Control of Fumonisin: Effects of Processing

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Of about 10 billion bushels of corn that are grown each year in the United States, less than 2% is processed directly into food products, and about 18% is processed into intermediates such as high-fructose corn syrup, ethanol, and cornstarch. The vast majority of the annual crop is used domestically for animal feed (60%), and about 16% is exported. Thus, any program for controlling residues of fumonisin (FB) in food must recognize that most of the crop is grown for something other than food. Studies on the effects of wet milling on FB residues found these residues nondetectable in cornstarch, the starting material for high-fructose corn syrup and most other wet-milled food ingredients. Similar effects are noted for the dry-milling process. FB residues were nondetectable or quite low in dry flaking grits and corn flour, higher in corn germ, and highest in corn bran. Extrusion of dry-milled products reduces FB concentrations by 30–90% for mixing-type extruders and 20–50% for nonmixing extruders. Cooking and canning generally have little effect on FB content. In the masa process measurable FB is reduced following the cooking, soaking, and washing steps, with little conversion of FB to the hydrolyzed form. Sheeting, baking, and frying at commercial times and temperatures generally have no effect. In summary, all available studies on the effects of processing corn into food and food ingredients consistently demonstrate substantial reductions in measurable FB. No studies have shown a concentration in FB residues in food products or ingredients. *Key words:* corn, food, fumonisin, masa, processing. — *Environ Health Perspect* 109(suppl 2):333–336 (2001).
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Maize (corn) has been an important part of the human food supply dating back thousands of years to the great Mesoamerican civilizations of the Aztecs, Mayans, and Incas. By the time Europeans arrived in the Americas in the late 15th century, corn was well established as an agricultural crop throughout South, Central, and North America, and the Caribbean islands. The importance of corn in the history of the Americas cannot be overstated. In the words of Governor Bradford concerning the plight of the Mayflower pilgrims experiencing their first New England winter: "And sure it was God's good providence that we found this corne for we know not how else we should have done" (*1*). To be sure, the generosity of the pilgrims' Native American neighbors was also crucial. The pilgrims' success at raising a crop of maize the following year and their gratitude to their Native American neighbors led to the current American feast of Thanksgiving (*1*). In the intervening years numerous uses for corn have been developed, and today it is found in mixes, sweeteners, breakfast cereals, and snack foods.

For Frito-Lay and many other food processors, the first indication of a potential issue involving fumonisin (FB) in corn came from a newspaper article (*2*) suggesting that a naturally occurring toxin may be present in the U.S. corn supply. Further investigation revealed that limits for FB in animal feed existed in Texas that ranged from 5 ppm in horse feed to 50 ppm in finishing cattle feed (*3*). The American Association of Laboratory Diagnosticians (*4*) also recommended limits on animal feed in 1993. No federal or state limits applied at that time to human food. In 1993 Frito-Lay began to monitor corn shipments and applied the lower Texas limit of 5 ppm FB to all corn grain and cornmeal used by the company.

A review of existing literature revealed that some research on the effects of food processing on FB residues existed. However, these studies were generally conducted on laboratory-scale processing lines and, in some cases, used spiked residues rather than naturally incurred residues. Food processors and millers who process corn into food products and food ingredients have also conducted processing studies to better address issues specific to their industries. In this article we summarize these studies.

Corn As a Commodity

It is important to realize that the vast majority of corn grown in the United States is used as animal feed (Figure 1). Only a small portion of the crop, less than 2%, is used for food production (Figure 2). Although the corn used for food production is generally of a higher quality, it is still the same basic commodity as animal feed—No. 2 yellow dent corn. Thus, food processors and corn millers have only a limited ability to influence this commodity market. More significant, because no agronomic practices have been identified that will reliably reduce FB residues, and no chemical treatments are known to be effective, growers are not able to control FB residues in the field.

To further complicate the issue, there is generally no difference in the visual appearance or physical attributes of corn with low or high residues of FB. To be sure, cracked, broken, and otherwise damaged corn can be quite high in FB, and removing these kernels from normal corn is an important step in controlling residues. The simple step of cleaning (screening) corn can reduce FB residues to less than half that of uncleaned corn. Beyond this obvious control measure, there appears to be no physical difference between low- and high-residue corn that are otherwise healthy in appearance.

Dry-Milled Products

The major food ingredients produced by dry millers are cornmeal, flour, and grits. These products are ingredients for foods such as breakfast cereals and snack foods, and baked goods such as corn bread and muffins. The most common type of dry milling is tempering degerming. The corn is first cleaned to remove dirt and debris and to separate fine and broken kernels from whole corn. The corn is tempered by increasing moisture, and the hull (pericarp), germ, and tip cap are removed, leaving the endosperm. This endosperm is then converted into flours, meals, and grits through a series of mills, sifters, and gravity tables (Figure 3). Corn germ is the raw material for corn oil; bran is generally an animal feed item but with further processing is used in some specialty foods as a source of fiber.

Katta et al. (*5*) monitored the FB residue in various fractions from a commercial corn mill. Although not a processing study per se, the data clearly demonstrated the effects of processing (Figure 4). The most important fractions in terms of food (cornmeal, flour, and grits) are greatly reduced or nondetectable for FB. The bran fraction from this particular

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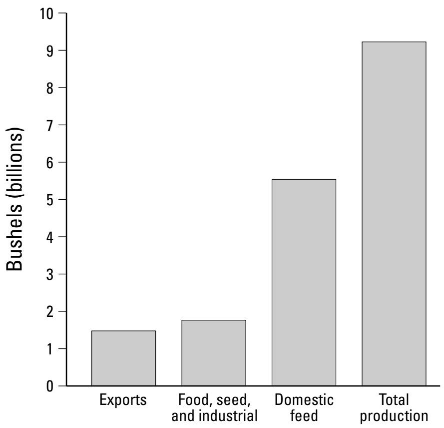

Figure 1. U.S. corn use pattern, 1997–1998 (*18*).

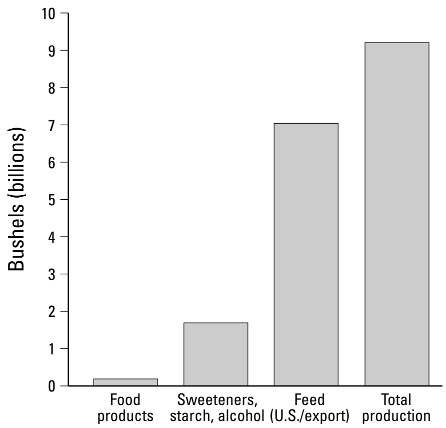

Figure 2. Food versus other corn uses (*18*).

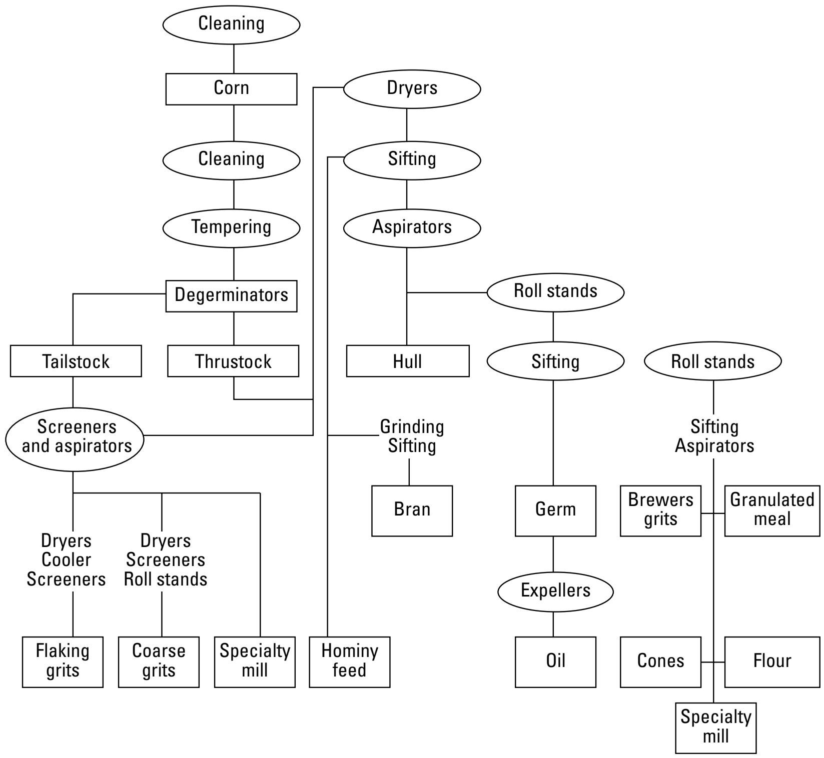

Figure 3. Basic flow diagram of a dry corn mill. Dry mill process courtesy of Illinois Cereal Mills, Inc.

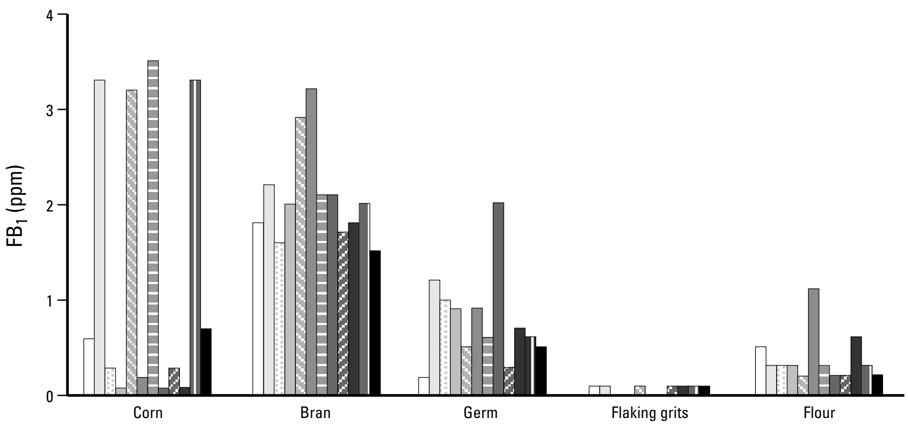

Figure 4. FB_1 content in corn and milled fractions. Each bar represents a sample of corn and various fractions from consecutive weeks. Data from Katta et al. (*5*).

mill is an animal feed item, and FB residues from the whole corn are largely associated with this fraction. Of further interest, the data in Figure 4 demonstrate the tremendous variation in residues that can occur within a single season and growing region, as all of the corn in this study came from within 100 miles of the mill (*6*). These data are consistent with other surveys of FB in grain or food products, which have consistently shown a large variability in residues in whole corn grain and a substantial reduction of FB levels overall in processed corn products (*7–10*).

Wet-Milled Products

The principal products resulting from the wet-mill process are cornstarch, high-fructose corn syrup (a sweetener), and ethanol from fermentation (Figure 5). Bennett et al. (*11*) studied the effects of this process on FB residues in a laboratory-scale process. Starch, which is the starting material for the food ingredients arising from this process, did not contain detectable FB residues (Table 1). FB is generally found in by-products of the process that are used as animal feed. These researchers also observed that the yields for process fractions (percent germ, fiber, starch, gluten) were similar for corn low in FB (1 ppm) and high-residue corn (13.9 ppm).

Masa-Type Processes

The masa process dates back at least to ancient Mesoamerican civilizations. This process for producing corn tortillas and tortilla chips is especially common in Latin America and in the Hispanic communities of the United States. In the traditional method the corn is cooked in alkaline water for a short period of time and then steeped overnight. The steeped liquor is discarded, and the cooked-steeped corn (nixtamal) is washed to remove alkali and loose pericarp, then ground to form masa. The masa can then be formed into flat discs and cooked on a griddle. Although technology and automation have brought greater efficiency to the process, most modern food-processing techniques involving masa can be traced in some form to ancient Native American inhabitants (*12*).

The basic process for making tortilla chips is shown in Figure 6. The only variation from the traditional tortilla process is that the masa is formed into a thin sheet, cut, baked and then fried briefly at high temperature to produce a thin, crisp chip. Under a Cooperative Research and Development Agreement, Frito-Lay and the U.S. Department of Agriculture (USDA) are studying the effects of the tortilla chip process on measurable FB residues. This process provides a good model for studying processing effects, as the corn is subjected to a variety of processing steps—cooking, soaking, washing, grinding, baking, and frying. Unlike other studies on processing effects, this research uses a full-scale production line and corn with naturally incurred FB residues. Many differences exist between bench-scale pilot studies and a commercial facility. The most significant difference is that commercial production lines are continuous operations, whereas static batch operations are used in most bench studies. Another important consideration is that the effects of working on a large, commercially relevant scale are not known and cannot be reproduced in bench-scale experiments. This is ongoing work and the following results should be considered preliminary.

The amounts of fumonisin B_1 (FB_1) and fumonisin B_2 (FB_2) were determined in raw corn and fried tortilla chips using high performance liquid chromatography (HPLC). The experiment was repeated four times, each time using a different lot of corn. FB_1 concentrations of the corn were approximately 0.22 ppm (lot 3), 1.5 ppm (lot 2), 2.1 ppm (lot 4), and 25 ppm (lot 5). Lot 5 consisted of screenings, i.e., cracked and broken kernels of corn that normally would be discarded. Lesser amounts of FB_2 were found and no hydrolyzed FB (HFB_1) was detected in the raw corn. On average, measurable FB_1 concentrations in the fried tortilla chips were reduced about 60% compared to the corn from which they were made. However, results were somewhat inconsistent, with reductions that ranged from about 40% (lots 3 and 4) to about 80% (lots 2 and 5). FB_2 concentrations generally followed the same pattern.

Measurements were extended to include intermediate products from lots 2 and 5. In each case FB_1 and FB_2 concentrations of the rinsed nixtamal (lot 5 only), masa, and baked chips were greatly reduced compared to the raw corn and were not appreciably different from their respective levels in the fried tortilla chips. Interestingly, FBs were not detected in the rinsed nixtamal (repeated analyses) from lot 2; the reason for this is not yet resolved. Nevertheless, a clear reduction in measurable FBs was achieved during manufacture of the fried tortilla chips and occurred almost entirely during the initial steps, that is, during conversion of raw corn into nixtamal (cooking/soaking/washing under alkali conditions).

During nixtamalization, FB_1 may be converted to its hydrolyzed form, HFB_1, and this compound has been reported in some processed foods (*13*). Using the highly contaminated corn (lot 5) as a model, HFB_1 concentrations in the intermediate products and fried tortilla chips were substantially less than the corresponding FB_1 concentrations (Figure 7). Masa contained slightly higher levels of HFB_1 than the nixtamal or baked chips and appreciably higher levels than the fried chips. HFB_1 concentration of the broken kernels, pericarp, etc. (collectively designated waste) that were separated (by rinsing) from the nixtamal was about twice that of the masa. Both FB_1 and HFB_1 were found in the cook/soak liquid. With time, HFB_1 concentrations increased and FB_1 concentrations decreased in this liquid; the ratio of FB_1:HFB_1 fell from about 1.4 after 2 hr of cooking to about 0.9 after 6 hr, and to 0.6 to 0.7 after 12 hr.

When all these observations are considered, certain preliminary conclusions may be reached. The overall process decreases the amount of measurable FB_1 and FB_2 by 40–80%. Most of this reduction appears to occur during the cooking/soaking steps under alkaline conditions, the first steps in the process. During these first steps the FBs are extracted into the soak water and with time are increasingly converted to HFB_1. Much of the remaining HFB_1 is associated with the pericarp and associated waste, which are removed from the nixtamal by rinsing, leaving relatively little HFB_1 in the masa and chips. Grinding, baking, and frying have negligible impact on measurable amounts of FB_1, FB_2, or HFB_1 in the intermediates and final product.

Work is continuing to verify these findings, to further study the fate of FBs during the cook/soak steps, to identify those factors that determine the degree of reduction in FB concentration, and to investigate whether products such as *N*-carboxymethyl-FB, FB-sugar, or other adducts are formed.

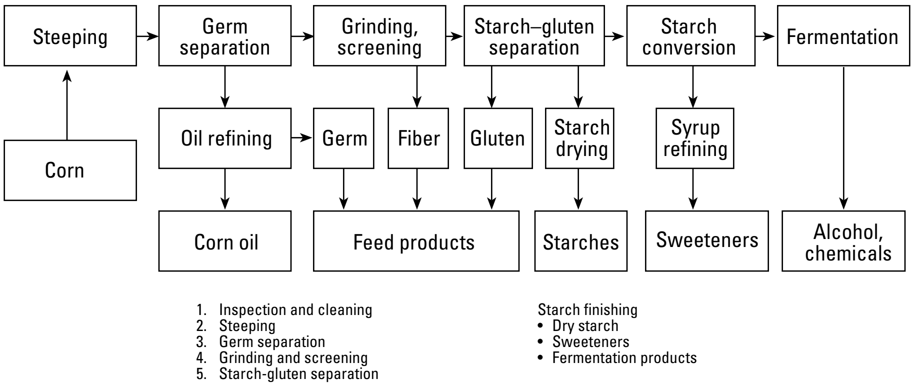

Figure 5. Corn wet-milling process. Wet mill process courtesy of Corn Refiners Association.

Table 1. Fumonisin residues in wet milled fractions of corn.[a,b,c]

Fraction	Replicate	FB_1	FB_2
Fiber	1	5.7	2.1
	2	2.7	3.1
Germ	1	1.3	0.7
	2	3.1	1.6
Gluten	1	5.8	4.7
	2	5.1	4.9
Starch	1	< 0.1	< 0.1
	2	< 0.1	< 0.1
Steep water	1	2.1	2.5
	2	0.3	—
Process water	1	< 0.1	< 0.1
	2	< 0.1	< 0.1

[a]From Bennett et al. (*11*). [b]Starting corn contained 13.9 ppm FB_1. [c]Analyses by HPLC; limit of detection 0.1 ppm.

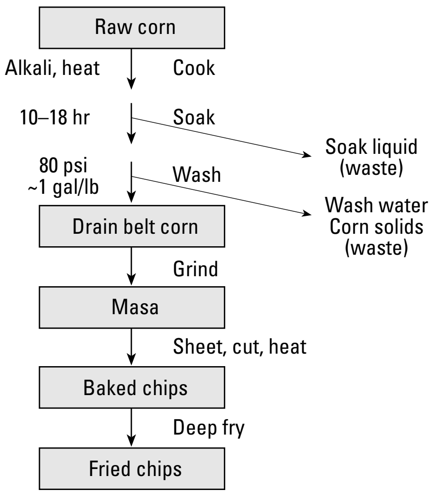

Figure 6. Basic tortilla chip process. Basic process for tortilla chips.

Effects of Cooking, Canning, and Extrusion

The FB molecule is quite stable to heat, and the temperatures/times required for thermal

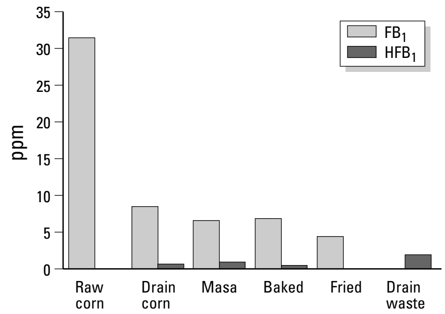

Figure 7. FB_1 and HFB_1, Cook 5, not recovery corrected. Preliminary findings showing a reduction of measured FB_1 and an increase in HFB_1 during the production of fried tortilla chips. Values are the mean of three measurements and are expressed as a percent of FB_1 in raw corn.

decomposition of FB generally exceed commercial cooking parameters (*13*). Baking of corn muffins and breads produced no effect, whereas canning produced only a slight reduction in FB concentration (*14*). In contrast, Pineiro et al. (*15*) found that frying polenta or autoclaving cornmeal produced reductions in FB_1 of 70–80% with no conversion to the hydrolyzed form.

Extrusion of cornmeal also appears to significantly reduce FB residues. Extrusion is a common process in the food industry, particularly for snack food and breakfast cereals. During extrusion cornmeal is subjected to high pressure, temperature, and shear force causing gelatinization of cornstarch. The extrudate can be shaped using a die, then baked or fried. Laboratory-scale studies using spiked FB in cornmeal demonstrate variable reductions in FB concentration of 20–70% (Figures 8, 9), with greatest reduction occurring in mixing type extrusion. The greater apparent reductions during mixing-type extrusion may be related to the higher shear forces that occur during such extrusion (*16,17*). Using naturally incurred residues, Pineiro et al. (*15*) also found reductions in FB concentration of 70–90% following extrusion of corn flour through a single-screw mixing-type extruder.

Conclusions

The overall flow of corn into the food-processing stream is depicted in Figure 10. Monitoring data indicate that a wide variation in residues can exist even within a localized region, necessitating a flexible approach for managing FB residues. Studies on the effects of corn processing indicate that commercial processes for conversion of corn into food products or ingredients (dry milling, wet milling, masa processes, and extrusion) produce significant reductions in the FB concentration of resultant products. No commercial process is known to concentrate FB residues. Two steps that appear to be important for reducing FB residues are removal of broken and damaged kernels through screening and aqueous treatment (i.e., soaking or washing) of corn. Cooking and canning generally appear to have little effect whereas extrusion appears to produce significant reductions in FB concentration. Further work is necessary to determine the nature of loss that occurs during processing, i.e., removal to waste streams versus decomposition/conversion to other forms. In addition, laboratory-scale studies using spiked corn should be replicated using commercial-scale facilities and naturally incurred residues.

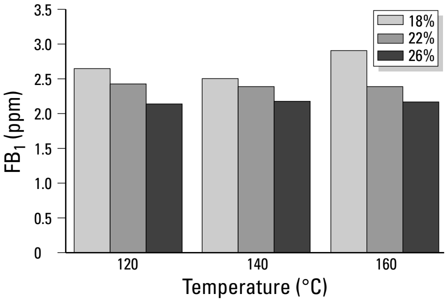

Figure 8. Effect of extrusion (mixing screw). Bars represent effect of extrusion on FB_1 concentration at different percentages of moisture and temperature. Data from Katta et al. (*16*) and Castelo et al. (*17*).

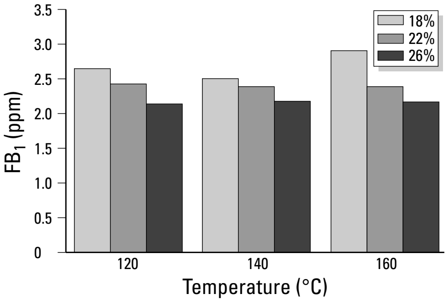

Figure 9. Effect of extrusion (nonmixing screw). Bars represent effect of extrusion on FB_1 concentration at different percentages of moisture and temperature. Daa from Katta et al. (*16*) and Castelo et al. (*17*).

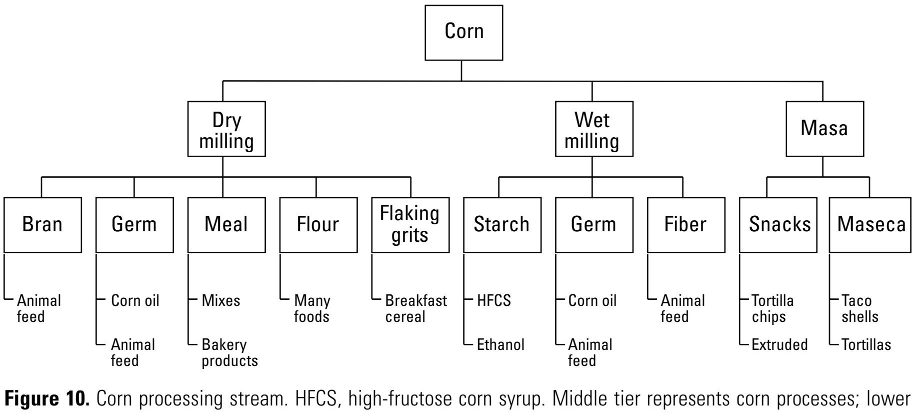

Figure 10. Corn processing stream. HFCS, high-fructose corn syrup. Middle tier represents corn processes; lower tiers represent milling fractions and resultant food products and ingredients.

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