



**U.S. GRAINS**  
COUNCIL

**2023/2024  
CORN HARVEST  
QUALITY REPORT**



**U.S. GRAINS**  
COUNCIL



Developing a report of this scope and breadth in a timely manner requires participation by several individuals and organizations. The U.S. Grains Council (Council) is grateful to Steve Hofing, Lee Singleton, Lisa Eckel, Alex Harvey and Dee Ann Hoffman of Centrec Consulting Group, LLC (Centrec) for their oversight and coordination in developing this report. A team of experts provided analysis and writing support. External team members include Drs. Tom Whitaker, Lowell Hill, Marvin R. Paulsen and Fred Below. In addition, the Council is indebted to the Illinois Crop Improvement Association's Identity Preserved Grain Laboratory (IPG Lab) and Champaign-Danville Grain Inspection (CDGI) for providing the corn quality testing services.

Finally, this report would not be possible without the thoughtful and timely participation of local grain elevators across the United States. We are grateful for their time and effort to collect and provide samples during their very busy harvest time.

*As a USDA programs participant, the U.S. Grains Council is committed to complying with non-discrimination policies from federal, state and local civil rights laws and those of the USDA. Visit the USDA website page (<https://www.usda.gov/non-discrimination-statement>) for details.*

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The U.S. Grains Council is pleased to present findings from its 13<sup>th</sup> annual corn quality survey in this *2023/2024 Corn Harvest Quality Report*.

The Council offers this report to provide reliable and timely information about the quality of the U.S. corn crop and assist industry leaders in making well-informed buying decisions. Through trade, the Council is committed to the furtherance of global food security and mutual economic benefit.

The 2023 U.S. corn crop was planted slightly ahead of the average pace of the previous five crops thanks to relatively warm and dry weather conditions in April and May. Dry conditions in June stressed the crop across many key areas of the Corn Belt and likely limited the yield potential of the crop. While near-normal temperatures and precipitation returned in July and August, a warm and dry September hastened the crop's maturity and dry-down.

The U.S. Department of Agriculture projects the United States to harvest 35.26 million hectares (87.10 million acres) of corn in 2023 with an average yield estimated at 10.97 metric tons per hectare (174.9 bushels per acre). Despite growing season challenges, yields are expected to be higher than the average of 10.86 metric tons per hectare (173.1 bushels per acre) from the previous five crops, and the area harvested is expected to be the highest total in the past 10 years. If realized, the 2023/2024 crop is projected to be 386.97 million metric tons (15,234 million bushels), making this year's crop the largest on record.

In addition to the record size of the 2023 corn crop, the United States produced a corn crop with high grain quality that will enable it to account for an estimated 26.4 percent of global corn exports during the marketing year.

The *2023/2024 Corn Harvest Quality Report* provides information about the quality of the current U.S. crop at harvest as it enters the domestic merchandising channel. Corn quality observed by buyers will be affected by subsequent handling, blending and storage conditions. A second Council report, the *2023/2024 Corn Export Cargo Quality Report*, will measure corn quality at the point of loading at export terminals and will be available in early 2024.

The Council offers this report as a service to our valued trading partners, and it serves as a means of fulfilling the Council's mission of developing markets, enabling trade and improving lives.

Sincerely,



Brent Boydston  
Chairman, U.S. Grains Council  
November 2023

While warm and dry conditions permitted a timely planting of the 2023 corn crop, the growing season could be characterized by a prompt but uneven crop emergence, scarce rains at pollination time, heat and drought during the grain-filling period and rapid dry-down at harvest. Despite these stressful conditions, average yield is still expected to be higher than the average of the previous five crops (5YA<sup>1</sup>). These conditions also permitted a timely harvest, thus maintaining the overall quality of the 2023 crop. The average aggregate quality of the representative samples tested for the *U.S. Grains Council 2023/2024 Corn Harvest Quality Report (2023/2024 Harvest Report)* was better than the grade factor requirements for U.S. No. 1 grade, indicating that an abundant amount of good quality corn is entering the market channel from the 2023 U.S. crop. The report also showed that 88.0% of the samples met the grade factor requirements for U.S. No. 1 grade, and 96.7% met the grade factor requirements for U.S. No. 2.

Relative to each quality factor's 5YA, the 2023 U.S. corn crop is entering the market channel with higher test weight, lower broken corn and foreign material (BCFM), lower total damage and similar moisture. However, the hot and dry conditions late in the growing season may have contributed to the increased stress cracks found in this year's samples. The following points highlight the key harvest results from the 2023 crop.

## GRADE FACTORS AND MOISTURE

**Test weight** of 58.4 pounds per bushel (lb/bu) (75.2 kilograms per hectoliter (kg/hl)) was similar to 2022 but higher than the 5YA.

Average U.S. Aggregate **BCFM** in 2023 (0.5%) was lower than 2022 (0.9%) and the 5YA (0.8%).

Average U.S. aggregate **total damage** in 2023 (0.9%) was lower than 2022 (1.2%) and the 5YA (1.5%).

Average U.S. Aggregate **heat damage** was 0.0% for the 2023 samples, the same as 2022 and the 5YA.

Average U.S. Aggregate **moisture** content in 2023 (16.3%) was the same as 2022 and similar to the 5YA (16.4%).

## CHEMICAL COMPOSITION

Average U.S. Aggregate **protein** concentration in 2023 (8.8% dry basis) was the same as 2022 and higher than the 5YA (8.5%).

Average U.S. Aggregate **starch** concentration in 2023 (71.9% dry basis) was the same as 2022 but lower than the 5YA (72.2%).

Average U.S. Aggregate **oil** concentration in 2023 (3.8% dry basis) was lower than 2022 and the 5YA (both 3.9%).

<sup>1</sup>The 5YA represents the simple average of the quality factors' average or standard deviation from the 2018/2019, 2019/2020, 2020/2021, 2021/2022 and 2022/2023 Harvest Reports.

## PHYSICAL FACTORS

Average U.S. Aggregate **stress cracks** in 2023 (19.2%) was higher than 2022 (6.9%) and the 5YA (6.3%).

Average U.S. Aggregate **100-kernel weight** in 2023 was 35.52 grams, which was higher than in 2022 (33.94 grams) and the 5YA (34.62 grams), indicating larger kernels than in previous reports.

U.S. Aggregate **kernel true density** in 2023 (1.250 grams per cubic centimeter (g/cm<sup>3</sup>)) was similar to 2022 (1.253 g/cm<sup>3</sup>) but lower than the 5YA (1.255 g/cm<sup>3</sup>).

U.S. Aggregate **whole kernels** averaged 92.5% in 2023, higher than 2022 (91.0%) and the 5YA (91.9%).

Average U.S. Aggregate **horneous (hard) endosperm** in 2023 (85%) was lower than 2022 (88%) but higher than the 5YA (82%).

## MYCOTOXINS

In 2023, 99.5% of the samples tested at or below the U.S. Food and Drug Administration (FDA) action level for **afatoxin** of 20.0 parts per billion (ppb), and 93.9% of the samples tested below 5.0 ppb, a higher proportion than in 2022.

All of the 2023 samples (100.0%) tested at or below the 5.0 parts per million (ppm) FDA advisory level for deoxynivalenol (**DON**). Also, 93.4% of the samples tested below 1.5 ppm, a slightly lower proportion than in 2022.

In 2023, 98.3% of the samples tested below the FDA's strictest guidance level for **fumonisin** of 5.0 ppm, a slightly lower proportion than in 2022.

For this year's *Harvest Report*, **ochratoxin A**, trichothecenes (**T-2**) and **zearalenone** were tested for the fourth year in a row. Results of the 181 samples tested for each additional mycotoxin can be found in the "Quality Test Results" section.

The *2023/2024 Harvest Report* has been designed to help international buyers of corn understand U.S. yellow corn's initial quality as it enters the market channel. This is the thirteenth annual survey of the quality of the U.S. corn crop at harvest. Thirteen years of results show patterns in the impact of weather and growing conditions on the quality of U.S. corn as it comes out of the field.

The 2023 growing season was characterized by timely planting, heat and drought in many areas during the pollination and grain-filling periods and quick dry-down during harvest. Despite the moderate stress experienced, average yield is projected to be higher than the 5YA. The relatively high projected yield, coupled with the highest projected area harvested since the 2013 crop, has led to a projected production of 386.97 million metric tons (15,234 million bushels). If realized, this would make the 2023 U.S. corn crop the largest on record.

The growing season's generally warm and dry conditions promoted a timely harvest and helped produce a crop with good grain quality. The 2023 crop had higher test weight, lower damage and lower BCFM compared to their respective 5YAs. However, these growing season conditions likely contributed to the highest average stress cracks observed in the history of the report.

With these quality factors, the 2023 crop, on average, is entering the market channel with characteristics that met or exceeded each grade factor's numerical requirements for U.S. No. 1 grade corn. The report also showed that 88.0% of the samples met all grade factor requirements for U.S. No. 1 grade, and 96.7% met the grade factor requirements for U.S. No. 2 grade corn.

Thirteen years of data have laid the foundation for evaluating trends and the factors which impact corn quality. The cumulative reports also enable export buyers to make year-to-year comparisons and assess patterns of corn quality based on crop growing conditions across the years.

The *2023/2024 Harvest Report* is based on 611 yellow corn samples taken from defined areas within 12 of the top corn-producing and exporting states. Inbound samples were collected from local grain elevators to measure and analyze quality at the point of origin and provide representative information about the variability of the quality characteristics across the diverse geographic regions.

#### Export Catchment Areas

##### **Pacific Northwest**

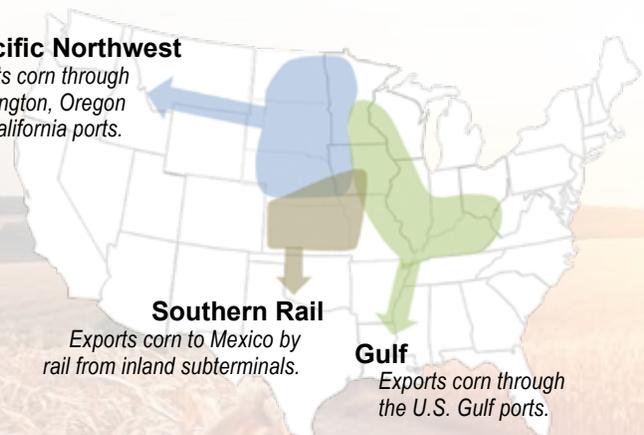
*Exports corn through Washington, Oregon and California ports.*

##### **Southern Rail**

*Exports corn to Mexico by rail from inland subterminals.*

##### **Gulf**

*Exports corn through the U.S. Gulf ports.*



The sampling areas in the 12 states are divided into three general groupings labeled Export Catchment Areas (ECAs). These three ECAs are identified by the three major pathways to export markets shown on the map.

Test results from the sample analysis are reported at the U.S. Aggregate level and for each of the three ECAs, providing a general perspective on U.S. corn quality's geographic variability.

The corn's quality characteristics identified at harvest establish the foundation for the grain's quality ultimately arriving at the export customers' doors. However, as corn passes through the U.S. marketing system, it is mingled with corn from other locations; aggregated into trucks, barges and railcars; then stored, loaded and unloaded several times. Therefore, the corn's quality and condition may change between the initial market entry and the export elevator. For this reason, the *2023/2024 Harvest Report* should be considered carefully in tandem with the Council's *2023/2024 Corn Export Cargo Quality Report*, to be published in early 2024. As always, the quality of an export cargo of corn is established by the contract between buyer and seller, and buyers are free to negotiate any quality factor important to them.

This report provides detailed information on each of the quality factors tested, including averages and standard deviations for the aggregate of all samples as well as the samples from each of the three ECAs. The "Quality Test Results" section summarizes the following quality factors:

- Grade Factors: test weight, BCFM, total damage and heat damage
- Moisture
- Chemical Composition: protein, starch and oil concentrations
- Physical Factors: stress cracks, 100-kernel weight, kernel volume, kernel true density, whole kernels and horneous (hard) endosperm
- Mycotoxins: aflatoxin, DON, fumonisin, ochratoxin A, T-2 and zearalenone

In addition, the *2023/2024 Harvest Report* includes brief descriptions of the U.S. crop and weather conditions; U.S. corn production, usage and outlook; detailed descriptions of survey, statistical analysis and testing analysis methods; and a historical perspective section displaying the average of each quality factor from all thirteen reports.

## A. GRADE FACTORS

USDA FGIS has established numerical grades, definitions and standards for measurement of many quality attributes. The attributes that determine the numerical grades for corn are test weight, BCFM, total damage and heat damage. A table with the numerical requirements for these attributes is in the “U.S. Corn Supporting Information” section of this report and on the following page.

### SUMMARY: GRADE FACTORS AND MOISTURE

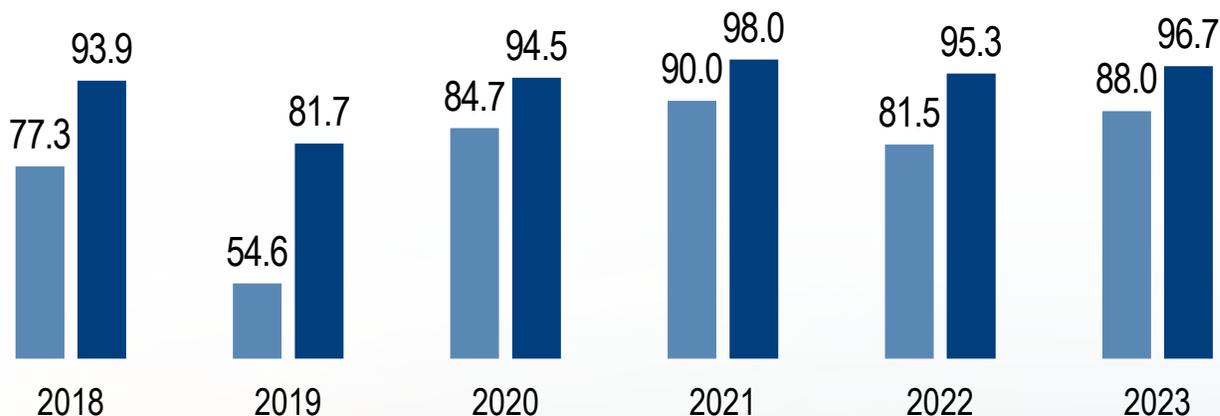
- The figure shown on the following page describes the percent of samples meeting grade factor limits for U.S. No. 1 and No. 2 grades by year. On average, 88.0% of the samples met all grade factor requirements for U.S. No. 1 grade, and 96.7% met the grade factor requirements for U.S. No. 2 grade.
- Average U.S. Aggregate test weight (58.4 lb/bu or 75.2 kg/hl) was well above the minimum for U.S. No. 1 grade (56.0 lb/bu). It was similar to 2022 (58.5 lb/bu or 75.3 kg/hl) and 2021 (58.3 lb/bu or 75.1 kg/hl) but higher than the 5YA (58.2 lb/bu or 75.0 kg/hl) and the 10YA (58.2 lb/bu or 74.9 kg/hl).
- Average U.S. Aggregate BCFM in 2023 (0.5%) was lower than 2022 (0.9%), 2021 (0.7%), the 5YA and 10YA (both 0.8%) and the maximum for U.S. No. 1 grade (2.0%).
- BCFM levels in 98.5% of the corn samples were equal to or below the 3.0% maximum allowed for No. 2 grade.
- Average BCFM levels for the Gulf, Pacific Northwest and Southern Rail ECAs were 0.6, 0.5 and 0.5%, respectively; all below the limit for U.S. No.1 grade.
- Average U.S. Aggregate broken corn averaged 0.4% in 2023, which was lower than 2022 (0.7%), 2021 (0.6%) and the 5YA and 10YA (both 0.6%).
- Average U.S. Aggregate foreign material (0.1%) in 2023 was lower than 2022, 2021, the 5YA and the 10YA (all 0.2%).
- Average total damage in the U.S. Aggregate samples in 2023 (0.9%) was higher than 2021 (0.7%), but lower than 2022 (1.2%), the 5YA and the 10YA (both 1.5%) and well below the limit for U.S. No. 1 grade (3.0%).
- A total of 95.1% of samples contained 3.0% or less damaged kernels. Average samples for the Gulf, Pacific Northwest and Southern Rail ECAs had total damage of 1.0, 0.6 and 0.9%, respectively. All were below the limit for U.S. No. 1 grade (3.0%).

## SUMMARY: GRADE FACTORS AND MOISTURE

- Average U.S. Aggregate heat damage was 0.0% for the 2023 samples, the same as 2022, 2021, the 5YA and the 10YA.
- Average U.S. Aggregate moisture content in 2023 (16.3%) was the same as 2022 and 2021 and similar to the 5YA and the 10YA (both 16.4%).
- The 2023 average moisture contents for the Gulf, Pacific Northwest and Southern Rail ECAs were 16.4, 16.5 and 15.8%, respectively. There were 30.8% of samples with moisture contents above 17.0% in 2023 compared to 32.3% in 2022 and 32.4% in 2021. Care should be taken to monitor and maintain moisture levels sufficiently low to prevent possible mold growth and loss of storage life.

Samples Meeting All Requirements by Grade (%)

■ U.S. No. 1 ■ U.S. No. 2



| U.S. Corn Grades and Grade Requirements |   |                        |                 |  |
|---|---|------------------------|-----------------|--|
| Grade                                   | Minimum Test Weight per Bushel (Pounds) | Maximum Limits of      |                 |  |
|   |   | Damaged Kernels        |                 | Broken Corn and Foreign Material (Percent) |
|   |   | Heat Damaged (Percent) | Total (Percent) |  |
| U.S. No. 1                              | 56.0                                    | 0.1                    | 3.0             | 2.0  |
| U.S. No. 2                              | 54.0                                    | 0.2                    | 5.0             | 3.0  |
| U.S. No. 3                              | 52.0                                    | 0.5                    | 7.0             | 4.0  |
| U.S. No. 4                              | 49.0                                    | 1.0                    | 10.0            | 5.0  |
| U.S. No. 5                              | 46.0                                    | 3.0                    | 15.0            | 7.0  |

## TEST WEIGHT

Test weight (weight per volume) is a measure of bulk density. It is often used as a general indicator of overall quality and as a gauge of endosperm hardness for alkaline cooking processors and dry millers. High test weight corn takes up less storage space than the same weight of corn with lower test weight. Genetic differences initially impact the structure of the kernel for test weight. However, it is also affected by the method of drying, physical damage to the kernel (broken kernels and scuffed surfaces), foreign material in the sample, kernel size, stress during the growing season, microbiological damage and moisture content. In general, if corn is dried gently, test weight may increase 0.25 to 0.33 lb/bu for a one percentage point reduction in moisture. However, other factors such as kernel size, shape, fine material, damage and rapidity of drying may influence the potential change in test weight.<sup>1</sup>

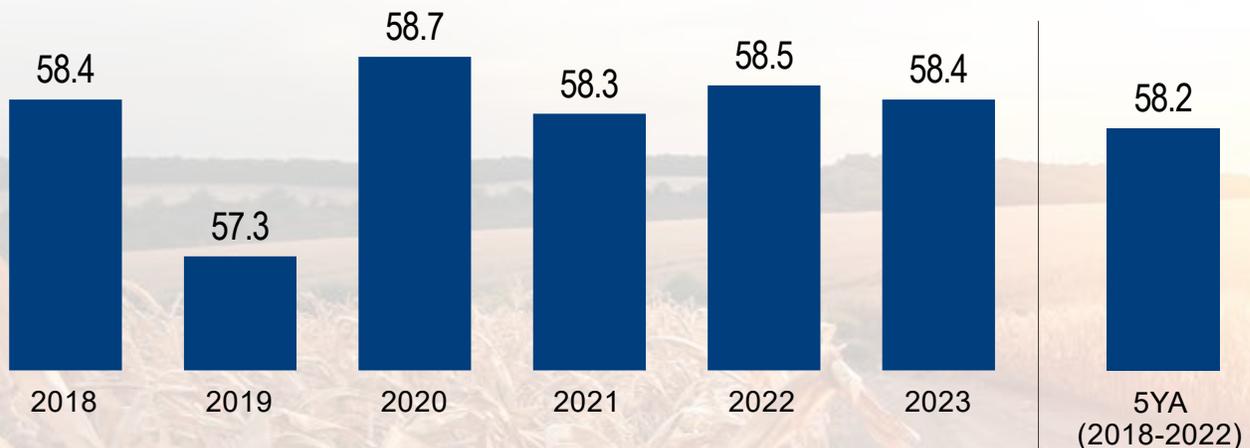
When sampled and measured at the point of delivery from the farm at a given moisture content, high test weight generally indicates high quality, a high percent of horny (or hard) endosperm and sound, clean corn. Test weight is positively correlated with true density and reflects kernel hardness and good maturation conditions.

## RESULTS

- Average U.S. Aggregate test weight in 2023 (58.4 lb/bu or 75.2 kg/hl) was well above the minimum for U.S. No. 1 grade (56.0 lb/bu). It was similar to 2022 (58.5 lb/bu or 75.3 kg/hl) and 2021 (58.3 lb/bu or 75.1 kg/hl) but higher than the 5YA (58.2 lb/bu or 75.0 kg/hl) and the 10YA (58.2 lb/bu or 74.9 kg/hl).

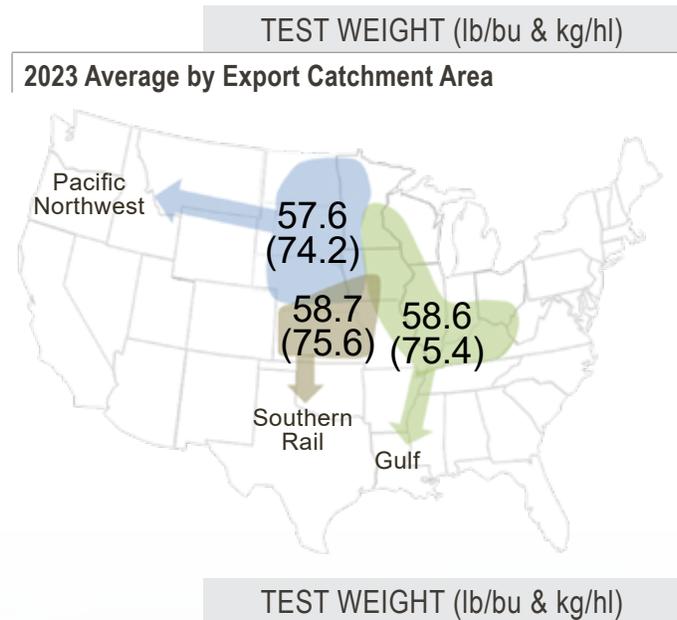
### TEST WEIGHT (lb/bu & kg/hl)

#### U.S. Aggregate Results Summary



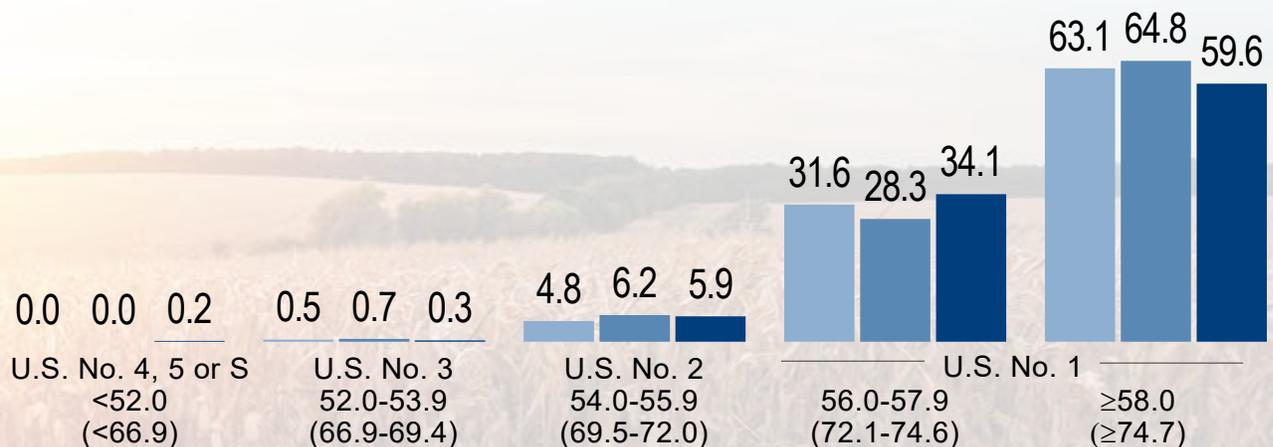
<sup>1</sup>Hellevang, K. (2019) Many Factors Influence Corn Test Weight. NDSU Agricultural Communication November 27, 2019, NDSU Extension Service.

- The standard deviation for U.S. Aggregate test weight in 2023 (1.23 lb/bu) was similar to 2022 (1.30 lb/bu), 2021 (1.18 lb/bu), the 5YA (1.26 lb/bu) and the 10YA (1.27 lb/bu).
- The range in values among the 2023 harvest samples was 16.6 lb/bu (46.4 to 63.0 lb/bu), which was greater than the 2022 range of 10.8 lb/bu (52.3 to 63.1 lb/bu) and the 2021 harvest range of 8.8 lb/bu (53.3 to 62.1 lb/bu).
- The 2023 test weight values were distributed with 93.7% of the samples at or above the factor limit for U.S. No. 1 grade (56.0 lb/bu) compared to 93.1% in 2022 and 94.7% in 2021. In 2023, 99.6% of the samples were above the limit for U.S. No. 2 grade (54.0 lb/bu), compared to 99.3% in 2022 and 99.5% in 2021.
- In 2023, the Pacific Northwest ECA (57.6 lb/bu) had the lowest average test weight. The Gulf and Southern Rail ECAs had test weights of 58.6 lb/bu and 58.7 lb/bu, respectively.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



**BROKEN CORN AND FOREIGN MATERIAL**

BCFM is an indicator of the amount of clean, sound corn available for feeding and processing. The lower the percentage of BCFM, the less foreign material or fewer broken kernels are in a sample. Higher levels of BCFM in farm-originated samples generally stem from harvesting practices or weed seeds in the field. BCFM levels will normally increase during drying and handling as a result of more broken kernels, depending on the methods used and the soundness of the kernels.

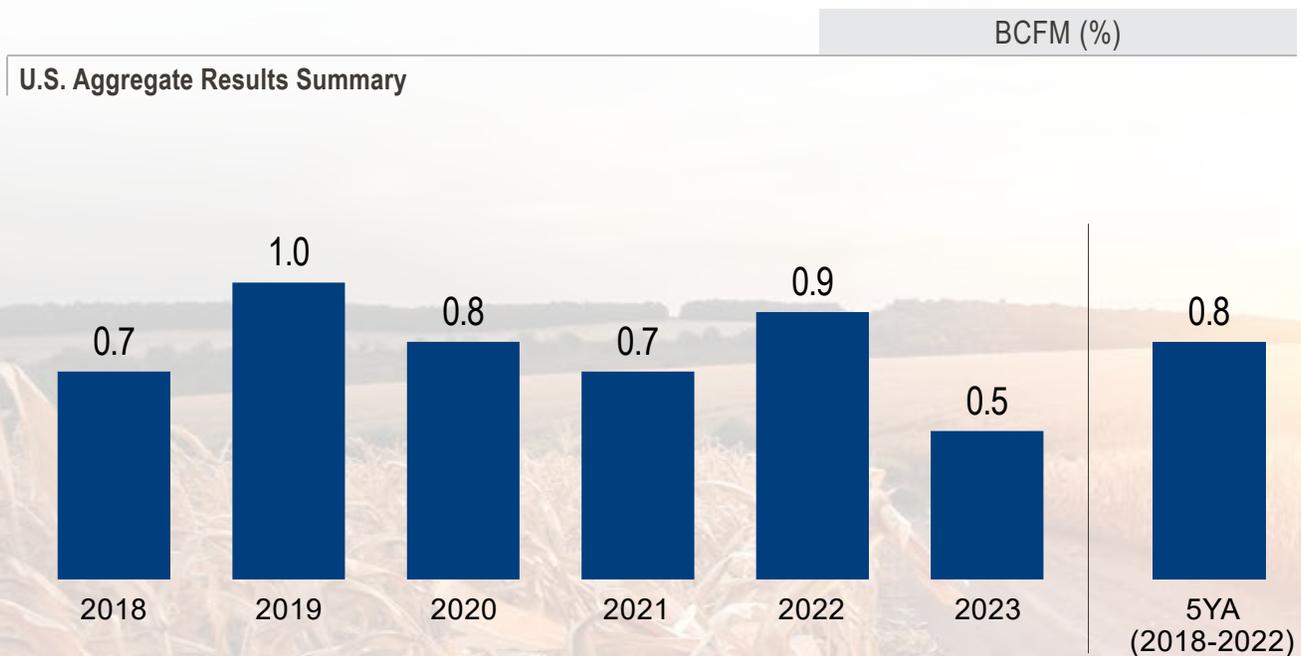
Broken corn (BC) is corn and any other material (such as weed seeds) small enough to pass through a 12/64<sup>th</sup>-inch round-hole sieve, and too large to pass through a 6/64<sup>th</sup>-inch round-hole sieve.

Foreign material (FM) is any non-corn material too large to pass through a 12/64<sup>th</sup>-inch round-hole sieve, as well as all fine material small enough to pass through a 6/64<sup>th</sup>-inch round-hole sieve.

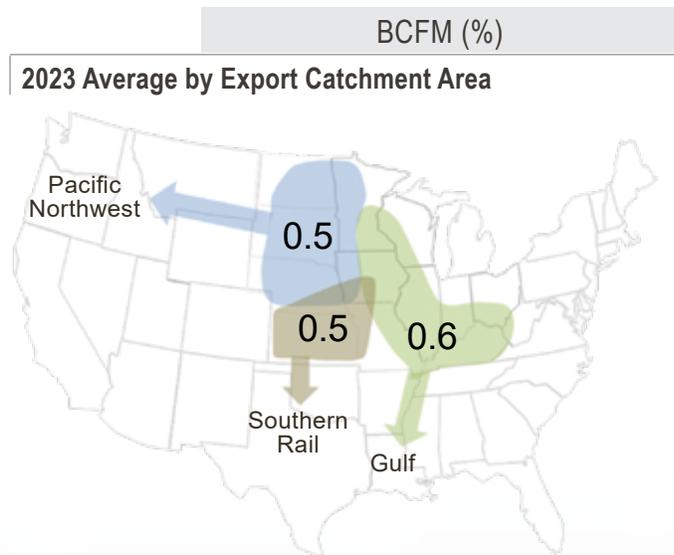
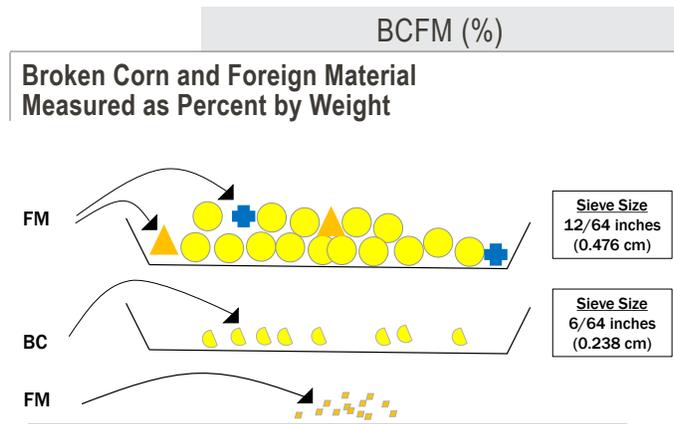
The diagram shown on the following page illustrates the measurement of broken corn and foreign material for the U.S. corn grades.

**RESULTS**

- Average U.S. Aggregate BCFM in 2023 (0.5%) was lower than 2022 (0.9%), 2021 (0.7%), the 5YA and 10YA (both 0.8%) and the maximum for U.S. No. 1 grade (2.0%).
- The variability of BCFM in the 2023 crop, based on standard deviation (0.45%), was lower than 2022 (0.59%), the 5YA (0.54%) and the 10YA (0.55%), and similar to 2021 (0.46%).



- The range between minimum and maximum BCFM values in the 2023 harvest samples was 5.9% (0.0 to 5.9%), which was intermediate to the 2022 samples with 7.0% (0.0 to 7.0%) and the 2021 samples with 3.4% (0.0 to 3.4%).
- The samples from the 2023 crop were distributed with 97.2% of the samples at or below the maximum BCFM level for U.S. No. 1 grade (2.0%), compared to 92.2% in 2022 and 96.6% in 2021. BCFM levels in nearly all samples (98.5%) were equal to or below the maximum 3.0% limit for U.S. No. 2 grade.
- Average BCFM levels for the Gulf, Pacific Northwest and Southern Rail ECAs were 0.6, 0.5 and 0.5%, respectively; all below the limit for U.S. No.1 grade.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



**BROKEN CORN**

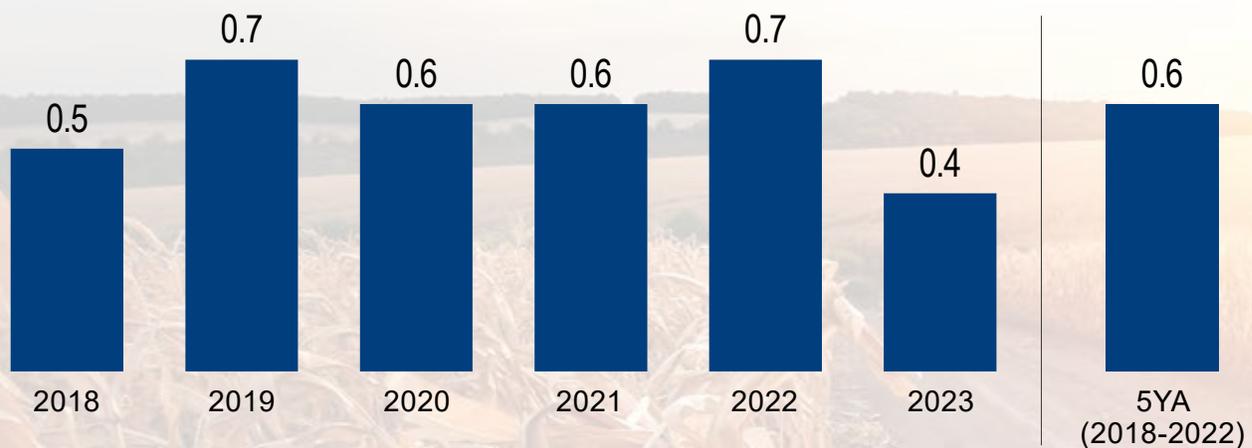
Broken corn in U.S. grades is based on particle size and usually includes a small percent of non-corn material. Broken corn is more subject to mold and insect damage than whole kernels, and it can cause problems in handling and processing. When not spread or stirred in a storage bin, broken corn tends to stay in the center of the bin, while whole kernels are likely to gravitate outward to the edges. The center area where broken corn tends to accumulate is known as a “spout-line.” If desired, the spout-line can be reduced by drawing this grain out of the center of the bin.

**RESULTS**

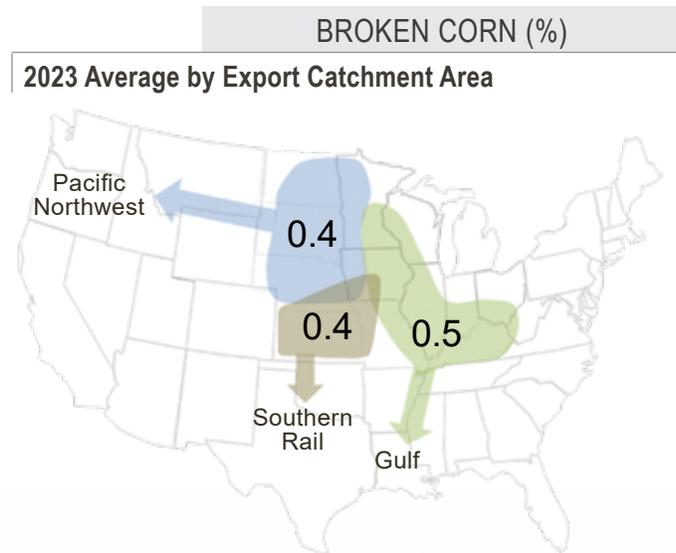
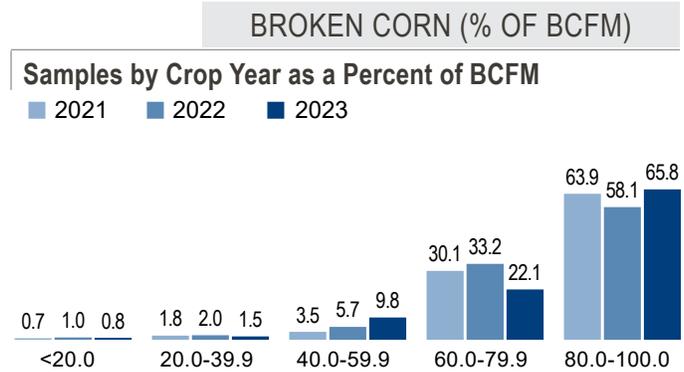
- Broken corn in the U.S. Aggregate samples averaged 0.4% in 2023, which was lower than 2022 (0.7%), 2021, the 5YA and the 10YA (all 0.6%).
- The variability among samples of broken corn for the 2023 crop was slightly lower than 2022, but similar to previous years, as measured by standard deviations. Standard deviations for 2023, 2022, 2021, the 5YA and the 10YA were 0.35, 0.44, 0.33, 0.38 and 0.39%, respectively.
- The range in broken corn values in 2023 was 5.0% (0.0 to 5.0%). This was intermediate to 2022 with 6.6% (from 0.0 to 6.6%) and 2021 with 2.3% (0.0 to 2.3%).

BROKEN CORN (%)

U.S. Aggregate Results Summary

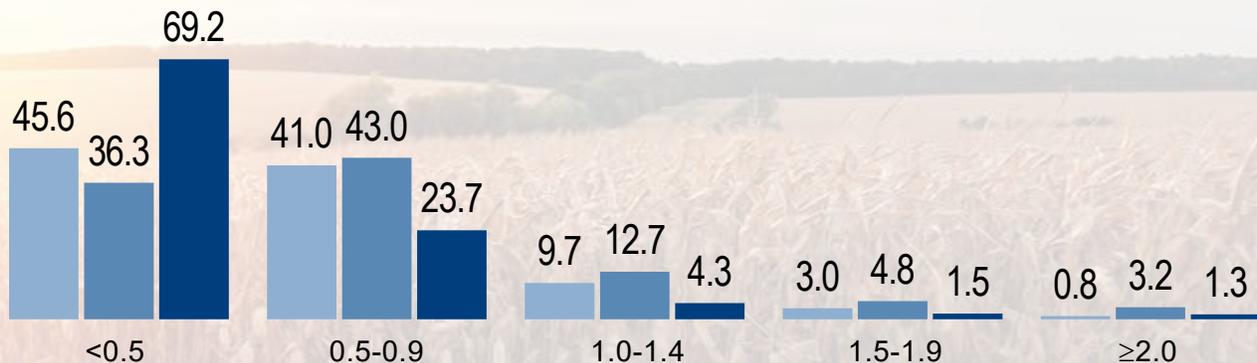


- The 2023 samples were distributed with 7.1% having 1.0% or more broken corn, compared to 20.7% in 2022 and 13.5% in 2021.
- The distribution chart to the right, displaying broken corn as a percentage of BCFM, shows that in 65.8% of the samples, BCFM consisted of at least 80.0% broken corn.
- The percentages of broken corn for the Gulf, Pacific Northwest and Southern Rail ECAs were 0.5, 0.4 and 0.4%, respectively.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



**FOREIGN MATERIAL**

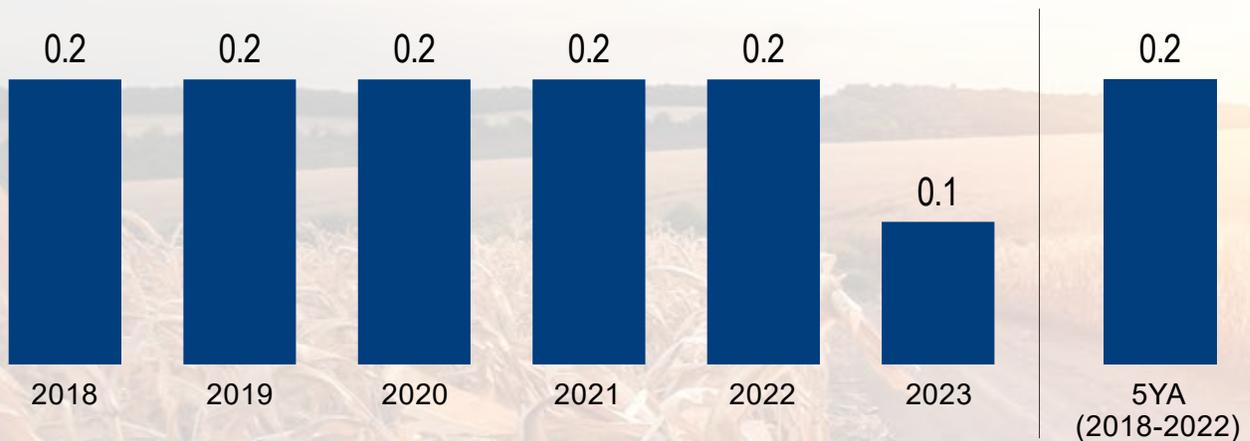
Foreign material is important because it has reduced feeding or processing value. It is also generally higher in moisture content than corn and, therefore, creates a potential for deterioration of corn quality during storage. Additionally, foreign material contributes to the spout-line (as mentioned in Broken Corn). It also has the potential to create more quality problems than broken corn due to its higher moisture level.

**RESULTS**

- Foreign material in the U.S. Aggregate samples averaged 0.1% in 2023 which is lower than 2022, 2021, the 5YA and the 10YA (all 0.2%). Combines, which are designed to remove most fine material, appear to be functioning well, given the consistently low level of foreign material measured across the years.
- Variability, measured by standard deviation, among the U.S. Aggregate samples in 2023 (0.16%) was lower than 2022 (0.23%), 2021 (0.18%), the 5YA and the 10YA (both 0.23%).
- Foreign material in the 2023 samples ranged from 0.0 to 2.3%, which was lower than 2022 (0.0 to 3.0%), but similar to 2021 (0.0 to 1.8%).

FOREIGN MATERIAL (%)

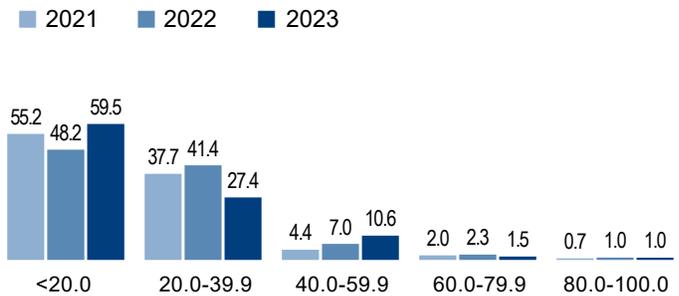
U.S. Aggregate Results Summary



- In the 2023 crop, 95.1% of the samples contained less than 0.5% foreign material, higher than 2022 (89.5%) and 2021 (93.4%).
- The distribution chart to the right, displaying foreign material as a percentage of BCFM, shows that in 59.5% of the samples, BCFM consisted of less than 20.0% foreign material.
- The percentages of foreign material for the Gulf, Pacific Northwest and Southern Rail ECAs (all 0.1%) were lower than those in 2022. All ECAs had average foreign material values of 0.3% or less for 2023, 2022, 2021, the 5YA and the 10YA.

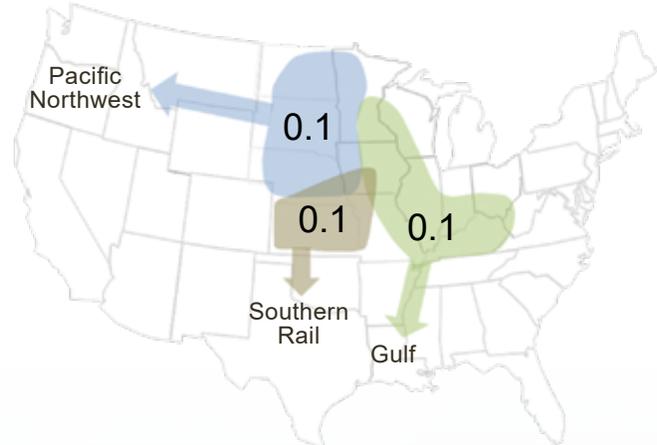
FOREIGN MATERIAL (% OF BCFM)

Samples by Crop Year as a Percent of BCFM



FOREIGN MATERIAL (%)

2023 Average by Export Catchment Area



FOREIGN MATERIAL (%)

Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



**TOTAL DAMAGE**

Total damage is the percent of kernels and pieces of kernels that are visually damaged in some way, including damage from mold, frost, insects, sprouting, disease, weather, ground, germ and heat. Heat damage is a subset of total damage and has separate allowances in the U.S. Grade standards. Most of these types of damage result in some discoloration or change in kernel texture. Damage does not include broken pieces of grain that are otherwise normal in appearance.

Mold damage is usually associated with higher moisture content and warm temperatures during the growing season or storage. Several field molds, such as *Diplodia*, *Aspergillus*, *Fusarium* and *Gibberella*, can lead to mold-damaged kernels during the growing season if the weather conditions are conducive to their development. While some fungi that produce mold damage can also produce mycotoxins, not all fungi produce mycotoxins. The chance of mold decreases as corn is dried and cooled to lower temperatures.

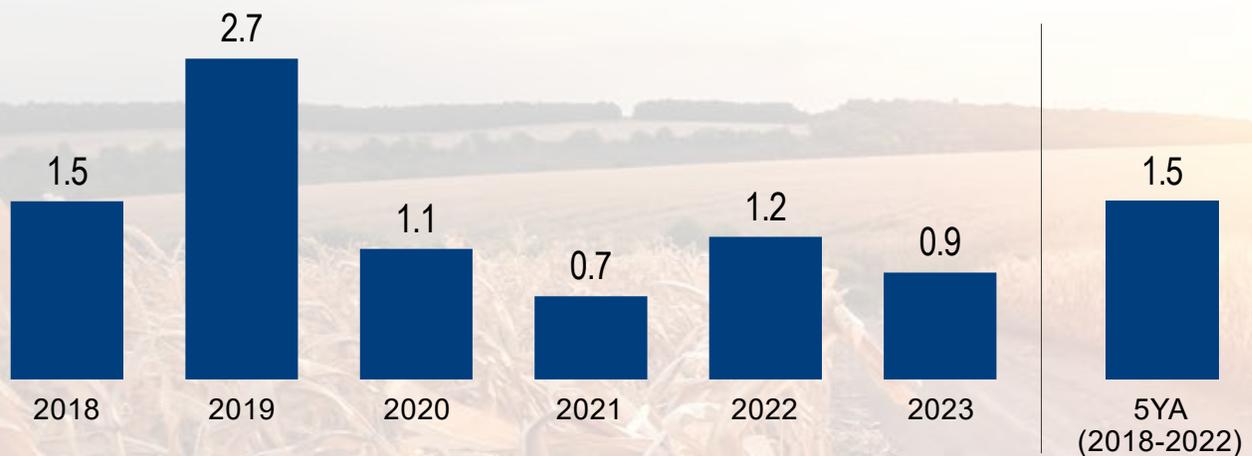
Heat damage can be caused by microbiological activity in warm, moist grain or high heat applied during drying. Heat damage is seldom present in corn delivered directly from farms at harvest.

**RESULTS**

- Average U.S. Aggregate total damage in 2023 (0.9%) was higher than 2021 (0.7%) but lower than 2022 (1.2%), the 5YA and the 10YA (both 1.5%). The 2023 total damage average was well below the limit for U.S. No. 1 grade (3.0%).

TOTAL DAMAGE (%)

U.S. Aggregate Results Summary



- Total damage variability in the 2023 crop, as measured by the standard deviation (0.88%), was intermediate to 2021 (0.59%) and 2022 (1.08%), the 5YA (1.28%) and the 10YA (1.23%).
- The range for total damage in 2023 (0.0 to 26.0%) was similar to 2022 (0.0 to 21.2%) but higher than 2021 (0.0 to 13.4%).
- The percent of samples having 3.0% or less total damage in 2023 (95.1%) was similar to 2022 (92.7%) and 2021 (97.9%).
- Average total damage was 1.0, 0.6 and 0.9% for the Gulf, Pacific Northwest and Southern Rail ECAs, respectively. Average total damage in all ECAs was at or below the limit for U.S. No. 1 grade (3.0%).
- Aggregate heat damage averaged 0.0% for the 2023 samples, the same as 2022, 2021, the 5YA and the 10YA. None of the samples in the 2023 survey tested above 0.0%.
- The lack of heat damage likely was due, in part, to fresh samples coming directly from farm to elevator with minimal artificial drying.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



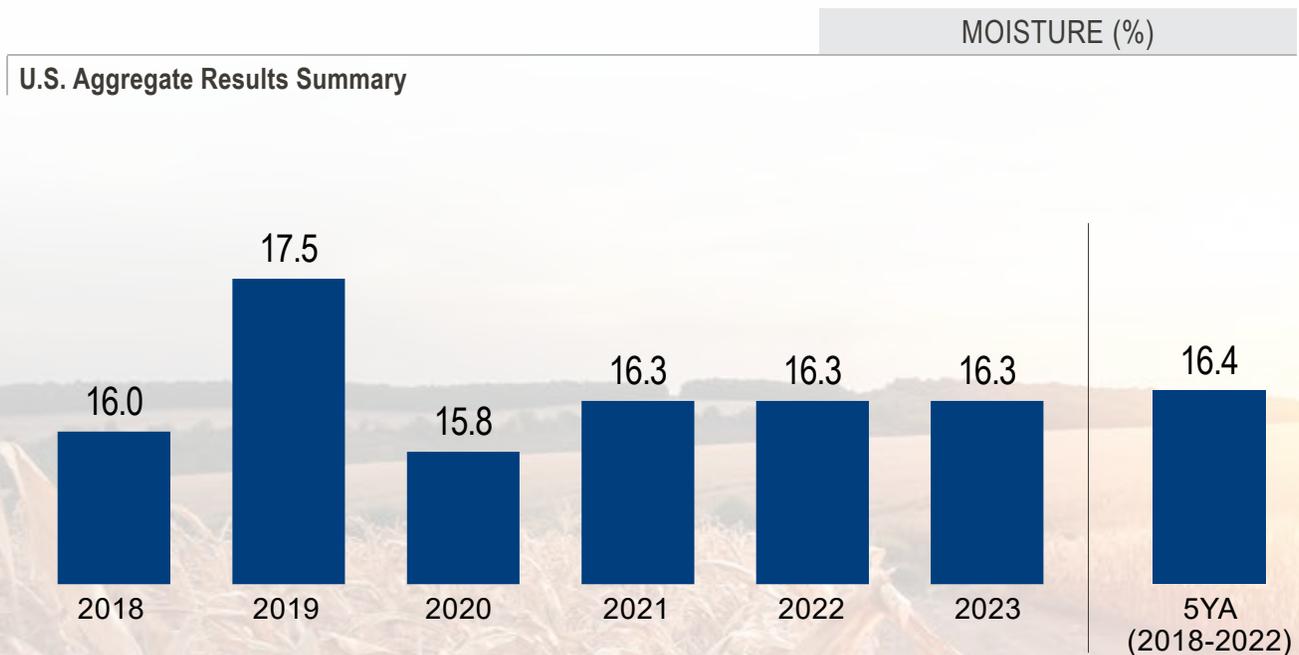
## B. MOISTURE

Moisture content is reported on official grade certificates, and maximum moisture content is usually specified in the contract. However, moisture is not a grade factor; therefore, it does not determine which numerical grade will be assigned to the sample. Moisture content is important because it affects the amount of dry matter being sold, is an indicator of the need for drying and has implications for storability. Higher moisture content at harvest increases the chance of kernel damage during harvesting and drying, with the amount of drying required also affecting stress cracks and breakage.

Extremely wet grain may be a precursor to high mold damage later in storage or transport. While the weather during the growing season affects yield, grain composition and kernel development, grain harvest moisture is influenced largely by crop maturation, the timing of harvest and harvest weather conditions. General moisture storage guidelines suggest that 14.0% is the maximum moisture content for storage up to six to twelve months for quality, clean corn in aerated storage under typical U.S. Corn Belt conditions, and 13.0% or lower moisture content for storage of more than one year.<sup>2</sup>

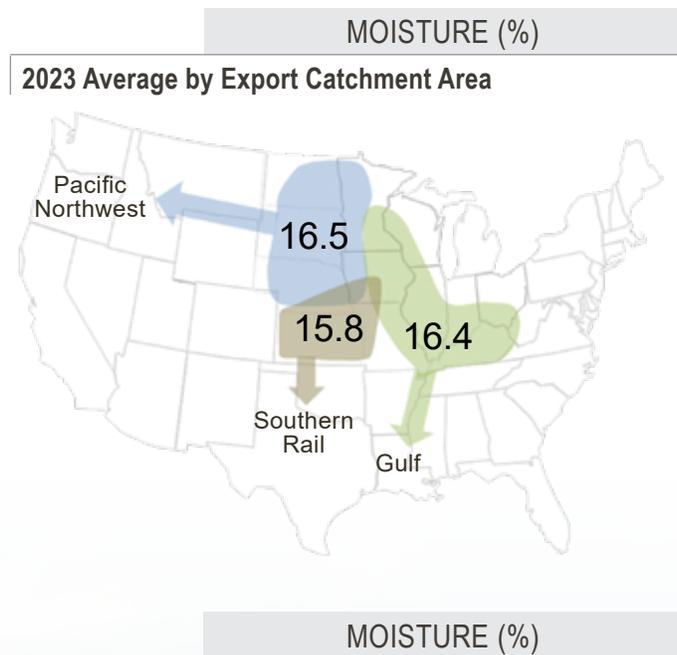
### RESULTS

- The average U.S. Aggregate moisture content recorded at elevators in 2023 was 16.3%, which was the same as 2022 and 2021, and similar to the 5YA and 10YA (both 16.4%). Over the past thirteen years, average U.S. Aggregate moisture content ranged from a low of 15.3% in the 2012 drought year to a high of 17.5% in 2019.



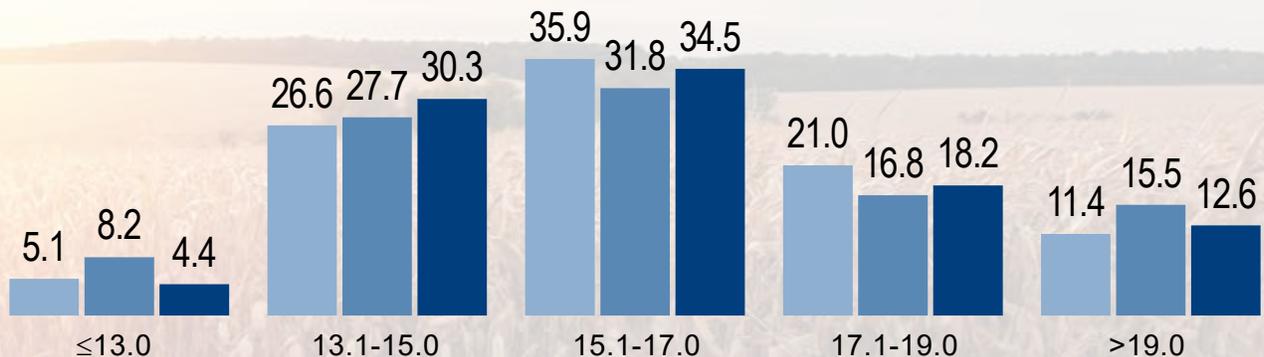
<sup>2</sup>MWPS-13. 2017. Grain Drying, Handling and Storage Handbook. Midwest Plan Service No. 13. Iowa State University, Ames, IA 50011.

- U.S. Aggregate moisture standard deviation in 2023 (1.95%) was similar to 2022 (2.09%), 2021 (1.79%), the 5YA (1.96%) and the 10YA (1.88%).
- In 2023, there were 30.8% of the samples above 17.0% moisture, compared to 32.3% in 2022 and 32.4% in 2021. Care should be taken to monitor and maintain moisture levels sufficiently low to prevent possible mold growth, reducing storage life.
- The 2023 moisture values were distributed with 34.7% of the samples containing 15.0% or less moisture. The base moisture used by elevators for discounts is generally 15.0%. This moisture content is considered safe for storage for only a short period during low wintertime temperatures.
- In the 2023 crop, 4.4% of the samples contained 13.0% or less moisture, compared to 8.2% in 2022 and 5.1% in 2021. Moisture content values of 13.0% and lower are generally considered safe for longer-term storage and transport.
- The 2023 average moisture contents for the Gulf, Pacific Northwest and Southern Rail ECAs were 16.4, 16.5 and 15.8%, respectively. Average moisture levels for the Southern Rail ECA have been the lowest among all ECAs in 2023, 2021, the 5YA and the 10YA.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



**SUMMARY: GRADE FACTORS AND MOISTURE**

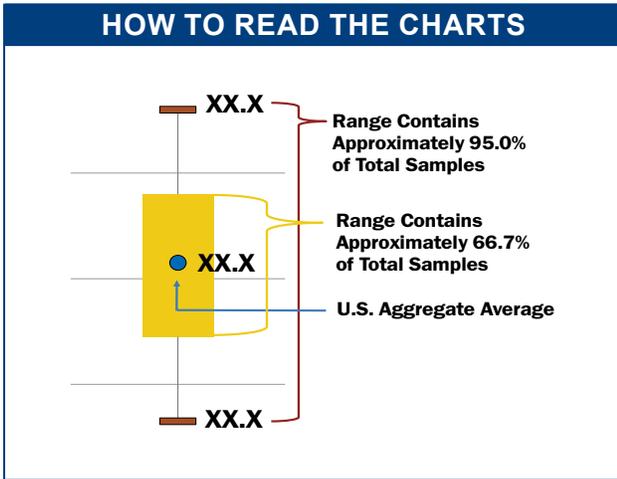
|                               | 2023 Harvest                |      |           |      |      | 2022 Harvest             |           | 2021 Harvest             |           | Five-Year Average (2018-2022) |           | Ten-Year Average (2013-2022) |           |
|-------------------------------|-----------------------------|------|-----------|------|------|--------------------------|-----------|--------------------------|-----------|-------------------------------|-----------|------------------------------|-----------|
|                               | No. of Samples <sup>1</sup> | Avg. | Std. Dev. | Min. | Max. | Avg.                     | Std. Dev. | Avg.                     | Std. Dev. | Avg.                          | Std. Dev. | Avg.                         | Std. Dev. |
| <b>U.S. Aggregate</b>         |                             |      |           |      |      | <b>U.S. Aggregate</b>    |           | <b>U.S. Aggregate</b>    |           | <b>U.S. Aggregate</b>         |           | <b>U.S. Aggregate</b>        |           |
| Test Weight (lb/bu)           | 596                         | 58.4 | 1.23      | 46.4 | 63.0 | 58.5                     | 1.30      | 58.3                     | 1.18      | 58.2*                         | 1.26      | 58.2*                        | 1.27      |
| Test Weight (kg/hl)           | 596                         | 75.2 | 1.58      | 59.7 | 81.1 | 75.3                     | 1.67      | 75.1                     | 1.51      | 75.0*                         | 1.62      | 74.9*                        | 1.63      |
| BCFM (%)                      | 608                         | 0.5  | 0.45      | 0.0  | 5.9  | 0.9*                     | 0.59      | 0.7*                     | 0.46      | 0.8*                          | 0.54      | 0.8*                         | 0.55      |
| Broken Corn (%)               | 608                         | 0.4  | 0.35      | 0.0  | 5.0  | 0.7*                     | 0.44      | 0.6*                     | 0.33      | 0.6*                          | 0.38      | 0.6*                         | 0.39      |
| Foreign Material (%)          | 608                         | 0.1  | 0.16      | 0.0  | 2.3  | 0.2*                     | 0.23      | 0.2*                     | 0.18      | 0.2*                          | 0.23      | 0.2*                         | 0.23      |
| Total Damage (%)              | 588                         | 0.9  | 0.88      | 0.0  | 26.0 | 1.2*                     | 1.08      | 0.7*                     | 0.59      | 1.5*                          | 1.28      | 1.5*                         | 1.23      |
| Heat Damage (%)               | 588                         | 0.0  | 0.00      | 0.0  | 0.0  | 0.0                      | 0.00      | 0.0                      | 0.00      | 0.0*                          | 0.00      | 0.0*                         | 0.00      |
| Moisture (%)                  | 571                         | 16.3 | 1.95      | 7.4  | 25.7 | 16.3                     | 2.09      | 16.3                     | 1.79      | 16.4                          | 1.96      | 16.4                         | 1.88      |
| <b>Gulf</b>                   |                             |      |           |      |      | <b>Gulf</b>              |           | <b>Gulf</b>              |           | <b>Gulf</b>                   |           | <b>Gulf</b>                  |           |
| Test Weight (lb/bu)           | 543                         | 58.6 | 1.26      | 46.4 | 63.0 | 58.5                     | 1.38      | 58.3*                    | 1.25      | 58.4*                         | 1.26      | 58.3*                        | 1.26      |
| Test Weight (kg/hl)           | 543                         | 75.4 | 1.62      | 59.7 | 81.1 | 75.3                     | 1.78      | 75.0*                    | 1.61      | 75.2*                         | 1.62      | 75.1*                        | 1.63      |
| BCFM (%)                      | 554                         | 0.6  | 0.51      | 0.0  | 5.9  | 0.9*                     | 0.60      | 0.7*                     | 0.45      | 0.8*                          | 0.54      | 0.8*                         | 0.54      |
| Broken Corn (%)               | 554                         | 0.5  | 0.39      | 0.0  | 5.0  | 0.7*                     | 0.46      | 0.6*                     | 0.32      | 0.6*                          | 0.38      | 0.6*                         | 0.38      |
| Foreign Material (%)          | 554                         | 0.1  | 0.17      | 0.0  | 2.3  | 0.2*                     | 0.22      | 0.2*                     | 0.17      | 0.2*                          | 0.23      | 0.2*                         | 0.23      |
| Total Damage (%)              | 540                         | 1.0  | 0.92      | 0.0  | 15.8 | 1.4*                     | 1.24      | 0.8*                     | 0.66      | 1.7*                          | 1.45      | 1.8*                         | 1.43      |
| Heat Damage (%)               | 540                         | 0.0  | 0.00      | 0.0  | 0.0  | 0.0                      | 0.00      | 0.0                      | 0.00      | 0.0*                          | 0.00      | 0.0*                         | 0.00      |
| Moisture (%)                  | 549                         | 16.4 | 2.08      | 7.4  | 25.7 | 16.8*                    | 2.22      | 16.8*                    | 1.90      | 16.8*                         | 2.04      | 16.7*                        | 1.95      |
| <b>Pacific Northwest</b>      |                             |      |           |      |      | <b>Pacific Northwest</b> |           | <b>Pacific Northwest</b> |           | <b>Pacific Northwest</b>      |           | <b>Pacific Northwest</b>     |           |
| Test Weight (lb/bu)           | 245                         | 57.6 | 1.03      | 53.4 | 62.2 | 58.1*                    | 1.14      | 58.1*                    | 1.05      | 57.5                          | 1.31      | 57.4*                        | 1.30      |
| Test Weight (kg/hl)           | 245                         | 74.2 | 1.33      | 68.7 | 80.1 | 74.8*                    | 1.47      | 74.8*                    | 1.35      | 74.1                          | 1.68      | 73.9*                        | 1.67      |
| BCFM (%)                      | 253                         | 0.5  | 0.31      | 0.0  | 3.5  | 0.9*                     | 0.57      | 0.8*                     | 0.51      | 0.9*                          | 0.60      | 0.9*                         | 0.60      |
| Broken Corn (%)               | 253                         | 0.4  | 0.23      | 0.0  | 2.8  | 0.7*                     | 0.39      | 0.6*                     | 0.36      | 0.7*                          | 0.41      | 0.7*                         | 0.42      |
| Foreign Material (%)          | 253                         | 0.1  | 0.12      | 0.0  | 1.7  | 0.3*                     | 0.26      | 0.2*                     | 0.20      | 0.2*                          | 0.25      | 0.2*                         | 0.25      |
| Total Damage (%) <sup>2</sup> | 240                         | 0.6  | 0.73      | 0.0  | 26.0 | 0.8*                     | 0.87      | 0.4*                     | 0.34      | 1.0*                          | 1.14      | 0.8*                         | 0.85      |
| Heat Damage (%)               | 240                         | 0.0  | 0.00      | 0.0  | 0.0  | 0.0                      | 0.00      | 0.0                      | 0.00      | 0.0*                          | 0.00      | 0.0*                         | 0.00      |
| Moisture (%)                  | 251                         | 16.5 | 1.74      | 8.0  | 23.6 | 15.7*                    | 1.81      | 15.7*                    | 1.57      | 16.2*                         | 1.97      | 16.1*                        | 1.85      |
| <b>Southern Rail</b>          |                             |      |           |      |      | <b>Southern Rail</b>     |           | <b>Southern Rail</b>     |           | <b>Southern Rail</b>          |           | <b>Southern Rail</b>         |           |
| Test Weight (lb/bu)           | 357                         | 58.7 | 1.35      | 46.4 | 63.0 | 58.9                     | 1.27      | 58.7                     | 1.12      | 58.8                          | 1.19      | 58.6                         | 1.23      |
| Test Weight (kg/hl)           | 357                         | 75.6 | 1.74      | 59.7 | 81.1 | 75.8                     | 1.64      | 75.6                     | 1.45      | 75.7                          | 1.53      | 75.4                         | 1.58      |
| BCFM (%)                      | 364                         | 0.5  | 0.46      | 0.0  | 5.9  | 0.9*                     | 0.59      | 0.7*                     | 0.42      | 0.8*                          | 0.47      | 0.8*                         | 0.48      |
| Broken Corn (%)               | 364                         | 0.4  | 0.35      | 0.0  | 5.0  | 0.7*                     | 0.44      | 0.6*                     | 0.29      | 0.6*                          | 0.34      | 0.6*                         | 0.35      |
| Foreign Material (%)          | 364                         | 0.1  | 0.17      | 0.0  | 2.3  | 0.2*                     | 0.24      | 0.2*                     | 0.19      | 0.2*                          | 0.21      | 0.2*                         | 0.21      |
| Total Damage (%) <sup>2</sup> | 355                         | 0.9  | 0.94      | 0.0  | 26.0 | 1.1*                     | 0.93      | 0.8                      | 0.72      | 1.4*                          | 0.97      | 1.4*                         | 1.04      |
| Heat Damage (%)               | 355                         | 0.0  | 0.00      | 0.0  | 0.0  | 0.0                      | 0.00      | 0.0                      | 0.00      | 0.0*                          | 0.00      | 0.0*                         | 0.00      |
| Moisture (%)                  | 363                         | 15.8 | 1.83      | 7.4  | 25.7 | 15.9                     | 2.13      | 15.5*                    | 1.74      | 15.5*                         | 1.68      | 15.7                         | 1.61      |

\*Indicates average was significantly different from current year, based on a 2-tailed t-test at the 95.0% level of significance.

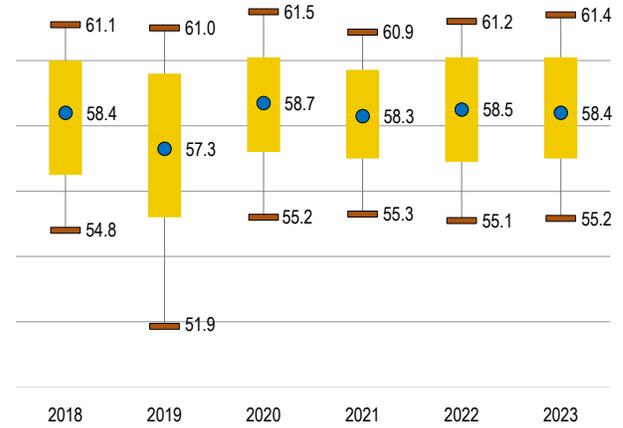
<sup>1</sup>Due to the ECA results being composite statistics, the sum of the samples from the ECAs is greater than the U.S. Aggregate. While 611 samples were tested for this year's report, the test results for each grade factor were less than 611 due to some samples weighing 1,000 grams or less being included. Moisture includes only 571 samples as the incoming moisture was not indicated on the sample bag by participating elevators for 40 samples.

<sup>2</sup>The Relative ME for predicting the harvest population average exceeded ±10.0%.

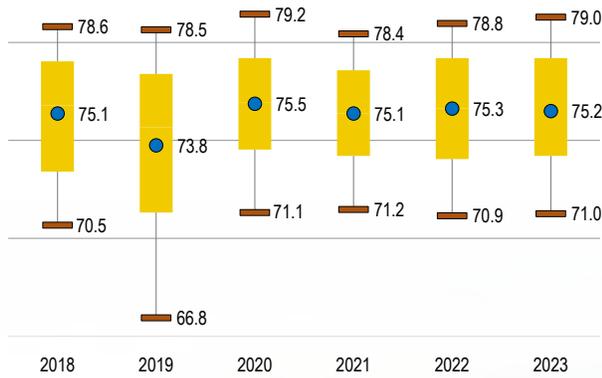
## GRADE FACTORS AGGREGATE SIX-YEAR COMPARISON



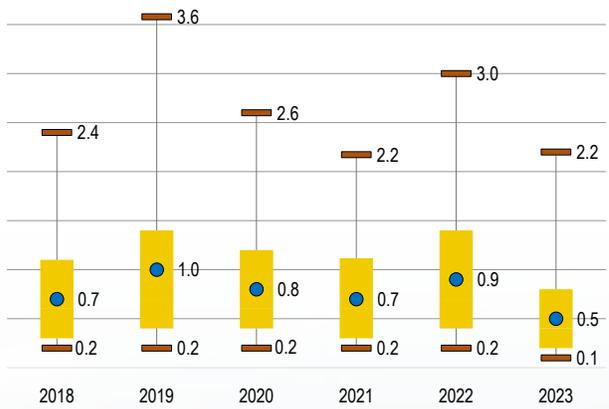
### Test Weight (lb/bu)



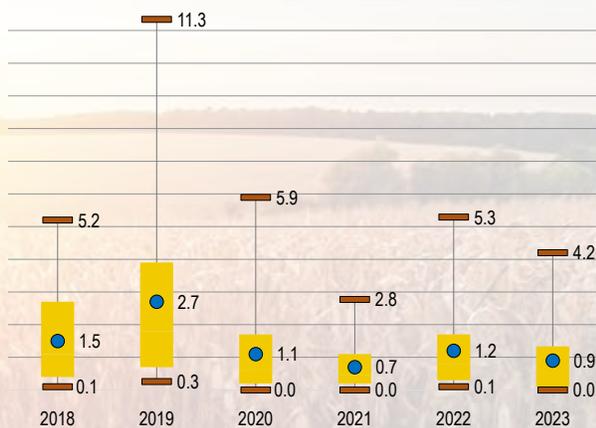
### Test Weight (kg/hl)



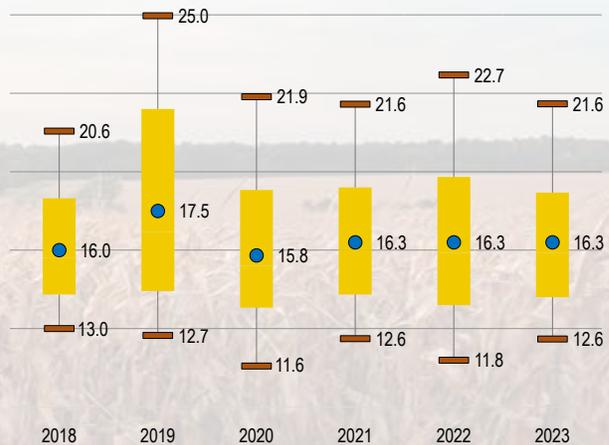
### BCFM (%)



### Total Damage (%)



### Moisture (%)



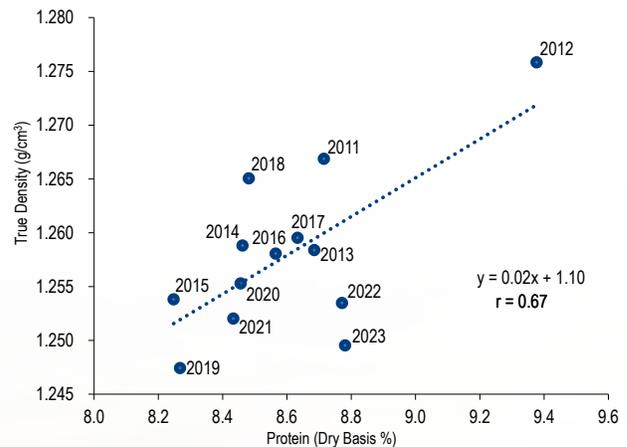
## C.CHEMICAL COMPOSITION

The chemical composition of corn consists primarily of protein, starch and oil. While these attributes are not graded factors, they are of significant interest to end-users. Chemical composition values provide additional information about nutritional value for livestock and poultry feeding, for wet milling uses and other processing uses of corn. Unlike many physical attributes, chemical composition values are not expected to change significantly during storage or transit.

### SUMMARY: CHEMICAL COMPOSITION

- Average U.S. Aggregate protein concentration in 2023 (8.8% dry basis) was the same as 2022, but higher than 2021 (8.4%), the 5YA and the 10YA (both 8.5%).
- The Gulf ECA had the highest average starch and lowest average protein concentration of all ECAs in 2023, 2022, 2021, the 5YA and the 10YA.
- Based on U.S. Aggregate averages over the past thirteen years, as protein concentration increases, true density also increases (resulting in a correlation coefficient of 0.67, as shown in the figure to the right. In general, protein concentration appears to be lower in years with lower true density and higher in years with higher true density.
- Average U.S. Aggregate starch concentration in 2023 (71.9% dry basis) was the same as 2022 but was lower than 2021 and the 5YA (both 72.2%) and the 10YA (72.7%).

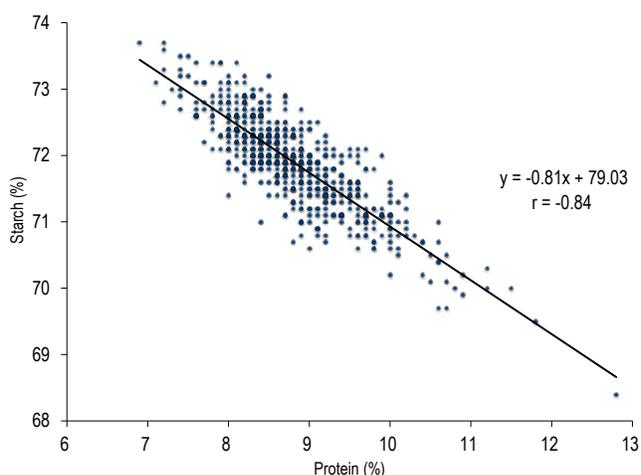
**True Density vs Protein  
U.S. Aggregate over Thirteen Years**



## SUMMARY: CHEMICAL COMPOSITION

- Since starch and protein are the two largest corn components, when the percentage of one goes up, the other usually goes down. This relationship is illustrated in the adjacent figure showing a negative correlation ( $r = -0.84$ ) between starch and protein.
- Average U.S. Aggregate oil concentration in 2023 (3.8% dry basis) was lower than 2022, the 5YA and 10YA (all 3.9%), but the same as 2021.
- The average oil concentrations for the Gulf, Pacific Northwest and Southern Rail ECAs in 2023 were all 3.8%. Oil concentration averages have consistently varied by 0.1% or less among the ECAs for 2023, 2022, 2021, the 5YA and the 10YA.

Starch vs Protein, U.S. Aggregate 2023



**PROTEIN**

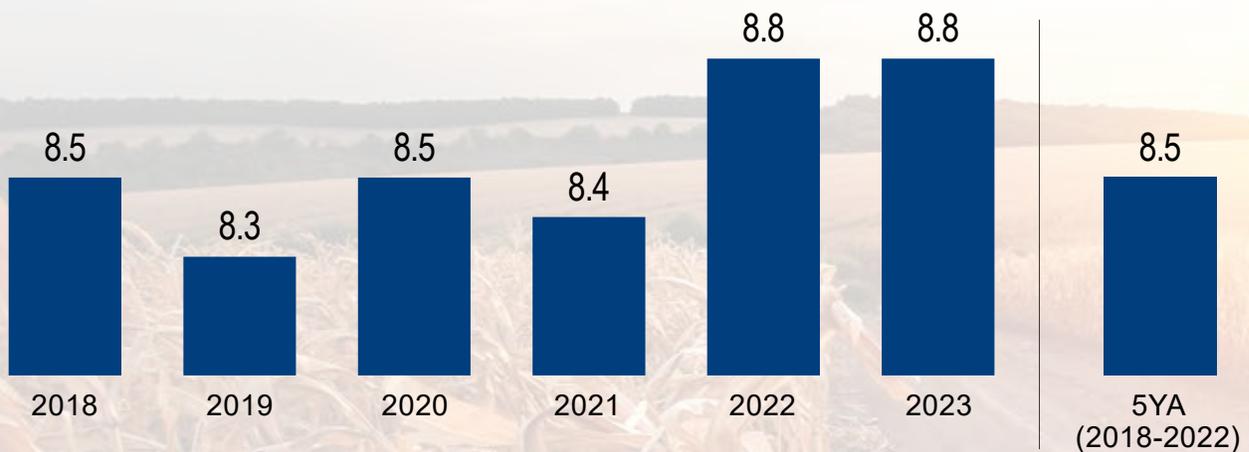
Protein is very important for poultry and livestock feeding because it supplies essential sulfur-containing amino acids and improves the feed conversion efficiency. Protein concentration tends to decrease with decreased available soil nitrogen and in years with high yields. Protein is usually inversely related to starch concentration. Results are reported on a dry basis.

**RESULTS**

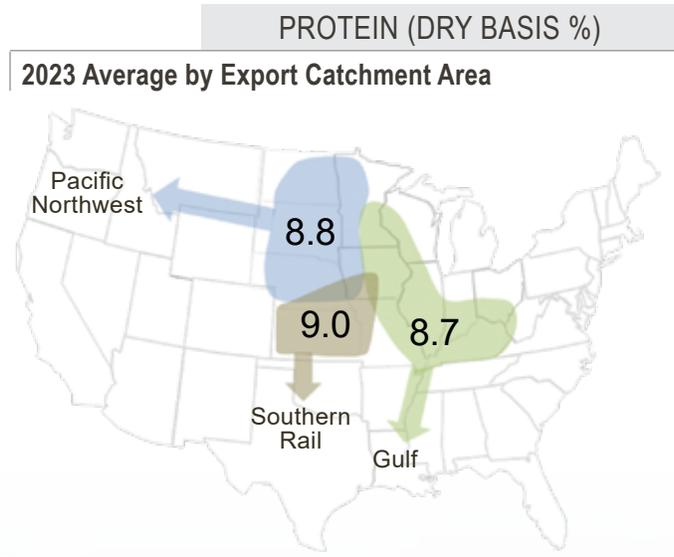
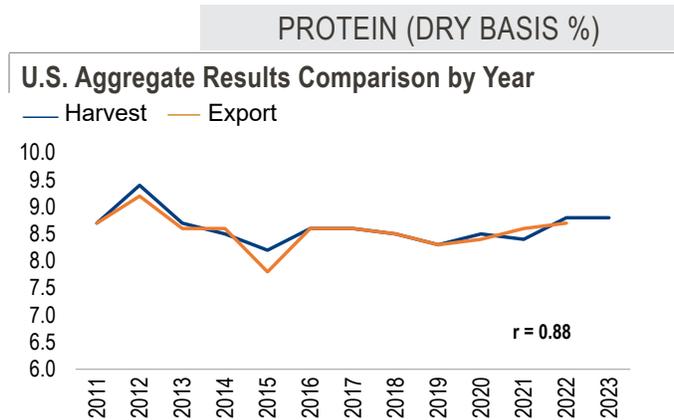
- Average U.S. Aggregate protein concentration in 2023 (8.8%) was the same as 2022, but higher than 2021 (8.4%), the 5YA and the 10YA (both 8.5%).
- Average U.S. Aggregate protein standard deviation in 2023 (0.56%) was similar to 2022 and 2021 (both 0.53%), the 5YA (0.54%) and the 10YA (0.55%).
- The range in protein concentration in 2023 (6.9 to 12.8%) was similar to ranges in 2022 (6.4 to 11.9%) and 2021 (6.4 to 11.8%).
- Protein concentrations in 2023 were distributed with 7.7% below 8.0%, 57.6% from 8.0 to 8.9% and 34.7% at or above 9.0%. The protein distribution in 2023 shows a similar number of high protein samples to 2022 but a higher number of high protein samples than in 2021.

PROTEIN (DRY BASIS %)

U.S. Aggregate Results Summary

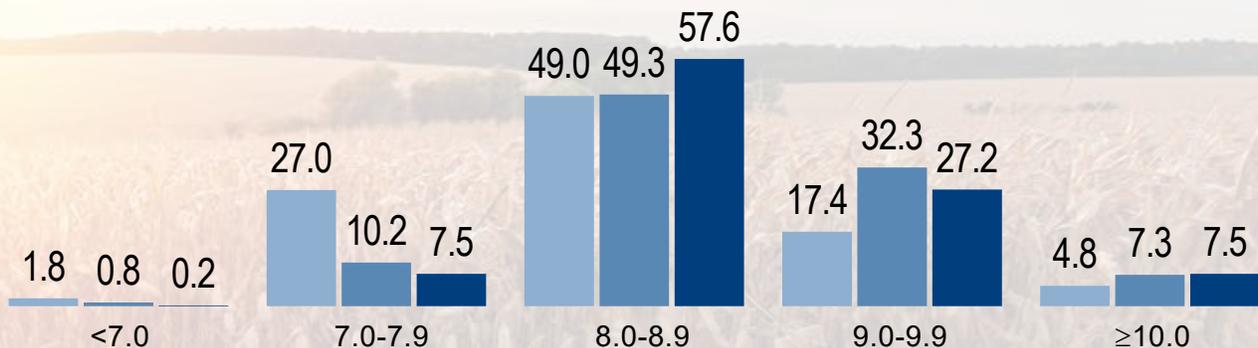


- Additional handling, blending and storage from harvest to export has little impact on average chemical composition. Similar chemical composition has been observed between each individual year's *Harvest Report* and *Export Cargo Report*. The line chart at the right displays the U.S. Aggregate protein concentrations observed in each of these reports from 2011 through 2023. The high correlation coefficient ( $r = 0.88$ ) illustrates this consistency.
- Protein concentration averages for Gulf, Pacific Northwest and Southern Rail ECAs were 8.7, 8.8 and 9.0%, respectively. Among ECAs, the Gulf had the lowest protein in 2023, 2022, 2021, the 5YA and the 10YA.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



**STARCH**

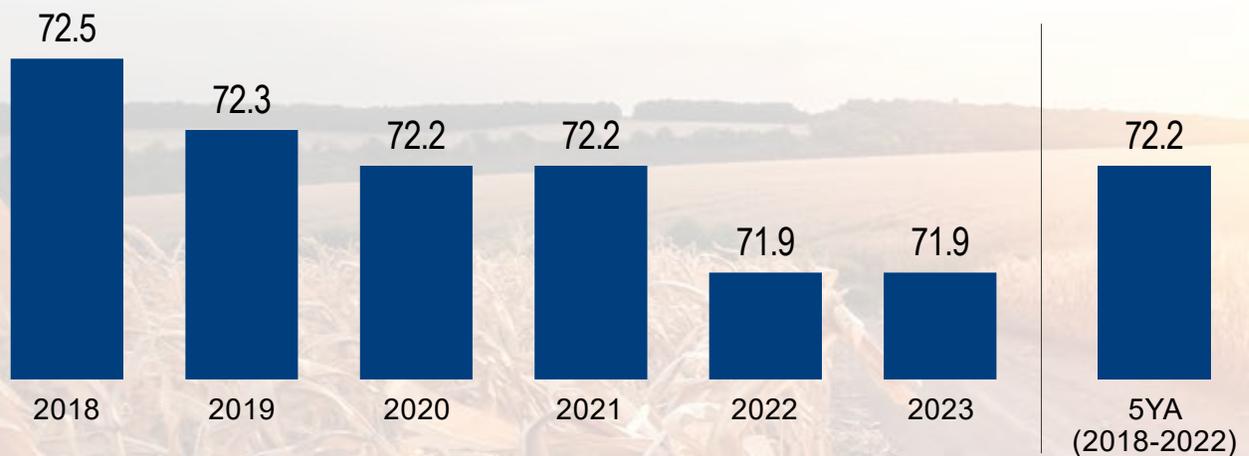
Starch is an important factor for corn used by wet millers and dry-grind ethanol manufacturers. High starch concentration is often indicative of good kernel growing/filling conditions and reasonably moderate kernel densities. Starch is usually inversely related to protein concentration. Results are reported on a dry basis.

**RESULTS**

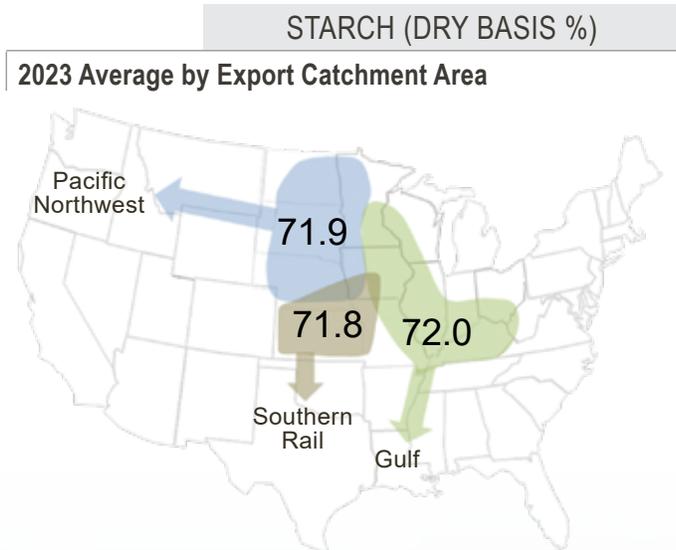
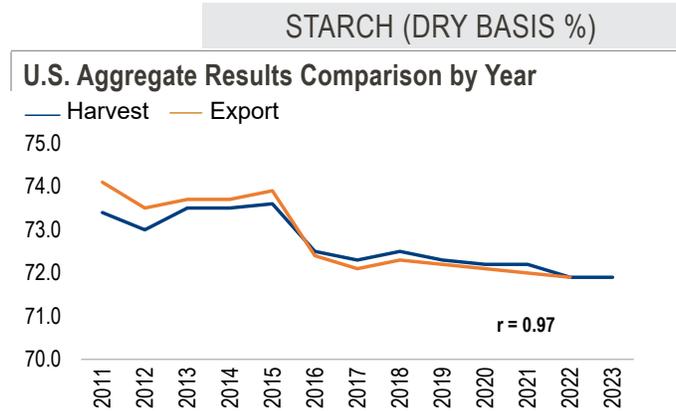
- Average U.S. Aggregate starch concentration in 2023 (71.9% dry basis) was the same as 2022 but was lower than 2021 (72.2%), the 5YA (72.2%) and the 10YA (72.7%).
- U.S. Aggregate starch standard deviation in 2023 (0.61%) was similar to 2022 (0.59%), 2021 (0.54%), the 5YA (0.59%) and the 10YA (0.61%).
- Starch concentration range in 2023 (68.4 to 73.7%) was similar to 2022 (69.1 to 74.3%) and 2021 (68.8 to 74.0%).
- Starch concentrations in 2023 were distributed with 50.7% of the samples below 72.0%, 44.0% from 72.0 to 72.9% and only 5.2% at 73.0% and higher. This distribution shows a lower number of high starch samples in 2023 and 2022 than in 2021.

STARCH (DRY BASIS %)

U.S. Aggregate Results Summary

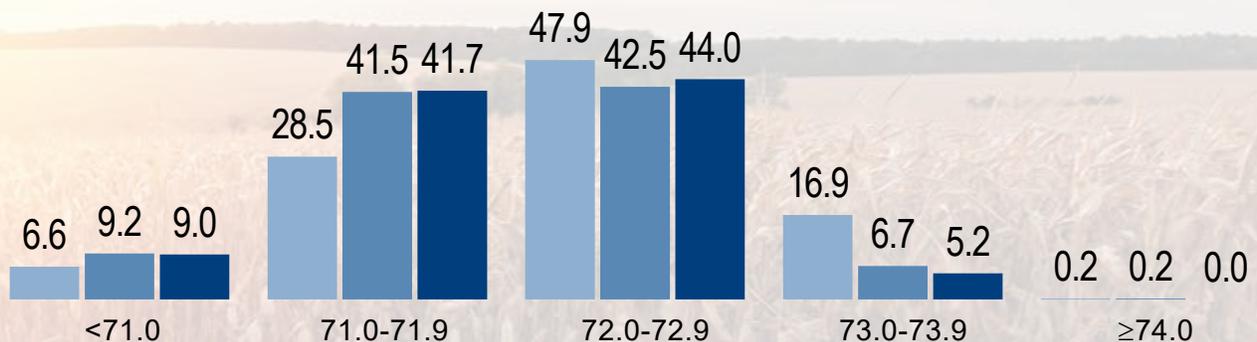


- Additional handling, blending and storage from harvest to export has little impact on average chemical composition. Similar chemical composition has been observed between each individual year's *Harvest Report* and *Export Cargo Report*. The line chart at the right displays the U.S. Aggregate starch concentrations observed in each of these reports. The high correlation coefficient ( $r = 0.97$ ) illustrates this consistency.
- Starch concentration averages for the Gulf, Pacific Northwest and Southern Rail ECAs were 72.0, 71.9 and 71.8%, respectively. Starch concentration averages were highest in the Gulf ECA in 2023, 2022, 2021, the 5YA and the 10YA. The Gulf ECA also had the lowest protein in 2023, 2022, 2021, the 5YA and 10YA.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



**OIL**

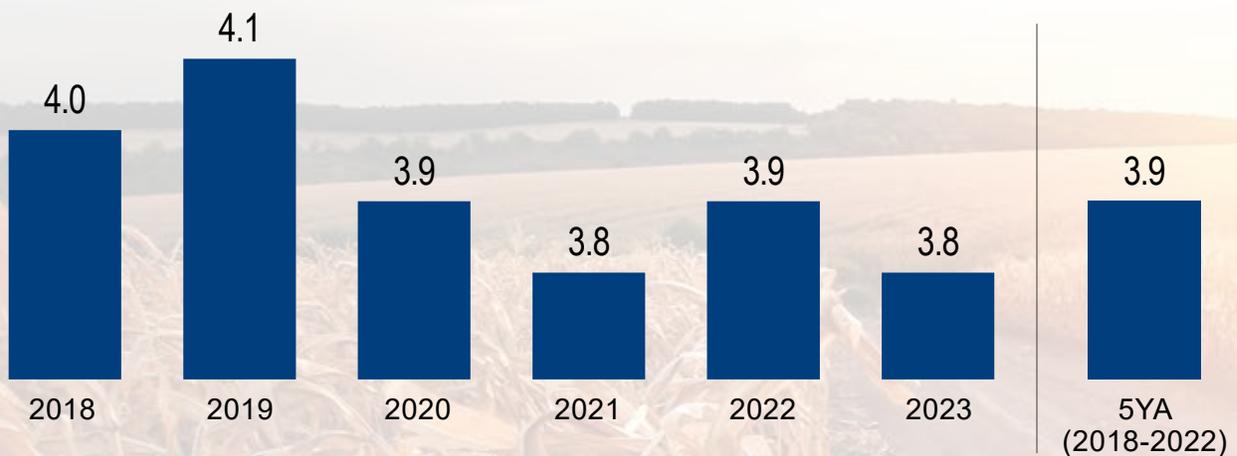
Oil is an essential component of poultry and livestock rations. It serves as an energy source, enables fat-soluble vitamins to be utilized, and provides certain essential fatty acids. Oil is also an important co-product of corn wet and dry milling. Results are reported on a dry basis.

**RESULTS**

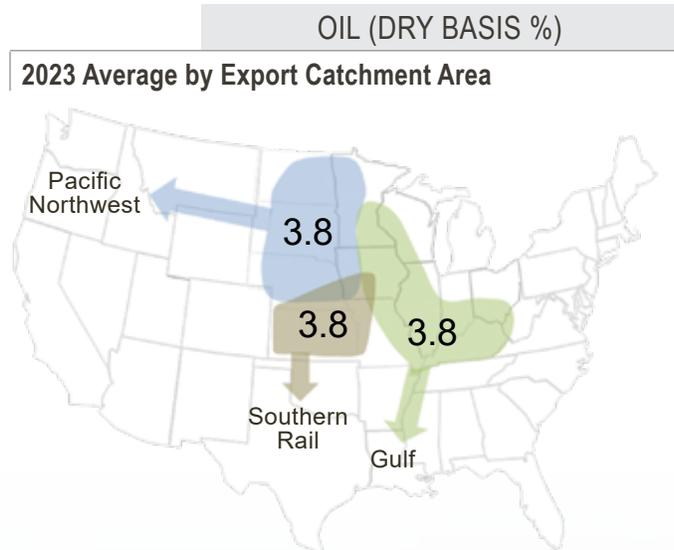
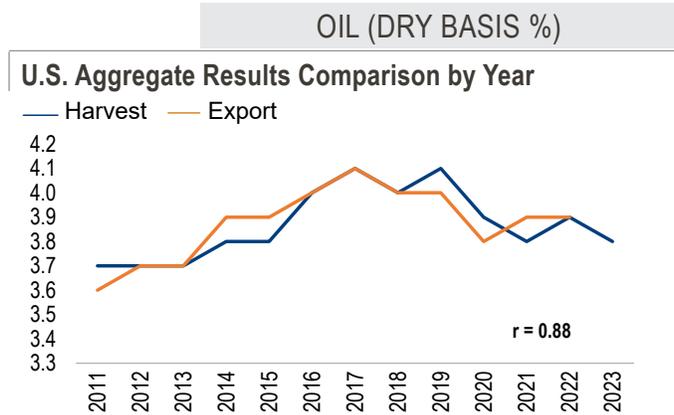
- Average U.S. Aggregate oil concentration in 2023 (3.8%) was lower than 2022, the 5YA and 10YA (all 3.9%), but the same as 2021.
- Standard deviation of U.S. Aggregate oil samples in 2023 (0.23%) was the same as 2021 and the 5YA and similar to 2022 (0.24%) and the 10YA (0.25%).
- Oil concentration range in 2023 (3.2 to 4.6%) was similar to 2022 (3.0 to 4.8%) and 2021 (3.0 to 4.5%).
- Oil concentrations in 2023 were distributed with 24.4% of the samples less than 3.7%, 71.2% of samples at 3.7 to 4.2% and 4.5% of samples at 4.3% and higher. This distribution shows a lower number of samples with oil concentrations at 4.0% or higher than in 2022 or in 2021.

OIL (DRY BASIS %)

**U.S. Aggregate Results Summary**

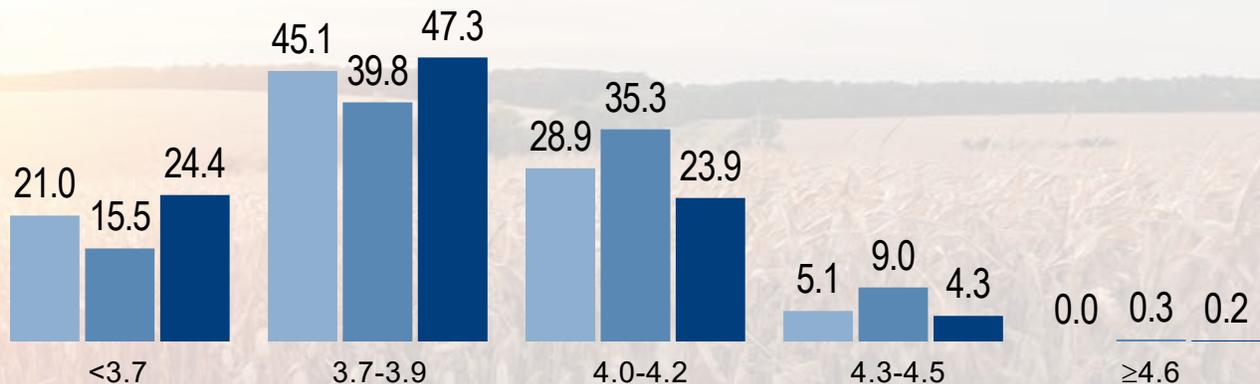


- Additional handling, blending and storage from harvest to export has little impact on average chemical composition. Similar chemical composition has been observed between each individual year's *Harvest Report* and *Export Cargo Report*. The line chart at the right displays the U.S. Aggregate oil concentrations observed in each of these reports. The high correlation coefficient ( $r = 0.88$ ) illustrates this consistency.
- Oil concentration averages for Gulf, Pacific Northwest and Southern Rail ECAs were all 3.8%. Oil concentration averages have varied by 0.1% or less among the ECAs for 2023, 2022, 2021, the 5YA and the 10YA.



Percent of Samples by Crop Year

■ 2021 ■ 2022 ■ 2023



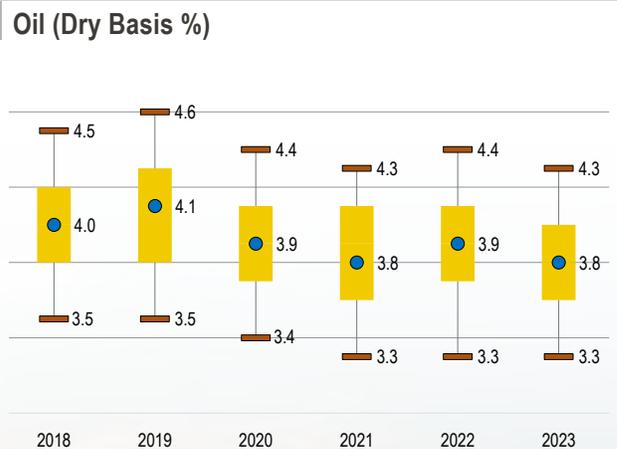
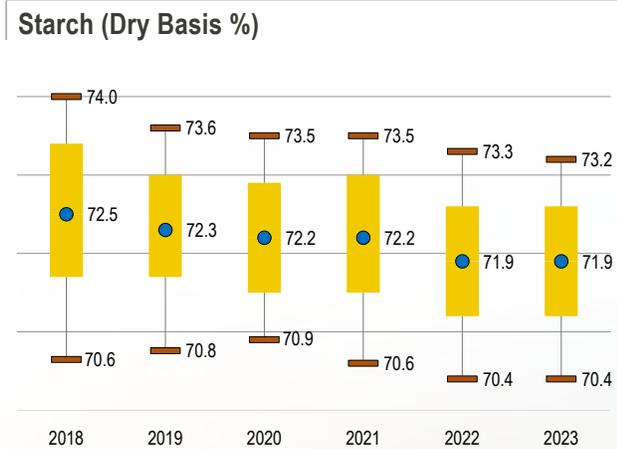
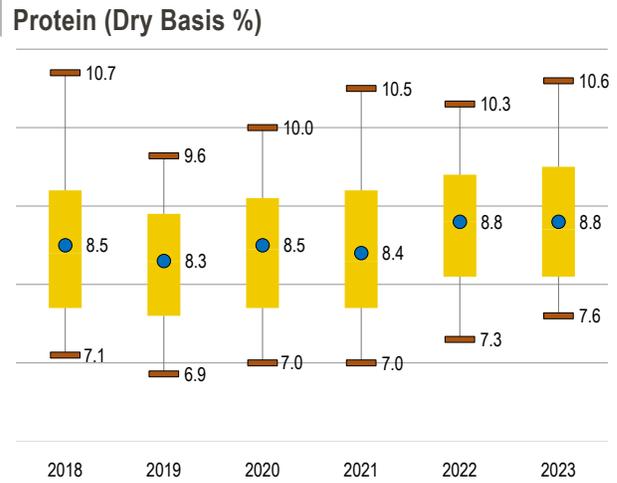
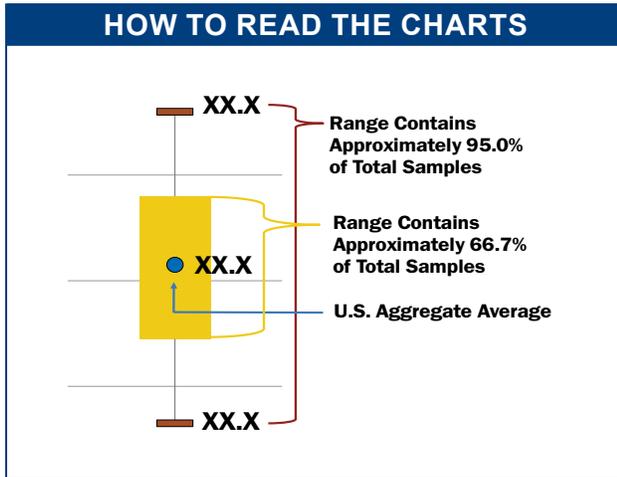
**SUMMARY: CHEMICAL COMPOSITION**

|                          | 2023 Harvest                |      |           |      |      | 2022 Harvest             |           | 2021 Harvest             |           | Five-Year Average (2018-2022) |           | Ten-Year Average (2013-2022) |           |
|--------------------------|-----------------------------|------|-----------|------|------|--------------------------|-----------|--------------------------|-----------|-------------------------------|-----------|------------------------------|-----------|
|                          | No. of Samples <sup>1</sup> | Avg. | Std. Dev. | Min. | Max. | Avg.                     | Std. Dev. | Avg.                     | Std. Dev. | Avg.                          | Std. Dev. | Avg.                         | Std. Dev. |
| <b>U.S. Aggregate</b>    |                             |      |           |      |      | <b>U.S. Aggregate</b>    |           | <b>U.S. Aggregate</b>    |           | <b>U.S. Aggregate</b>         |           | <b>U.S. Aggregate</b>        |           |
| Protein (Dry Basis %)    | 611                         | 8.8  | 0.56      | 6.9  | 12.8 | 8.8                      | 0.53      | 8.4*                     | 0.53      | 8.5*                          | 0.54      | 8.5*                         | 0.55      |
| Starch (Dry Basis %)     | 611                         | 71.9 | 0.61      | 68.4 | 73.7 | 71.9                     | 0.59      | 72.2*                    | 0.54      | 72.2*                         | 0.59      | 72.7*                        | 0.61      |
| Oil (Dry Basis %)        | 611                         | 3.8  | 0.23      | 3.2  | 4.6  | 3.9*                     | 0.24      | 3.8                      | 0.23      | 3.9*                          | 0.23      | 3.9*                         | 0.25      |
| <b>Gulf</b>              |                             |      |           |      |      | <b>Gulf</b>              |           | <b>Gulf</b>              |           | <b>Gulf</b>                   |           | <b>Gulf</b>                  |           |
| Protein (Dry Basis %)    | 557                         | 8.7  | 0.51      | 6.9  | 12.8 | 8.6*                     | 0.50      | 8.2*                     | 0.52      | 8.3*                          | 0.53      | 8.4*                         | 0.54      |
| Starch (Dry Basis %)     | 557                         | 72.0 | 0.59      | 68.4 | 73.7 | 72.1*                    | 0.59      | 72.4*                    | 0.53      | 72.4*                         | 0.58      | 72.8*                        | 0.61      |
| Oil (Dry Basis %)        | 557                         | 3.8  | 0.24      | 3.2  | 4.6  | 3.9*                     | 0.25      | 3.8                      | 0.24      | 3.9*                          | 0.24      | 3.9*                         | 0.26      |
| <b>Pacific Northwest</b> |                             |      |           |      |      | <b>Pacific Northwest</b> |           | <b>Pacific Northwest</b> |           | <b>Pacific Northwest</b>      |           | <b>Pacific Northwest</b>     |           |
| Protein (Dry Basis %)    | 254                         | 8.8  | 0.66      | 7.1  | 11.8 | 9.0*                     | 0.55      | 8.9*                     | 0.53      | 8.6*                          | 0.57      | 8.7                          | 0.58      |
| Starch (Dry Basis %)     | 254                         | 71.9 | 0.65      | 69.5 | 73.7 | 71.7*                    | 0.57      | 71.7*                    | 0.53      | 72.0*                         | 0.59      | 72.5*                        | 0.61      |
| Oil (Dry Basis %)        | 254                         | 3.8  | 0.23      | 3.2  | 4.6  | 3.9*                     | 0.21      | 3.9                      | 0.21      | 4.0*                          | 0.22      | 3.9*                         | 0.24      |
| <b>Southern Rail</b>     |                             |      |           |      |      | <b>Southern Rail</b>     |           | <b>Southern Rail</b>     |           | <b>Southern Rail</b>          |           | <b>Southern Rail</b>         |           |
| Protein (Dry Basis %)    | 365                         | 9.0  | 0.57      | 7.2  | 12.8 | 9.0                      | 0.55      | 8.5*                     | 0.53      | 8.7*                          | 0.54      | 8.7*                         | 0.56      |
| Starch (Dry Basis %)     | 365                         | 71.8 | 0.62      | 68.4 | 73.4 | 71.8                     | 0.61      | 72.2*                    | 0.57      | 72.1*                         | 0.59      | 72.5*                        | 0.60      |
| Oil (Dry Basis %)        | 365                         | 3.8  | 0.22      | 3.2  | 4.4  | 3.9*                     | 0.24      | 3.9*                     | 0.22      | 3.9*                          | 0.22      | 3.9*                         | 0.24      |

\*Indicates average was significantly different from current year, based on a 2-tailed t-test at the 95.0% level of significance.

<sup>1</sup>Due to the ECA results being composite statistics, the sum of the sample numbers from the three ECAs is greater than the U.S. Aggregate.

## CHEMICAL COMPOSITION AGGREGATE SIX-YEAR COMPARISON

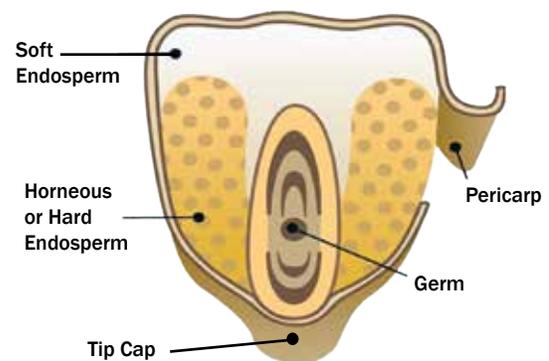


## D. PHYSICAL FACTORS

Physical factors are other quality attributes that are neither grade factors nor chemical composition. Physical factors include stress cracks, kernel weight, kernel volume, true density, percent whole kernels and percent horneous (hard) endosperm. Tests for these physical factors provide additional information about the processing characteristics of corn for various uses, as well as corn's storability and potential for breakage in handling. The physical composition of the corn kernel influences the quality attributes, which is, in turn, affected by genetics and growing and handling conditions.

Corn kernels are made up of four parts: the germ or embryo, the tip cap, the pericarp or outer covering and the endosperm. The endosperm represents about 82% of the kernel. It consists of soft (also referred to as floury or opaque) endosperm and of horneous (also called hard or vitreous) endosperm, as shown to the right. The endosperm contains primarily starch and protein, the germ contains oil and some protein, and the pericarp and tip cap are mostly fiber.

Corn Kernel



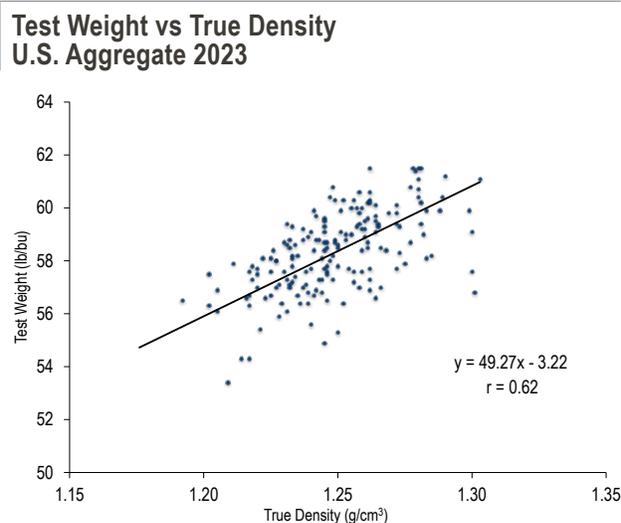
Source: Adapted from Corn Refiners Association, 2011

### SUMMARY: PHYSICAL FACTORS

- Average U.S. Aggregate stress cracks in 2023 (19.2%) was higher than 2022 (6.9%), 2021 (5.1%), the 5YA (6.3%) and the 10YA (6.0%).
- The Gulf, Pacific Northwest and Southern Rail ECAs had stress crack averages of 22.9, 11.5 and 17.7%, respectively. Among ECAs, the Gulf had the highest stress crack averages in 2023, 2022, 2021, the 5YA and the 10YA.
- Average U.S. Aggregate 100-k weight in 2023 averaged 35.52 g, higher than 2022 (33.94 g), but similar to 2021 (34.98 g), the 5YA and the 10YA (both 34.62 g).
- Average U.S. Aggregate kernel volume was 0.28 cm<sup>3</sup> in 2023, higher than 2022 (0.27 cm<sup>3</sup>) and the same as 2021. Average kernel volume in 2023 was statistically different (higher) from the 5YA and 10YA (both 0.28 cm<sup>3</sup>).
- The Pacific Northwest ECA had the lowest 100-k weight and the lowest kernel volume of the ECAs in 2023, 2022, 2021, the 5YA and the 10YA.

## SUMMARY: PHYSICAL FACTORS

- U.S. Aggregate kernel true density averaged 1.250 g/cm<sup>3</sup> in 2023, similar to 2022 (1.253 g/cm<sup>3</sup>) and 2021 (1.252 g/cm<sup>3</sup>) and lower than the 5YA (1.255 g/cm<sup>3</sup>) and the 10YA (1.256 g/cm<sup>3</sup>).
- Of the ECAs, the Pacific Northwest had the lowest true density and lowest test weight in 2023, 2022, 2021, the 5YA and the 10YA.
- Test weight, also known as bulk density, is based on the amount of mass contained in a quart cup. Test weight is influenced by true density, as shown in the adjacent figure ( $r = 0.62$ ). Test weight is also affected by moisture content, pericarp damage (whole kernels), breakage and other factors.
- U.S. Aggregate whole kernels averaged 92.5% in 2023, higher than 2022 (91.0%) and the 5YA (91.9%), but similar to 2021 (92.3%) and the 10YA (92.6%).
- Of the 2023 samples, 78.2% had 90.0% or higher whole kernels, compared to 2022 (67.3%) and 2021 (76.2%). This distribution indicates that 2023 had a higher percentage of whole kernels than in 2022 which is consistent with the lower BCFM found in 2023 as compared to the previous year.
- Average U.S. Aggregate homeous (hard) endosperm in 2023 (85%) was lower than 2022 (88%), but higher than 2021 (81%) and the 5YA and 10YA (both 82%).



**STRESS CRACKS**

Stress cracks are internal fissures in the horneous (hard) endosperm of a corn kernel. The pericarp (or outer covering) of a stress-cracked kernel is typically not damaged, so the kernel may appear unaffected at first glance, even if stress cracks are present.

The cause of stress cracks is pressure buildup due to moisture and temperature gradients within the kernel’s horneous endosperm. This can equate to the internal cracks that appear when dropping an ice cube into a lukewarm beverage. A kernel may vary in severity of stress cracking and can have one or multiple stress cracks. The most common cause of stress cracks is high-temperature drying or low-humidity conditions during drying that rapidly remove moisture. The impact of high levels of stress cracks on various uses includes:

**General:** Increased susceptibility to breakage during handling, requiring more removal of broken corn during cleaning operations.

**Wet Milling:** Lower starch yields due to increased difficulty in separating starch and protein. Stress cracks may also alter steeping requirements.

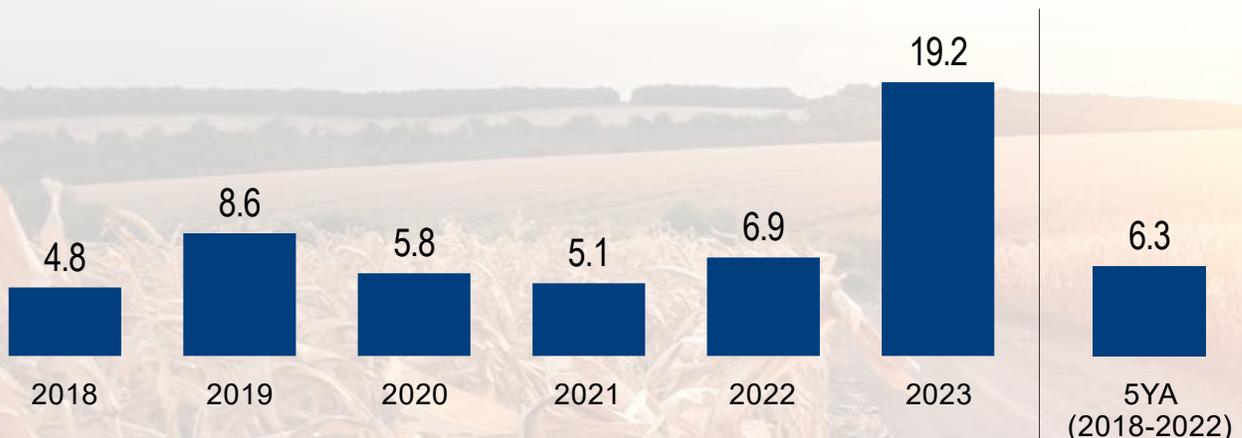
**Dry Milling:** Lower yield of large flaking grits.

**Alkaline Cooking:** Non-uniform water absorption leading to over or under cooking, which affects the process balance.

Growing conditions will affect crop maturity, timeliness of harvest and the need for artificial drying, all of which influence the degree of stress cracking. For example, late maturity or late harvest caused by rain-delayed planting or cool temperatures may increase the need for artificial drying, thus potentially increasing the occurrence of stress cracks.

STRESS CRACKS (%)

U.S. Aggregate Results Summary



## RESULTS

- U.S. Aggregate stress cracks in 2023 averaged 19.2%, which was higher than 2022 (6.9%), 2021 (5.1%), the 5YA (6.3%) and the 10YA (6.0%).
- The standard deviation for U.S. Aggregate stress cracks in 2023 (18.6%) was higher than 2022 (5.2%), 2021 (6.0%), the 5YA (6.0%) and the 10YA (6.7%).
- The percentage of samples with less than 5.0% stress cracks in 2023 (42.2%) was lower than in 2022 (42.7%) and 2021 (73.0%). Stress crack distributions indicate that 2023 corn may be higher in breakage susceptibility than corn from 2022 and 2021.
- U.S. Aggregate stress crack averages for Gulf, Pacific Northwest and Southern Rail ECAs were 22.9, 11.5 and 17.7%, respectively. Among all ECAs, the Gulf had the highest stress crack averages in 2023, 2022, 2021, the 5YA and the 10YA. Drought stress combined with early field-drying may have led to increased levels of stress cracks in 2023, even though breakage levels remained relatively low.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



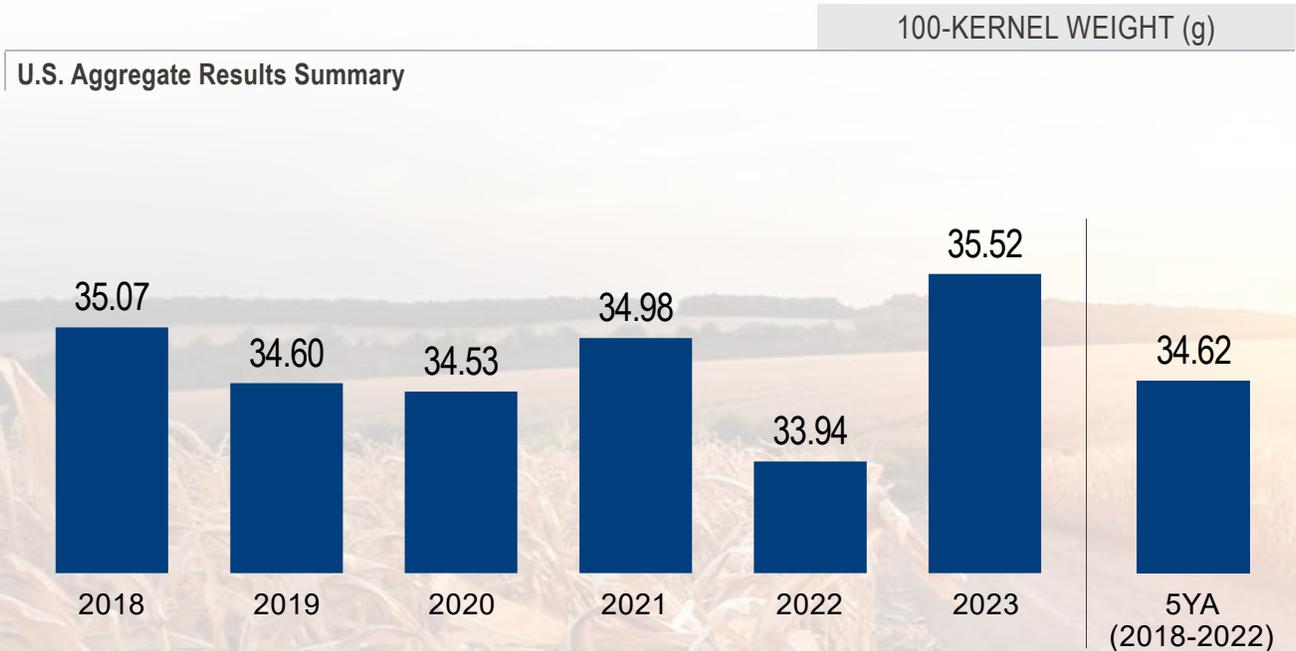
**100-KERNEL WEIGHT**

100-kernel (100-k) weight, reported in grams (g), indicates a larger kernel size as 100-k weight increases. Kernel size affects drying rates. As the kernel size increases, the volume-to-surface-area ratio becomes higher; and as the ratio gets higher, drying becomes slower. In addition, large, uniform-sized kernels often enable higher flaking grit yields in dry milling. Kernel weights tend to be higher for specialty varieties of corn with high amounts of horneous (hard) endosperm. The 100-k weight is determined from the average weight of two 100-kernel replicates using an analytical balance that measures to the nearest 0.1 milligrams.

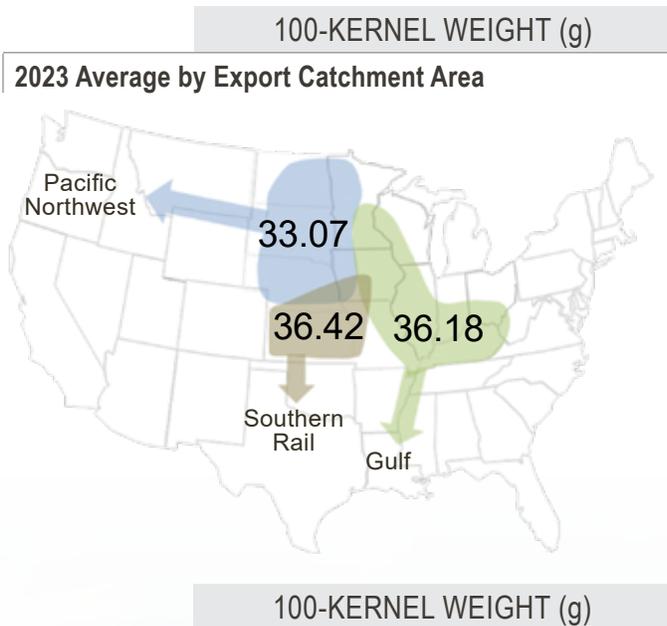
Beginning with the *2020/2021 Harvest Report*, only the samples tested for mycotoxins were tested for 100-k weight. While this protocol reduced the number of samples tested for 100-k weight to 181 in the current *Harvest Report*, this quality factor’s relative margin of error was expected to remain well below the targeted level of precision of no greater than 10.0%. Further details on the sampling criteria employed by this study are described in the “Survey and Statistical Analysis Methods” section.

**RESULTS**

- U.S. Aggregate 100-k weight in 2023 averaged 35.52 g, higher than 2022 (33.94 g), but similar to 2021 (34.98 g), the 5YA and 10YA (both 34.62 g).
- Variability in the 2023 U.S. Aggregate 100-k weight (standard deviation of 3.76 g) was lower than 2022 (4.13 g) but higher than 2021 (3.50 g), the 5YA (3.31 g) and the 10YA (2.97 g).

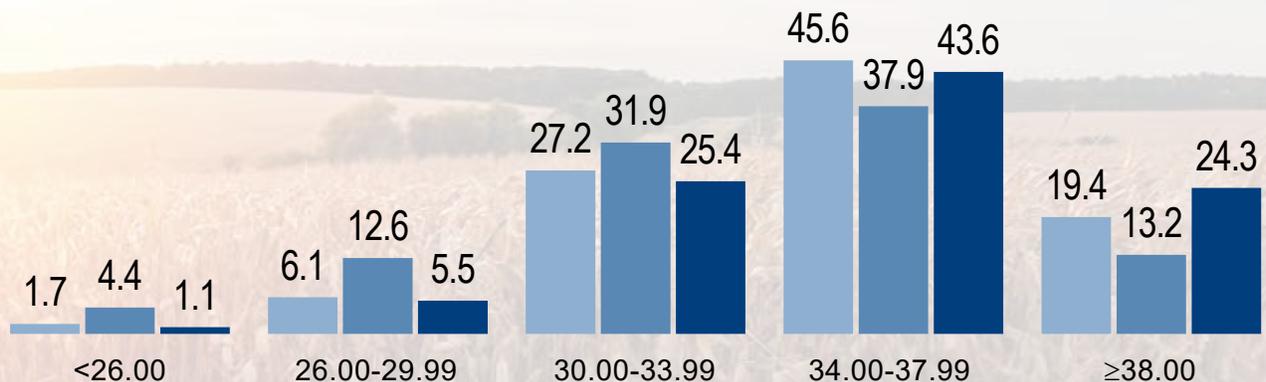


- The range in 100-k weight in 2023 (17.60 to 45.40 g) was higher than 2022 (22.05 to 43.32 g) and 2021 (23.52 to 43.87 g).
- The 100-k weights in 2023 were distributed with 67.9% of the samples having a 100-k weight of 34.0 g or greater, compared to 51.1% in 2022 and 65.0% in 2021. This distribution indicates a much higher percentage of large kernels was found in 2023 as compared to 2022.
- The average 100-k weight was lowest for the Pacific Northwest ECA (33.07 g), compared to the Gulf (36.18 g) and Southern Rail (36.42 g) ECAs. The Pacific Northwest ECA had the lowest 100-k weight in 2023, 2022, 2021, the 5YA and the 10YA.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



**KERNEL VOLUME**

Kernel volume is calculated using a helium pycnometer and expressed in cubic centimeters (cm<sup>3</sup>). Kernel volume is often indicative of growing conditions. If conditions are dry, kernels may be smaller than average. If a drought hits later in the season, kernels may have lower fill. Small or round kernels are more difficult to degerm. Additionally, small kernels may lead to increased cleanout losses for processors and higher yields of fiber.

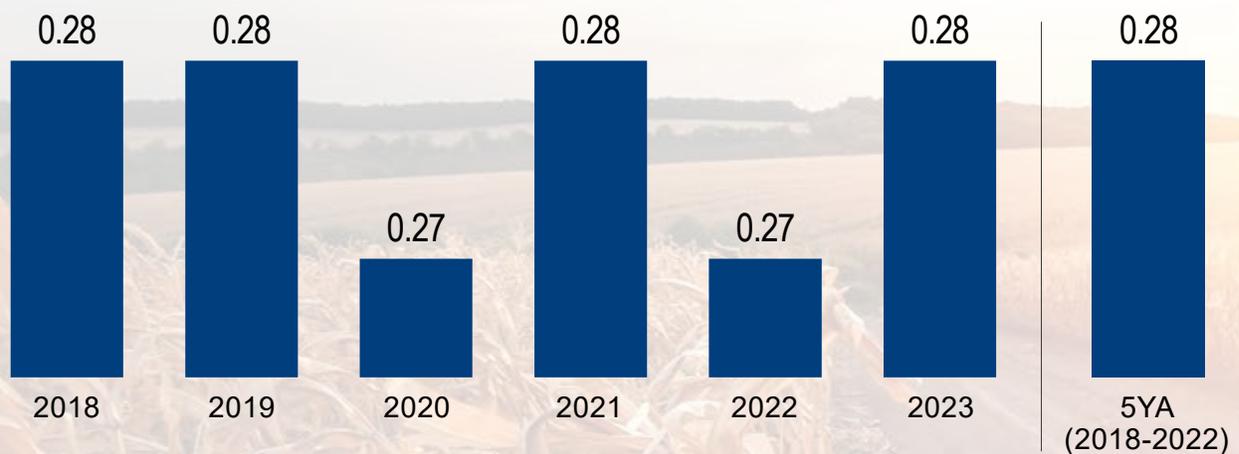
Beginning with the *2020/2021 Harvest Report*, only the samples tested for mycotoxins were tested for kernel volume. While this protocol reduced the number of samples tested for kernel volume to 181 in the current *Harvest Report*, this quality factor’s relative margin of error was expected to remain well below the targeted level of precision of no greater than 10.0%. Further details on the sampling criteria employed by this study are described in the “Survey and Statistical Analysis Methods” section.

**RESULTS**

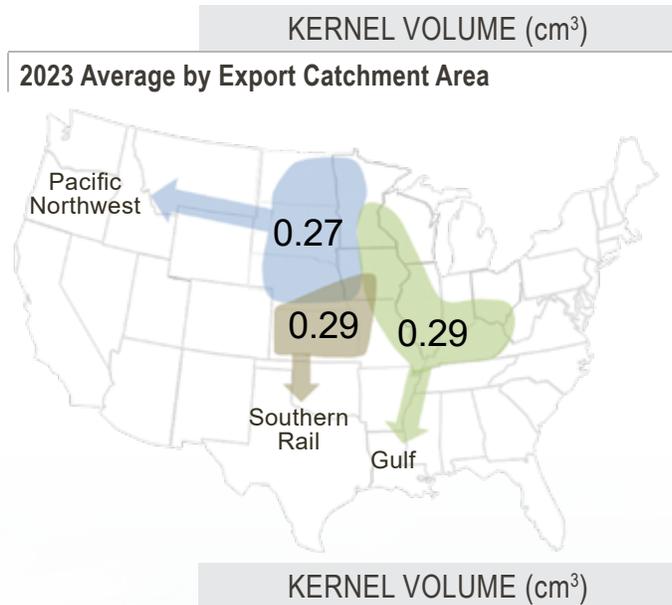
- U.S. Aggregate kernel volume averaged 0.28 cm<sup>3</sup> in 2023, higher than 2022 (0.27 cm<sup>3</sup>) and the same as 2021. Average kernel volume in 2023 was statistically different (higher) from the 5YA and 10YA (both 0.28 cm<sup>3</sup>).
- The standard deviation for U.S. Aggregate kernel volume in 2023 was 0.03 cm<sup>3</sup>, the same as 2022 and 2021, but higher than the 5YA and the 10YA (both 0.02 cm<sup>3</sup>).

KERNEL VOLUME (cm<sup>3</sup>)

U.S. Aggregate Results Summary

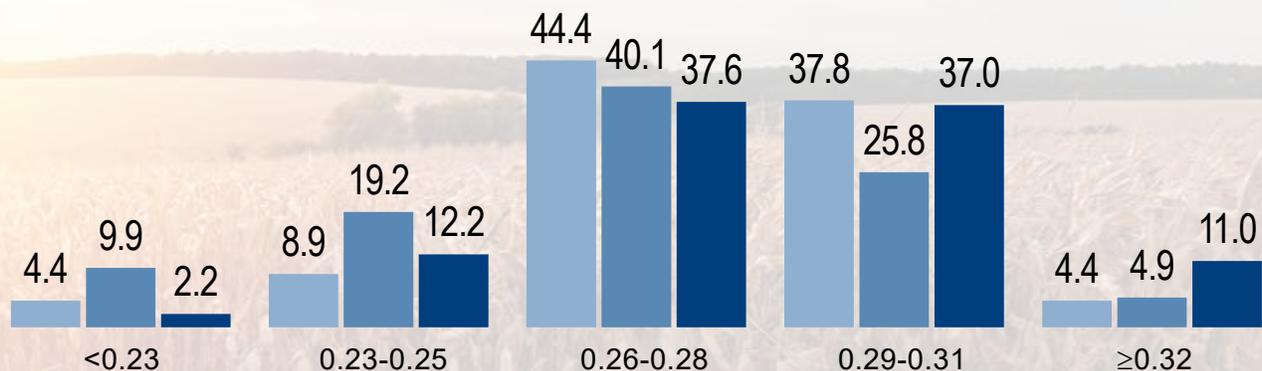


- Kernel volume range in 2023 (0.15 to 0.36 cm<sup>3</sup>) was similar to 2022 (0.18 to 0.33 cm<sup>3</sup>) and 2021 (0.19 to 0.35 cm<sup>3</sup>).
- The kernel volumes in 2023 samples were distributed with 48.0% having kernel volumes of 0.29 cm<sup>3</sup> or greater, compared to 2022 (30.7%) and 2021 (42.2%). This distribution indicates a higher percentage of large kernels in 2023 than in 2022 and 2021.
- Kernel volume for the Gulf, Pacific Northwest and Southern Rail ECAs averaged 0.29, 0.27 and 0.29 cm<sup>3</sup>, respectively. Among the ECAs, the Pacific Northwest has had the lowest average kernel volume in 2023, 2022, 2021, the 5YA and the 10YA.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



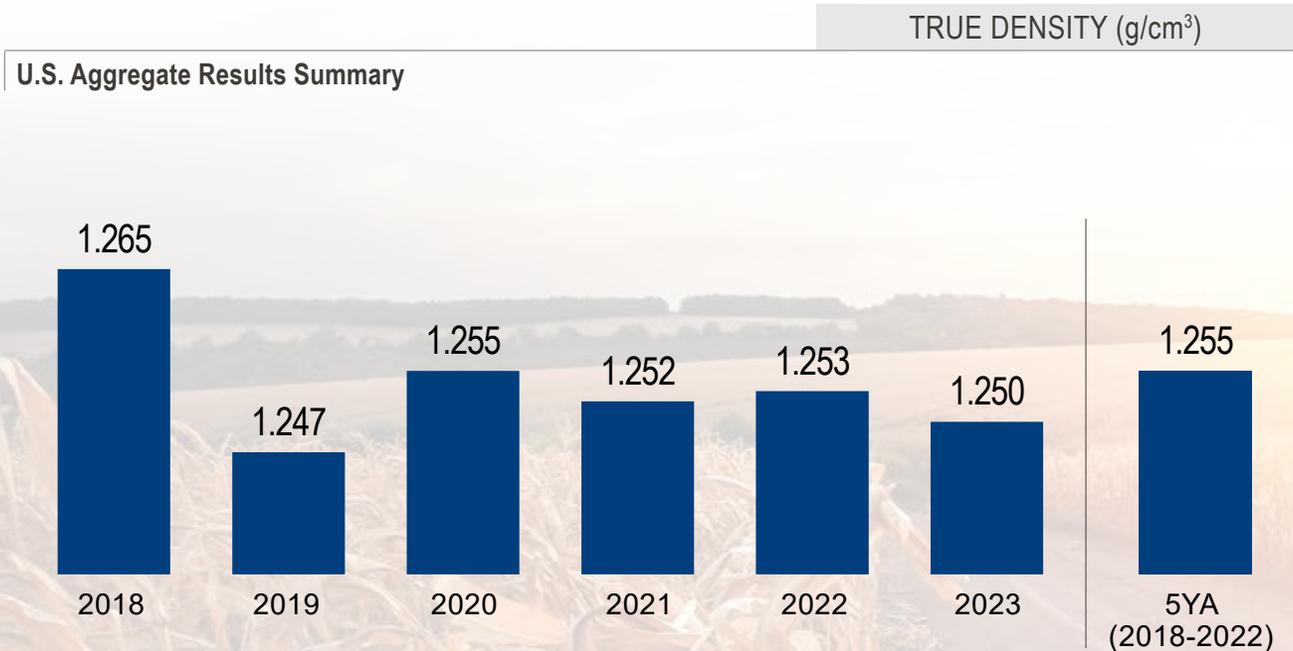
**KERNEL TRUE DENSITY**

Kernel true density is calculated as the weight of a 100-k sample divided by the volume, or displacement, of those 100 kernels and reported as grams per cubic centimeter (g/cm<sup>3</sup>). True density is a relative indicator of kernel hardness, useful for alkaline cooking processes and dry millers. True density may be affected by the genetics of the corn hybrid and the growing environment. Corn with a higher density is typically less susceptible to breakage in handling than lower density corn but is also more at risk of developing stress cracks if high-temperature drying is employed. True densities above 1.30 g/cm<sup>3</sup> indicate very hard corn, typically desirable for dry milling and alkaline cooking processes. True densities near the 1.275 g/cm<sup>3</sup> level and below tend to be softer and process well for wet milling and feed use.

Beginning with the *2020/2021 Harvest Report*, only the samples tested for mycotoxins were tested for 100-k weight and kernel volume, which are the two analytical tests needed for the calculation of true density. While this protocol reduced the number of samples with true density results to 181 in the current *Harvest Report*, this quality factor’s relative margin of error was expected to remain well below the targeted level of precision of no greater than 10.0%. Further details on the sampling criteria employed by this study are described in the “Survey and Statistical Analysis Methods” section.

**RESULTS**

- Average U.S. Aggregate kernel true density in 2023 (1.250 g/cm<sup>3</sup>) was similar to 2022 (1.253 g/cm<sup>3</sup>) and 2021 (1.252 g/cm<sup>3</sup>) but lower than the 5YA (1.255 g/cm<sup>3</sup>) and the 10YA (1.256 g/cm<sup>3</sup>). Over the past thirteen years, true densities have tended to be higher in years with higher protein with a correlation coefficient of 0.67.

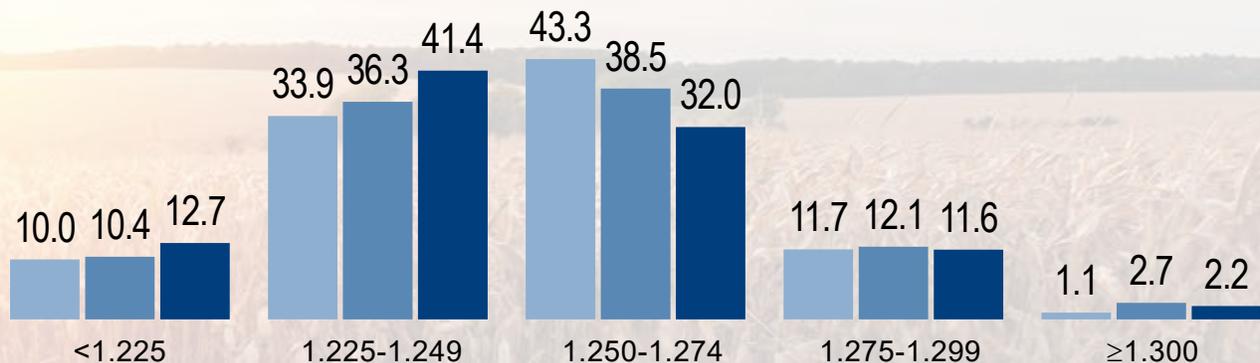


- Variability, based on the standard deviation, in 2023 (0.023 g/cm<sup>3</sup>) was similar to 2022 (0.022 g/cm<sup>3</sup>), 2021 (0.021 g/cm<sup>3</sup>) the 5YA (0.021 g/cm<sup>3</sup>) and the 10YA (0.020 g/cm<sup>3</sup>).
- True densities in 2023 ranged from 1.176 to 1.303 g/cm<sup>3</sup> compared to 2022 (1.169 to 1.316 g/cm<sup>3</sup>) and 2021 (1.196 to 1.305 g/cm<sup>3</sup>).
- In the 2023 samples, 13.8% had true densities at or above 1.275 g/cm<sup>3</sup> compared to 14.8% in 2022 and 12.8% in 2021. Since corn with values above 1.275 g/cm<sup>3</sup> is often considered to represent hard corn and values below 1.275 g/cm<sup>3</sup> are often considered to represent soft corn, this distribution indicates the hardness of the corn in 2023 samples was similar to the previous two years.
- Kernel true densities for the Gulf, Pacific Northwest and Southern Rail ECAs averaged 1.252, 1.236 and 1.257 g/cm<sup>3</sup>, respectively. The Pacific Northwest ECAs average true density and bulk density (test weight) were lower than the other ECAs' values in 2023, 2022, 2021, the 5YA and the 10YA.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



**WHOLE KERNELS**

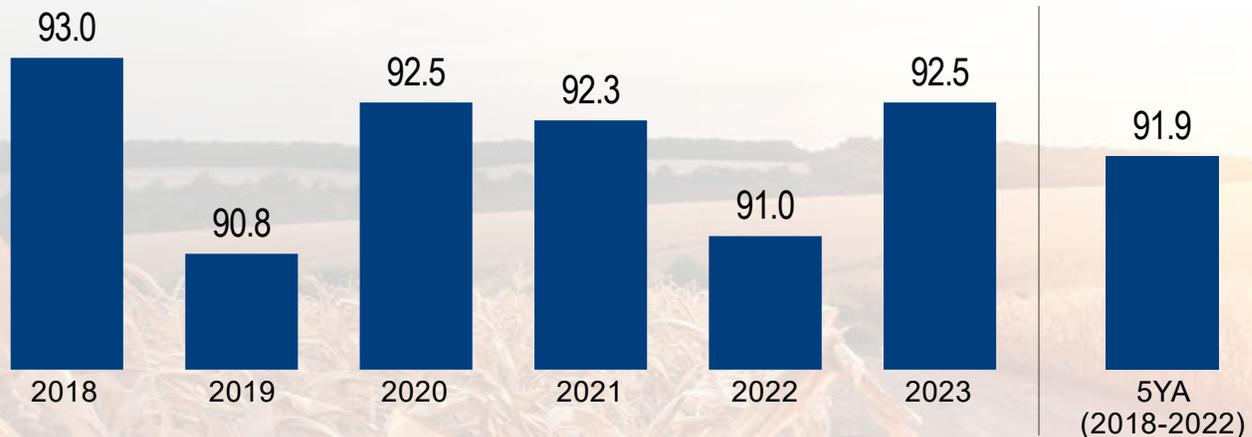
Though the name suggests some inverse relationship between whole kernels and BCFM, the whole kernels test conveys different information than the broken corn portion of the BCFM test. Broken corn is defined solely by the size of the material. As the name implies, whole kernels are the percent of fully intact kernels in the sample with no pericarp damage or kernel pieces chipped away.

The exterior integrity of the corn kernel is very important for two key reasons. First, it affects water absorption for alkaline cooking processes and steeping operations. Kernel nicks or pericarp cracks allow water to enter the kernel faster than intact or whole kernels. Too much water uptake during cooking can result in loss of soluble, non-uniform cooking, expensive shutdown time, or products that do not meet specifications. Some companies pay contracted premiums for corn delivered above a specified level of whole kernels.

Second, intact whole kernels are less susceptible to storage molds and breakage in handling. While hard endosperm lends itself to preserving more whole kernels than soft corn, the primary factor in delivering whole kernels is harvesting and handling. This begins with proper combine adjustment followed by the severity of kernel impacts due to conveyors and the number of handlings required from the farm field to the end-user. Each subsequent handling will generate additional breakage. Actual amounts of breakage increase exponentially as moisture decreases, drop heights increase, or a kernel's velocity at impact increases.<sup>3</sup> In addition, harvesting at higher moisture content (e.g., greater than 25%) will usually lead to soft pericarps and more pericarp damage to corn than when harvesting at lower moisture levels.

WHOLE KERNELS (%)

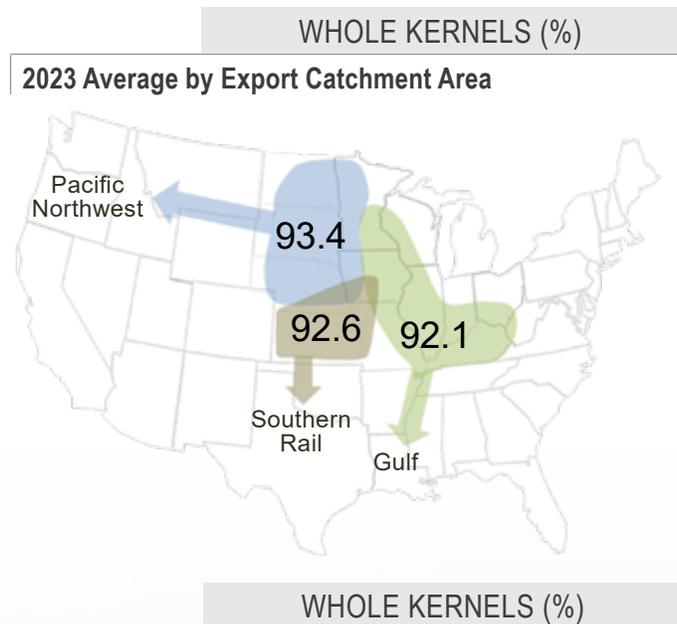
U.S. Aggregate Results Summary



<sup>3</sup>Foster, G. H. and L. E. Holman. 1973. Grain Breakage Caused by Commercial Handling Methods. USDA. ARS Marketing Research Report Number 968.

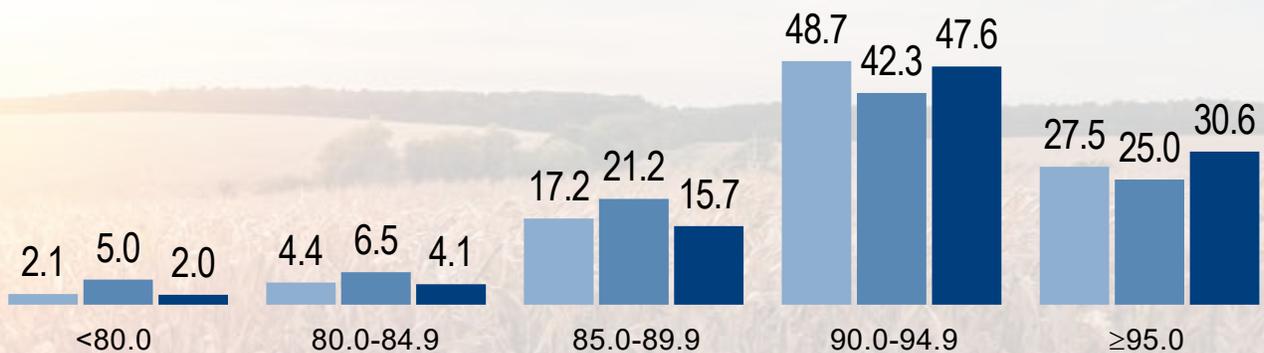
## RESULTS

- U.S. Aggregate whole kernels averaged 92.5% in 2023, higher than 2022 (91.0%) and the 5YA (91.9%), but similar to 2021 (92.3%) and the 10YA (92.6%).
- The standard deviation for whole kernel samples in 2023 (3.9%) was lower than 2022 (4.6%), similar to 2021 (3.7%), the same as the 5YA and similar to the 10YA (3.7%).
- Whole kernel range in 2023 (63.2 to 100.0%) was similar to 2022 (65.2 to 100.0%), but greater than 2021 (72.0 to 99.4%).
- Of the 2023 samples, 78.2% had 90.0% or higher whole kernels, compared to 2022 (67.3%) and 2021 (76.2%). This distribution indicates that 2023 had a higher percentage of whole kernels than the samples in 2022. This higher percentage of whole kernels is consistent with the lower BCFM percentages found in 2023 as compared to the previous year.
- Whole kernel averages for Gulf, Pacific Northwest and Southern Rail ECAs were 92.1, 93.4 and 92.6%, respectively.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



**HORNEOUS (HARD) ENDOSPERM**

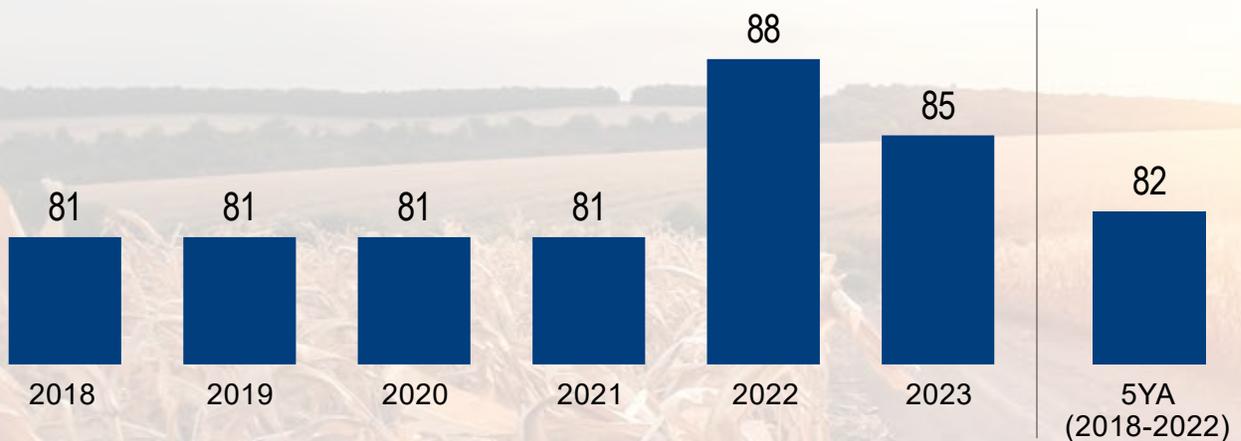
The horneous (hard) endosperm test measures the percent of horneous or hard endosperm out of the total endosperm in a kernel, with a potential value from 70 to 100%. The greater the amount of horneous endosperm relative to soft endosperm, the harder the corn kernel is said to be. The degree of hardness is important, depending on the type of processing. A hard kernel is needed to produce high yields of large flaking grits in dry milling. Desired hardness is hard to medium for alkaline cooking processes, and desired hardness is medium to soft for wet milling and livestock feeding. Hardness is correlated to breakage susceptibility, feed utilization/efficiency and starch digestibility. The internal stresses causing stress cracks do not build up as much in the soft, floury endosperm as in the hard, horneous endosperm. Therefore, corn with a higher percentage of horneous endosperm is more susceptible to stress cracking than softer grain.

As a test of overall hardness, there is no good or bad value for horneous endosperm. There is only a preference by different end-users for particular ranges. Many dry millers and alkaline cooking processors would like greater than 85% horneous endosperm, while wet millers and feeders would typically like values from 70 to 85%. However, there are certainly exceptions in user preference.

Beginning with the *2019/2020 Harvest Report*, only the samples tested for the mycotoxin were tested for horneous endosperm. Continuation of this protocol resulted in 181 samples tested for horneous endosperm in the current *Harvest Report*. This quality factor’s relative margin of error did not exceed 0.4% in the *2011/2012 Harvest Report* through the *2018/2019 Harvest Report* when all samples were tested for this quality factor. Further details on the sampling criteria employed by this study are described in the “Survey and Statistical Analysis Methods” section.

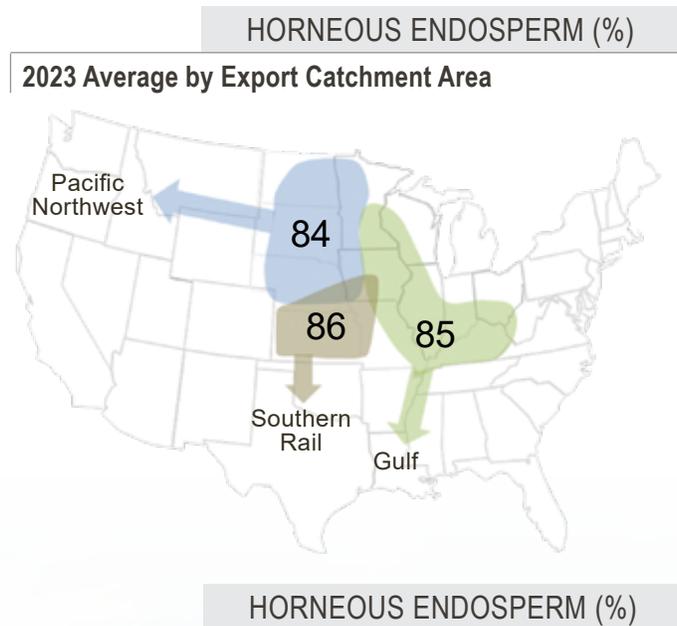
HORNEOUS ENDOSPERM (%)

**U.S. Aggregate Results Summary**



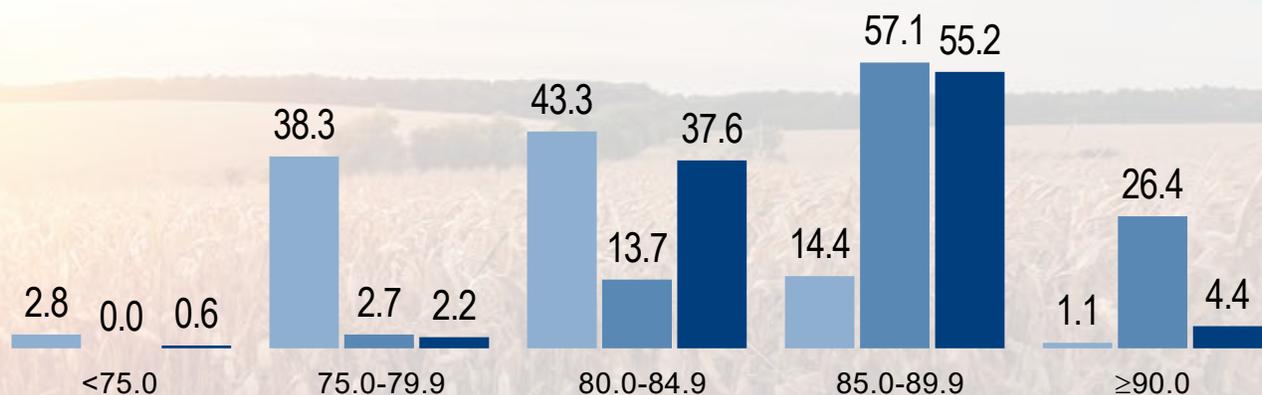
## RESULTS

- Average U.S. Aggregate horneous endosperm in 2023 (85%) was lower than 2022 (88%), but higher than 2021 (81%) and the 5YA and 10YA (both 82%).
- The standard deviation for U.S. Aggregate horneous endosperm was 3% in 2023, 2022 and the 5YA, which was lower than in 2021 and the 10YA (both 4%).
- The 2023 horneous endosperm range (75 to 94%) was similar to 2022 (78 to 95%) and 2021 (72 to 90%).
- Of the 2023 samples, 97.2% contained more than 80% horneous endosperm, which was the same as 2022, but higher than 2021 (58.8%).
- Average horneous endosperm values for the Gulf, Pacific Northwest and Southern Rail ECAs were 85, 84 and 86%, respectively.



**Percent of Samples by Crop Year**

■ 2021 ■ 2022 ■ 2023



**SUMMARY: PHYSICAL FACTORS**

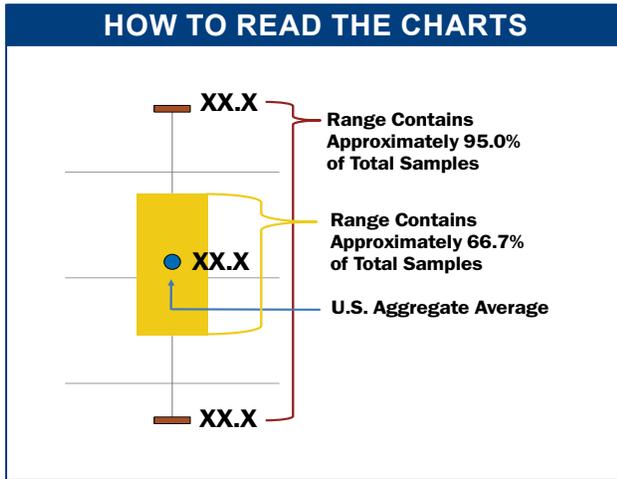
|                                   | 2023 Harvest                |       |           |       |       | 2022 Harvest             |           | 2021 Harvest             |           | Five-Year Average (2018-2022) |           | Ten-Year Average (2013-2022) |           |
|-----------------------------------|-----------------------------|-------|-----------|-------|-------|--------------------------|-----------|--------------------------|-----------|-------------------------------|-----------|------------------------------|-----------|
|                                   | No. of Samples <sup>1</sup> | Avg.  | Std. Dev. | Min.  | Max.  | Avg.                     | Std. Dev. | Avg.                     | Std. Dev. | Avg.                          | Std. Dev. | Avg.                         | Std. Dev. |
| <b>U.S. Aggregate</b>             |                             |       |           |       |       | <b>U.S. Aggregate</b>    |           | <b>U.S. Aggregate</b>    |           | <b>U.S. Aggregate</b>         |           | <b>U.S. Aggregate</b>        |           |
| Stress Cracks (%)                 | 611                         | 19.2  | 18.6      | 0     | 98    | 6.9*                     | 5.2       | 5.1*                     | 6.0       | 6.3*                          | 6.0       | 6.0*                         | 6.7       |
| 100-Kernel Weight (g)             | 181                         | 35.52 | 3.76      | 17.60 | 45.40 | 33.94*                   | 4.13      | 34.98                    | 3.50      | 34.62*                        | 3.31      | 34.62*                       | 2.97      |
| Kernel Volume (cm <sup>3</sup> )  | 181                         | 0.28  | 0.03      | 0.15  | 0.36  | 0.27*                    | 0.03      | 0.28                     | 0.03      | 0.28*                         | 0.02      | 0.28*                        | 0.02      |
| True Density (g/cm <sup>3</sup> ) | 181                         | 1.250 | 0.023     | 1.176 | 1.303 | 1.253                    | 0.022     | 1.252                    | 0.021     | 1.255*                        | 0.021     | 1.256*                       | 0.020     |
| Whole Kernels (%)                 | 611                         | 92.5  | 3.9       | 63.2  | 100.0 | 91.0*                    | 4.6       | 92.3                     | 3.7       | 91.9*                         | 3.9       | 92.6                         | 3.7       |
| Horneous Endosperm (%)            | 181                         | 85    | 3         | 75    | 94    | 88*                      | 3         | 81*                      | 4         | 82*                           | 3         | 82*                          | 4         |
| <b>Gulf</b>                       |                             |       |           |       |       | <b>Gulf</b>              |           | <b>Gulf</b>              |           | <b>Gulf</b>                   |           | <b>Gulf</b>                  |           |
| Stress Cracks (%)                 | 557                         | 22.9  | 22.0      | 0     | 98    | 7.8*                     | 6.1       | 5.9*                     | 6.8       | 6.9*                          | 6.7       | 6.6*                         | 7.4       |
| 100-Kernel Weight (g)             | 163                         | 36.18 | 3.74      | 17.60 | 45.40 | 35.08*                   | 3.99      | 35.82                    | 3.19      | 35.52*                        | 3.19      | 35.37*                       | 2.92      |
| Kernel Volume (cm <sup>3</sup> )  | 163                         | 0.29  | 0.03      | 0.15  | 0.36  | 0.28*                    | 0.03      | 0.29                     | 0.02      | 0.28*                         | 0.02      | 0.28*                        | 0.02      |
| True Density (g/cm <sup>3</sup> ) | 163                         | 1.252 | 0.023     | 1.176 | 1.303 | 1.256                    | 0.022     | 1.253                    | 0.021     | 1.257*                        | 0.021     | 1.259*                       | 0.020     |
| Whole Kernels (%)                 | 557                         | 92.1  | 4.1       | 63.2  | 100.0 | 90.1*                    | 5.15      | 91.8                     | 3.9       | 91.7                          | 4.0       | 92.5*                        | 3.7       |
| Horneous Endosperm (%)            | 163                         | 85    | 3         | 75    | 94    | 87*                      | 3         | 81*                      | 3         | 82*                           | 3         | 82*                          | 4         |
| <b>Pacific Northwest</b>          |                             |       |           |       |       | <b>Pacific Northwest</b> |           | <b>Pacific Northwest</b> |           | <b>Pacific Northwest</b>      |           | <b>Pacific Northwest</b>     |           |
| Stress Cracks (%) <sup>2</sup>    | 254                         | 11.5  | 10.8      | 0     | 92    | 5.8*                     | 4.4       | 4.3*                     | 5.4       | 6.1*                          | 5.8       | 5.9*                         | 6.3       |
| 100-Kernel Weight (g)             | 80                          | 33.07 | 5.04      | 22.00 | 42.90 | 31.71*                   | 3.65      | 33.40                    | 3.29      | 32.76                         | 3.04      | 32.55                        | 2.76      |
| Kernel Volume (cm <sup>3</sup> )  | 80                          | 0.27  | 0.04      | 0.18  | 0.34  | 0.25*                    | 0.03      | 0.27                     | 0.03      | 0.26                          | 0.02      | 0.26                         | 0.02      |
| True Density (g/cm <sup>3</sup> ) | 80                          | 1.236 | 0.138     | 1.202 | 1.281 | 1.247                    | 0.022     | 1.248                    | 0.018     | 1.245                         | 0.021     | 1.247                        | 0.020     |
| Whole Kernels (%)                 | 254                         | 93.4  | 3.2       | 64.0  | 99.8  | 92.2*                    | 3.88      | 93.1                     | 3.3       | 92.0*                         | 3.9       | 92.5*                        | 3.7       |
| Horneous Endosperm (%)            | 80                          | 84    | 10        | 75    | 90    | 88*                      | 3         | 81*                      | 4         | 82                            | 3         | 81*                          | 3         |
| <b>Southern Rail</b>              |                             |       |           |       |       | <b>Southern Rail</b>     |           | <b>Southern Rail</b>     |           | <b>Southern Rail</b>          |           | <b>Southern Rail</b>         |           |
| Stress Cracks (%) <sup>2</sup>    | 365                         | 17.7  | 17.8      | 0     | 97    | 5.5*                     | 3.7       | 4.0*                     | 4.3       | 4.6*                          | 4.1       | 4.3*                         | 4.5       |
| 100-Kernel Weight (g)             | 100                         | 36.42 | 3.65      | 17.60 | 45.40 | 33.77*                   | 4.12      | 34.59*                   | 3.38      | 34.61*                        | 3.27      | 34.88*                       | 2.97      |
| Kernel Volume (cm <sup>3</sup> )  | 100                         | 0.29  | 0.03      | 0.15  | 0.36  | 0.27*                    | 0.03      | 0.28*                    | 0.03      | 0.27*                         | 0.02      | 0.28*                        | 0.02      |
| True Density (g/cm <sup>3</sup> ) | 100                         | 1.257 | 0.022     | 1.176 | 1.303 | 1.255                    | 0.022     | 1.256                    | 0.021     | 1.261                         | 0.020     | 1.262*                       | 0.019     |
| Whole Kernels (%)                 | 365                         | 92.6  | 4.4       | 63.2  | 100.0 | 92.1                     | 3.85      | 92.5                     | 3.8       | 92.4                          | 3.5       | 92.8                         | 3.4       |
| Horneous Endosperm (%)            | 100                         | 86    | 3         | 75    | 94    | 88*                      | 3         | 81*                      | 4         | 83*                           | 3         | 82*                          | 4         |

\*Indicates average was significantly different from current year, based on a 2-tailed t-test at the 95.0% level of significance.

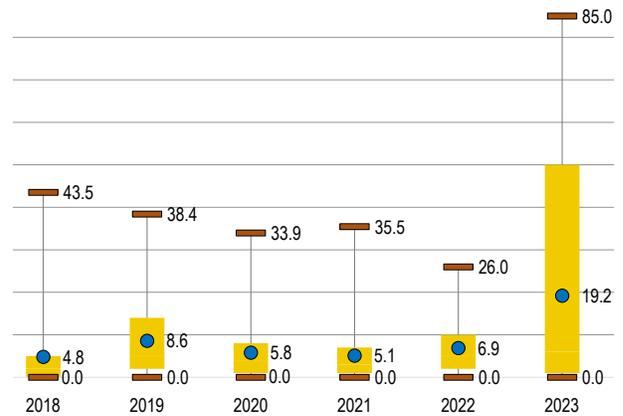
<sup>1</sup>Due to the ECA results being composite statistics, the sum of the sample numbers from the three ECAs is greater than the U.S. Aggregate.

<sup>2</sup>The Relative ME for predicting the harvest population average exceeded ±10.0%.

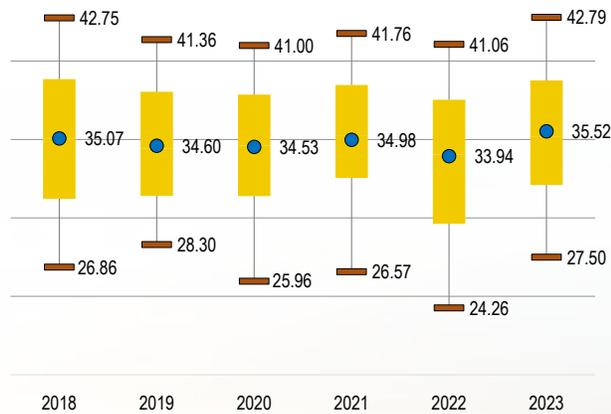
## PHYSICAL FACTORS AGGREGATE SIX-YEAR COMPARISON



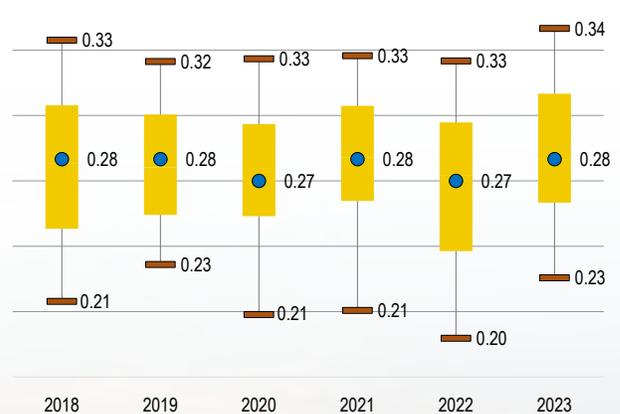
### Stress Cracks (%)



### 100-Kernel Weight (g)

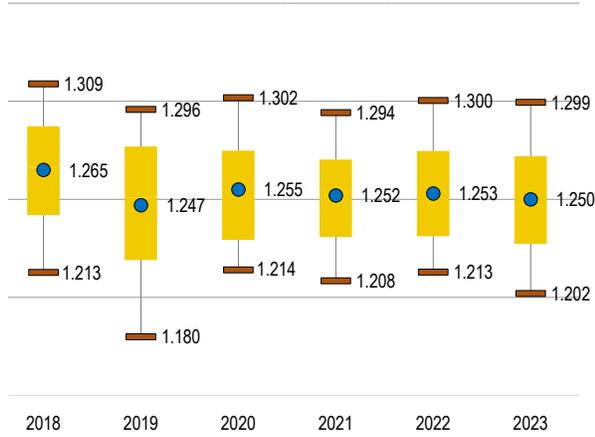


### Kernel Volume (cm<sup>3</sup>)

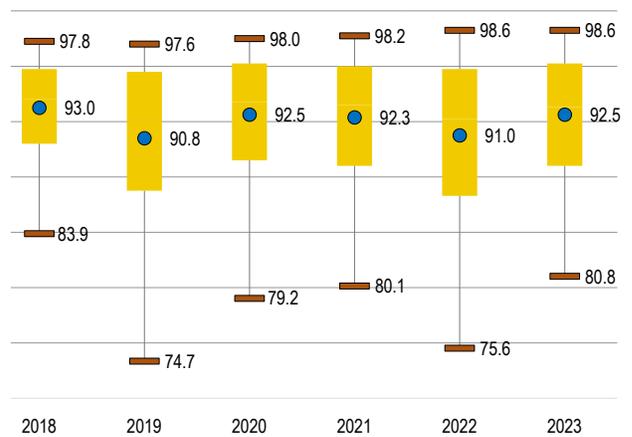


**PHYSICAL FACTORS**  
AGGREGATE SIX-YEAR COMPARISON

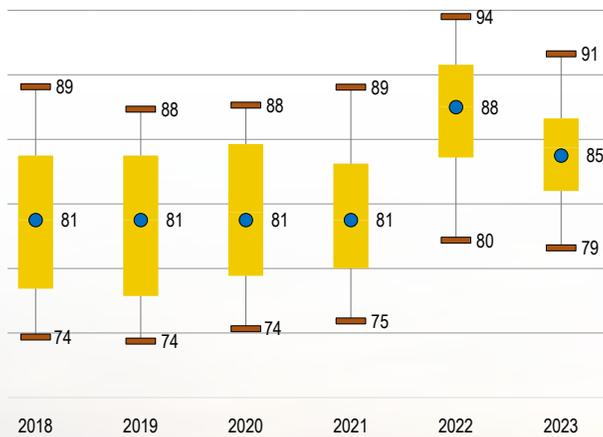
**True Density (g/cm<sup>3</sup>)**



**Whole Kernels (%)**



**Horneous Endosperm (%)**



## E. MYCOTOXINS

Mycotoxins are toxic compounds produced by fungi that occur naturally in grains. When consumed at elevated levels, mycotoxins may cause sickness in humans and animals. Aflatoxin, DON and fumonisin are considered to be three of the most common mycotoxins found in corn.

A subset of the harvest samples have been tested for aflatoxin and DON in all thirteen years of *Harvest Reports*. Fumonisin was added to the list of mycotoxins tested beginning with the *2019/2020 Harvest Report*. The *2020/2021 Harvest Report* also began testing samples for ochratoxin A, T-2 and zearalenone.

Depending on the year, environmental conditions under which the corn is produced and stored may or may not be conducive to developing a particular mycotoxin to levels that impact the corn's use for human and livestock consumption. Humans and livestock are sensitive to mycotoxins at varying levels. As a result, the FDA has issued action levels for aflatoxin, advisory levels for DON and fumonisin by intended use.

Action levels specify limits of contamination above which the agency is prepared to take regulatory action. Action levels signal that the FDA believes it has data to support regulatory or court action if a toxin or contaminant is present at levels exceeding the action level if the agency chooses to do so. If imports or domestic feed supplements are analyzed in accordance with valid methods and found to exceed action levels, they are considered adulterated and may be seized and removed from interstate commerce by the FDA.

Advisory levels guide the industry concerning levels of a substance present in food or feed believed by the agency to provide an adequate margin of safety to protect human and animal health. While the FDA reserves the right to take regulatory enforcement action, enforcement is not the fundamental purpose of an advisory level.

Since growing conditions heavily influence the production of mycotoxins, the *Harvest Report's* objective is strictly to report on instances when mycotoxins are detected in the corn crop at harvest and not to predict the level at which mycotoxins might appear in U.S. corn exports. Due to the multiple stages of the U.S. grain merchandising channel and the laws and regulations guiding the industry, mycotoxin levels that appear in corn exports may be less than what initially appear at harvest. The *Harvest Report's* results should be used only as one indicator of the potential for mycotoxin presence in the corn at harvest. The *2023/2024 Corn Export Cargo Quality Report* will report corn quality at export points and be a more accurate indication of mycotoxin presence in U.S. corn export shipments.

The sampling criteria, described in the "Survey and Statistical Analysis Methods" section, resulted in a total number of 181 samples tested for mycotoxins. Details on the testing methodology employed in this study for the mycotoxins are in the "Testing Analysis Methods" section.

## AFLATOXIN

The most important type of mycotoxin associated with corn is aflatoxin. There are several types of aflatoxin produced by different species of *Aspergillus*, with the most prominent species being *A. flavus*. The growth of the fungus and aflatoxin contamination of grain can occur in the field before harvest or in storage. However, contamination before harvest is considered to cause most of the problems associated with aflatoxin. *A. flavus* grows well in hot, dry environmental conditions or where drought occurs over an extended period. It can be a serious problem in the southern United States, where hot and dry conditions are common. The fungus usually attacks only a few kernels on the ear and often penetrates kernels through wounds produced by insects. Under drought conditions, it also grows down silks into individual kernels.

There are four types of aflatoxin naturally found in foods – aflatoxins B1, B2, G1 and G2, commonly referred to as “aflatoxin” or “total aflatoxin.” Aflatoxin B1 is the most commonly found aflatoxin in food and feed and is also the most toxic. Research has shown that B1 is a potent, naturally-occurring carcinogen in animals with a strong link to human cancer incidence. Additionally, dairy cattle will metabolize B1 to a different form of aflatoxin called aflatoxin M1, which may accumulate in milk.

Aflatoxin expresses toxicity in humans and animals primarily by attacking the liver. The toxicity can occur from short-term consumption of very high doses of aflatoxin-contaminated grain or long-term ingestion of low levels of aflatoxin, possibly resulting in death for poultry, the most sensitive of the animal species. Livestock may experience reduced feed efficiency or reproduction, and both human and animal immune systems may be suppressed due to ingesting aflatoxin.

The FDA has established action levels for aflatoxin M1 in milk intended for human consumption and aflatoxin in human food, grain and livestock feed in parts per billion (table below).

The FDA has established additional policies and legal provisions concerning the blending of corn with levels of aflatoxin exceeding these threshold levels. In general, the FDA currently does not permit corn blended to reduce the aflatoxin content to be sold in general commerce.

| Aflatoxin Action Level  | Criteria  |
|-------------------------|---|
| 20.0 parts per billion  | Dairy animals, pets of all ages, immature animals (including immature poultry) and when the animal's destination is not known |
| 100.0 parts per billion | Breeding beef cattle, breeding swine and mature poultry   |
| 200.0 parts per billion | Finishing swine of 100 pounds or greater  |
| 300.0 parts per billion | Finishing (i.e., feedlot) beef cattle   |

Source: [www.ngfa.org](http://www.ngfa.org)

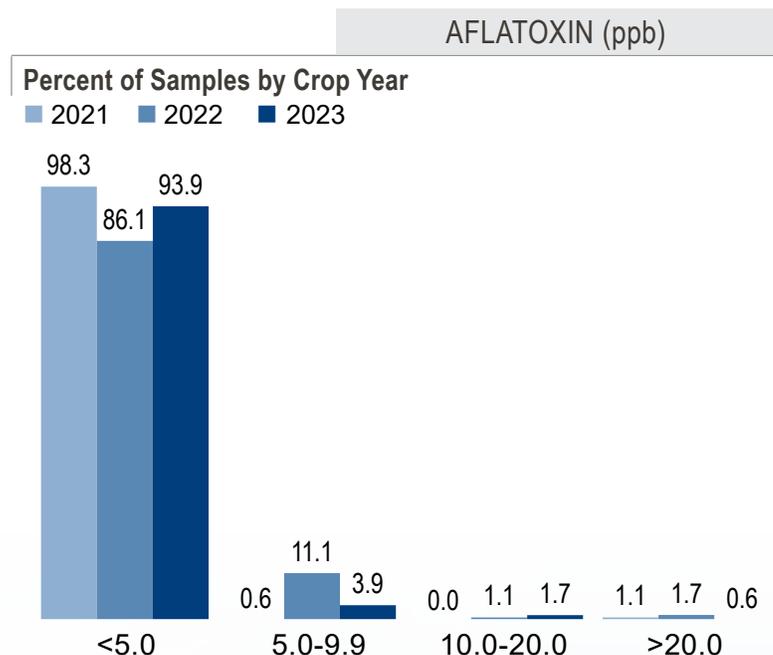
For additional information, see the National Grain and Feed Association's guidance document titled "FDA Mycotoxin Regulatory Guidance" found at [https://drive.google.com/file/d/1tqeS5\\_eOtsRmxZ5RrTnYu7NCIr896KGX/view](https://drive.google.com/file/d/1tqeS5_eOtsRmxZ5RrTnYu7NCIr896KGX/view).

According to federal law, unless the contract exempts it, corn exported from the United States must be tested by FGIS for aflatoxin. Corn above the FDA action level of 20.0 ppb cannot be exported unless other strict conditions are met. This results in relatively low levels of aflatoxin in exported grain.

## RESULTS

A total of 181 samples were analyzed for aflatoxin in 2023, compared to 180 samples tested for aflatoxin in both 2022 and 2021, respectively. Results of the 2023 survey are as follows:

- One hundred seventy (170) samples, or 93.9% of the 181 samples, had no detectable levels of aflatoxin (below the FGIS lower conformance limit of 5.0 ppb). This is higher than the percentage of samples tested with no detectable levels of aflatoxin in 2022 (86.1%) and slightly lower than 2021 (98.3%).
- Seven (7) samples or 3.9% of the 181 samples showed aflatoxin levels greater than or equal to 5.0 ppb but less than 10.0 ppb. This percentage is lower than 2022 (11.1%) and higher than 2021 (0.6%).
- Three (3) samples or 1.7% of the 181 samples showed an aflatoxin level greater than or equal to 10.0 ppb, but less than or equal to the FDA action level of 20.0 ppb. This percentage, while slightly higher, is similar to both 2022 (1.1%) and 2021 (0.0%).
- One (1) sample, or 0.6% of the 181 samples, showed an aflatoxin level greater than the FDA action level of 20.0 ppb. This percentage is slightly lower than 2022 (1.7%) and 2021 (1.1%).



These results denote that there is slightly less aflatoxin in samples surveyed in the 2023 crop season than in the 2022 crop season and about the same levels as in 2021. These favorable sample results may be due, in part, to weather conditions that were not conducive to aflatoxin development in 2023 (see the “Crop and Weather Conditions” section for more information on 2023 growing conditions).

## DEOXYNIVALENOL (DON OR VOMITOXIN)

DON is another mycotoxin of concern to some importers of corn. It is produced by certain species of *Fusarium*, the most important of which is *Fusarium graminearum* (*Gibberellazeae*), which also causes Gibberella ear rot (or red ear rot). *Gibberellazeae* can develop when cool or moderate temperatures and wet weather occur at flowering. The fungus grows down the silks into the ear. In addition to producing DON, it produces conspicuous red discoloration of kernels on the ear. The fungus can also continue to grow and rot ears when corn is left standing in the field. Mycotoxin contamination of corn caused by *Gibberellazeae* is often associated with excessive postponement of harvest or storage of high-moisture corn.

DON is mostly a concern with monogastric animals, where it may irritate the mouth and throat. As a result, the animals may eventually refuse to eat the DON-contaminated corn and may have low weight gain, diarrhea, lethargy and intestinal hemorrhaging. It may cause suppression of the immune system, resulting in susceptibility to several infectious diseases.

FGIS is not required to test for DON on corn bound for export markets but will perform either a qualitative or quantitative test for DON at the buyer's request.

The FDA has issued advisory levels for DON. For products containing corn, the advisory levels are shown below.

| DON Advisory Level     | Criteria  |
|------------------------|---|
| 5.0 parts per million  | Swine, not to exceed 20% of their diet                                  |
| 5.0 parts per million  | All other animals not otherwise listed, not to exceed 40% of their diet |
| 10.0 parts per million | Chickens, not to exceed 50% of their diet                               |
| 10.0 parts per million | Ruminating beef and dairy cattle older than four months                 |

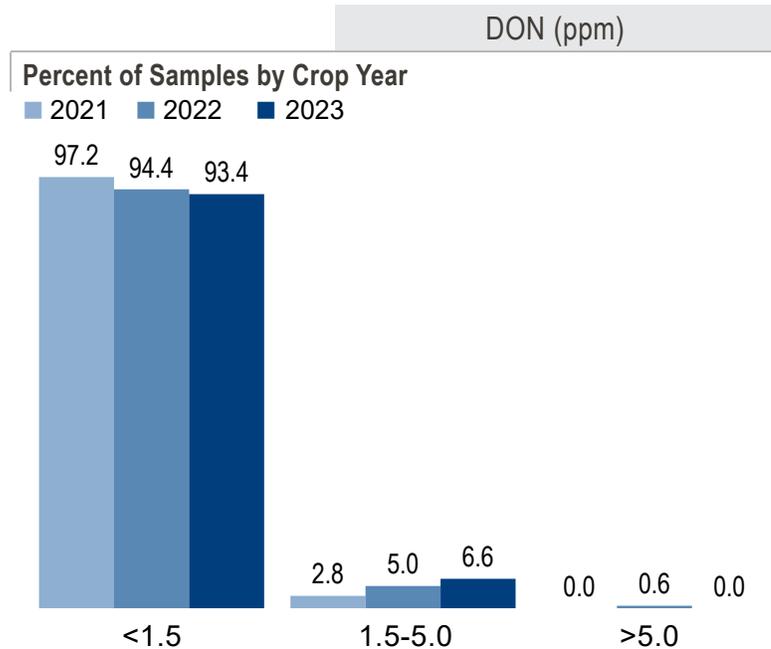
Source: [www.ngfa.org](http://www.ngfa.org)

For additional information, see the National Grain and Feed Association's guidance document titled "FDA Mycotoxin Regulatory Guidance" found at [https://drive.google.com/file/d/1tqeS5\\_eOtsRmxZ5RrTnYu7NC1r896KGX/view](https://drive.google.com/file/d/1tqeS5_eOtsRmxZ5RrTnYu7NC1r896KGX/view).

## RESULTS

A total of 181 samples were analyzed collectively for DON in 2023, compared to 180 samples tested for DON in both 2022 and 2021. Results of the 2023 survey are as follows:

- One hundred sixty-nine (169) samples, or 93.4% of the 181 samples, tested less than 1.5 ppm. This percentage for 2023 is slightly lower than 2022 (94.4%) and 2021 (97.2%).
- Twelve (12) samples, or 6.6% of the 181 samples, tested greater than or equal to 1.5 ppm, but less than or equal to the FDA advisory level of 5.0 ppm. This percentage for 2023 is higher than 2022 (5.0%) and 2021 (2.8%).
- Zero (0) samples or 0.0% of the 181 samples tested above the FDA advisory level of 5.0 ppm, which was similar to 2022 (0.6%) and the same as 2021.



Having a relatively high percentage of samples in 2023 testing above 1.5 ppm may be attributed to weather conditions that were conducive to DON development in 2023.

## FUMONISIN

Fumonisin is a naturally occurring mycotoxin found mostly in cereal grains, mainly corn. Fumonisin is a more recent discovery compared to aflatoxin and DON. Fumonisin is produced by several fungi of the *Fusarium* genus. The fumonisin family consists of fumonisin B1, fumonisin B2 and fumonisin B3. Fumonisin B1 is the most abundant, accounting for about 70 to 80% of total fumonisins. The main concern with fumonisins is feed contamination that can have detrimental effects, particularly to horses and pigs. Fungal and fumonisin formation occurs mainly before harvest. Insects play an important role in fumonisin contamination since they act as a wounding agent. Temperature and rainfall conditions are related to fungal growth and fumonisin contamination. In general, fumonisin contamination is related to plant stress, insect damage, drought and soil moisture. In 2001, the FDA issued guidance levels for fumonisins in corn-based foods and feed to reduce human and animal exposure. FDA advisory levels are shown below.

| Fumonisin Advisory Level | Criteria  |
|--------------------------|---|
| 5.0 parts per million    | Equids (i.e., horses) and rabbits, not to exceed 20% of diet  |
| 20.0 parts per million   | Swine and catfish, not to exceed 50% of diet  |
| 30.0 parts per million   | Breeding ruminants, breeding poultry and breeding mink, not to exceed 50% of diet                                     |
| 60.0 parts per million   | Ruminants older than three months raised for slaughter and mink raised for pelt production, not to exceed 50% of diet |
| 100.0 parts per million  | Poultry raised for slaughter, not to exceed 50% of diet   |
| 10.0 parts per million   | All other animals not otherwise listed, not to exceed 50% of their diet   |

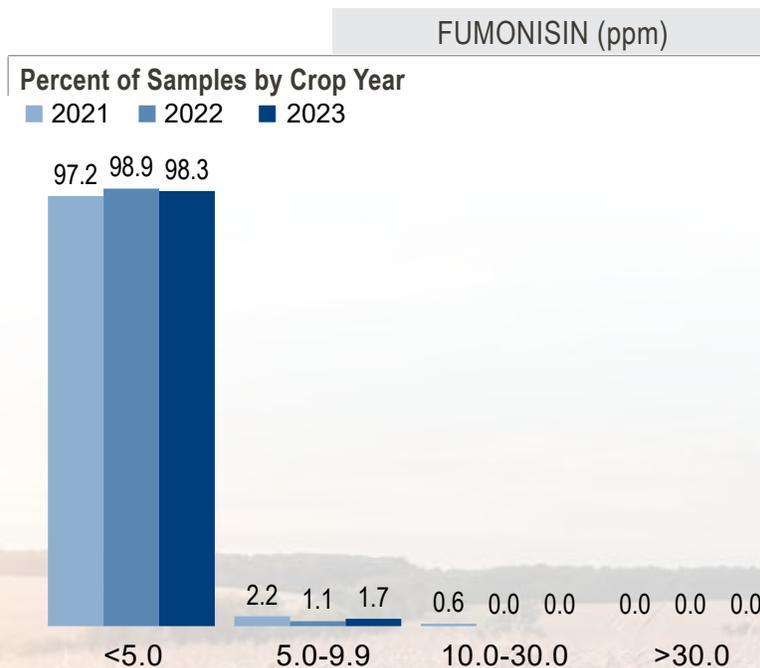
Source: [www.ngfa.org](http://www.ngfa.org)

For additional information, see the National Grain and Feed Association's guidance document titled "FDA Mycotoxin Regulatory Guidance" found at [https://drive.google.com/file/d/1tqeS5\\_eOtsRmxZ5RrTnYu7NC1r896KGX/view](https://drive.google.com/file/d/1tqeS5_eOtsRmxZ5RrTnYu7NC1r896KGX/view).

## RESULTS

A total of 181 samples were analyzed collectively for fumonisin in 2023. Survey samples have been tested for fumonisin since the *2019/2020 Harvest Report*. Results of the 2023 survey are as follows:

- One hundred seventy-eight (178) or 98.3% of the 181 samples tested below 5.0 ppm, the lowest advisory level for animals (equids and rabbits). This percentage for 2023 is similar to 2022 (98.9%) and slightly higher than 2021 (97.2%).
- Three (3) or 1.7% of the 181 samples tested greater than or equal to 5.0 ppm, but less than 10.0 ppm. This percentage for 2023 is slightly higher than 2022 (1.1%) and slightly lower than 2021 (2.2%).
- Zero (0) or 0.0% of the 181 samples tested greater than or equal to 10.0 ppm, but not greater than 30.0 ppm. This percentage for 2023 is the same as 2022 and similar to 2021 (0.6%).
- Zero (0) or 0.0% of the 181 samples tested greater than 30.0 ppm, which is the advisory level for breeding ruminants, poultry and mink. This percentage for 2023 is the same as in 2022 and 2021.



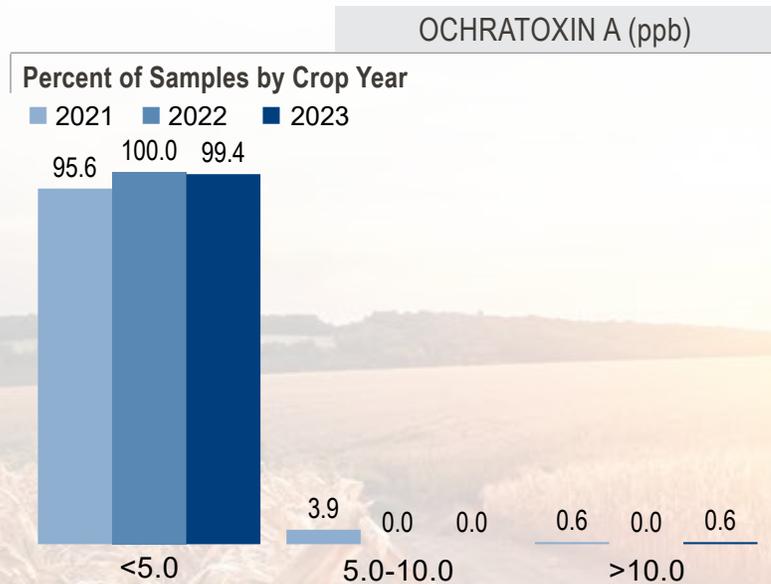
## OCHRATOXIN A

Ochratoxins are considered a hazardous mycotoxin produced by a number of fungal species such as *Penicillium verrucosum* and *Aspergillus ochraceus* that can colonize grains, cereals and a range of other food products. Of these products, grains and cereals are considered to represent 50–80% of the intake of ochratoxins. The fungi can produce ochratoxins A, B and C, but ochratoxin A is produced in the greatest quantity. While ochratoxin A can occur all along the production chain from the field to storage, it is primarily considered a storage problem. Grains stored under high moisture/humidity (>14%) at warm temperatures (>20°C) and/or inadequately dried have the potential to become contaminated with the fungi and produce ochratoxins. Also, damage to the grain by mechanical means, physical means or insects can provide a portal of entry for the fungus. Initial growth of fungi in grains can form sufficient moisture from metabolism to allow for further growth and mycotoxin formation. Because grains and cereal products represent a large portion of the human diet, several countries have established maximum levels for ochratoxin A in unprocessed cereals. The European Commission established a maximum level for ochratoxin A in raw cereals at 5.0 parts per billion. The FDA has issued no advisory levels for ochratoxin A.

## RESULTS

Survey samples have been tested for ochratoxin A since the *2020/2021 Harvest Report*. Results of the 181 samples analyzed for ochratoxin A in 2023 are as follows:

- One hundred eighty (180) or 99.4% of the 181 samples tested below 5.0 ppb, the European Commission’s established a maximum level for ochratoxin A. This percentage is similar to 2022 (100.0%) and higher than 2021 (95.6%).
- Zero (0) or 0.0% of the samples tested greater than or equal to 5.0 ppb, but not greater than 10.0 ppb. This percentage for 2023 is the same as 2022 and lower than 2021 (3.9%).
- One (1) or 0.6% of the samples tested greater than 10.0 ppb. This percentage for 2023 is slightly higher than 2022 (0.0%) and the same as 2021.



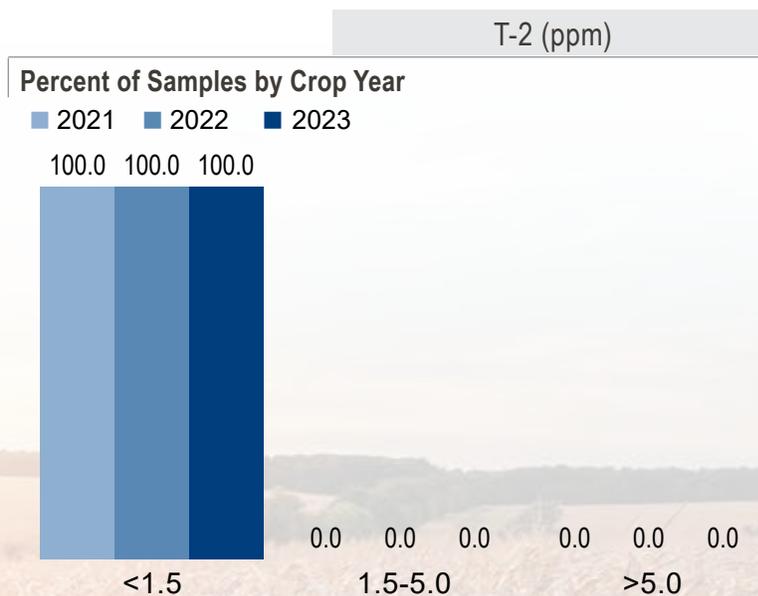
T-2

T-2 is one of several mycotoxins (including Deoxynivalenol or DON) belonging to a group of mycotoxins called trichothecenes. T-2 toxin is produced in growing cereal grain crops by various *Fusarium* species of fungi. The fungi can grow over a wide range of temperatures (-2 to 35°C) and only at a water activity above 0.88. As a result, T-2 is not normally found in grain at harvest but in grain that has suffered water damage when left in the field after harvest (especially over winter). However, T-2 can occur in storage if the grain has suffered water damage in storage. The FDA has issued no advisory levels for T-2 toxin.

RESULTS

Survey samples have been tested for T-2 since the *2020/2021 Harvest Report*. Results of the 181 samples analyzed for T-2 in 2023 are as follows:

- One hundred eighty-one (181) or 100.0% of the 181 samples tested below 1.5 ppm. This percentage for 2023 is the same as 2022 and 2021.
- Zero (0) or 0.0% of the samples tested greater than or equal to 1.5 ppm, but not greater than 5.0 ppm, which is the same as 2022 and 2021.
- Zero (0) or 0.0% of the samples test greater than 5.0 ppm, which is the same as 2022 and 2021.



## ZEARALENONE

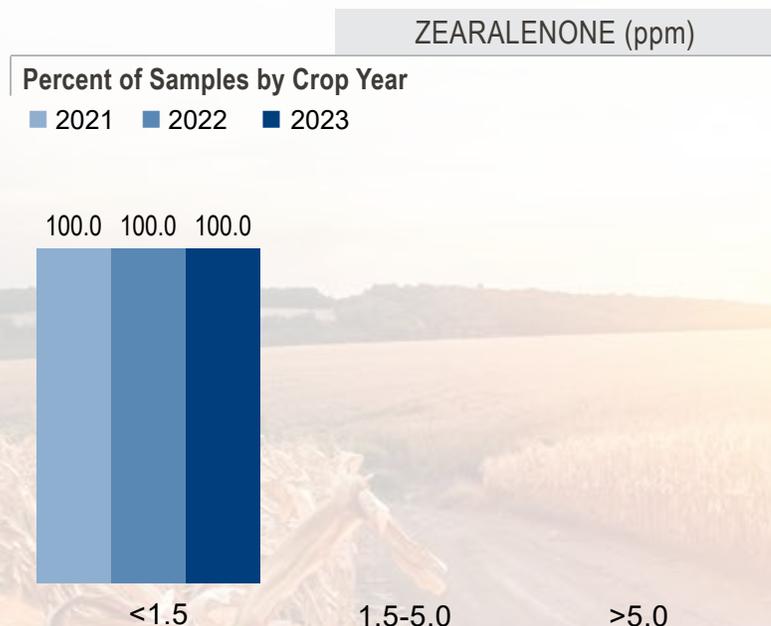
Zearalenone is a mycotoxin that is very similar to deoxynivalenol (DON) in most aspects, with a few exceptions. Both are produced by *Fusarium* species of fungi. As a result, it would not be uncommon to find both mycotoxins in grain and grain products at the same time. The growing conditions for zearalenone production are very comparable to DON, with the optimal temperatures ranging from 65 to 85°F. A drop in temperature during growth also stimulates the production of toxins by the fungi. A moisture content of 20% or greater is required by the fungi to produce zearalenone, which is also similar to that needed to produce DON. But if the moisture content during growth drops below 15%, the production of toxins is halted. This is one of the reasons that it is recommended that corn for storage should be dried to moisture levels less than 15%. Levels of as little as 0.1 ppm to 5.0 ppm have been shown to cause reproductive problems in swine, so great care should be used when feeding possibly contaminated grain to pigs. The FDA has issued no advisory levels for zearalenone but recommends only that the levels of concern for DON be observed.

Results of the 181 samples were tested to assess the impact of this year’s growing conditions on zearalenone are shown below. The sampling criteria and the testing methodology employed are described in the “Survey and Statistical Analysis Methods” and “Testing Analysis Methods” sections, respectively.

## RESULTS

Survey samples have been tested for zearalenone since the *2020/2021 Harvest Report*. Results of the 181 samples analyzed in 2023 are as follows:

- One hundred eighty-one (181) or 100.0% of the samples tested for below 1.5 ppm. This percentage is the same as 2022 and 2021.
- Zero (0) or 0.0% of the samples tested greater than or equal to 1.5 ppm, but not greater than 5.0 ppm. This percentage is the same as 2022 and 2021.
- Zero (0) or 0.0% of the 181 samples tested greater than 5.0 ppm, which is the same as in 2022 and 2021.



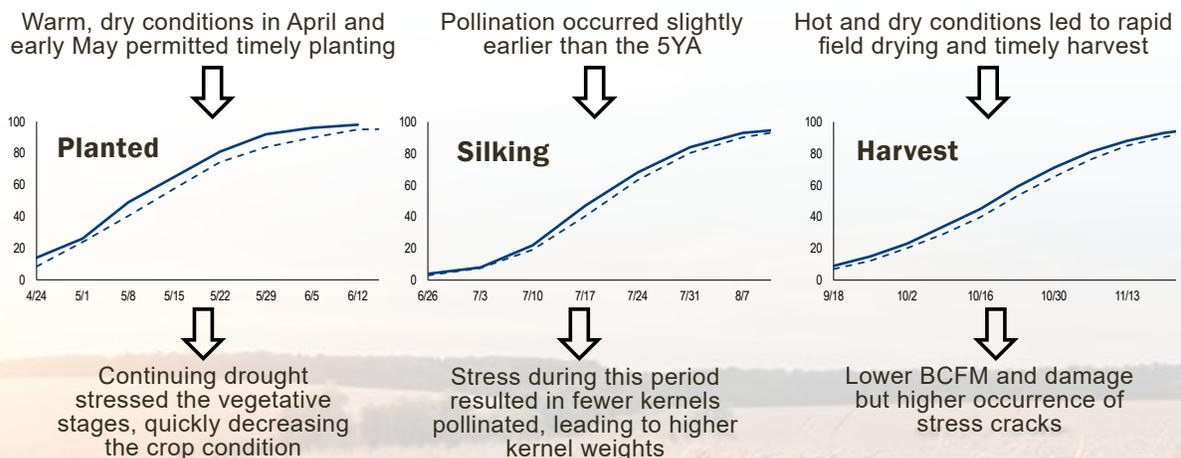
## A. 2023 HARVEST HIGHLIGHTS

Weather plays a large role in the corn planting process, growing conditions and grain development in the field. These, in turn, impact final grain yield and quality. Overall, 2023 was characterized by a timely crop emergence, scarce rains at pollination time, heat and drought during the grain-filling period and rapid dry-down and harvest. This crop was planted earlier than average and experienced an overall dry growing season, with the good-to-excellent crop condition rating<sup>1</sup> declining quickly early in the season compared to the 5YA. The weather conditions increased the crop’s average kernel weight and protein level compared to the 5YA. The following highlights the key events of the 2023 growing season:

- Warm and dry conditions led to timely planting, but continuing drought stressed the vegetative stages, quickly decreasing the crop condition.
- Pollination (silking stage) was slightly earlier than the 5YA, fewer kernels were pollinated leading to greater kernel weight.
- Grain developed under mostly warm and dry conditions, which enhanced protein and hard endosperm concentrations.
- Hot and dry conditions at the end of the season led to rapid field drying and timely harvest with few broken kernels.

### Growing Conditions and Impact on Crop Development

— 2023 — 2018-2022



<sup>1</sup>The U.S. Department of Agriculture rates the U.S. corn crop weekly during the production cycle. The rating is based on yield potential and plant stress due to a number of factors, including extreme temperatures, excessive or insufficient moisture, disease, insect damage and/or weed pressure.

## B. PLANTING AND EARLY GROWTH CONDITIONS

### *Timely planting, but drought stress*

*Weather factors impacting corn yield and quality include the amount of precipitation and the temperature just prior to and during the corn-growing season. These weather factors interact with the corn variety planted and soil fertility. Grain yield is a function of the number of plants per acre, the number of kernels per plant and the weight of each kernel. Cold or wet weather at planting could reduce plant numbers or hinder plant growth, which may result in lower yields per area. Some dryness at planting and early growth time is beneficial. It promotes a deeper root system to access water better later in the season and keeps nitrogen fertilizer available for later plant growth.*

### **2023**

Overall in 2023, corn emergence occurred a few days earlier than the 5YA due to dry, warm fields. However, the warmer temperatures combined with drought caused uneven emergence and stress. Continued drought stress during the late vegetative stages in June was moderated by Canadian wildfire smoke, which limited heat stress. These conditions caused many plants to decrease the potential kernels on each ear. However, the dryness prompted the plants to grow deep roots to reach water, which helped later in the season.

In the Pacific Northwest ECA, young plants primarily grew under warm and dry conditions.

In the Gulf ECA, about 85% of the area was abnormally dry or under drought stress during early plant growth, with more rapid drought development than in 2012, leading to a rapid decrease in the crop condition.

Plants in the Southern Rail ECA also were primarily in drought, but irrigation gave some relief.

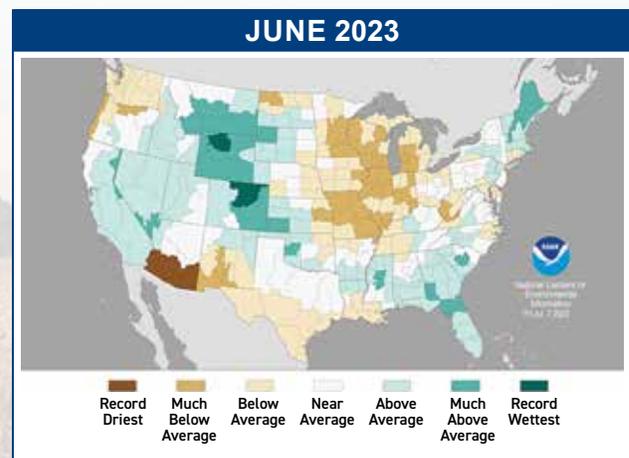
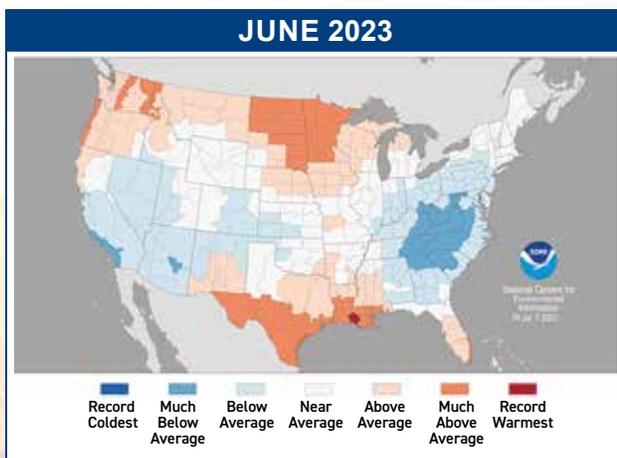
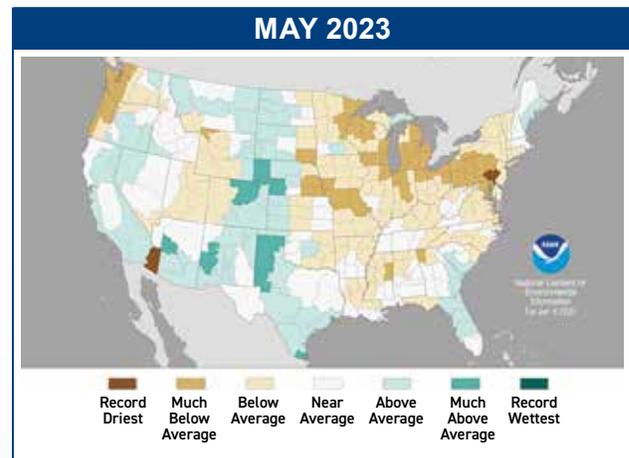
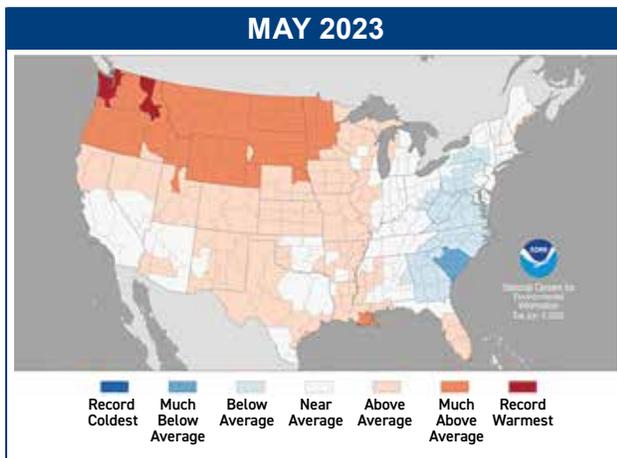
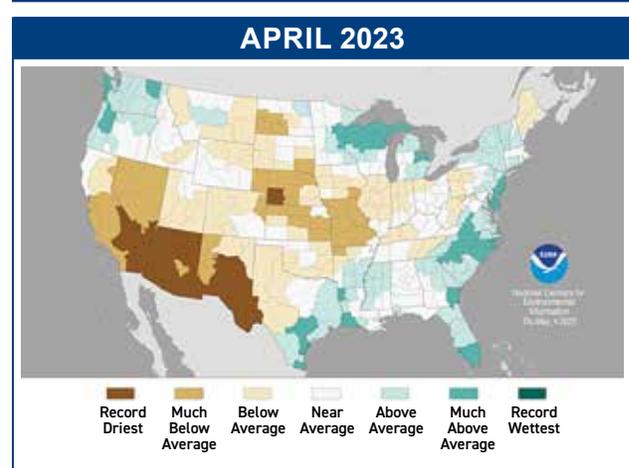
## DIVISIONAL AVERAGE TEMPERATURE RANKS

(Period: 1895-2023)



## DIVISIONAL PRECIPITATION RANKS

(Period: 1895-2023)



Source: NOAA/Regional Climate Centers

Source: NOAA/Regional Climate Centers

## C.POLLINATION AND GRAIN-FILL CONDITIONS

### *Drought stress reduced grain numbers, but increased kernel protein*

*Corn pollination typically occurs in July. At pollination time, greater-than-average temperatures or lack of rain typically reduce the number of kernels. During the early grain-filling period in July and August, the weather conditions are critical to determining final grain composition. At pollination, moderate rainfall and cooler-than-average temperatures, especially overnight temperatures, lead to increased yields. Less rainfall and high temperatures, especially in the second half of grain-fill (August to September), lead to more protein. Nitrogen also remobilizes from the leaves to the grain during late grain-filling, leading to increases in grain protein and hard endosperm.*

*In terms of mycotoxin development, aflatoxin production is induced by heat stress, low precipitation and drought conditions during flowering followed by periods of high humidity with warmth. While the production of DON is associated with harvest delay or storage of high-moisture corn, the fungal infections responsible for DON's production are promoted by cool (26 to 28°C) or wet conditions within three weeks after pollination by infecting through the silks of the corn ear.*

### **2023**

Overall in 2023, pollination occurred under mild temperatures, with some rain in the Gulf and Pacific Northwest ECAs, but drier conditions in the Southern Rail ECA. The stressed conditions before and during pollination led to fewer kernels pollinated, but consequently greater kernel volume of those that did develop. These weather conditions limited photosynthesis, and therefore starch and oil production, but increased the horneous endosperm level. A record heatwave combined with dry air in the southern portion of the Gulf ECA and the Southern Rail ECA during the middle of grain-fill may have led to some early field drying and stress cracks. While the weather conditions were concerning, there was no widespread aflatoxin or DON development.

The Gulf ECA received rains in July in the eastern and southern portions, which assisted pollination. However, the western portion was more warm and dry, favoring protein and hard endosperm accumulation.

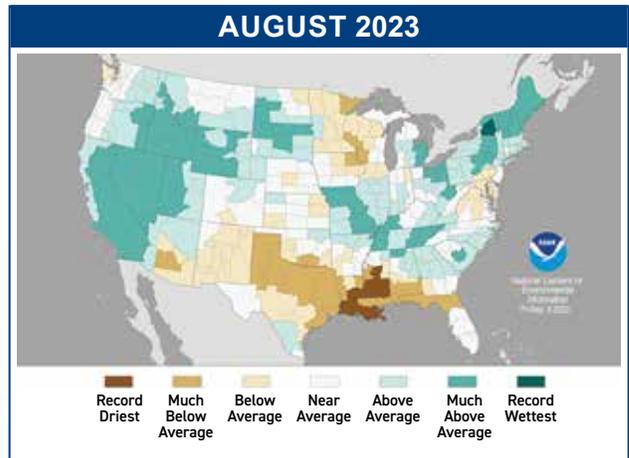
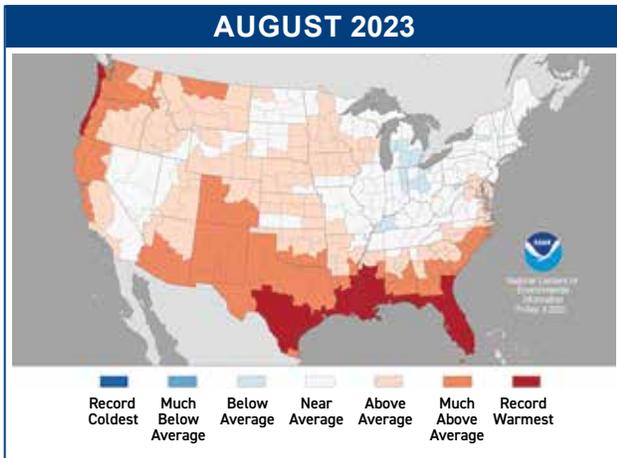
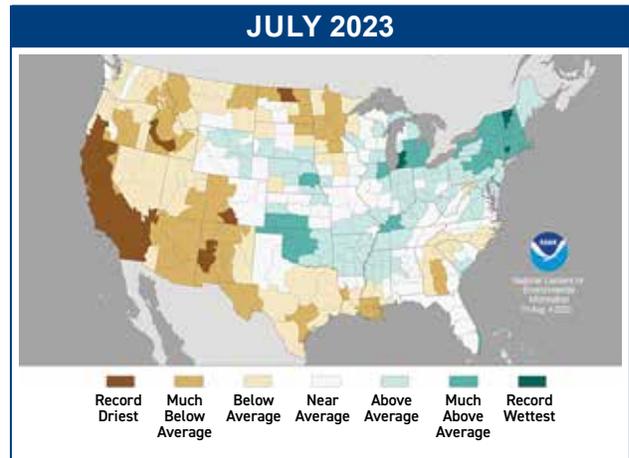
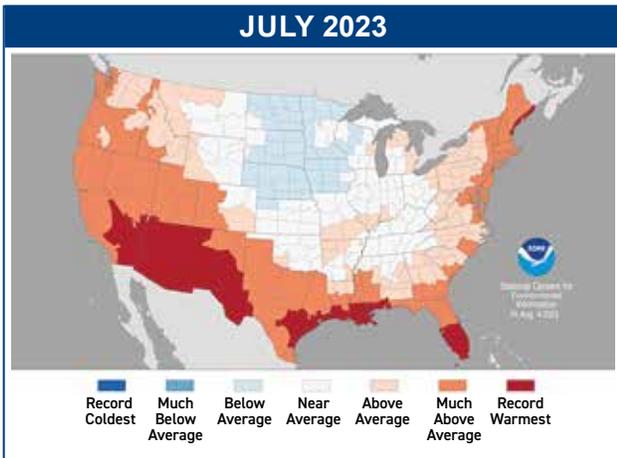
In the Pacific Northwest and Southern Rail ECAs, the southern region had plentiful rains, alleviating drought stress for pollination and grain development. There were good conditions for pollination, but heat stress during early-to-mid grain development.

**DIVISIONAL AVERAGE TEMPERATURE RANKS**

(Period: 1895-2023)

**DIVISIONAL PRECIPITATION RANKS**

(Period: 1895-2023)



Source: NOAA/Regional Climate Centers

Source: NOAA/Regional Climate Centers



## D. HARVEST CONDITIONS

### *Dry, early harvest*

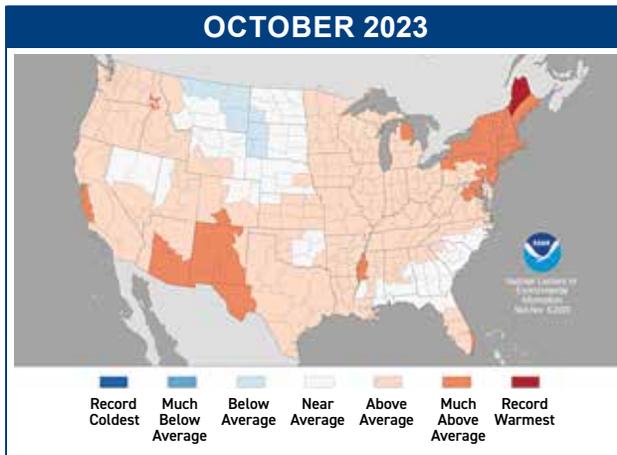
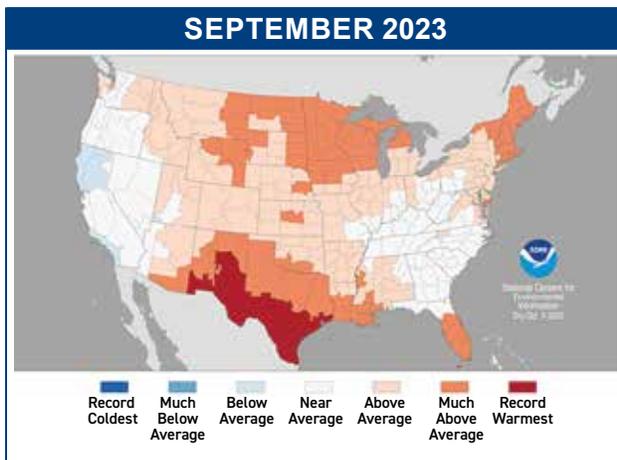
*Corn grain at maturity ranges from 25 to 35% moisture. At the end of the growing season, the dry-down rate of the grain to the ideal level of 15 to 20% moisture depends on sunshine, temperature, humidity and soil moisture. Corn can most effectively dry down with the least adverse impact on quality amid sunny, warm and dry days. One weather concern at the end of the growing season is freezing temperatures. Early freezing before the grain can sufficiently dry down may lead to lower yield, true density and test weight. If harvested prematurely, higher moisture grain may be susceptible to more stress cracks and greater breakage than drier grain. Very hard grain may also be susceptible to more stress cracks.*

### **2023**

The warm, dry conditions limited leaf diseases, but led to variable grain moistures and a crop that dried quickly. Continued dry conditions after maturity allowed producers to harvest the grain about a week earlier than the 5YA without rain delays or freezing weather.

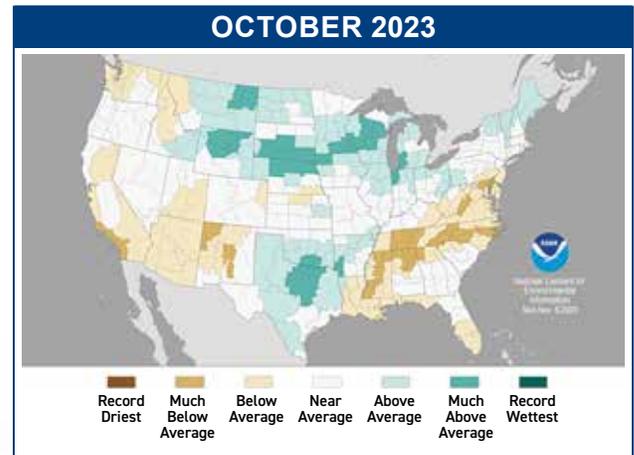
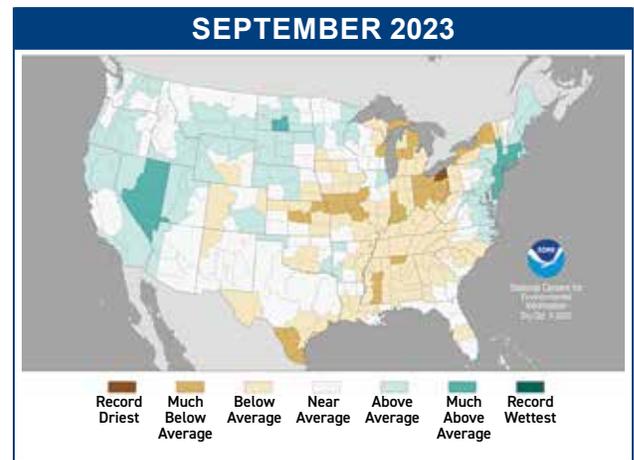
The warm conditions experienced by the crop at the end of the growing season were not conducive for major development of mycotoxins such as DON, fumonisin, ochratoxin A, T-2 or zearalenone.

## DIVISIONAL AVERAGE TEMPERATURE RANKS (Period: 1895-2023)



Source: NOAA/Regional Climate Centers

## DIVISIONAL PRECIPITATION RANKS (Period: 1895-2023)



Source: NOAA/Regional Climate Centers

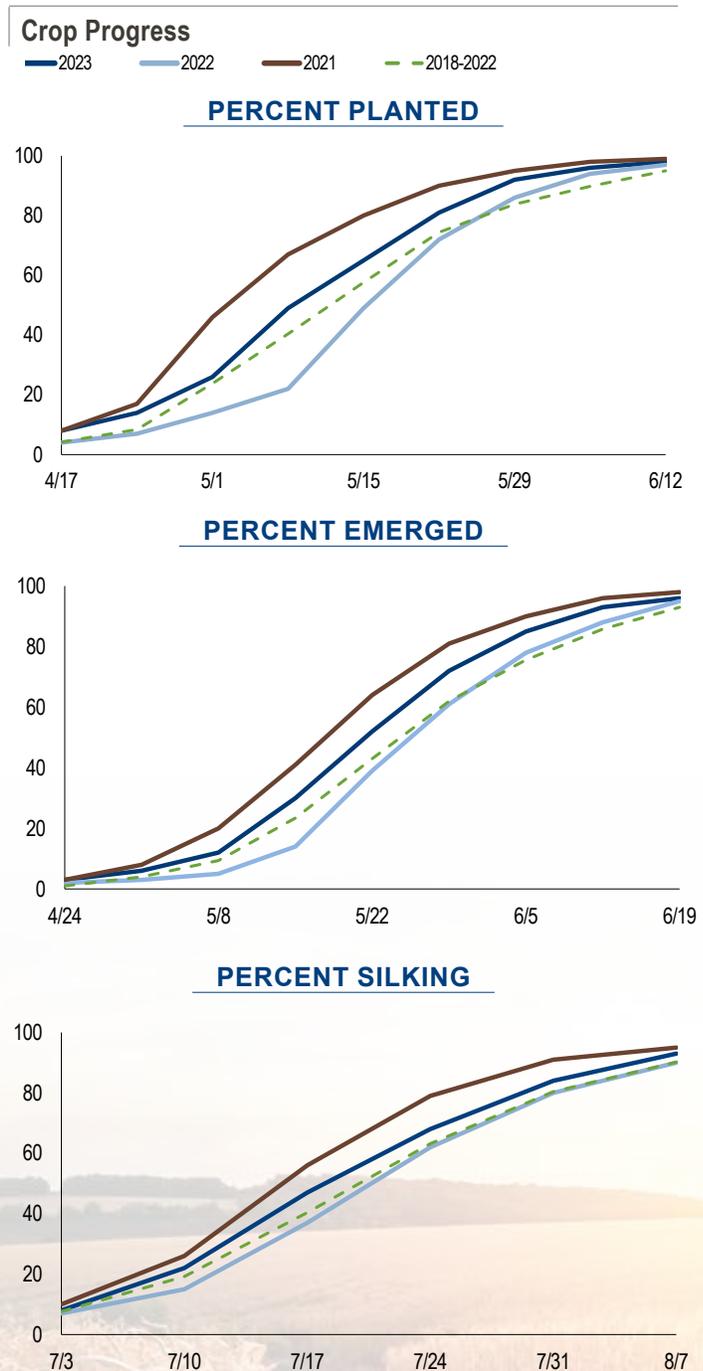
**E. COMPARISON OF 2023 TO 2022, 2021 AND THE 5YA**

*2023 crop developed under moderate drought stress*

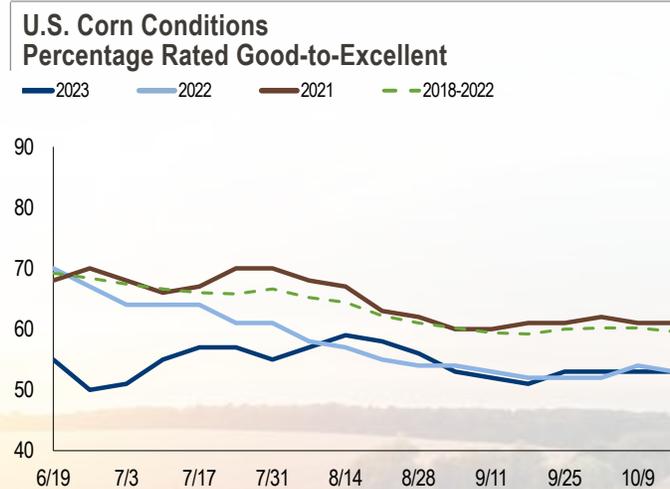
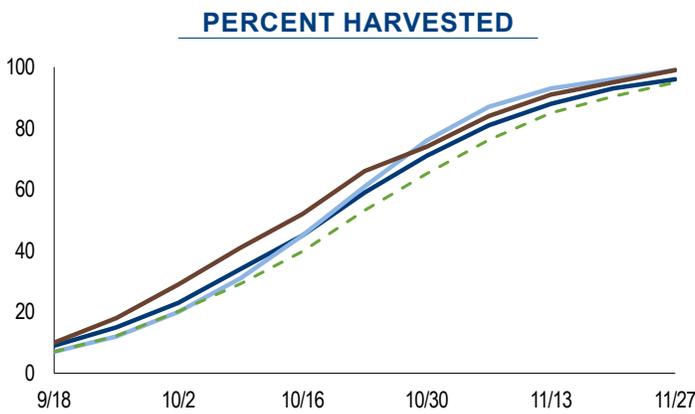
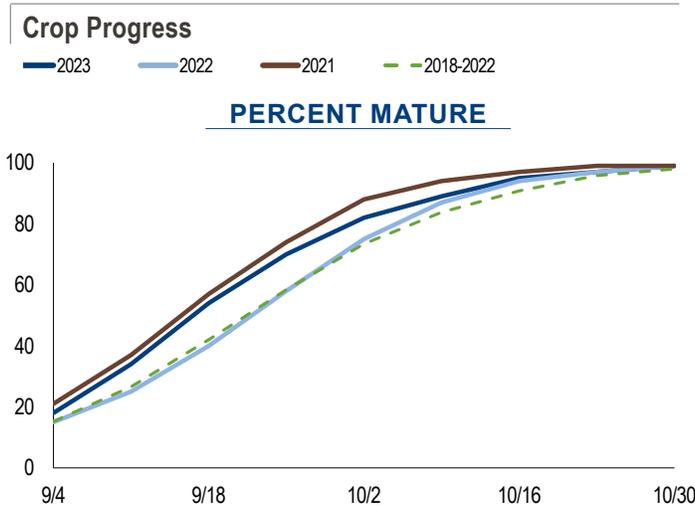
Warm, dry conditions led the 2023 crop to be planted slightly earlier than 2021 and the 5YA. A cold, wet April led to planting the 2022 crop two weeks behind 2021 and 2023.

Warm, dry conditions led the 2023 crop to emerge slightly later than 2021, but earlier than 2022 and the 5YA. Continued heat and drought throughout vegetative growth in 2023 limited kernel numbers.

In 2023, the silking/pollination was slightly earlier than 2022 and the 5YA, but not as early as 2021 due to early planting in 2021. Rain in 2023 and cooler temperatures in 2021 helped pollination.



Source: USDA NASS



Source: USDA NASS

Dry conditions matured the 2023 crop similarly to 2022 and the 5YA. In 2021, smoke from Canadian wildfires cooled temperatures and inhibited some photosynthesis and starch accumulation. In 2022 and 2023, hot and dry conditions also limited photosynthesis, and thereby starch and oil accumulation, but favored protein and hard endosperm.

The 2023 crop was harvested early due to rapid maturation from drought conditions and heat. Harvests in 2023 and 2021 were also earlier than the 5YA due to dry conditions and concern of plants falling down.

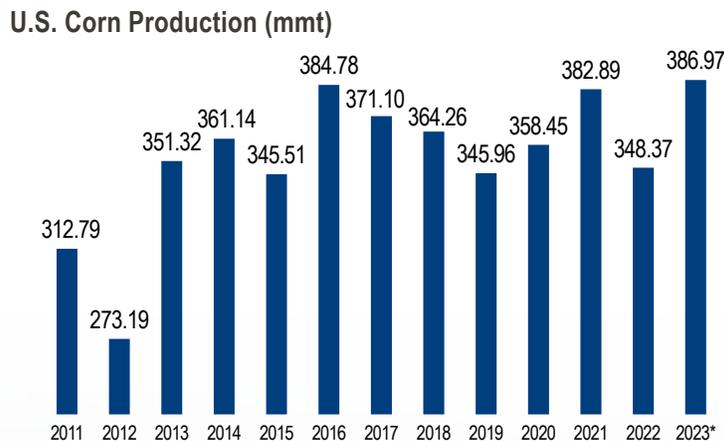
In 2023, the crop started with a somewhat low good-to-excellent condition rating.<sup>2</sup> Excessive heat and drought quickly decreased the rating below the 2021, 2022 and 5YA during the vegetative development stages, then stabilized. The 2022 crop had sustained drought and heat stress, which steadily decreased the rating. In 2021, the crop initially had a high good-to-excellent condition rating and remained near the 5YA throughout the season.

<sup>2</sup>A good rating means that yield prospects are normal; moisture levels are adequate; and disease, insect damage and weed pressures are minor. An excellent rating means that yield prospects are above normal; the crop is experiencing little or no stress; and disease, insect damage and weed pressures are insignificant.

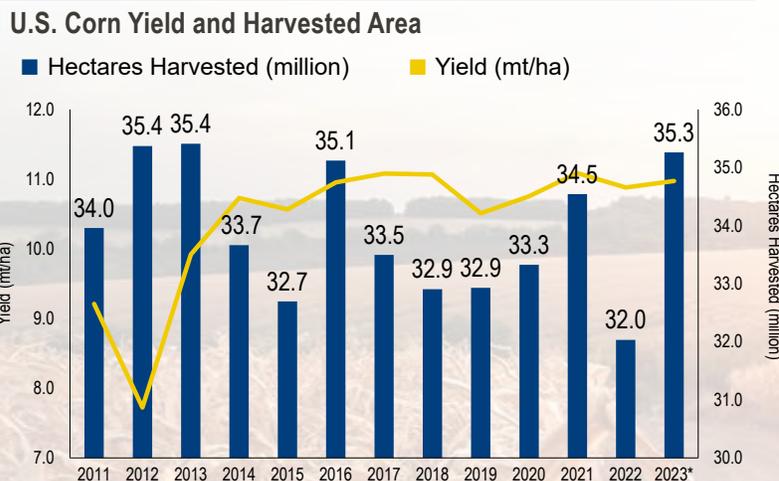
## A. U.S. CORN PRODUCTION

### U.S. Average Production and Yields

According to the November 2023 USDA World Agricultural Supply and Demand Estimates (WASDE) report, U.S. corn production in 2023 is projected to be 386.97 million metric tons (15,234 million bushels). If realized, this amount would surpass the size of the 2016/2017 crop (384.78 million metric tons or 15,148 million bushels) as the largest U.S. corn crop on record. This higher projected production in 2023 is the result of the high harvested area and yield expected. A total of 35.26 million hectares (87.10 million acres) are projected to be harvested in 2023 compared to the 5YA of 33.44 million hectares (82.6 million acres). Average yield is also estimated to be higher than the 5YA. Average yield is projected to be 10.97 metric tons per hectare (174.9 bushels per acre) compared to an average of 10.86 metric tons per hectare (173.1 bushels per acre) from the previous five crops.



\*Projected  
Source: USDA NASS

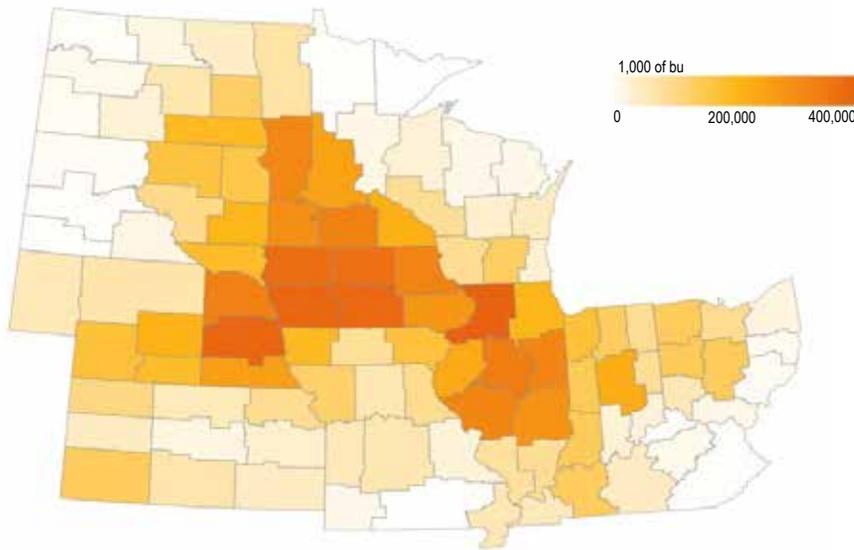


\*Projected  
Source: USDA NASS

## ASD and State-Level Production

The geographic areas included in the *2023/2024 Corn Harvest Quality Report* encompass the United States' highest corn-producing regions. The map below shows the projected 2023 corn production by USDA Agricultural Statistical District (ASD). These states represent more than 90% of U.S. corn exports.<sup>1</sup>

Projected 2023 U.S. Corn Production by ASD



Sources: USDA NASS and Centrec estimates

<sup>1</sup>Sources: USDA NASS, USDA GIPSA and Centrec estimates.

The U.S. Corn Production by State chart and table summarize the production changes between each state's 2022 and projected 2023 corn crops. The table also includes an indication of the relative changes in harvested acres and yield. A green bar indicates a relative increase, and a red bar indicates a relative decrease from 2022 to projected 2023.

Seven of the 12 key corn-producing states expect large increases (at least 10%) in production relative to their 2022 crops. Only Illinois and Wisconsin are projected to have year-over-year decreases in production in 2023. Only Illinois, Wisconsin, Minnesota and Missouri are expecting decreased yields relative to 2022 while harvested acres are expected to be higher in each of the 12 key corn-producing states.

**U.S. Corn Production by State**

| State             | 2022          | 2023*         | Difference   |              | Relative % Change <sup>†</sup> |       |
|-------------------|---------------|---------------|--------------|--------------|--------------------------------|-------|
|                   |               |               | MMT          | Percent      | Acres                          | Yield |
| Illinois          | 57.62         | 56.72         | (0.90)       | -1.6%        |                                |       |
| Indiana           | 24.76         | 27.33         | 2.57         | 10.4%        |                                |       |
| Iowa              | 62.74         | 64.01         | 1.27         | 2.0%         |                                |       |
| Kansas            | 12.97         | 16.38         | 3.41         | 26.3%        |                                |       |
| Kentucky          | 5.35          | 6.97          | 1.62         | 30.3%        |                                |       |
| Minnesota         | 37.10         | 37.70         | 0.60         | 1.6%         |                                |       |
| Missouri          | 12.72         | 13.70         | 0.99         | 7.7%         |                                |       |
| Nebraska          | 36.97         | 42.14         | 5.18         | 14.0%        |                                |       |
| North Dakota      | 8.82          | 13.59         | 4.77         | 54.1%        |                                |       |
| Ohio              | 15.11         | 16.69         | 1.59         | 10.5%        |                                |       |
| South Dakota      | 16.80         | 21.58         | 4.78         | 28.5%        |                                |       |
| Wisconsin         | 13.85         | 13.47         | (0.39)       | -2.8%        |                                |       |
| <b>Total U.S.</b> | <b>348.37</b> | <b>386.97</b> | <b>38.60</b> | <b>11.1%</b> |                                |       |

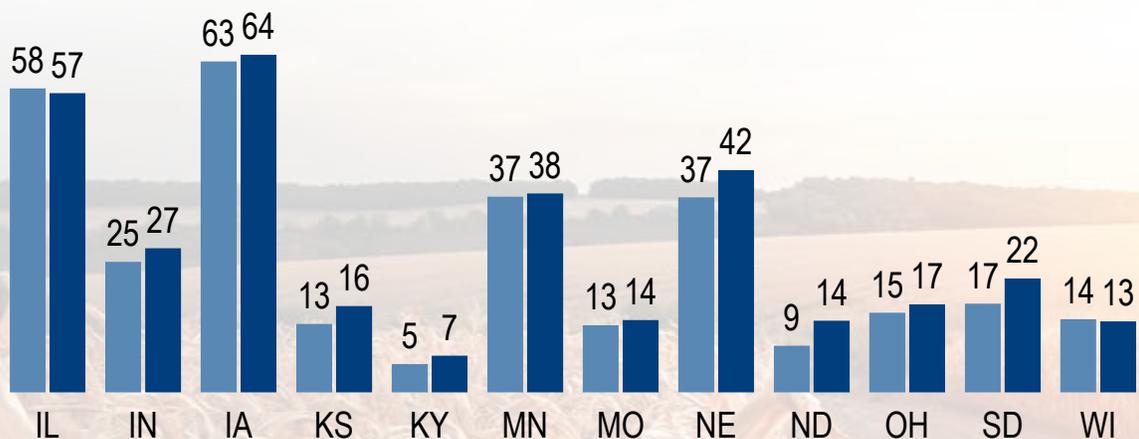
<sup>†</sup>Green indicates higher than previous year, and red indicates lower than previous year with height of bar indicating the relative amount.

\*Projected

Source: USDA NASS

**U.S. Corn Production by State (mmt)**

■ 2022 ■ 2023\*



\*Projected

Source: USDA NASS

## B.U.S. CORN USE AND ENDING STOCKS

U.S. corn usage for all categories and ending stocks decreased in marketing year 22/23 relative to 21/22 following the year-over-year decrease in corn production of 9.0%.

Corn for food, seed and other non-ethanol industrial purposes, which typically remains consistent over time, fell by 3.8% in marketing year 22/23 relative to 21/22.

Corn used for domestic ethanol production steadily increased in marketing years 20/21 and 21/22 as the U.S. recovered from the COVID-19 pandemic but saw a year-over-year decrease of 2.7% in 22/23. The amount of corn used for domestic ethanol production is largely dependent on U.S. consumption of finished gasoline. The year-over-year decrease in corn usage in marketing year 22/23 is partially explained by the year-over-year decrease in the average weekly finished gasoline supplied by U.S. refiners.<sup>2</sup>

The direct consumption of corn as a feed ingredient in domestic livestock and poultry rations in marketing year 22/23 also decreased, falling by 3.1% relative to marketing year 21/22.

While total domestic use decreased by 3.0% in marketing year 22/23 relative to 21/22, the effects of the smaller U.S. corn crop in 2022 were reflected the most in U.S. exports as corn exports fell by 32.8% relative to marketing year 21/22.

Ending stocks experienced a year-over-year decrease of 1.1% in marketing year 22/23. Despite reduced total domestic consumption, the smaller U.S. corn crop in 2022 kept ending stocks at the second lowest level since marketing year 13/14.

<sup>2</sup>U.S. Energy Information Administration, *Weekly Petroleum Status Report*, Accessed on November 15, 2023, from <https://www.eia.gov/petroleum/supply/weekly/>. Weekly estimates of U.S. product supplied of finished motor gasoline (thousand barrels per day) were averaged from September through August to make this comparison consistent with the U.S. corn marketing year.

## C.OUTLOOK

### U.S. Outlook

The 2023 U.S. corn crop is projected to be the largest crop on record and 38.60 million metric tons (1,519 million bushels) higher than the 2022 crop (11.1% increase). Given the record crop, higher levels of consumption and exports are anticipated in marketing year 23/24.

Marketing year 23/24 corn use for ethanol is projected to return to a level near that of 21/22, which is a 2.9% increase relative to 22/23.

Domestic corn use for feed and residual use in marketing year 23/24 is expected to be 143.52 million metric tons. This estimate is 2.58 million metric tons higher (1.8% increase) than in marketing year 22/23 but still 1.94 million metric tons lower (1.3% decrease) than 21/22 (145.46 million metric tons).

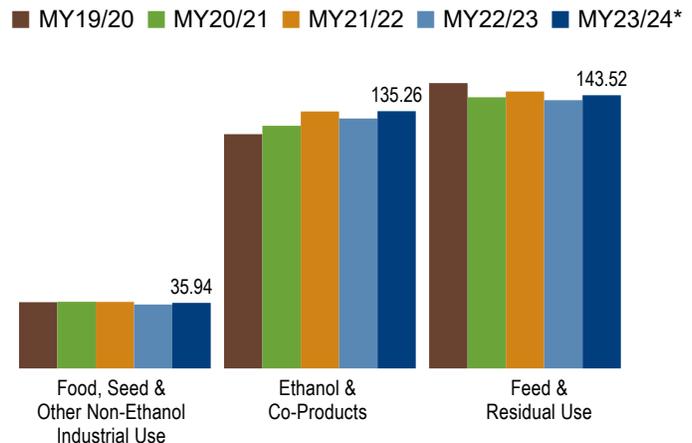
Corn use for food, seed and non-ethanol industrial purposes is expected to be 35.94 million metric tons, returning to a level near the 5YA (36.08 million metric tons).

Higher U.S. corn exports are projected for marketing year 23/24 due to the record corn crop anticipated. U.S. corn exports are projected to be 52.71 million metric tons in marketing year 23/24, which is an increase of 10.51 million metric tons (24.9% increase) from marketing year 22/23 but still 1.79 million metric tons lower (3.3% lower) than the 5YA.

U.S. ending stocks are projected to be 54.77 million metric tons in marketing year 23/24, a year-over-year increase of 20.19 million metric tons (58.4% increase). If realized, this would be the highest U.S. ending stocks since marketing year 18/19, which had ending stocks of 56.41 million metric tons.

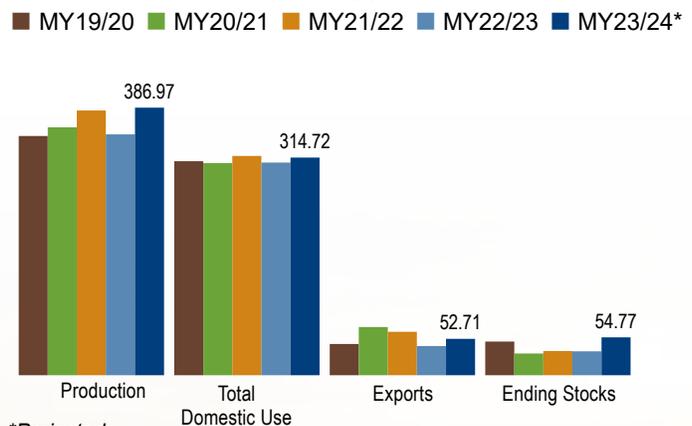
In terms of the stocks-to-use ratio, marketing year 23/24 is projected to be 14.9%, the highest value since marketing year 18/19 (15.5%).

**U.S. Corn Use by Marketing Year (mmt)**



\*Projected  
 Sources: USDA WASDE and ERS

**U.S. Corn Production & Disappearance (mmt)**



\*Projected  
 Sources: USDA WASDE and ERS

## International Outlook<sup>3</sup>

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### *Global Supply*

Global corn production during marketing year 23/24 is expected to be 1,220.79 million metric tons. This 63.71 million metric ton increase (5.5% increase) in production from marketing year 22/23 is largely due to higher production anticipated in the United States and Argentina.

In addition, global corn exports during marketing year 23/24 are expected to be 199.62 million metric tons, an 18.68 million metric ton increase (10.3% increase) from marketing year 22/23. Increased exports from the United States and Argentina are anticipated to offset for lower exports by Brazil and Ukraine.

### *Global Demand*

Global corn consumption is expected to increase from 1,168.20 million metric tons in marketing year 22/23 to 1,205.03 million metric tons in marketing year 23/24, a 3.2% increase. The United States, China, the European Union, Brazil and Argentina are all anticipated to consume at least 2.00 million metric tons more corn in marketing year 23/24 than in the previous marketing year. In comparison, only India is anticipated to have a decrease in corn consumption in marketing year 23/24 of more than 1.00 million metric tons relative to the previous marketing year.

Increases in year-over-year imports of at least 1.00 million metric tons are anticipated in China, Egypt, Iran, Saudi Arabia, Canada and the European Union. Only Turkey is anticipated to have a year-over-year decrease in corn imports in marketing year 23/24 of at least 0.50 million metric tons relative to the previous marketing year.

<sup>3</sup>USDA/Foreign Agricultural Service- Production, Supply and Distribution Database. Data retrieved November 2023.

**U.S. CORN SUPPLY AND USAGE SUMMARY BY MARKETING YEAR**

| Metric Units                               | 19/20         | 20/21         | 21/22         | 22/23         | 23/24*        |
|--|---------------|---------------|---------------|---------------|---------------|
| <b>Acreage (million hectares)</b>          |               |               |               |               |               |
| Planted                                    | 36.33         | 36.72         | 37.77         | 35.87         | 38.42         |
| Harvested                                  | 32.93         | 33.33         | 34.54         | 32.03         | 35.26         |
| Yield (mt/ha)                              | 10.51         | 10.75         | 11.09         | 10.88         | 10.97         |
| <b>Supply (million metric tons)</b>        |               |               |               |               |               |
| Beginning stocks                           | 56.41         | 48.76         | 31.36         | 34.97         | 34.58         |
| Production                                 | 345.96        | 358.45        | 382.90        | 348.37        | 386.97        |
| Imports                                    | 1.06          | 0.62          | 0.62          | 0.98          | 0.64          |
| <b>Total Supply</b>                        | <b>403.44</b> | <b>407.82</b> | <b>414.87</b> | <b>384.33</b> | <b>422.19</b> |
| <b>Usage (million metric tons)</b>         |               |               |               |               |               |
| Food, seed, other non-ethanol industry use | 36.31         | 36.55         | 36.50         | 35.10         | 35.94         |
| Ethanol and co-products                    | 123.37        | 127.71        | 135.14        | 131.48        | 135.26        |
| Feed and residual                          | 149.83        | 142.43        | 145.46        | 140.94        | 143.52        |
| Exports                                    | 45.18         | 69.78         | 62.80         | 42.20         | 52.71         |
| <b>Total Use</b>                           | <b>354.68</b> | <b>376.46</b> | <b>379.89</b> | <b>349.72</b> | <b>367.43</b> |
| Ending Stocks                              | 48.76         | 31.36         | 34.97         | 34.58         | 54.77         |
| Average Farm Price (\$/mt)**               | 140.15        | 178.34        | 236.21        | 257.47        | 190.93        |

| English Units                              | 19/20         | 20/21         | 21/22         | 22/23         | 23/24*        |
|--|---------------|---------------|---------------|---------------|---------------|
| <b>Acreage (million acres)</b>             |               |               |               |               |               |
| Planted                                    | 89.7          | 90.7          | 93.3          | 88.6          | 94.9          |
| Harvested                                  | 81.3          | 82.3          | 85.3          | 79.1          | 87.1          |
| Yield (bu/ac)                              | 167.5         | 171.4         | 176.7         | 173.4         | 174.9         |
| <b>Supply (million bushels)</b>            |               |               |               |               |               |
| Beginning stocks                           | 2,221         | 1,919         | 1,235         | 1,377         | 1,361         |
| Production                                 | 13,620        | 14,111        | 15,074        | 13,715        | 15,234        |
| Imports                                    | 42            | 24            | 24            | 39            | 25            |
| <b>Total Supply</b>                        | <b>15,883</b> | <b>16,055</b> | <b>16,333</b> | <b>15,130</b> | <b>16,621</b> |
| <b>Usage (million bushels)</b>             |               |               |               |               |               |
| Food, seed, other non-ethanol industry use | 1,429         | 1,439         | 1,437         | 1,382         | 1,415         |
| Ethanol and co-products                    | 4,857         | 5,028         | 5,320         | 5,176         | 5,325         |
| Feed and residual                          | 5,899         | 5,607         | 5,726         | 5,549         | 5,650         |
| Exports                                    | 1,778         | 2,747         | 2,472         | 1,661         | 2,075         |
| <b>Total Use</b>                           | <b>13,963</b> | <b>14,821</b> | <b>14,956</b> | <b>13,768</b> | <b>14,465</b> |
| Ending Stocks                              | 1,919         | 1,235         | 1,377         | 1,361         | 2,156         |
| Average Farm Price (\$/bu)**               | 3.56          | 4.53          | 6.00          | 6.54          | 4.85          |

\*Projected

\*\*Farm prices are weighted averages based on the volume of farm shipment.

The average farm price for 23/24 based on the projected price from the November 2023 WASDE.

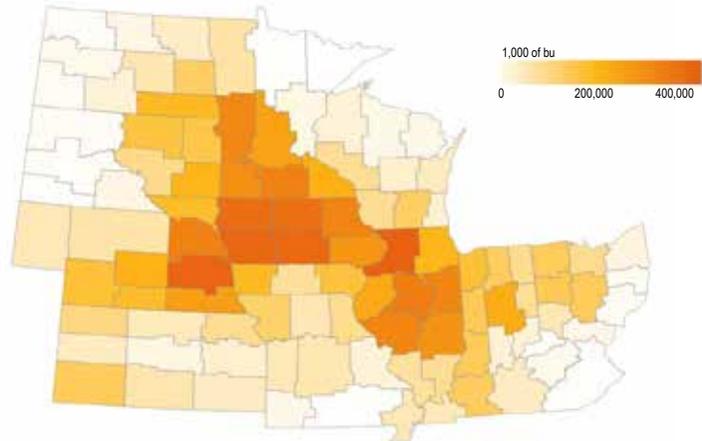
Sources: USDA WASDE and ERS

## A. OVERVIEW

The key points for the survey design, sampling methodology and statistical analysis for this 2023/2024 *Harvest Report* are as follows:

- Following the methodology developed for the previous twelve *Harvest Reports*, the samples were proportionately stratified according to ASDs across 12 key corn-producing states representing more than 90% of U.S. corn exports.
- A total of 600 samples collected from the 12 states was targeted to achieve a relative margin of error no higher than 10.0% for U.S. Aggregate's quality factor estimates at the 95.0% confidence level.
- A total of 611 unblended corn samples was received and tested for the report. These samples were pulled from inbound farm-originated trucks by local elevators from August 23 through November 17, 2023.
- The mycotoxin testing across the ASDs in the 12 states surveyed for the other quality factors used a proportionate stratified sampling technique. This sampling resulted in testing 181 samples for aflatoxin, DON, fumonisin, ochratoxin A, T-2 and zearalenone.
- Weighted averages and standard deviations following standard statistical techniques for proportionate stratified sampling were calculated for the U.S. Aggregate and the three ECAs.
- Each quality factor's relative margin of error was calculated for the U.S. Aggregate and each of the three ECAs to evaluate the statistical validity of the samples. No quality factor had a relative margin of error above 10.0% for the U.S. Aggregate. However, the Pacific Northwest ECA had relative margin of errors for total damage and stress cracks of 16.0 and 11.6%, respectively. The relative margin of errors for total damage and stress cracks were also above 10.0% in the Southern Rail ECA (11.5 and 10.3%, respectively). While these levels of precision are less than desired, they do not invalidate the estimates.
- Two-tailed t-tests at the 95.0% confidence level were calculated to measure statistical differences between this year's quality factor averages and those from the previous two reports, the 5YA and the 10YA.

Projected 2023 U.S. Corn Production by ASD



Sources: USDA NASS and Centrec estimates

## B. SURVEY DESIGN AND SAMPLING

### Survey Design

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For this *2023/2024 Harvest Report*, the target population was yellow corn from the 12 key U.S. corn-producing states representing more than 90% of U.S. corn exports.<sup>1</sup> A **proportionate stratified, random sampling** technique was applied to ensure a sound statistical sampling of the U.S. corn crop at the first stage of the market channel. Three key characteristics define the sampling technique: the **stratification** of the population to be sampled, the **sampling proportion** per stratum and the **random sample** selection procedure.

**Stratification** involves dividing the survey population of interest into distinct, non-overlapping subpopulations called strata. For this study, the survey population was corn produced in areas likely to export corn to foreign markets. The USDA divides each state into several ASDs and estimates corn production for each ASD. The USDA corn production data, accompanied by foreign export estimates, were used to define the survey population in the 12 key corn-producing states. The ASDs were the subpopulations or strata used for this corn quality survey. From those data, the Council calculated each ASD's proportion of the total production and foreign exports to determine the **sampling proportion** (the percent of total samples per ASD) and, ultimately, the number of corn samples to be collected from each ASD. The number of samples collected for the *2023/2024 Harvest Report* differed among the ASDs due to their different shares of estimated production and foreign export levels.

Establishing the **number of samples collected** allowed the Council to estimate the true averages of the various quality factors with a certain level of precision. The level of precision chosen for the *2023/2024 Harvest Report* was a relative margin of error no greater than 10.0%, estimated at a 95.0% level of confidence.

To determine the number of samples for the relative margin of error target, ideally, the population variance (i.e., the variability of the quality factor in the corn at harvest) for each of the quality factors should be used. Greater variation among the levels or values of a quality factor requires more samples to estimate the true mean with a given confidence limit. In addition, the variances of the quality factors typically differ from one another. Therefore, different sample sizes would be needed for each quality factor for the same level of precision.

<sup>1</sup>Source: USDA NASS, USDA GIPSA and Centrec estimates

Since the population variances for the 16 quality factors evaluated for this year's corn crop were unknown, the variance estimates from the *2022/2023 Harvest Report* were used as proxies. The variances and, ultimately, the estimated number of samples needed for the relative margin of error to be no higher than 10.0% for 13 quality factors were calculated using the 2022 results of 600 samples. Broken corn, foreign material and heat damage were not examined. Based on these data, a minimum sample size of 600 would allow the Council to estimate the true averages of the quality characteristics with the desired level of precision for the U.S. Aggregate.

While the relative margin of error for stress cracks was not higher than 10.0% in the 2022 results for the U.S. Aggregate, this quality factor has had a relative margin of error slightly higher than 10.0% in three of the twelve previous reports. Given the *2023/2024 Harvest Report's* sample size and the unpredictability of this quality factor's variance, there was the potential that stress cracks may not meet the targeted level of precision for the U.S. Aggregate. However, the relative margin of error for stress cracks has never been above 12% for the U.S. Aggregate in past reports.

The testing of the grade, moisture, chemical and physical characteristics used the same proportionate stratified sampling approach for the mycotoxin testing of the corn samples. In addition to using the same sampling approach, the same level of precision of a relative margin of error no higher than 10.0%, estimated at a 95.0% level of confidence, was desired.

Testing at least 25% of the minimum number of samples (600) was estimated to provide that level of precision. In other words, testing at least 150 samples would provide a 95.0% confidence level that the percent of tested samples with aflatoxin results below the FDA action level of 20.0 ppb and the percent of tested samples with DON results below the FDA advisory level of 5.0 ppm would have a relative margin of error no higher than 10.0%. There was no targeted level of precision for fumonisin, ochratoxin A, T-2 and zearalenone for this year's report. The proportionate stratified sampling approach also required testing at least one sample from each ASD in the sampling area. To meet the sampling criteria of testing 25% of the minimum number of samples (600) and at least one sample from each ASD, the targeted number of samples to test for mycotoxins was 180.

Beginning with the *2019/2020 Harvest Report*, only the samples tested for mycotoxins would be tested for horneous endosperm. This testing protocol was extended to 100-k weight, kernel volume and kernel true density in the *2020/2021 Harvest Report*. These quality factors' relative margin of errors never exceeded 0.6%, well below the targeted maximum level of precision of 10.0%, in the samples tested from the ten reports prior to the *2020/2021 Harvest Report*. Thus, reducing the number of samples tested for horneous endosperm, 100-k weight, kernel volume and kernel true density would likely keep the precision of these quality factors' estimates well below the targeted maximum level 10.0%.

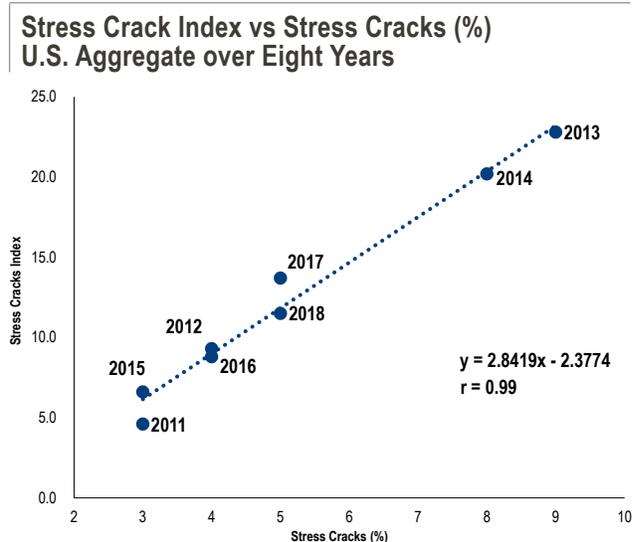
In the first eight years of the *Harvest Report*, the stress crack index was reported in addition to the percent stress cracks to indicate the severity of stress cracking. The stress crack index is determined using the following calculation:

$$[\text{SSC} \times 1] + [\text{DSC} \times 3] + [\text{MSC} \times 5]$$

Where

- **SSC** is the percentage of kernels with only one crack;
- **DSC** is the percentage of kernels with exactly two cracks; and
- **MSC** is the percentage of kernels with more than two cracks.

The U.S. Aggregate percent stress cracks and stress crack index from the first eight *Harvest Reports* are displayed in the scatter chart to the right. Given its strong correlation ( $r = 0.99$ ) to percent stress cracks, it was determined that the stress crack index provided limited additional value and was discontinued following the *2018/2019 Harvest Report*.



## Sampling

Soliciting local grain elevators in the 12 states by email and phone provided the **random selection** process. Postage-paid sampling kits were mailed to elevators agreeing to provide the 2,050 to 2,250-gram corn samples requested. Elevators were told to avoid sampling loads of old crop corn from farmers cleaning out their bins for the current crop. The individual samples were pulled from inbound farm-originated trucks when the trucks underwent the elevators' normal testing procedures. The number of samples each elevator provided for the survey depended on the targeted number of samples needed from the ASD along with the number of elevators willing to provide samples. However, each sampling kit mailed to the participating locations contained bags to collect a maximum of four samples to ensure geographic variation in the samples collected. A total of 611 unblended corn samples pulled from inbound farm-originated trucks were received and tested from local elevators. The participating elevators indicated that these samples were pulled from inbound farm-originated trucks from August 23 through November 17, 2023, by writing the collection date on each sample bag.

## C. STATISTICAL ANALYSIS

The sample test results for the grade factors, moisture, chemical composition and physical factors were summarized as the U.S. Aggregate and three composite groups that supply corn to each of three major ECAs.

In analyzing the sample test results, the Council followed the standard statistical techniques employed for proportionate stratified sampling, including **weighted averages** and **standard deviations**.<sup>2</sup>

In addition to the weighted averages and standard deviations for the U.S.

Aggregate, weighted averages and standard deviations were estimated for the composite ECAs. The geographic areas from which exports flow to each of these ECAs overlap due to available transportation modes. Therefore, composite statistics for each ECA were calculated based on estimated proportions of grain flowing to each ECA. As a result, corn samples could be reported in more than one ECA. These estimations were based on industry input, export data and evaluation of studies of grain flow in the United States.

The *2023/2024 Harvest Report* contains a simple average of the quality factors' averages and standard deviations of the previous five *Harvest Reports* (2018/2019, 2019/2020, 2020/2021, 2021/2022 and 2022/2023). These simple averages are calculated for the U.S. Aggregate and each of the three ECAs and are referred to as the "5YA" in the text and summary tables of the report. References to the "10YA" are also made throughout the report. The 10YA represents the simple average of the quality factors' averages from the *2013/2014 Harvest Report* through the *2022/2023 Harvest Report*.

The relative margin of error was calculated for each of the quality factors for the U.S. Aggregate and each of the ECAs. None of the quality factor estimates had relative margin of errors above 10.0% for the U.S. Aggregate. However, the Pacific Northwest ECA had relative margin of errors for total damage and stress cracks of 16.0 and 11.6%, respectively. The relative margin of errors for total damage and stress cracks were also above 10.0% in the Southern Rail ECA (11.5 and 10.3%, respectively). While these levels of precision are less than desired, they do not invalidate the estimates. Footnotes in the summary tables indicate that the quality factor's relative margin of error exceeded 10.0%.

Two-tailed t-tests validated references in the "Quality Test Results" section to statistical or significant differences between this year's quality factor averages and those from the previous two reports, the 5YA and the 10YA at the 95.0% confidence level. Differences between this year's quality factor averages and those from the previous two reports, the 5YA and the 10YA will be described as "similar" unless the difference is statistically significant at the 95.0% confidence level.

### Export Catchment Areas

#### Pacific Northwest

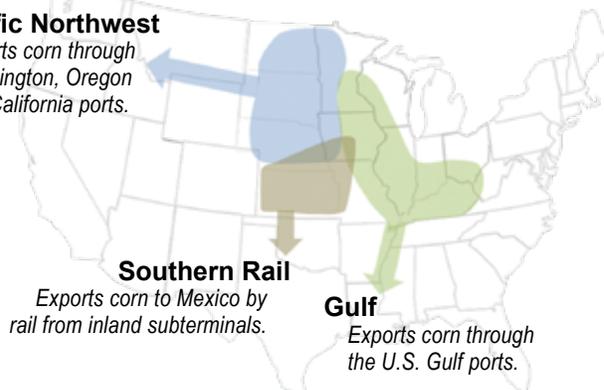
Exports corn through Washington, Oregon and California ports.

#### Southern Rail

Exports corn to Mexico by rail from inland subterminals.

#### Gulf

Exports corn through the U.S. Gulf ports.



<sup>2</sup>The reported standard deviations for horneous endosperm, 100-k weight, kernel volume and kernel true density were not weighted due to the reduced number of samples tested.

The *2023/2024 Harvest Report* samples (each about 2,200 grams) were sent directly from the local grain elevators to the Illinois Crop Improvement Association's Identity Preserved Grain Laboratory (IPG Lab) in Champaign, Illinois. The general process is as follows:

- Upon arrival, samples were analyzed for chemical composition and moisture via Near-Infrared Transmission Spectroscopy (NIR). This analysis provides the sample test results for protein, starch and oil.
- Participating elevators were asked to record the moisture measured by their own electronic moisture meters at the time of delivery on each sample bag. These moisture results are reported instead of the results provided by the NIR analysis conducted upon each sample's arrival.
- While not reported, moisture results provided by the NIR analysis conducted upon each sample's arrival were used to determine if further drying was necessary to reduce the sample's moisture content to a suitable level to prevent any subsequent deterioration during the testing period. Samples above 16.0% moisture were dried using an ambient-air drying technique to prevent stress cracking and heat damage.
- Next, the samples were split into two subsamples of about 1,100 grams each using a Boerner divider while keeping the grain sample's attributes even between the two subsamples.
- One subsample was delivered to the Champaign-Danville Grain Inspection (CDGI) in Urbana, Illinois, for grading. CDGI is the official grain inspection service provider for east-central Illinois as designated by the USDA FGIS. The grade testing procedures were in accordance with FGIS's Grain Inspection Handbook and are described in the following section.
- The other subsample was analyzed at IPG Lab for physical factors and mycotoxin contamination following either industry norms or well-established procedures. IPG Lab has received accreditation under the ISO/IEC 17025:2017 International Standard for chemical composition, stress cracks, 100-kernel weight, kernel volume and kernel true density. The full scope of accreditation is available at <https://www.ilcrop.com/about/lab-services/>.

## A. GRADE FACTORS

### Test Weight

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Test weight is a measure of the volume of grain required to fill a Winchester bushel (2,150.42 cubic inches). Test weight is a part of the FGIS Official U.S. Standards for Corn grading criteria.

The test involves filling a test cup of known volume through a funnel held at a specific height above the test cup to the point where grain begins to pour over the test cup's sides. A strike-off stick is used to level the grain in the test cup, and the grain remaining in the cup is weighed. The weight is then converted to and reported in the traditional U.S. unit, pounds per bushel (lb/bu).

### Broken Corn and Foreign Material

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BCFM is part of the FGIS Official U.S. Standards for Grain and grading criteria.

The BCFM test determines the amount of all matter that passes through a 12/64<sup>th</sup>-inch round-hole sieve and all matter other than corn that remains on the top of the sieve. BCFM measurement can be separated into broken corn and foreign material. Broken corn is defined as all material passing through a 12/64<sup>th</sup>-inch round-hole sieve and retained on a 6/64<sup>th</sup>-inch round-hole sieve. The definition of foreign material is all material passing through the 6/64<sup>th</sup>-inch round-hole sieve and the coarse non-corn material retained on top of the 12/64<sup>th</sup>-inch round-hole sieve. BCFM is reported as a percentage of the initial sample by weight.

### Total Damage and Heat Damage

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Total damage is part of the FGIS Official U.S. Standards for Grain grading criteria.

A trained and licensed inspector visually examines a representative working sample of 250 grams of BCFM-free corn for damaged kernels. Types of damage include blue-eye mold, cob rot, dryer-damaged kernels (different from heat-damaged kernels), germ-damaged kernels, heat-damaged kernels, insect-bored kernels, mold-damaged kernels, mold-like substance, silk-cut kernels, surface mold (blight), mold (pink *Epicoccum*) and sprout-damaged kernels. Total damage is reported as the weight percentage of the working sample that is total damaged grain.

Heat damage is a subset of total damage and consists of kernels and pieces of corn kernels that are materially discolored and damaged by heat. Heat-damaged kernels are determined by a trained and licensed inspector visually inspecting a 250-gram sample of BCFM-free corn. Heat damage, if found, is reported separately from total damage.

## B. MOISTURE

The moisture recorded by the elevators' electronic moisture meters at the time of delivery is reported. Electronic moisture meters sense an electrical property of grains called the dielectric constant that varies with moisture—the dielectric constant rises as moisture content increases. Moisture is reported as a percent of total wet weight.

## C. CHEMICAL COMPOSITION

### Near-Infrared Transmission Spectroscopy (NIR) Proximate Analysis

The chemical composition (protein, oil and starch concentrations) of corn is measured using NIR. The technology uses unique interactions of specific wavelengths of light with each sample. It is calibrated to traditional chemistry methods to predict protein, oil and starch concentrations in the sample. This procedure is nondestructive to the corn.

Chemical composition tests for protein, oil and starch were conducted using a 550 to 600-gram sample in a whole-kernel Foss Infratec 1241 NIR instrument. The NIR was calibrated to chemical tests, and the standard errors of predictions for protein, oil and starch were about 0.22, 0.26 and 0.65%, respectively. Comparisons of the Foss Infratec 1229 used in *Harvest Reports* before 2016 to the Foss Infratec 1241 on 21 laboratory check samples showed the instruments averaged within 0.25, 0.26 and 0.25% points of each other for protein, oil and starch, respectively. Results are reported on a dry basis percentage (percent of non-water material).

## D. PHYSICAL FACTORS

### 100-Kernel Weight, Kernel Volume and Kernel True Density

The 100-kernel weight is determined from the average weight of two 100-kernel replicates using an analytical balance that measures to the nearest 0.1 milligrams. The averaged 100-kernel weight is reported in grams.

The kernel volume for each 100-kernel replicate is calculated using a helium pycnometer and is expressed in cubic centimeters (cm<sup>3</sup>) per kernel. Kernel volumes usually range from 0.14 cubic centimeters to 0.36 cubic centimeters per kernel for small and large kernels, respectively.

True density of each 100-kernel sample is calculated by dividing the mass (or weight) of the 100 externally sound kernels by the volume (displacement) of the same 100 kernels. The two replicate results are averaged. True density is reported in grams per cubic centimeter (g/cm<sup>3</sup>). True densities typically range from 1.20 grams per cubic centimeter to 1.30 grams per cubic centimeter at “as is” moisture contents of about 12 to 15%.

## Stress Crack Analysis

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Stress cracks are evaluated by using a backlit viewing board to accentuate the cracks. A sample of 100 intact kernels with no external damage is examined kernel by kernel. The light passes through the horneous or hard endosperm, so each kernel's stress crack damage can be evaluated. Kernels are sorted into two categories: (1) no cracks; (2) one or more cracks. Stress cracks, expressed as a percent, are all kernels containing one or more cracks divided by 100 kernels. Lower levels of stress cracks are always better since higher stress cracks lead to more breakage in handling. Some end-users will specify by contract the acceptable level of cracks based on the intended use.

## Whole Kernels

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In the whole kernels test, 50 grams of cleaned (BCFM-free) corn are inspected by the kernel. Cracked, broken or chipped grain, along with any kernels showing significant pericarp damage, are removed. The whole kernels are then weighed, and the result is reported as a percentage of the original 50-gram sample. Some companies perform the same test but report the "cracked & broken" percentage. A whole kernel score of 97.0% equates to a cracked & broken rating of 3.0%.

## Horneous (Hard) Endosperm

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The horneous (or hard) endosperm test is performed by visually rating 20 externally sound kernels, placed germ facing up, on a backlit viewing board. Each kernel is rated for the estimated portion of the kernel's total endosperm that is horneous endosperm. The soft endosperm is opaque and will block light, while the horneous endosperm is translucent. The rating is made from standard guidelines based on the degree to which the soft endosperm at the crown of the kernel extends down toward the germ. The average of horneous endosperm ratings for the 20 externally sound kernels is reported. Ratings of horneous endosperm are made on a scale of 70 to 100%, though most individual kernels fall in the 70 to 90% range.

## E. MYCOTOXINS

Detection of mycotoxins in corn is complex. The fungi producing the mycotoxins often do not grow uniformly in a field or across a geographic area. As a result, the detection of any mycotoxin in corn, if present, is highly dependent upon the concentration and distribution of the mycotoxin among kernels in a lot of corn, whether a truckload, a storage bin or a railcar.

The objective of the FGIS sampling process is to minimize underestimating or overestimating the true mycotoxin concentration since accurate results are imperative for corn exports. However, the objective of the *2023/2024 Harvest Report's* assessment of mycotoxins is only to report the frequency of occurrences of mycotoxins in the current crop and not to report specific levels of mycotoxins in corn exports.

To report the frequency of occurrences of aflatoxin, DON and fumonisin for the *2023/2024 Harvest Report*, IPG Lab performed the mycotoxin tests using FGIS protocol and approved test kits. FGIS's protocol requires a minimum of a 908-gram (two-pound) sample from trucks to grind for aflatoxin testing, approximately a 200-gram sample to grind for DON testing and a 908-gram (two-pound) sample for fumonisin testing. For this study, a 1,000-gram laboratory sample was subdivided from the two-kilogram survey sample of shelled kernels for the aflatoxin analysis. The one-kilogram survey sample was ground in a Romer Model 2A mill so that 60 to 75% would pass through a 20-mesh screen. From this well-mixed ground material, a 50-gram test portion was removed for each mycotoxin tested. EnviroLogix AQ 309 BG, AQ 304 BG and AQ 411 BG quantitative test kits were used for the aflatoxin, DON and fumonisin analysis, respectively. DON and fumonisin were extracted with water (5:1), while the aflatoxin was extracted with buffered water (3:1). The extracts were tested using the EnviroLogix QuickTox lateral flow strips, and the QuickScan system quantified the mycotoxins.

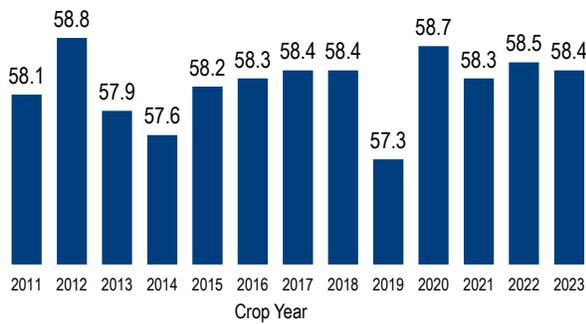
The EnviroLogix quantitative test kits report specific concentration levels of the mycotoxin if the concentration level exceeds a specific level called a "Limit of Detection." The limit of detection is defined as the lowest concentration level that can be measured with an analytical method that is statistically different from measuring an analytical blank (absence of a mycotoxin). The limit of detection will vary among different types of mycotoxins, test kits and commodity combinations. The limit of detection for the EnviroLogix AQ 309 BG is 2.7 parts per billion for aflatoxin. The limit of detection for DON using the EnviroLogix AQ 304 BG is 0.1 parts per million. For the fumonisin tests, the EnviroLogix AQ 411 BG has a limit of detection of 0.1 parts per million. FGIS has issued a letter of performance for the quantification of aflatoxin, DON and fumonisin using the Envirologix AQ 309 BG, AQ 304 BG and AQ 411 BG kits, respectively.

Beginning with the *2020/2021 Harvest Report*, ochratoxin A, T-2 and zearalenone were added to the list of mycotoxins analyzed to complement the information provided by the aflatoxin, DON and fumonisin test results. The testing for these three additional mycotoxins was continued in this year's *Harvest Report*. EnviroLogix AQ 113 BG, AQ 314 BG, and AQ 412 BG quantitative test kits were used for ochratoxin A, T-2 and zearalenone, respectively. The EnviroLogix AQ 113 BG quantitative test kit used for the ochratoxin A tests has a limit of detection of 1.5 parts per billion. The ochratoxin A was extracted with a grain buffer (five milliliters per gram). For the T-2 tests, the AQ 314 BG quantitative test kit has a limit of detection of 50 parts per billion. T-2 was extracted with water (five milliliters per gram). The EnviroLogix AQ 412 BG quantitative test kit used for the zearalenone tests has a limit of detection of 50 parts per billion. The zearalenone test uses a 25-gram test portion of corn. The zearalenone was extracted using a reagent of EB17 extraction powder and a water buffer of 75 milliliters per sample.

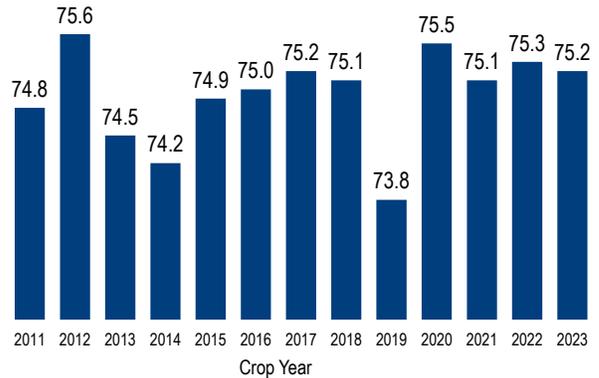
## A. GRADE FACTORS AND MOISTURE

Since 2011, the Council’s *Harvest Quality Reports* have provided clear, concise and consistent information about each U.S. crop’s quality entering international merchandising channels. This series of quality reports have used a consistent and transparent methodology to allow for insightful comparisons across time. The following charts display the average U.S. Aggregate from all *Harvest Reports* for each quality factor tested to provide historical context to this year’s results.

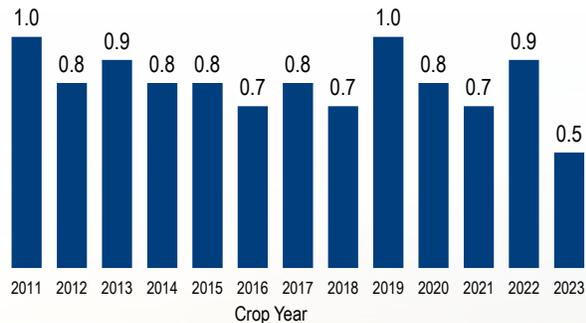
**Test Weight (lb/bu) by Crop Year**



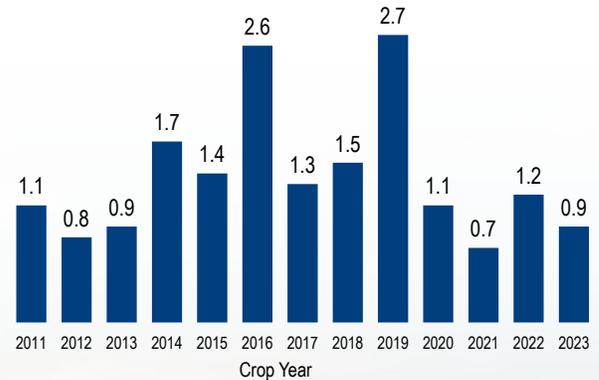
**Test Weight (kg/hl) by Crop Year**



**BCFM (%) by Crop Year**



**Total Damage (%) by Crop Year**

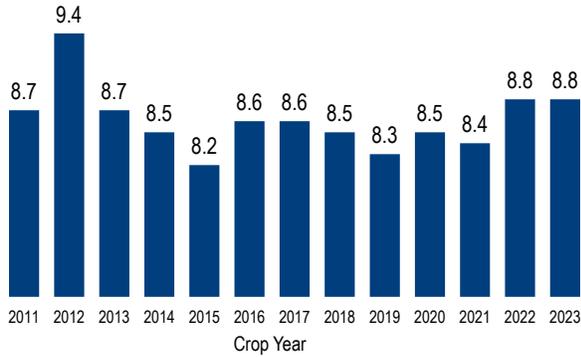


**Moisture (%) by Crop Year**

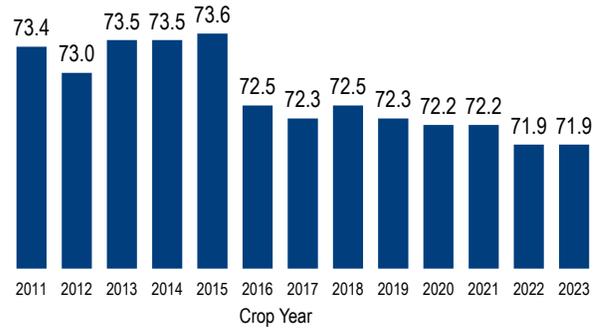


**B. CHEMICAL COMPOSITION**

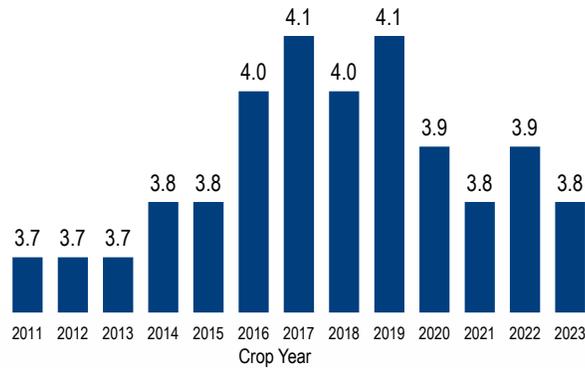
**Protein (Dry Basis %) by Crop Year**



**Starch (Dry Basis %) by Crop Year**

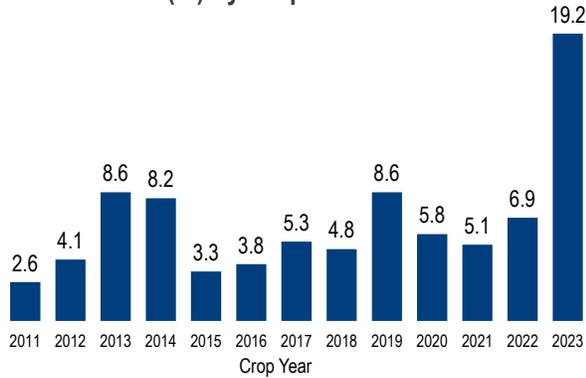


**Oil (Dry Basis %) by Crop Year**

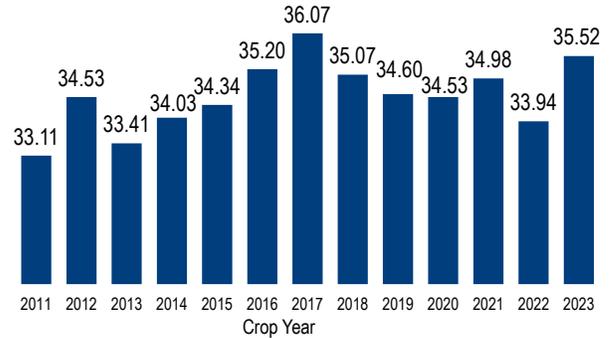


## C. PHYSICAL FACTORS

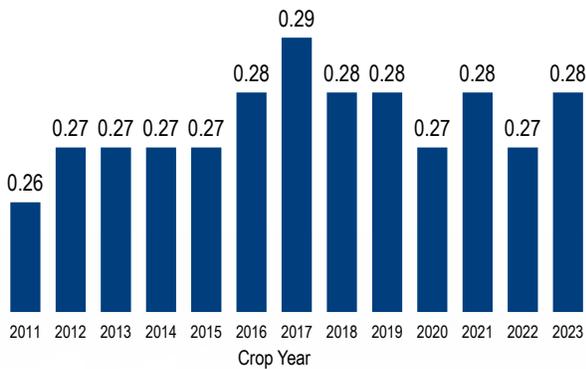
**Stress Cracks (%) by Crop Year**



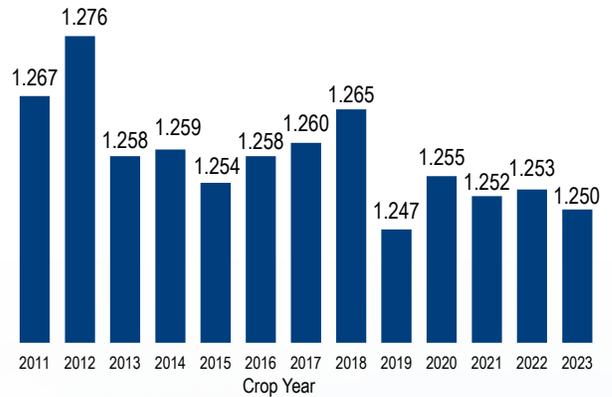
**100-Kernel Weight (g) by Crop Year**



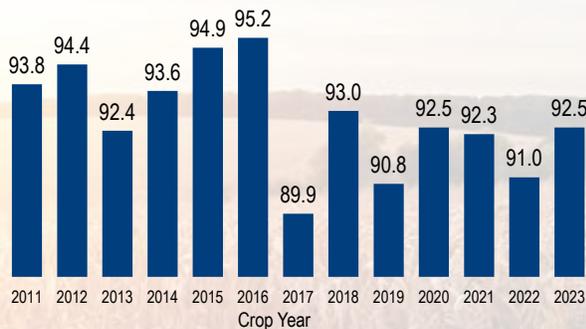
**Kernel Volume (cm<sup>3</sup>) by Crop Year**



**True Density (g/cm<sup>3</sup>) by Crop Year**



**Whole Kernels (%) by Crop Year**



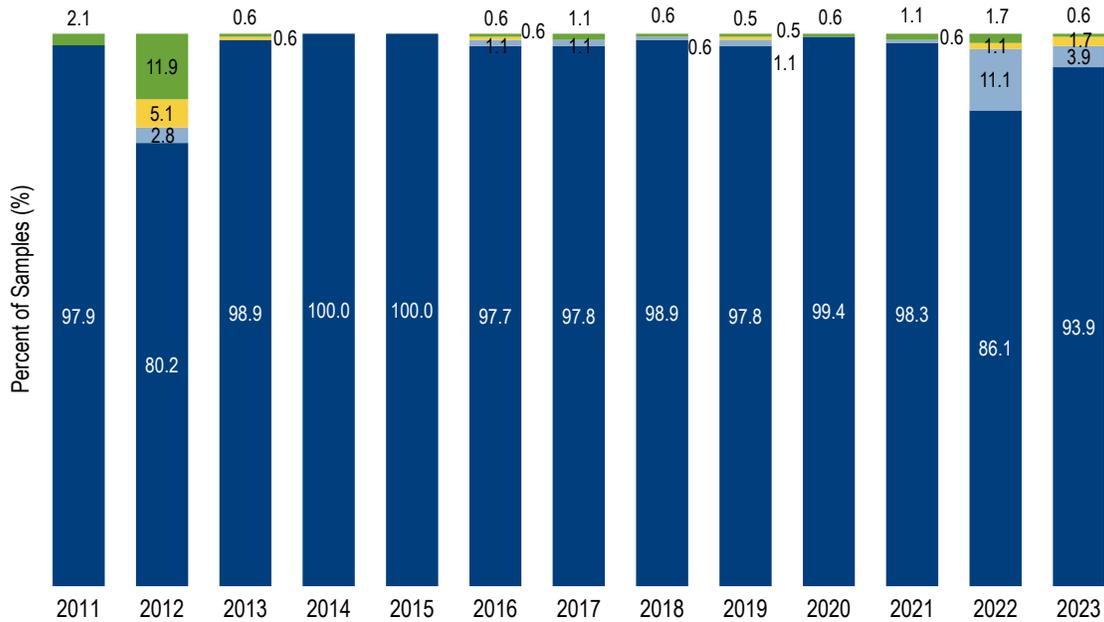
**Horneous Endosperm (%) by Crop Year**



**D.MYCOTOXINS**

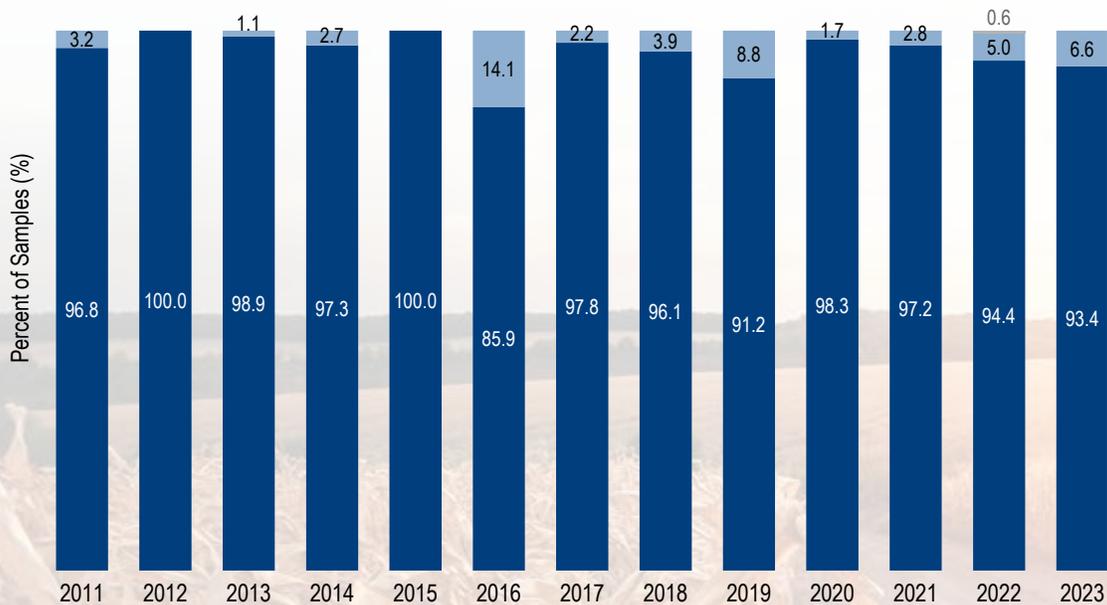
**Aflatoxin Results (ppb) by Crop Year**

■ <5.0 ■ 5.0-9.9 ■ 10.0-20.0 ■ >20.0



**Deoxynivalenol (DON or Vomitoxin) Results (ppm) by Crop Year**

■ <1.5 ■ 1.5-5.0 ■ >5.0



## U.S. CORN GRADES AND GRADE REQUIREMENTS

| Grade      | Minimum Test Weight per Bushel (Pounds) | Maximum Limits of      |                 |  |
|------------|---|------------------------|-----------------|--|
|            |   | Damaged Kernels        |                 | Broken Corn and Foreign Material (Percent) |
|            |   | Heat Damaged (Percent) | Total (Percent) |  |
| U.S. No. 1 | 56.0                                    | 0.1                    | 3.0             | 2.0  |
| U.S. No. 2 | 54.0                                    | 0.2                    | 5.0             | 3.0  |
| U.S. No. 3 | 52.0                                    | 0.5                    | 7.0             | 4.0  |
| U.S. No. 4 | 49.0                                    | 1.0                    | 10.0            | 5.0  |
| U.S. No. 5 | 46.0                                    | 3.0                    | 15.0            | 7.0  |

U.S. Sample Grade is corn that: (a) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or (b) Contains stones with an aggregate weight in excess of 0.1% of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria spp.*), 2 or more castor beans (*Ricinus communis L.*), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 8 or more cockleburrs (*Xanthium spp.*), or similar seeds singly or in combination, or animal filth in excess of 0.2% in 1,000 grams; or (c) Has a musty, sour, or commercially objectionable foreign odor; or (d) Is heating or otherwise of distinctly low quality.

Source: Code of Federal Regulations, Title 7, Part 810, Subpart D, United States Standards for Corn

## U.S. AND METRIC CONVERSIONS

| Corn Equivalents                          | Metric Equivalents                       |
|---|--|
| 1 bushel = 56 pounds (25.40 kilograms)    | 1 pound = 0.4536 kg                      |
| 39.368 bushels = 1 metric ton             | 1 hundredweight = 100 pounds or 45.36 kg |
| 15.93 bushels/acre = 1 metric ton/hectare | 1 metric ton = 2204.6 lbs                |
| 1 bushel/acre = 62.77 kilograms/hectare   | 1 metric ton = 1000 kg                   |
| 1 bushel/acre = 0.6277 quintals/hectare   | 1 metric ton = 10 quintals               |
| 56 lbs/bushel = 72.08 kg/hectoliter       | 1 quintal = 100 kg                       |
|   | 1 hectare = 2.47 acres                   |

## ABBREVIATIONS

|  |
|--|
| cm <sup>3</sup> = cubic centimeters            |
| g = grams                                      |
| g/cm <sup>3</sup> = grams per cubic centimeter |
| kg/hl = kilograms per hectoliter               |
| lb/bu = pounds per bushel                      |
| ppb = parts per billion                        |
| ppm = parts per million                        |



A global network of professionals building worldwide demand and developing markets for U.S. grains and ethanol.



## HEADQUARTERS

20 F Street NW, Suite 900 • Washington, D.C., 20001  
Phone: 202-789-0789 • Fax: 202-898-0522  
Email: [grains@grains.org](mailto:grains@grains.org) • Website: [grains.org](http://grains.org)

### PEOPLE'S REPUBLIC OF CHINA: Beijing

Tel1: 011-86-10-6505-1314 • Tel2: 011-86-10-6505-2320  
Fax: 011-86-10-6505-0236 • [china@grains.org](mailto:china@grains.org)

### JAPAN: Tokyo

Tel: 011-81-3-6206-1041 • Fax: 011-81-3-6205-4960  
[japan@grains.org](mailto:japan@grains.org) • [www.grainsjp.org](http://www.grainsjp.org)

### KOREA: Seoul

Tel: 011-82-2-720-1891 • Fax: 011-82-2-720-9008  
[seoul@grains.org](mailto:seoul@grains.org)

### TAIWAN: Taipei

Tel: 011-886-2-2523-8801 • Fax: 011-886-2-2523-0189  
[taipei@grains.org](mailto:taipei@grains.org)

### MIDDLE EAST, AFRICA AND EUROPE: Tunis

Tel: 011-216-71-191-640 • Fax: 011-216-71-191-650  
[tunis@grains.org](mailto:tunis@grains.org)

### INDIA: New Delhi

Tel: +91-11-4603-6437 • [usgcindia@grains.org](mailto:usgcindia@grains.org)

### SOUTH EAST ASIA: Kuala Lumpur

Tel: 011-603-2093-6826 • [kl@grains.org](mailto:kl@grains.org)

### LATIN AMERICA: Panama City

Tel: 011-507-315-1008 • [lta@grains.org](mailto:lta@grains.org)

### MEXICO: Mexico City

Tel1: 011-52-55-5282-0244 • Tel2: 011-52-55-5282-0973  
Tel3: 011-52-55-5282-0977 • Fax: 011-52-55-5282-0974  
[mexico@grains.org](mailto:mexico@grains.org)