates pericarp removal. Alkaline hydrolysis releases gums from the pericarp and saponified lipids from the germ that improve the rheological properties of the dough (elasticity, resistance to tearing and cracking). Alkali-soluble non-cellulosic wall polysaccharides (mainly arabinoxylan) show interesting functional properties as adhesives, thickeners, stabilizers, emulsifiers and film formers[7]. According to these authors, the presence of germ, which is not lost during nixtamalization, gives more machinability to the *masa*, with a higher tolerance to mixing and less susceptibility to breakdown. So, the traditional process results in *masa* with desirable properties of cohesiveness and adhesiveness. This is attributed to swelling of starch granules, to the presence of fibre gums from the nixtamalized pericarp and of saponified lipids from the germ.

During **steeping**, the grains absorb water and are softened due to the distribution of water[7]. Cooking alters starch crystallinity and reassociation of starch molecules during steeping is important to develop the rheological properties of nixtamal dough. **Grinding** disrupts the grain structure, dispersing cellular components and starch polymers. *Masa* can be considered to be a network of solubilized starch polymers with dispersed, uncooked and swollen starch granules, cell fragments and lipids[8].

According to Gómez et al.[9], swollen and partially gelatinized starch granules in a network of dispersed starch polymers, allows *tortilla* shaping during kneading and gas retention (puffing) during baking. Protein bodies swell, lose their shape and in some cases are physically destroyed during baking or drying[6]. After **baking**, starch granules and endosperm pieces are glued together by amylose, protein, lipids and cell wall components. During the 45-60 sec of baking time, water evaporates from the *tortilla* surface. Granules on the surface are partially gelatinized and more dehydrated; those in the middle are more gelatinized[9]. This results in stretchable and elastic *tortillas* that are resistant to tearing and cracking.

Organoleptic changes brought about by nixtamalization are probably the most important for consumers. Colour intensity, smell and flavour are affected by lime, conferring desired organoleptic characteristics. Lime affects *tortilla* colour and its intensity is related to carotenoid pigments, flavonoids and pH. The development of colour during nixtamalization is more complex, as calcium hydroxide reacts with different pigments[10]. *Tortilla* flavour is enhanced by Maillard browning reactions occurring between reducing sugars and peptides and unsaturated fatty acids.

LIME-COOKING ALTERATIONS THAT RESULT IN NUTRITIONAL IMPROVEMENTS

Dry matter losses occur during lime cooking and steeping and this is a drawback of nixtamalization. Total dry matter losses in commercially processed corn have been reported to be 2.8 to 10.7% between cooking and steeping and 1.6-2.0% during washing. The average composition of the suspended solids in “nejayote” (the cooking, steeping and washing water, which is discarded) was: 64% non-starch polysaccharides (mainly pericarp fiber), 20% starch and 1.4% solids washing[11]. However, the alkaline process induces some significant favourable compositional changes in maize:

Changes in protein content and quality

According to Bressani et al.[12], the protein content of raw maize varies from 9.4 to 10.2%, of cooked maize from 10.0 to 10.6% and of *tortillas* from 9.5 to 11.0%. Regarding lysine and tryptophan, which are the two most limiting aminoacids in maize, the same authors reported that lysine content does not change significantly due to processing (158-166 mg/g N in raw maize to 152-165 mg/g N in cooked maize, to 145-175 mg/ g N in *tortilla*), but lime cooking and tortilla baking decrease tryptophan content in maize from an average value of 38 mg/g of nitrogen in raw maize to 26 mg/g of N in *tortillas*. Another report[2], indicates that there are considerable losses of total nitrogen during the cooking process, but the relative amount of lysine in nixtamal is increased 2.8 times, tryptophan is increased slightly and the isoleucine/leucine ratio increases 1.8 times.

Regarding protein quality, Bressani et al.[12] showed that rats fed a casein diet showed weight gain, food intake and protein efficiency ratio (PER) significantly greater than those for rats fed diets on raw and processed maize, confirming other reports on the low quality of maize protein. However, the beneficial effect of lime cooking was demonstrated, as animals consuming diets made from maize dough and *tortillas* showed a weight gain and PER significantly ($p < 0.01$) greater than animals fed raw maize diets.

Nixtamalization alters the solubility patterns of maize proteins. Lime cooking and *tortilla* baking decrease the solubility of albumins and globulins (salt-water-soluble) and prolamins (alcohol-soluble). This alters the molecular weight distribution of the different protein fractions[13]. Bressani and Scrimshaw[14] showed that cooking with lime selectively enhances the nutritional quality of corn and that this probably results from a relative decrease in the solubility of the zein portion (deficient in lysine and tryptophan) of the corn proteins. This procedure selectively enhances the quality of the corn protein that is available for enzymatic digestion.

Minerals

One of the most important contributions of nixtamalization is the increase in the calcium content of *tortillas*. Serna-Saldívar et al.[13] reported it increases 750%, which is over 85% available[15]. This is relevant, as calcium intake from dairy products in developing countries is limited by their high cost and problems associated with lactose intolerance. Low calcium intake also causes osteoporosis, which affects mainly post- and premenopausic women and elderly men. Nixtamalization also improves the calcium/phosphorous ratio[16]. Martínez-Flores et al.[17] studied the effect of calcium absorption on physical properties and composition of rat femurs, comparing rats fed with raw whole corn (RC), *tortillas* made from extruded *masa* with 0.25% lime content (TEWL) and without lime (TE), and nixtamal *tortillas* (NT). The femurs of rats fed with TEWL and NT were heavier, thicker, and longer, showed greater crystallinity and were more resistant to fracture than the femurs of rats fed with RC and TE.

Phytic acid (*myo*-inositol hexaphospohoric acid), which reduces the bioavailability of minerals, is found in relatively high concentrations in the germ (which is not eliminated during nixtamalization). This is reduced from 8% (when low calcium concentration, 0.4%, is used to nixtamalize maize) to 30-45% (when high, 1.2% calcium concentration is used). This reduction can be attributed to its lability to heat[16]. The same authors reported that the amount of calcium in nixtamal is considerably greater than the amount of phytic acid in the grain, so that this could be easily saturated by calcium. This would prevent iron from binding to it and be available for absorption. They showed that higher calcium concentrations used for nixtamalization led to higher increments in ionizable iron. Soaking time did not affect these parameters.

Bressani et al.[18] evaluated the composition of *tortillas* made by 5 different families and the maize used to prepare them. Besides the increase in calcium content (from 48.3 $\pm$ 12.3 in maize to 216.6 $\pm$ 41.5 in *tortilla*), Ca:P balance improved and Fe (4.8 $\pm$ 1.9 in maize to 7.0 $\pm$ 4.8 in *tortilla*), Cu (1.3 $\pm$ 0.2 in maize to 2.0 $\pm$ 0.5 in *tortilla*) and Zn (4.6 $\pm$ 1.2 in maize to 5.4 $\pm$ 0.4 in *tortilla*) concentrations increased. They proposed these minerals come from the lime or from the containers used to nixtamalize maize.

Vitamins

Maize is deficient in niacin, so a population whose diet consists mainly on maize would be likely to develop pellagra if other dietary constituents were not present[2]. The alkaline treatment releases bound niacin and makes it available[19]; this is the reason why pre-Columbian civilizations did not suffer pellagra. On the other hand, Cravioto et al.[20] reported small losses of thiamin, riboflavin and niacin and a 40% loss in yellow corn *tortillas* carotene during nixtamalization.

Dietary fiber and fat

The nixtamalization process helps to eliminate the pericarp, so insoluble dietary fiber decreases from raw to nixtamalized maize; however the relatively high levels that remain in the dough are of nutritional significance. According to Bressani et al.[12], who studied chemical changes during rural *tortilla* production in Guatemala, dietary fiber of nixtamal dough (9.3 - 9.6%) is lower than that of raw maize (12.2 - 12.8%); however total dietary fiber content of *tortillas* is higher (10.3 - 11.7%), possibly due to the development of insoluble compounds when the maize dough is placed in the hot plate to bake *tortilla*. The same authors reported that total fat content decreases from 4.7% (w/w) in raw maize to 2.8 (w/w) in *tortillas*, but the lime cooking process does not cause changes in fatty acid distributions.

Mycotoxins

The maize grain is frequently invaded by moulds of the genera *Aspergillus, Fusarium* and *Penicillium*. In addition to the nutritional benefits mentioned earlier, lime-cooking has also been found to reduce significantly the amount of mycotoxins that are present in maize[21,22]. *Fusarium verticillioides* and *Fusarium proliferatum* are capable of producing fumonisins and frequently found in corn. Apart from causing animal diseases, human esophageal squamous cell carcinoma has been linked with consumption of fumonisin-contaminated corn. Dombrink-Kurtzman et al.[21] reported that *tortillas* made with naturally contaminated maize contained 18.5% of the initial concentration.

The traditional nixtamalization process has been reported to reduce levels of aflatoxin B1 by 94% and aflatoxin M1 by 90%[22].

INDUSTRIALIZATION OF *TORTILLAS*

Tortilla elaboration has gone beyond the home-made procedure to become an artisanal process, with small "nixtamal mills" and "tortillerías". About 100,000 establishments are dedicated to *tortilla* elaboration[1]. These are small family-type shops, where most of the population goes everyday to get fresh *tortillas*. These places are very important, because of the high preference for ready-made *tortillas*. Important agroindustries have also developed to obtain dry nixtamal flour. In 1996, Torres Salcido[23] reported about 34% of *tortillas* was made in Mexico from nixtamal flour.

Although the use of maize in Mexican cooking has received international recognition, its daily consumption for an important part of the population is a monotonous diet of *tortillas* and beans, which does not provide enough nutrients for a good physical and mental development. Fortification of foods that are generally consumed, as *tortillas*, can benefit most of the undernourished population. In 1997 Mexico established the addition of 7 micronutrients in nixtamal flour: vitamins A and C, riboflavin, niacin, folic acid, iron and zinc, to counteract deficiencies in the diet of the rural population especially. For this reason, fortified nixtamal flour is distributed by the government at subsidized prices[24].

NIXTAMAL FERMENTATION

Fermentation of nixtamal further enhances its nutritional properties. According to Cravioto et al.[25], after natural fermentation of nixtamal dough to obtain *pozol* (a beverage prepared by suspending in water this acidified dough), riboflavin, niacin and protein concentrations increase. Tryptophan and lysine concentrations increased from 0.46 g/100 g protein in maize to 0.71 g/100g in *pozol* and 3.05 g/100 g in maize to 3.96 g/100 g in *pozol*, respectively. The calculated biological value of *pozol* proteins was 66.75%, compared to that of maize (55.60). In accordance with this, protein efficiency ratio values for *pozol* and maize were 1.52 and 1.05 weight increase of rats/g consumed protein, respectively.

Conclusion

The quality of maize is greatly improved by the ancient technology of nixtamalization. It induces favourable modifications in its organoleptic attributes, rheological properties and nutritional value. Being simple and inexpensive, conditions to promote the use of this ancient technology to Africa could be assessed to contribute to improve the nutritional quality of maize based foods. Furthermore, it would be interesting to investigate if such a technology could apply for some other cereals (e.g. sorghum) widely consumed in Africa.

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