Industrial Approaches to Micronutrient Fortification of Traditional Nixtamal Tortillas

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Nixtamalization is the process of steeping dried corn in hot water with calcium hydroxide (lime). The resulting product, called nixtamal, is further processed into tortillas, a staple in the Mexican diet. Corn tortillas are prepared directly from nixtamal, from nixtamalized corn flour, or from a mixture of the two. A technology for adding micronutrients to fresh nixtamal tortillas is discussed. Liquid and dry micronutrient premixes containing iron, zinc, folic acid, niacin, riboflavin, and thiamin were evaluated. Low-cost dosing equipment was adapted for use in small nixtamal mills and enrichment trials were conducted in commercial mills in México. The cost of liquid premix was prohibitive and ferrous lactate in the premix imparted an off-color to the tortillas. In addition, dosing separate vitamin and mineral premixes with the liquid pump proved difficult. The dry enrichment premix utilized electrolytic iron and gave sensory properties similar to unfortified samples. The dry dosification system is readily adaptable in most conventional mills, yields consistent fortification levels in sequential tortilla samples, and results in significant nutrient increases compared to unfortified tortillas. The new technology is commercially feasible and has a minimal cost. Extended production trials are underway to establish the new technology in different parts of México.

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doi:10.1094/CFW-52-5-0240

- Dry fortification enrichment is capable of producing tortillas with sensory properties comparable to control tortillas.
- The method is cost-effective, easy to use, and has minimal impact on the existing process.
- These fortified tortillas contain significantly greater quantities of iron, zinc, thiamin, riboflavin, niacin, and folic acid.
- Dry premix variants using ferric pyrophosphate and electrolytic iron as the iron sources were at statistical parity to the control in all sensory attributes tested.

Diet and Nutritional Status of Mexican Population

The traditional diet among a large segment of the Mexican population in rural and marginal-urban areas is deficient in several key micronutrients. The National Nutrition Survey, conducted by the National Institute of Public Health of México, estimated that iron and zinc deficiencies affect approximately 52% and 33%, respectively, of children under five years of age (14). Iron, zinc, and folic acid deficiencies were estimated to affect 36%, 20%, and 10%, respectively, of children between five and eleven years of age. Additionally, 41% and 39% of women ages 12–49 had iron and zinc deficiencies, respectively. Commenting on the results of this survey, government scientists at the Institute concluded that severe growth retardation and micronutrient deficiencies are serious public health issues in México, particularly in rural areas, in the south, and in Indigenous populations (14).

These micronutrient deficiencies are largely linked to the limitations of the traditional diet among certain segments of the population. On average, corn tortillas represent nearly 50% of individual energy intake in México, with those of lower socioeconomic status having the greatest dependence on tortillas (1). Annual per capita consumption of tortillas in some Mexican groups is higher than 120 kg (3). Although widely consumed, tortillas do not provide the full complement of micronutrients at the levels required for growth, development, and maintenance of the human body. Tortillas are considered an excellent source of calories due to their high starch content; but corn tortillas lack good quality protein and adequate levels of key vitamins and minerals. Significant reliance on tortillas in the diet, without supplementation from other high-quality protein foods, can lead to kwashiorkor in infants due to the lack of two essential amino acids: lysine and tryptophan. The use of quality protein maize or supplementation of regular corn tortillas with beans or other legumes and/or animal products is the best alternative to alleviate protein malnutrition. Inclusion of fruits, vegetables, and meat or dairy products in the tortilla-based diet is also a means of eliminating the widespread micronutrient deficiencies common in many populations. However, many people are economically unable to procure this essential variety in their diet. Consequently, additional dietary intervention is needed to help reduce deficiencies of key vitamins and minerals among those segments of the population that are most at risk.

Impact of Cereal Fortification on Public Health

In the last century, the scientific community has made significant progress towards improving the general health and well-being of the world populace. At the forefront of this progress has been the significant reduction in diseases and physiological defects and dysfunctions related to micronutrient deficiencies. Food fortification programs have been key elements in this fight against micronutrient malnutrition, with flours, breads, and other cereal products serving as the primary vehicles for micronutrient enrichment. The potential benefits of cereal product enrichment were clearly demonstrated in the United States by the dramatic decline in pellagra deaths following the inception of bread enrichment in the early 1940s (13). Even in recent years, the impact of cereal fortification has been seen in the 20–50% decline in spinal birth defects in the United States and other countries resulting from folic acid fortification of cereal products beginning in the 1990s (7). Such a dramatic result in developed countries like the United States and Canada within the last decade is indicative of the potential impact that more extensive cereal fortification might have on a global scale.

In developing countries, enrichment and fortification of staple foods are the most effective ways to upgrade the nutritional status of the population (12). When widely practiced, enrichment improves nutrient consumption, individual work performance, and general public health (12). Micronutrient fortification programs applied to staple foods are among the most cost-effective public health interventions that can be employed (23).

In order for micronutrient enrichment programs to be effective, the food in which the fortifying ingredient is incorporated should be consumed by a large percentage of the population on a regular basis (13). Due to their very high consumption rates in México and Central America, corn tortillas are ideal vehicles for fortification and enrichment aimed at reducing protein malnutrition and micronutrient deficiencies in target populations. A major advantage of such fortification is that it would not require conscious cooperation of the target group in order to be effective. All that is required is for at-risk populations to continue consuming their regular diet.

Micronutrient Fortification of Cereal Products in México

While addition of iron, folic acid, thiamin, niacin, and riboflavin to wheat flour is now mandatory in most Central American countries, cereal product fortification requirements in México are still under development (22). In 1996, a requirement for the fortification of wheat flour with iron and folic acid was introduced in México, specifying addition of 2 mg of folic acid and 35 mg of iron (as ferrous ion) per kilo of flour (18). In September 1998, an effort was made to include additional micronutrients in wheat flour, with concurrent extension of fortification to dry corn masa flour as well. At that time, industry and government representatives in México signed an agreement to fortify wheat and dry corn masa flour with iron, folic acid, and zinc, and to restore the thiamin, niacin, and riboflavin lost during processing (22). Proposed micronutrient addition under this voluntary agreement was 5 mg thiamin, 3 mg riboflavin, 35 mg niacin, 2 mg folic acid, 30 mg iron, and 20 mg zinc per kilo of flour. In 2005, a new federal regulation was proposed, increasing the levels of iron and zinc to 40 mg/kg from specified sources or their bioavailable equivalents (17). Because the existing agreement is voluntary, not all millers participate in flour enrichment. Current practice among participating millers in México is to enrich nixtamalized dry masa flours with 24–40 and 16–26 mg iron and zinc per kg, respectively. With this level of enrichment, corn tortillas made from enriched flour (42% moisture content) will contain approximately 3.5 mg iron and 3.25 mg zinc per 100 g serving. Iron is currently being added in the reduced form and zinc as an oxide. The new 2005 regulatory proposal specifies that iron be derived from a more bioavailable source such as ferrous sulfate or ferrous fumarate. The potentially negative impact on color and stability associated with these more reactive iron sources have led flour industry representatives to push back strongly against this new proposal. Consequently, the Comisión Federal para la Protección Contra Riesgos Sanitarios or COFEPRIS (The Federal Commission for the Protection against Sanitary Risk, essentially the Mexican equivalent of FDA) has incorporated a clause allowing other iron sources to be used as long as they deliver an equivalent bioavailable amount of iron. The latest proposed regulatory requirements for enrichment of wheat flour and nixtamalized corn flour are shown in Table I.

Tortillas as a Vehicle for Micronutrient Fortification

The technology for corn tortilla production was developed by early Mesoamerican civilizations. In present day México and Central America, tortillas are produced using traditional as well as more modern industrial processes. In the traditional process, maize is lime-cooked in clay pots over a fire, followed by steeping for 8–16 h (generally overnight). The alkaline cooking liquor, or nejayote (nay-haw-yo-tay), is discarded and then the cooked maize, which is called nixtamal (nix-tah-mawl) when prepared by this traditional alkaline process, is hand washed with fresh water. Nixtamal is ground into a fine masa with a stone grinder called a mano (mah-no) and metate (may-tah-tay) or with hand-operated mechanical grinders. Masa is hand-molded or pressed into discs, which are baked on a hot griddle or comal. Traditionally made tortillas are generally produced on a daily basis and are usually thicker and heavier than their industrially produced counterparts (9,19). The origins of this unusual nixtamalization process are somewhat of a mystery. However, the end-results of steeping corn in the hot, alkaline medium are altered flavor, color, and texture, as well as chemical changes affecting nutrition—such as increased bioavailability of niacin, increased calcium content, and reduction in some amino acids due to alkaline interactions with the protein (6).

The larger-scale industrial manufacturing process for corn tortillas varies from region to region in México, but essentially follows the same traditional process described previously (see Fig. 1). Cooking and steeping are typically carried out in large steam-fired vats or kettles. Following the steeping process, the nixtamal is drained, washed, and then milled, typically by passing through volcanic grinding stones in an electric mill. The resulting masa is packaged for transport and sale or mechanically formed into tortilla rounds and baked in a triple-pass, gas-fired oven. Industrial manufacturers are divided into three groups: those that produce tortillas exclusively from nixtamalized dry masa flour (lime-cooked, steeped, and ground corn that has been dried and reground), those that produce masa directly from fresh nixtamal, and manufacturers that blend flour masa with fresh masa.

The technology exists—and is now being used—to fortify nixtamalized dry masa flour with vitamins and minerals. However, since up to 67% of corn tortillas are made exclusively from unfortified nixtamal, rather than dry masa flour, a large number of Mexicans are effectively left beyond the reach of current cereal fortification programs (1). Development of an industrial process for fortification of nixtamal tortillas would extend the benefits of micronutrient enrichment to a much larger segment of the population. Consequently, a research effort has been undertaken by SUSTAIN in collaboration with the Instituto Nacional de Salud Publica, Brigham Young University (BYU), and Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), evaluating the potential technical approaches to micronutrient fortification of nixtamal tortillas.

While several researchers have carried out fortification trials with corn tortillas, these have been either dry masa flour tortillas or nixtamal tortillas prepared in small-scale laboratory experiments or limited nonproduction trials in commercial mills (4,5,15,16,21). There remains a critical need to build on this previous experience and develop a viable commercial process that can successfully be used to fortify nixtamal tortillas in a representative, continuous production setting.

Challenges of Micronutrient Fortification of Nixtamal Tortillas

The nature of the nixtamalization process, limited technical resources in most of the small- and medium-size masa mills, and the alkaline pH of the end product make enrichment of nixtamal tortillas a definite challenge. In addition to these technical challenges, there is a long religious and historical tradition in Mesoamerica attributing sacred or divine properties to corn. The ancient inhabitants of México believed that God created the current human race from maize kernels (2). Because of the long tradition of corn consumption, and possibly due to this past connection to the divine, there is often considerable resistance among traditional producers and consumers toward inclusion of additives in the nixtamal tortilla, even when these additives impart significant benefits in shelf life or nutrition.

While some large industrial flour tortilla manufacturing operations exist, the tortilla industry is largely comprised of very small mills producing masa for one or more neighborhood tortillerias. The small size of these operations make their exact number difficult to determine. Consequently, estimates as to the number of nixtamal mills in México vary widely—from 5,000 to 15,000 (1). A 1999 national economic census placed this number at 12,213 corn masa mills country wide (8). Even the larger nixtamal tortilla producers typically have many small mills, rather than a few large manufacturing operations. Mill workers are typically poorly educated, and in some cases illiterate. Furthermore, the tortilla market, though highly competitive, is virtually a commodity market, with very low economic margins. Consequently, in order for a fortification program to be widely adopted by the Mexican nixtamal tortilla industry, the following requirements would need to be met:

1) The fortification process should fit into the existing milling process without requiring significant changes;
2) Fortification should not significantly increase the cost of the manufacturing process or the finished product;
3) The means of incorporating the nutrient premix should be easy to teach, easy to learn, and should be relatively straightforward to carry out in a reproducible fashion;
4) The process should ensure a homogenous distribution of micronutrients throughout the masa;
5) There should be an adequate level of nutrient retention after passing through the milling and baking processes (comparable to tortillas made from fortified, nixtamalized corn flour);
6) The fortified tortillas must meet consumer acceptance requirements (statistically at parity with unfortified tortillas in overall acceptance).

Probably the two biggest hurdles to overcome in developing a feasible process for fortification of nixtamal tortillas are the nature of the nixtamalization process itself and the limited economic means to incorporate sophisticated dosing technology.

The nixtamalization process used on an industrial scale in México is relatively simple and does not require much in the way of equipment. A boiler or gas cooker,

Table I. Proposed micronutrient enrichment levels for nixtamalized corn and wheat flours. Norma Oficial Mexicana PROY-NOM-000-SSA1-2005 (18).

Nutrient	Minimum level of addition in flour (mg/kg)	Recommended source	Function (11)
Folic acid	2	Folic acid	Essential for cell replication and maintenance, especially in infancy and pregnancy; combats neural tube defects; needed for DNA and RNA synthesis; required for synthesis of normal red blood cells; associated with improved cardiovascular benefits in adults.
Iron	40	Sulfate or fumarate[a]	Essential component of proteins and enzymes; involved in oxygen transport, regulation of cell growth and differentiation, proper immune response.
Thiamin	5	Thiamin mononitrate	Helps convert carbohydrates into energy; essential for the functioning of the heart, muscles, and nervous system.
Riboflavin	3	Riboflavin	Essential for function of other B vitamins; important for body growth and red blood cell production; helps release energy from carbohydrates.
Niacin	35	Nicotinamide	Assists in functioning of the digestive system, and development and maintenance of skin and nerves; important for the conversion of food to energy.
Zinc	40	Zinc oxide[a]	Supports a healthy immune system; needed for wound healing; helps maintain sense of taste and smell; needed for DNA synthesis; and supports normal growth and development during pregnancy, childhood, and adolescence.

[a] It is permissible to use other sources of iron and zinc as long as the amount added delivers a bioavailable amount equivalent to the recommended sources.

a cooking vat (with or without agitators), a steeping tank or tanks, a grated hopper for washing, and a grinding mill are the standard pieces of equipment. Some mills also utilize an auger to transfer washed nixtamal from the wash hopper to the mill hopper. Clearly, none of these pieces of equipment is specifically designed or suited for incorporation of a micronutrient enrichment premix. Furthermore, the process is an entirely wet process from start to finish. Incorporation of micronutrients at any process stage prior to washing would have limited efficacy as the majority of the added nutrients would be lost on draining of the nejayote and subsequent washing. Furthermore, the hot, alkaline medium would negatively impact vitamin stability. Tovar and Larios-Saldaña (21) investigated iron and zinc addition during nixtamalization, where the minerals were mixed with the lime and added during the cooking step. Actual increases in iron and zinc were 5–10 times lower than expected theoretical increases. Obviously losses of more labile, water-soluble vitamins would be even greater. A means of incorporating an enrichment premix into the product somewhere between the washer hopper and packaging of the tortillas seems to be a more suitable approach to enrichment of nixtamal tortillas.

In order to achieve a homogenous distribution of micronutrients in the final product, a mixing or distribution step is required. However, it is clear from the flow-diagram in Figure 1 that there is very little mixing equipment available beyond the initial cooking tank at the beginning of the process. Many mills also have a small stand-alone paddle mixer for making masa from flour or for blending in other ingredients for specific clients. A paddle mixer could be used to blend a micronutrient premix with washed nixtamal or masa. However, not all mills have these mixers. Furthermore, the small batch size accommodated by these mixers would slow the throughput of the mill to such an extent that it would not be practical. Additionally, some millers have indicated that an additional 10–15 minutes of mixing in a paddle blender (the amount of time potentially needed to give good nutrient homogeneity) would have a negative effect on the texture of the masa, making it excessively sticky. As part of the preliminary research leading up to the study reported here, the authors used a paddle blender to incorporate premix into whole nixtamal prior to milling. This method of enrichment resulted in a gummy texture in the nixtamal, which impeded its ability to flow well into the grinding stones (unpublished preliminary work by authors). The only other potential mixing elements in the process flow are the auger used to transfer nixtamal from the wash-hopper to the mill-hopper and the auger in the bottom of the mill-hopper that feeds the grinding stones. Previous efforts by one tortilla equipment manufacturer to incorporate additives into nixtamal using an elevated feed auger have not been successful. Powder additives tend to cake on the auger housing and liquid additives tend to gravity flow with residual water back into the washer-hopper (Alfredo Juarez, 2004, personal commun.). Incorporating enrichment premix into nixtamal in the auger feeding the grinding stones appears to be the most feasible approach for enrichment in the typical milling process. This method of enrichment would be semi-continuous and would not unduly impede production throughput.

Another approach further downstream in the process would be application of a dry or liquid micronutrient premix to the surface of the tortillas before or after baking. However, the potential for development of off-flavors and colors on the exposed surface, the potentially significant vitamin loss that would take place in the oven due to direct contact with the heating surface (the tortilla is normally flipped twice during baking), and the negative impact on shelf-life that might result from spraying a liquid onto the tortillas prior to packaging are all concerns with this general method of application.

Following due consideration of all of these potential methodologies, the best mechanized approach for enrichment of

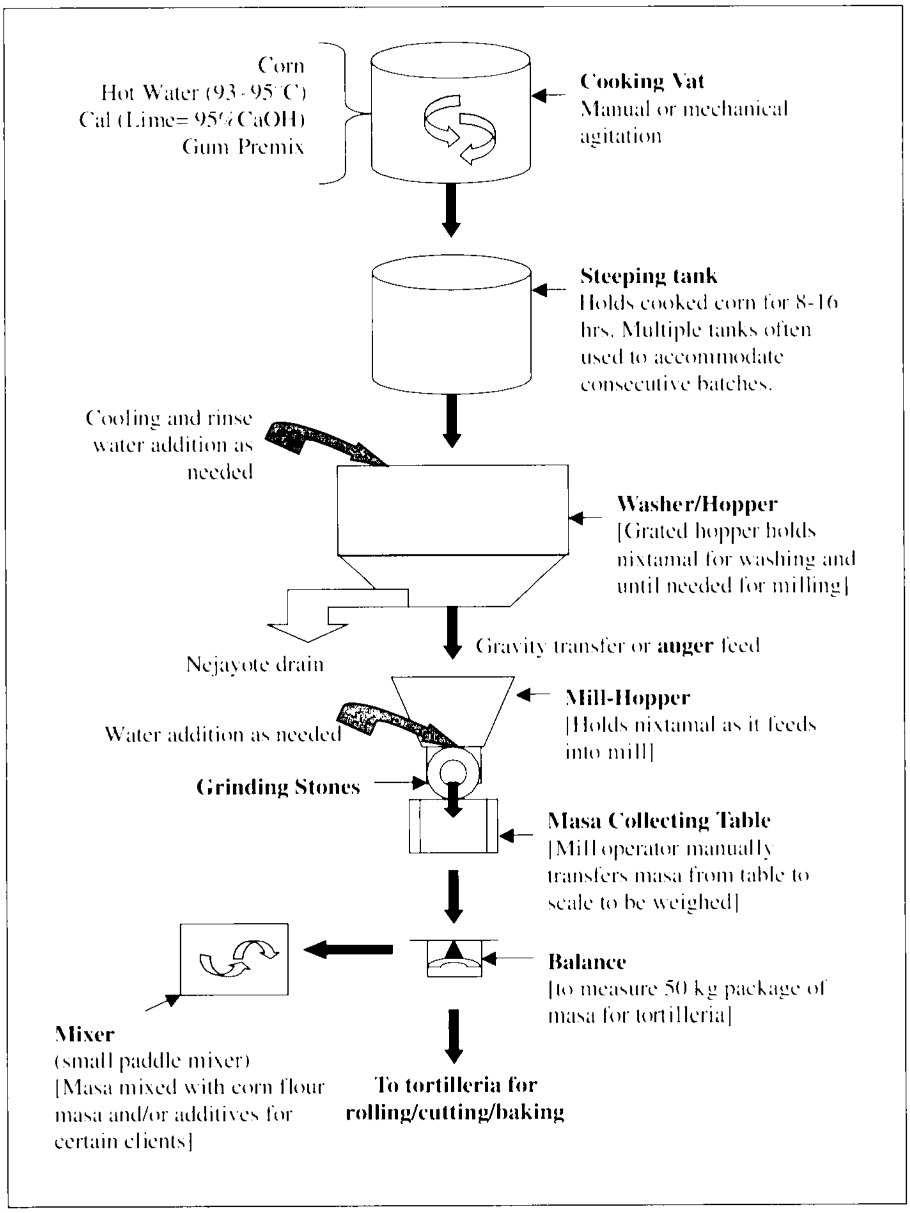

Fig. 1. Typical industrial nixtamal tortilla process in México.

nixtamal tortillas would appear to be a dosification system that incorporates a liquid or powder premix into the nixtamal feed stream as it passes into the grinding stones during milling. The remainder of this article presents preliminary results of efforts that have been made to commercialize this approach to fortification of nixtamal tortillas.

Commercial Fortification Trials in México

In 2004, SUSTAIN initiated a research program to address the technological barriers to fortification of tortillas produced from fresh nixtamal or masa. This work was undertaken in partnership with Brigham Young University (BYU) and the Centro de Investigación en Nutrición y Salud (CINyS) (Center for Research in Nutrition and Health) of the National Institute of Public Health of México (Instituto Nacional de Salud Pública), in consultation with scientists and industrialists from the Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán (INCMNSZ), the Consejo Empresarial del Maíz y sus Derivados (an association of nixtamal and tortilla producers in México and neighboring states), ITESM, and specialists representing the micronutrient premix and tortilla milling sectors.

To provide broad-based guidance to the project, CINyS and SUSTAIN convened a working group made up of representatives of both the flour and nixtamal corn tortilla industries, as well as ingredient suppliers, nutritional premix manufacturers, food scientists, nutritionists, and government officials. This group provided valuable input and review during development of a research protocol by the principal investigator from BYU. The working group met periodically in México City to review technical issues and discuss project strategies. Ultimately, the working group endorsed evaluation of dosifiers for incorporation of dry or liquid micronutrient premixes into nixtamal prior to grinding. A third approach, involving the use of highly fortified masa flour, was recommended in those mills blending fresh masa (from nixtamal) with flour masa.

Suitable dry and liquid premixes, based on Mexican government fortification objectives for corn flour, were developed with support from DSM Nutritionals México, one of the leading vitamin and mineral premix manufacturers operating in México. Micronutrient levels were in keeping with the proposed regulation for masa flour previously detailed in Table I, with adjustments made for the higher moisture content of the masa (see Table II).

Development of a stable liquid premix was hindered by incompatible solubilities and negative interactions between the vitamins and minerals, leading to precipitation and vitamin degradation. Of particular concern was the limited solubility of ferrous sulfate and ferrous fumarate in the aqueous matrix of the liquid premix. These were the two iron sources proposed in the flour enrichment regulation, and they were evaluated first. Ultimately, the minerals and vitamins were prepared as separate premixes with ferrous lactate, a somewhat more soluble form of iron, being selected as the iron source. The dual premixes exhibited good stability at room temperature, but precipitation was still found to occur upon refrigeration. The concentration of micronutrients in the liquid premix was such that a dose of 2 g of each premix per kg of masa yielded the target nutrient levels in the finished tortilla.

Development of the dry premix was less complicated. Following the recommendation in the proposed regulation, ferrous sulfate was initially used as the iron source. However, ferrous sulfate resulted in significant blue-green discoloration of the tortillas in laboratory trials and was replaced by ferrous fumarate, which gave a more acceptable, though darker, color in the tortillas. Ultimately, millers participating in preliminary trials expressed a strong concern relating to the darker color of tortillas enriched with ferrous fumarate, and the premix was again reformulated. The final premix contained electrolytic iron, added at twice the proposed level (46.22 mg/kg) in order to deliver an equivalent bioavailable amount (20). The concentration of micronutrients in the dry premix was such that a dose of one gram of premix per kg of masa yielded the target nutrient levels in the finished tortilla.

Substantial work was involved in identifying and adapting low-cost dosification equipment for the proposed enrichment methods. A group of millers, participating as members of the project working group, agreed that the cost of the dosifier should probably not exceed US$1,200 in order to be affordable for the majority of millers producing masa from fresh nixtamal. Most conventional equipment used for liquid and powder dosing in food and pharmaceutical applications far exceeded this cost objective, ranging closer to $5,000–$12,000 per unit. Finally, a peristaltic pump system, used to add preservatives to tortillas made from fresh nixtamal, was adapted as a low-cost approach for addition of liquid nutrient premixes (Fig. 2). A two-lobed pump, capable of metering two liquids simultaneously, was employed. This type of pump costs only $500–$700 per unit, which was within the cost target.

Table II. Micronutrient addition to nixtamal based on COFEPRIS proposal for corn masa flour[a]

Micronutrient	Fortification of corn masa flour (mg/kg)	Fortification of nixtamal[b] (mg/kg)
Iron	40.0	23.11
Zinc	40.0	23.11
Folic acid	2.0	1.16
Niacin	35.0	20.22
Riboflavin	3.0	1.73
Thiamin	5.0	2.89

[a] COFEPRIS or Comisión Federal para la Protección Contra Riesgos Sanitarios (The Federal Commission for the Protection against Sanitary Risks).

[b] Conversion based on estimated average of 90% solids content in flour and 52% solids content in nixtamal.

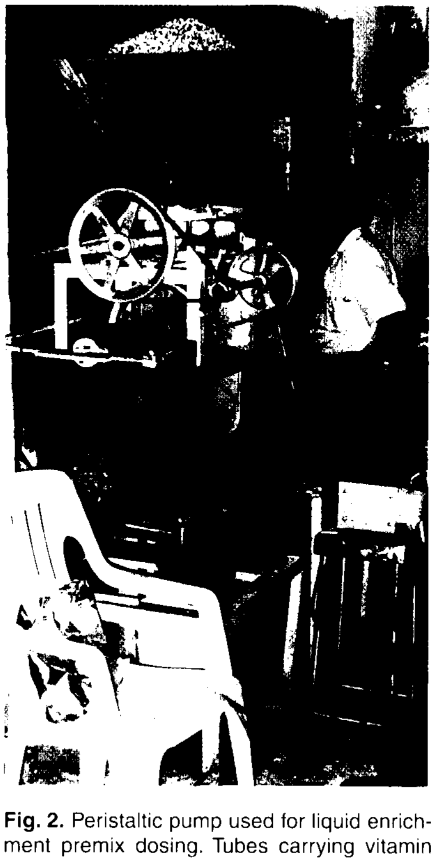

Fig. 2. Peristaltic pump used for liquid enrichment premix dosing. Tubes carrying vitamin and mineral premixes are shown.

The equipment selected for dosing the dry premix was a unit designed by Probst (Probst S.A. de C.V., Tlalnepantla, México), a supplier of additives for the flour and food industry in México, for adding powdered additives to wheat flour (see Fig. 3). The current price of this unit is US$1,200, though this cost could probably be reduced if there were significant purchase volume. Based on the dry premix dose (1g/kg), the powder dosifier is capable of feeding both small and large capacity stone mills (approximately from 5 to 30 kg masa/min).

Initial testing of the liquid premix yielded tortillas with significantly darker, reddish-brown color compared to the unfortified control. Most of the millers indicated that they would not be willing to produce tortillas with this level of discoloration. The liquid premixes also proved to be significantly more expensive than the powder premix and would have forced the millers to sell the fortified tortillas at a higher price. Enrichment with the liquid premix would have increased the cost of the tortillas by 0.20 Mexican pesos (2 U.S. cents) per kg, as compared to an incremental cost of 0.04 pesos (0.4 U.S. cents) per kg for the dry premix enrichment. Consequently, further work on the liquid premix was discontinued due to the potential instability of the premix at cooler temperatures, the resulting off-color in the tortilla and the higher cost of fortification.

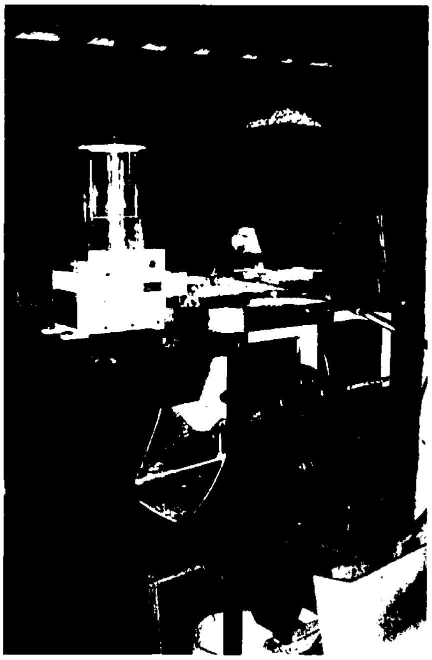

Fig. 3. Powder dosifier used for addition of dry enrichment premix to nixtamal.

The powder dosifier was commercially tested in two different mills, one in Guadalajara and the other in México City. The dosifier required some installation steps to mount the equipment over the mill, but once set up, it was relatively easy to operate. The proper dosification rate was determined by measuring the feed rate of masa through the mill in kg/minute, then setting the feed-rate of the powder dosifier to dose an equal number of grams per minute (target dose was 1 g premix per kg of masa). Subsequent discussion with the manufacturers has led to several modifications of the dosifier, designed to make the equipment even more suitable for use in nixtamal mills.

The mill in Guadalajara had a small external hopper with an exposed auger feeding the mill stones. The premix was dosed directly on top of this auger. The auger in the México City mill, on the other hand, was located in the bottom of the main mill hopper and was completely covered by the nixtamal in the hopper. A short length of exposed auger was created by welding a small wall across the front of the hopper to hold back the nixtamal. A semi-circular hole in the bottom of the wall allowed the auger to convey nixtamal through the wall into the millstones. The dosifier in this mill was situated directly over this gap and a chute was added to the dosifier to direct the flow of premix directly onto the auger feeding the grinding stones. Other than these relatively simple modifications, fortification with the dry premix did not significantly alter the manufacturing process.

A commercial trial in the Guadalajara mill indicated that the dosifier yielded very consistent iron levels in consecutive tortilla samples collected during a 30-minute production run (iron was used as a test marker due to its stability through the process and ease of analysis in the laboratory). Production in these small, traditional mills is not continuous, but takes place in a number of short production runs—lasting typically from 30 to 90 minutes—throughout the day. Thus a 30-minute production run is considered of typical duration. Within this time frame, variation in iron levels in fortified tortillas, enriched using the powder dosifier, had a comparable coefficient of variation (CV) to that observed in control tortillas (Table III). The dry dosification system had a CV of 7.04%, compared to 8.82% for the control.

Table III. Iron content (mg/kg) of consecutive samples of unfortified tortillas and tortillas enriched with dry micronutrient premix during commercial production

Sample	Unfortified	Dry premix
1	44.20	75.92
2	43.80	59.33
3	38.10	70.13
4	39.20	66.76
5	37.00	68.45
6	47.90	65.76
7	41.30	69.44
8	37.40	68.90
9	39.00	74.14
10	38.60	75.42
11	37.00	76.21
12	37.00	71.57
Average	40.04	70.17
Std. Dev.	3.53	4.94
CV %	8.82	7.04

The dry premix enrichment produced tortillas with sensory properties comparable to control tortillas. A consumer test was conducted at INCMNSZ in México City, including tortilla variants prepared with different iron sources added at equivalent bioavailable levels (see Table IV). In this test, 100 consumers evaluated all variants in side-by-side comparisons. Consumers rated the overall appearance, flavor, aroma, texture, and color of each tortilla using a nine-point scale, with one meaning "dislike very much" and nine meaning "like very much." Results indicate that dry premix variants utilizing ferric pyrophosphate and electrolytic iron as the iron sources were at statistical parity to the control in all attributes tested. However, the ferrous lactate liquid premix variant scored lower in appearance, color, and flavor; and the ferrous fumarate dry premix variant scored lower in appearance, though not color. The results confirmed millers' concerns that fortification with certain forms of iron could negatively impact consumer perception of tortilla appearance

Table IV. Average sensory scores for tortillas fortified with dry and liquid vitamin/mineral premixes using iron from different molecular sources*

Iron source	Added iron mg/kg masa	Appearance	Aroma	Flavor	Texture	Color
Control	0	6.94^{a}	6.84^{a}	6.62^{a}	6.44^{a}	6.80^{a}
Ferric pyrophosphate	46.22	6.72^{ab}	6.73^{a}	6.66^{a}	6.62^{a}	6.80^{a}
Electrolytic	46.22	6.79^{ab}	6.62^{a}	6.51^{ab}	6.32^{a}	6.78^{a}
Ferrous fumarate	23.11	6.37^{bc}	6.49^{a}	6.15^{ab}	6.27^{a}	6.48^{ab}
Ferrous lactate (liquid)	23.11	6.02^{c}	6.42^{a}	5.97^{b}	6.30^{a}	6.10^{b}

* Based on hedonic scale from one to nine, where one equals dislike extremely and nine equals like extremely. Like superscripts within columns indicate no significant difference ($p > 0.05$).

and color in a commodity market where small changes can mean lost sales.

The final requirement for a viable fortification process is an adequate level of nutrient retention in the finished tortilla. The primary concern is with the added vitamins in the premix. Accordingly, two replicate samples of fortified and unfortified tortillas were analyzed for vitamin content by DSM Nutritionals México. Table V indicates that the vitamin content of the fortified tortillas was significantly improved, with all vitamins except folic acid showing large increases as a result of fortification. The folic acid increase, while statistically significant, was much smaller than expected, and differed from previous BYU results carried out on commercially prepared tortillas in Utah, where folate levels showed a ninefold increase after fortification. One possible explanation of the conflicting folate results is use of different analytical methods. The soon to be published BYU study utilized the approved AACC International microbiological assay for total folic acid (AACC International 86-47 and AOAC 992.05), whereas the DSM lab was not equipped to run the microbiological assay and used an HPLC method instead. HPLC analysis of total folate is known to give variable results in complex food systems (10). Additional testing on commercially prepared tortillas in México is being conducted to confirm the retention of this important vitamin.

The fortification system presented here appears to be a commercially viable means of fortifying nixtamal tortillas. The method is cost-effective, easy to use, has minimal impact on the existing process, produces tortillas of comparable quality to currently unfortified counterparts, and results in a dramatic improvement in nutrient content. Introduction of this technology in nixtamal mills throughout México would have a very significant impact on the nutritional well-being of those populations utilizing the corn tortilla as a staple in the diet. As part of SUSTAIN's effort to disseminate this technology, the project team is supporting the commercial introduction of this technology in two mills in different parts of México. A promotional campaign will be conducted to educate patrons of the two mills on the benefits of the fortified tortilla. Training manuals and quality control materials are also being provided, along with technical support from Tecnológico de Monterrey (ITESM) and Brigham Young University over the first three months of production. Mill owners participating in these extended trials have expressed a great interest in this technology and are enthusiastic about the prospect of providing a meaningful benefit to their patrons. It is hoped that success in these two regions will result in a more widespread dissemination of the technology in the future.

Acknowledgment

This initiative was organized by SUSTAIN with support provided through the generosity of the Bill & Melinda Gates Foundation, and through contributions by project partners (Brigham Young University, Tecnológico de Monterrey, Instituto Nacional de Salud Pública), GAIN, the General Mills Foundation and volunteer experts. Significant cooperation was also provided by nixtamal millers, micronutrient suppliers, equipment manufacturers, and other public and private collaborators from México.

Table V. Increase in vitamin content of commercially fortified nixtamal tortillas on dry-weight basis (average of two samples per treatment)

Treatment	Thiamin (mg/kg)	Riboflavin (mg/kg)	Niacin (mg/kg)	Folic acid (mg/kg)
Control	2.53[a]	0.43[a]	9.28[a]	1.43[a]
Fortified*	7.97[b]	1.91[b]	35.66[b]	1.99[b]

* Using powder dosifier and dry premix also containing electrolytic iron and zinc oxide.
[a,b] Different superscripts within columns indicate significant difference ($p > 0.05$).

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