GRAIN QUALITY IN HUMID TROPICAL STORAGE: ROLE OF BROKEN CORN AND FOREIGN MATERIAL

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Purpose

U.S. corn storage in hot, humid tropical climates present unique challenges, with higher risks of mold, insect pests, and grain deterioration. Broken corn and foreign material (BCFM), long considered a waste fraction, retain nearly all the nutritional value of whole kernels (~98% of protein, starch, and other nutrients) but are more susceptible to spoilage and aflatoxin contamination. This factsheet presents data on imported U.S. corn stored in Mexico, tracking changes in corn composition (protein, oil, starch), moisture, test weight, susceptibility to spoilage, and aflatoxin contamination from reception to drawdown and the effects of BCFM on corn susceptibility to spoilage and aflatoxin contamination under humid tropical conditions.

Research Overview – What was done

Under real-world storage settings across several sites in southeast Mexico, corn quality was monitored at four commercial storage facilities over a two-year period (June 2023 – April 2025) to assess quality changes from reception to drawdown and the impact of BCFM on spoilage and aflatoxin risks under humid tropical conditions.

In the first year (June 2023 to May 2024), samples were collected at four drawdown phases—from initial reception (100% full), 75%, 50% to final consumption (25% or less full). Each batch represented a full storage cycle, typically lasting 21–45 days (Fig. 1). Stored grain monitoring was conducted using an AmberAg sensor module (Model AZR-REG-001, AmberAg, Chicago, IL, USA) having CO_2, temperature, and RH sensors installed in the headspace above the grain.

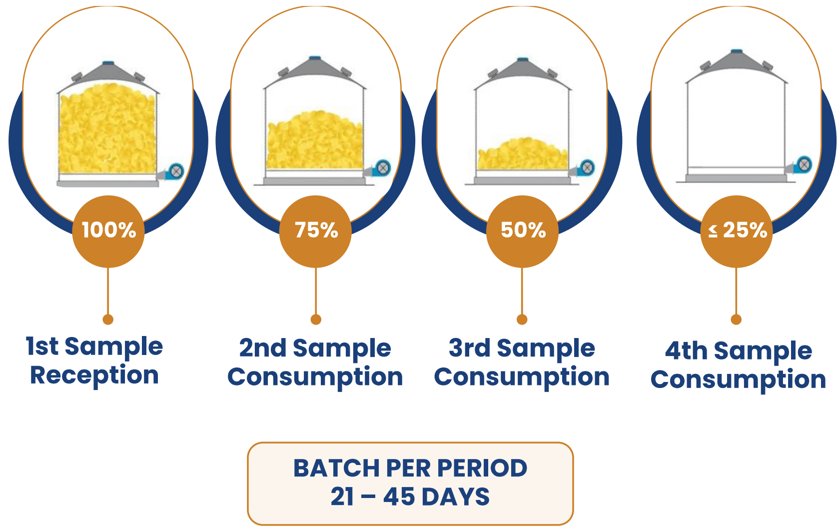

Figure 1. Year 1 drawdown sampling strategy across storage stages (June 2023–May 2024).

Nutritional content (protein, oil, and starch) of stored corn samples (three replicates of 300–350 g) through drawdown was measured using a near-infrared reflectance (NIR) spectrometer, Foss Infratec 1229 Whole Grain Analyzer (FOSS, Hilleroed, Denmark). Also measured was the moisture content and test weight (bulk density) using a Dickey-John GAC 2400 moisture analyzer (Dickey-John, Auburn, Illinois).

The susceptibility of corn to spoilage by fungi was measured on replicates of corn samples collected from reception through drawdown using the Solvita grain test kit (Woods End Laboratories, Augusta, ME). Likewise, aflatoxin levels were measured at various drawdown stages using the EnviroLogix TotalTox Kit (EnviroLogix Inc., Portland, Maine).

To determine whether corn quality differed significantly over the storage period as the bin was drawn down from full capacity (100%) to 75%, 50%, and 25% capacity, a one-way repeated measures ANOVA was conducted at an alpha level of 0.05. For batches that included only two fill levels, paired *t*-tests were used to assess whether corn quality differed significantly between the two storage levels.

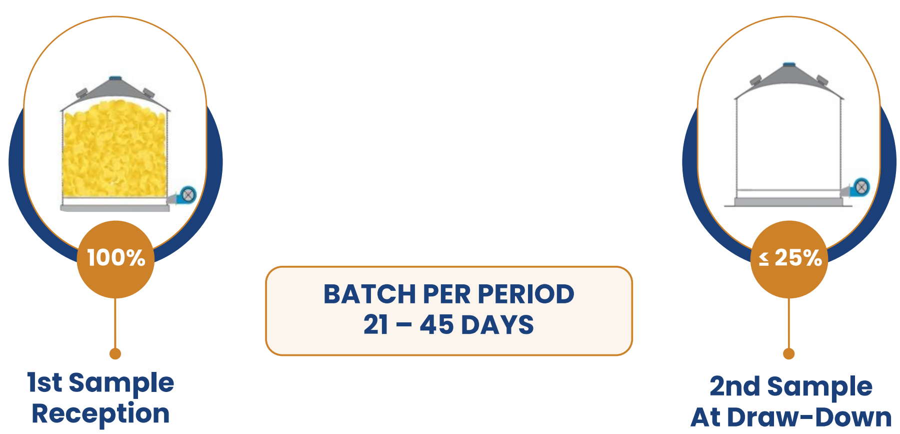

Figure 2. Drawdown sampling strategy across storage stages (June 2024–April 2025).

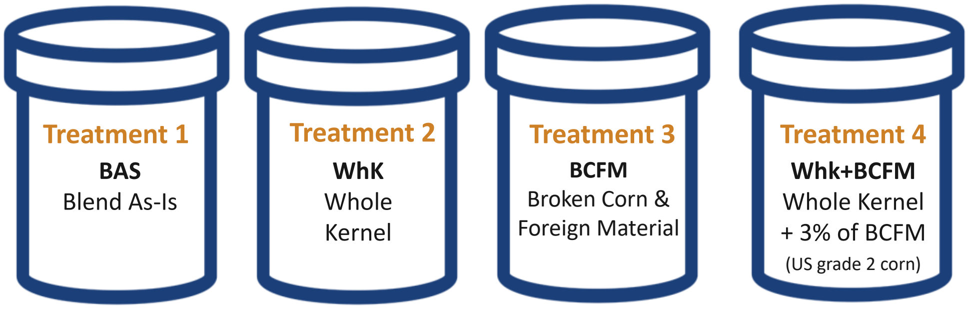

Figure 3. Four treatments were formulated to assess the impact of BCFM on the susceptibility of corn to spoilage and aflatoxin contamination in comparison to whole kernels.

In the second year, (June 2024 to April 2025), corn samples were collected in two phases, (1) during bin filling at reception denoted as 100% fill and (2) when the bin was drawn down to or less than 25% full (Fig. 2). From the corn samples collected at both sampling phases, four different treatments were formulated to determine the impact of BCFM on susceptibility of corn to spoilage and aflatoxin contamination. Samples were homogenized using a Boerner Divider and then carefully split into the four experimental treatments: Batch As-Is (BAS), only Whole Kernels (WhK), only BCFM, and Whole Kernels + 3% BCFM, as shown in Figure 3. A series of repeatable analyses was conducted on the four experimental treatments with varying BCFM levels shown in Fig. 3. Two primary spoilage indicators were evaluated: aflatoxin concentration (ppb), representing fungal contamination, and susceptibility to fungal spoilage, measured using the Solvita Grain Spoilage Test.

Independent of storage stage, a one-way ANOVA was used to determine whether mean aflatoxin concentrations differed significantly among the four corn treatments, thereby assessing the effect of BCFM on aflatoxin levels. In addition, two-way ANOVAs were conducted for both aflatoxin concentration and Solvita test results to evaluate the main effects of BCFM and storage stage, as well as their interaction.

Key Findings

Tables 1 and 2 show nutrient (protein, oil, starch), moisture, bulk density (test weight), corn susceptibility to spoilage (Solvita CO_2 and color grade), and aflatoxin levels of samples collected at four different stages of drawdown during storage in a grain silo at a feed mill and a grain silo at a cattle feedlot.

The Year 1 storage results, summarized in Tables 1 and 2, show that:

- Nutritional composition (protein, oil, starch) and moisture content remained stable across all drawdown stages during the 21 to 45-day storage period.
- High headspace humidity (>70%) and temperature (>30°C) corresponded with elevated CO_2 levels, indicating greater spoilage risk and increasing aflatoxin levels over time.

- Despite these conditions, aflatoxin concentrations remained below the U.S. FDA actionable limit of 20 ppb, demonstrating that U.S. corn can be safely stored for up to one month under the humid tropical conditions of southern Mexico.

Table 1. Grain quality is monitored in a silo at a feed mill at different stages of drawdown.

Parameter	100% Full	75% Full	50% Full	25% Full
Protein (%)	8.03 (0.14)$^{n=9a}$	8.05 (0.11)$^{n=4a}$	8.08 (0.09)$^{n=3a}$	8.11 (0.08)$^{n=8a}$
Oil (%)	3.45 (0.05)$^{n=9a}$	3.47 (0.04)$^{n=4a}$	3.48 (0.03)$^{n=3a}$	3.50 (0.02)$^{n=8a}$
Starch (%)	61.45 (0.48)$^{n=9a}$	61.30 (0.52)$^{n=4a}$	61.25 (0.46)$^{n=3a}$	61.20 (0.43)$^{n=8a}$
Moisture (%)	13.62 (0.18)$^{n=9a}$	13.68 (0.16)$^{n=4a}$	13.74 (0.14)$^{n=3a}$	13.80 (0.13)$^{n=8a}$
Bulk Density (lb/bu)	55.72 (0.60)$^{n=9a}$	55.70 (0.53)$^{n=4a}$	55.62 (0.47)$^{n=3a}$	55.55 (0.42)$^{n=8a}$
Solvita CO_2 (ppm)	4.28 (0.45)$^{n=9a}$	5.20 (0.88)$^{n=4a}$	7.11 (1.19)$^{n=3b}$	9.56 (1.65)$^{n=8c}$
Solvita Color Grade	1.89 (0.27)$^{n=9a}$	2.17 (0.50)$^{n=4a}$	2.44 (0.57)$^{n=3a}$	2.78 (0.66)$^{n=8a}$
Aflatoxin (ppb)	0.45 (0.05)$^{n=9a}$	1.02 (0.60)$^{n=4a}$	5.75 (2.11)$^{n=3b}$	11.76 (3.28)$^{n=8c}$

Table 2. Grain quality is monitored in a silo at a feedlot at different stages of drawdown.

Parameter	100% Full	75% Full	50% Full	25% Full
Protein (%)	7.15 (0.21)$^{n=12a}$	7.08 (0.26)$^{n=3a}$	7.18 (0.33)$^{n=6a}$	7.32 (0.12)$^{n=15a}$
Oil (%)	3.47 (0.11)$^{n=12a}$	3.31 (0.14)$^{n=3a}$	2.94 (0.18)$^{n=6a}$	3.31 (0.07)$^{n=15a}$
Starch (%)	60.90 (0.13)$^{n=12b}$	60.86 (0.16)$^{n=3b}$	62.21 (0.20)$^{n=6a}$	61.15 (0.07)$^{n=15a}$
Moisture (%)	13.70 (0.15)$^{n=12a}$	13.63 (0.18)$^{n=3a}$	13.89 (0.23)$^{n=6a}$	13.78 (0.08)$^{n=15a}$
Bulk Density (lb/bu)	58.22 (0.79)$^{n=12a}$	58.20 (0.96)$^{n=3a}$	59.36 (1.25)$^{n=6a}$	57.71 (0.45)$^{n=15a}$
Solvita CO_2 (ppm)	4.04 (2.23)$^{n=12a}$	9.74 (2.72)$^{n=3a}$	17.31 (3.52)$^{n=6b}$	13.17 (1.26)$^{n=15b}$
Solvita Color Grade	0.49 (0.55)$^{n=12a}$	1.17 (0.66)$^{n=3a}$	2.71 (0.31)$^{n=6b}$	2.72 (0.31)$^{n=15b}$
Aflatoxin (ppb)	2.47 (0.82)$^{n=12b}$	0.55 (0.99)$^{n=3c}$	6.39 (1.29)$^{n=6a}$	8.06 0.46)$^{n=15a}$

- Numbers in parentheses indicate standard deviation.

- Each value represents the mean of n independent samples per fill stage, shown in superscript as n=x, followed by the same letter across columns, which are not significantly different according to the LSD post-hoc test at the P-value ≥ 0.05 level.

Tables 3 and 4 present the Year 2 storage results on how BCFM levels affect corn's susceptibility to spoilage and aflatoxin contamination. Key conclusions are:

- BCFM substantially increased spoilage risk, with higher aflatoxin levels and elevated microbial activity (Solvita CO_2 and color grade) later in storage.
- Aflatoxin in BCFM was 11 times higher than in whole kernels screened free of BCFM.
- Screening BCFM reduced spoilage susceptibility in whole kernels by fourfold.
- Aflatoxin levels in both whole kernels and BCFM remained below the U.S. FDA actionable threshold of 20 ppb.

Table 3. Aflatoxin concentration (ppb) across corn treatments and storage stages.

Treatment	100% Full (Reception)	≤25% Full (Drawdown)
Blend As-Is (BAS)	1.77 (1.29)^{aA}	7.76 (2.89)^{bB}
Only Whole Kernels	1.03 (0.73)^{aA}	4.52 (0.89)^{aB}
Only BCFM	11.64 (0.70)^{cA}	59.67 (3.00)^{dB}
Whole +3% BCFM	1.18 (0.47)^{aA}	9.58 (1.03)^{bB}

- Values represent the mean aflatoxin concentration (in parts per billion, ppb), with the standard deviation in parentheses. Treatments containing BCFM exhibited higher aflatoxin levels, particularly under drawdown storage conditions.
- Each mean is based on n = 7 independent observations per treatment and storage stage.
- Different superscript lowercase letters within each column indicate statistically significant differences among treatment groups ($p < 0.05$) and different uppercase letters between columns indicate statistically significant differences between storage periods ($p < 0.05$), based on the results of one-way and two-way ANOVA.

Table 4. CO_2 concentration (ppm CO_2–C) across corn treatments and storage stages.

Treatment	100% Fill (Reception)	≤25% Fill (Drawdown)
Blend As-Is (BAS)	12.2 (2.4)^{bA}	34.1 (3.2)^{bB}
Only Whole Kernels	7.8 (1.6)^{aA}	16.9 (2.9)^{aB}
Only BCFM	37.4 (3.1)^{cA}	65.7 (4.4)^{cB}
Whole +3% BCFM	11.6 (2.5)^{bA}	31.5 (3.5)^{bB}

- Values represent mean carbon dioxide concentrations (in ppm CO_2–C), with standard deviation in parentheses. Higher CO_2 values indicate greater biological respiration and spoilage activity.
- Each mean is based on n = 7 independent observations per treatment and storage stage.
- Different superscript lowercase letters within each column indicate statistically significant differences among treatment groups ($p < 0.05$) and different uppercase letters between columns indicate statistically significant differences between storage periods ($p < 0.05$), based on the results of one-way and two-way ANOVA.

Recommendations for BCFM Management

Although BCFM has a similar energy and nutrient profile to whole kernels, it is more prone to fungal deterioration, aflatoxin contamination, and insect infestation because its protective outer layer is already broken. Proper management is therefore essential to safely capture its value in feed. Recommended practices include:

- Use BCFM quickly after screening to prevent rapid aflatoxin development.

- Screen at reception when possible so BCFM can be handled appropriately. And use it immediately.
- Adopt low-cost, facility-specific strategies (feed mill vs. feedlot) to maximize BCFM utilization.

Figure 4 shows a schematic of the process and benefits of screening BCFM from corn for optimal utilization and stored grain management.

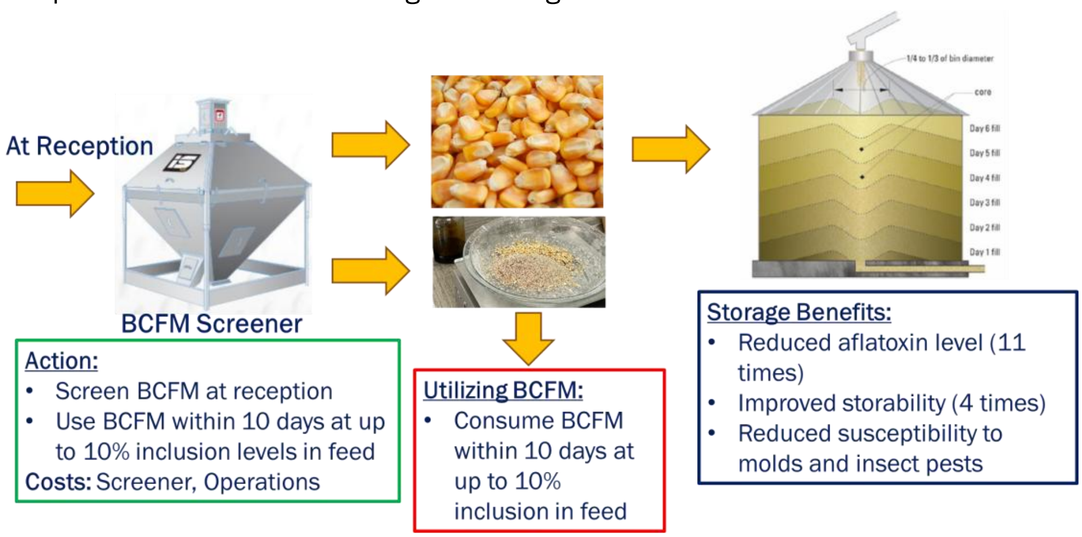

Figure 4. Best management option for utilizing BCFM in imported U.S. corn.

Conclusions

The results from the two-year storage study in southern Mexico's humid tropical climate show that although BCFM has similar nutritional value to whole corn, it is significantly more prone to fungal spoilage and aflatoxin contamination than whole kernels or corn containing only 3% BCFM. As a result, BCFM must be carefully managed—especially under humid tropical conditions, where both corn and BCFM deteriorate more rapidly. Screening BCFM from corn at reception helps maintain overall grain quality and improves its storability by fourfold, but the screened fraction must be used promptly to prevent aflatoxin buildup. Effective management, therefore, requires a combination of BCFM screening, continuous monitoring of storage conditions, and timely inventory turnover. These practices are the most reliable strategies for reducing spoilage and aflatoxin risks in warm, humid climates.

References

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