Chapter 1

U.S. Grains – Commodity Overview, Production Cycles and Descriptions

Cereal grains are small, hard, dry seeds that are harvested for human or animal consumption. They are commonly milled for food or feed, with a germ that can be pressed for oil.

Grain has played a critical role in human civilization for more than 10,000 years. While there are hundreds of grain species, wheat, rice, maize, barley, sorghum, oats and rye comprise the vast majority of grain produced in modern times.

Grains

In scientific classification, cereal grains are caryopses - the seeds of plants in the grass family, with or without an attached hull or fruit layer. In business and commerce, seeds or fruits from other plant families are called grains if they resemble caryopses.

Grains are well suited to modern industrial agriculture. They are high yielding and can be mechanically harvested. After being harvested and dried, grains are extremely durable. They can be easily warehoused and stored for long periods of time, as well as transported by road, rail or ship. These valuable characteristics have allowed the development of today's modern global commodity markets.

This manual focuses on three widely traded grains: maize (corn) *(Zea mays)*, barley *(Hordeum vulgare)*, and grain sorghum (milo) (*Sorghum bicolor*).

MAIZE (CORN) (*Zea mays*)

Maize, also known in North American as "corn", is a cereal grain first domesticated by indigenous peoples of the Americas about 10,000 years ago from teosinte ("grain of the gods").[i] All corn varieties, from heirloom multi-colored strains to the latest hybrids developed using CRISPr[ii] are variants of this ancient grass.

Corn

Most historians believed maize was domesticated in the Tehuacán Valley of Mexico. However, research conducted in the early 21st century has led many experts to identify the adjacent Balsas River Valley of south-central Mexico as the center of domestication.[iii]

Modern varieties of maize are cultigens, i.e. plants that requires human intervention to successfully propagate. Whether or not seed kernels fell off the plant to propagate naturally or were collected and sown later (by man) is a key piece of evidence archaeologists use to distinguish domesticated maize from its teosinte ancestor. [iv]

There are six major types of maize: 1) Dent corn, 2) Flint corn, 3) Pod corn, 4) Popcorn, 5) Flour corn, and 6) Sweet corn.

Reid's Yellow Dent Corn Monument – Delavan, Illinois[v]

Most of today's hybrid corn varieties and cultivars are derived from Dent corn (*Zea mays var. indentata*). Dent corn received its name because of the small indentation, or "dent", at the crown of each ripe dry kernel of corn. This type of field corn is noted for its high soft starch content.[vi]

Yellow Dent Corn

All dent corn varieties today can be traced back to “Reid's Yellow Dent,” a variety developed by central Illinois farmer James L. Reid and his father, Robert Reid in the late 19th Century. They moved from Brown County, Ohio to Tazewell County, Illinois in 1846, bringing with them a red corn variety known as "Johnny Hopkins". They crossed it with (local?) varieties of flint corn and flour corn, and were able to capture attributes of each. This new variety not only won a prize at the 1893 World's Fair in Chicago, Illinois,[vii] but created the foundation for the proliferation of other dent varieties through the present day.

Dent corn is typically cultivated and grown as a commercial row crop for grain and fodder. These commercial cultivars are either single- or double-cross hybrids bred for specific growing areas, soils, or climatic conditions. The plant has an adventitious, dense, fibrous root system that develops aerial roots at nodes near the soil surface. It is a fast-growing, vertically erect, short-lived annual plant, commonly growing to a height of 6 – 9 feet (2 - 3 meters).

In 2021/22 world production of corn exceeded 1,200 million metric tons (mmts), with the United States accounting for more than 380 mmts, or more than 30%.[viii]

While used overwhelmingly for feed, dent corn is the main variety used in food manufacturing as the base ingredient for various products, including cornmeal flour (for cornbread), corn chips, tortillas, and taco shells. In addition, its high starch content also makes dent corn a preferred variety for producing fructose and high-fructose corn syrup - a sweetener used in many processed foods and beverages.

Maize (which in the U.S. is interchangeably referred to as corn) is indigenous to the Americas. Due to its productivity and profitability, it has become the most widely grown cultivated crop throughout the U.S. No other country can match its productivity as each year U.S. farmers devote more than 1 in 4 planted acres to its production. In addition, U.S. has long led the world in corn yields, as well as total production. As a result, this has helped U.S. become a world leader in production of animal feed stuffs and ethanol. The U.S. livestock industry is the world’s most efficient due to the availability of inexpensive, energy-efficient, and sustainable corn.

In addition, the extensive waterway system which runs throughout the grain producing areas of North America provides a natural and dependable transportation network, which provides the basis of a world class bulk handling and export supply chain making the U.S. the a top exporter of corn.

As the demand from new and traditional sources is expected to continue to increase in the coming years, vast productive capacity remains untapped in the United States. Improved hybrid strains, along with more efficient and ecologically sound farm practices will likely enable the U.S. to meet expanding demand through the 21st century.

CORN PRODUCTION CYCLE: SEASONAL FACTORS

The versatile corn plant can thrive in climates as diverse as the arid desert plains of the southwestern United States to the high Andean mountain plains of Ecuador and Peru. But it is in the temperate plains of the U. S. Corn Belt (Iowa, Illinois, Nebraska, Minnesota, Indiana and Ohio) where corn yields continue to astonish the agricultural world. It is at these attitudes that corn flourishes.

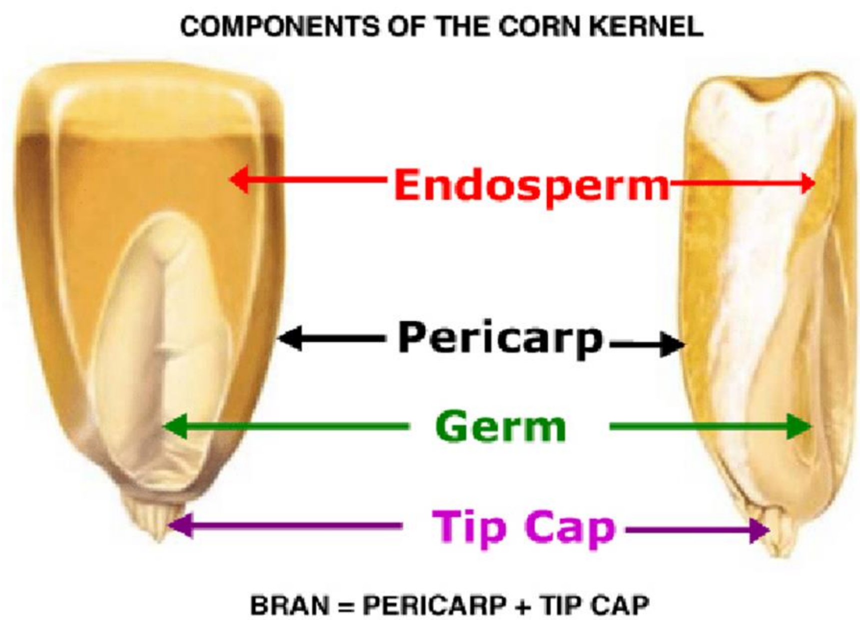
Throughout the growing season, the corn plant undergoes a series of developmental stages as it grows from a seed at planting to a tall plant with an ear at harvest. The following information highlights various stages of growth and development of corn throughout the growing season and various problems during planting and germination.

As we try to understand why yields are greater or less than expected, we must start when the seed is planted and end when the ear this is successfully harvested and the grain delivered into store. Understanding how the corn plant grows, develops, and produces grain, we have a better chance of knowing what will affect plant growth and consequently how to manage the crop for best production.

Generally, higher yields are strongly correlated with a longer growing season, and hybrids with 110 days or more until maturity are typically planted in the United States. However, let’s consider the age of the corn in terms of plant development rather than in days. A corn plant requires a certain number of growing degree units (GDUs) to reach maturity, regardless of the number of calendar days it takes to accumulate. The relationship of GDU accumulation and corn development, along with utilizing the estimated number of days to reach a certain growth stage, can help predict when important growth stages will occur.

Before planting, considerable planning and preparation goes into corn production. The crop is dependent on the genetic and environmental characteristics in which the plant was grown. Quality seed that has a viable embryo that contains sufficient stored energy to get the plant established, and that has an intact seed coat to prevent attack by disease organisms.

Let's start with the seed. Corn seed is made up of three primary parts (the Figure below): the embryo from which the new plant will develop; the endosperm or starchy part, the energy source for germination and emergence until the plant can function on its own; and the pericarp, or seed coat, which protects both the endosperm and the embryo.



Generally, seed is planted in soil moist and warm 12.5 degrees Celsius (mid-50 degrees Fahrenheit) or higher, enough to allow rapid germination and emergence. With increased adoption of no-tillage and reduced tillage farming, planting dates are earlier, on average, than on plowed fields.

Germination and seedling establishment follow quickly upon planting. The practice of early planting, which generally results in higher yields, allows for more intensified and potentially profitable cropping systems. As a result of planting early, however, corn seed is often planted in very cool soils where the 2-inch depth temperature is often closer to the minimally acceptable for germination (10 degrees Celsius) than the optimum (12.5 degrees Celsius or greater). Colder soil temperatures result in an extended time period to achieve emergence, but does not generally adversely impact yields, while the opportunity for a longer growing season will typically add additional yield.

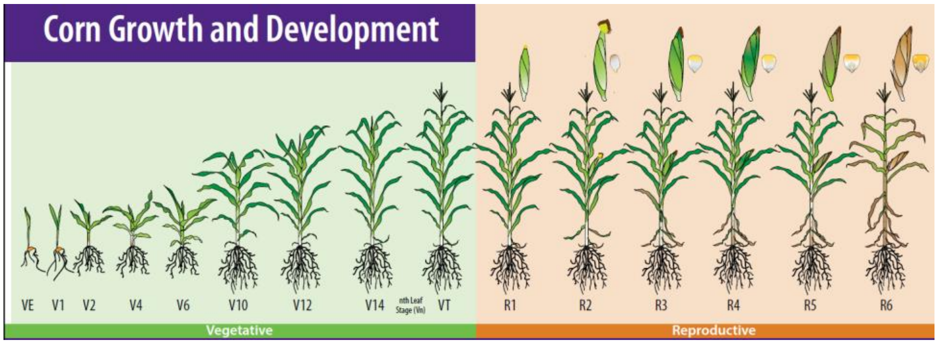
If the soil is too dry, the seed may not germinate or the seedling may not take root.
Surprisingly, the soil moisture content at planting time supplies from 50% to 70% of the plant's moisture needs. No amount of rain in the later stages of the growing season will counteract an early loss of a plant population during the germination period. Consequently, moisture conditions heading into the spring, when corn is planted in the United States, are very important to potential yield. Crop forecasters base their initial crop predictions on a formula derived from soil moisture levels before the farmers set out to seed their fields.

It is extremely unusual for high levels of precipitation or soil moisture to adversely affect corn production. Hence the old saying; ***"Rain makes grain!"*** However, wet soils can delay planting and slow maturity. This will expose the plant to additional risk during the pollination period. But standing water or the complete saturation of the soil provides benefits that generally outweigh any risk.

Once established, the corn plant is very strong. As the plant grows it develops through a number of vegetative and reproduction stages. Corn growth stage development will vary according to corn maturity, as an early maturing variety may produce fewer leaves or develop through growth stages faster than a later maturing variety. It is important to remember development corn is determined by temperature and GDUs.

Generally, this most critical period of the growing season for corn is during the pollination period which occurs with tasseling (VT) and silking (R1). Across the U.S. Corn Belt this usually encompasses the entire month of July. This period also coincides with some of the hottest temperatures of summer that can put added stress on the developing crop. Extreme hot temperatures or drought can prevent pollen from fertilizing individual silks, resulting in fewer kernels on each ear. Hot temperatures during this period can inflict much greater harm on the crop than heat in August and September.

Early frosts have a marginal effect on yields, cutting short the kernel filling and drying stages (R4 thru R6). Temperatures below 0 degrees Centigrade at this late stage in the crop's development are more likely to effect quality than final yields.



Source: Kansas State University Agricultural Experiment Station and Cooperative Extension Service MF3305 June 2016 Ignacio A. Ciampitti, Crop Production and Cropping Systems Specialist, Department of Agronomy, Kansas State University[ix]

VE – Emergence: Emergence occurs when the first leaves, called the spike or the coleoptile, appear above the soil surface. The seed absorbs water (about 30% of its weight) and oxygen for germination. The radicle root quickly emerges near the tip of the kernel, depending on soil moisture and temperature conditions. The coleoptile emerges from the embryo side of the kernel and is pushed to the soil surface by mesocotyl elongation. The mesocotyl encloses the plumule leaves that open as the structure approaches the soil surface.
Management - Ideal soil temperatures (50 to 55 degrees Fahrenheit) and moisture conditions promote rapid emergence (5 to 7 days). Optimum seed placement varies from 1 to 2 inches deep. Appropriate planting depth is critical for optimal emergence. Cold, dry, and deep planting can delay emergence for several days.

V1 – First-Leaf: One leaf with collar visible (structure found at the base of the leaf). The first leaf in corn has a rounded tip. From this point until flowering (R1 stage), leaf stages are defined by the uppermost leaf with visible collars. The growing point is located below the surface until the late V5 stage.
Management - Scout for proper emergence (e.g., 30 plants in 171/2 feet for 30-inch row spacing = 30,000 plants per acre), early season weeds, insects, diseases, and other production issues.

V2 – Second-Leaf: Nodal roots begin to emerge below ground. Seminal roots begin to senesce. Frost is unlikely to damage corn seedling, unless it is extremely cold or the corn was shallowly planted.

V4 – Fourth-Leaf: Nodal roots are dominant, occupying more soil volume than seminal roots. Leaves still developing on apical meristem (primary growth of the plant).

V6 – Sixth-Leaf: Six leaves with collar visible. The first leaf with the rounded tip is senescent; consider this point when counting leaves. The growing point emerges above the soil surface. All plant parts are

initiated. Sometime between V6 and V10, the potential number of rows (ear girth) is determined. Potential row
Number is affected by genetics and environment and is reduced by stress conditions. The plant increases in height due to stalk elongation; nodal roots are established in the lowest, below-ground nodes of the plant.
Management - Scout for weeds, insects, and diseases. Rapid nutrient uptake begins at this stage. Timing nutrient applications to match this uptake enhances the potential for greater nutrient use efficiency, particularly for mobile nutrients such as nitrogen.

V10 – Tenth-Leaf: Brace roots begin to develop in the lower above-ground nodes of the plants. Until this stage, rate of leaf development is approximately 2 to 3 days per leaf.
Management - Nutrient (potassium = K > nitrogen = N > phosphorous = P) and water (0.25 inch per day) demands for the crop are high. Heat, drought, and nutrient deficiencies will affect potential number of kernels and ear size. Scout for root lodging issues and diseases (e.g., common rust, brown spot). Weed control is critical since corn does not tolerate early-season competition for water, nutrients, and radiation well.

V14 – Fourteen-Leaf: Rapid growth. This stage occurs approximately two weeks before flowering. Highly sensitive to heat and drought stress. Four to six extra leaves will expand from this stage until VT.
Management - Scout for root lodging issues, green-snap (likely to occur from V10 to VT) and diseases (e.g., common rust, brown spot). Abnormal corn ears can occur and be obvious from this time until flowering.

VT – Tassel: Potential kernels per row is set, final potential grain number (number of ovules), and potential ear size are being determined. Last branch of the tassel is visible at the top of the plant. Silks may or may not have emerged. The plant is almost at its maximum height.
Management - Nutrient (K > N > P) and water (0.30 inch per day) demands for the crop are close to maximum. Heat and drought will affect potential number of kernels. Scout for insects (e.g., corn leaf aphid, western bean cutworm, corn earworm, fall armyworm) and diseases (e.g., gray leaf spot, southern rust, northern leaf blight). Total leaf defoliation severely affects final yields.

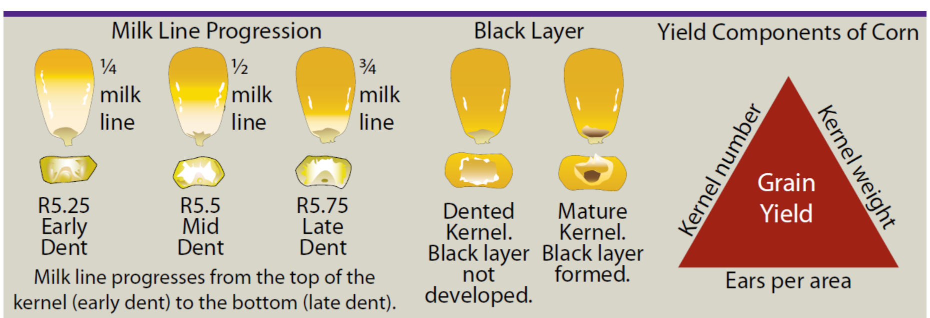
R1 – Silking: Flowering begins when a silk is visible outside the husks. The first silks to emerge from the husk leaves are those attached to potential kernels near the base of the ear. Silks remain active until pollinated. Pollen falls from the tassel to the silks, fertilizing the ovule to produce an embryo. Potential kernel number is determined. Maximum plant height is achieved. Following fertilization, cell division is occurring within the embryo.

Management - Nutrient (N and P accumulation is still progressing, K is almost complete) and water (0.33 inch per day) demands are at the peak. Heat and drought will affect pollination and final grain number. Defoliation by hail or other factors such as insects will produce a large yield loss.

R2 – Blister: Silks darken and begin to dry out (approximately 12 days after R1). Kernels are white and blister-like in shape and contain a clear fluid. Kernels are approximately 85% moisture; embryos develop in each kernel. Cell division is complete. Grain filling commences.
Management - Stress can reduce yield potential by reducing final number of kernels due to abortion.

R3 – Milk: Silks dry out (approximately 20 days after R1). Kernels are yellow, and a milk-like fluid can be squeezed out of the kernels when crushed between fingers. This fluid is the result of the starch accumulation process.
Management - Stress will still cause kernel abortion, initially from the ear tip.

R4 – Dough: Starchy material within the kernels has dough-like consistency (approximately 26 to 30 days after R1). Rapid accumulation of starch and nutrients occurs; kernels have 70% moisture and begin to dent on the top. Material squeezed out of the kernel has dough-like consistency.
Management - Stress can produce unfilled or shallow kernels and "chaffy" ears. Impact of frost on grain quality can be severe when it occurs at this stage (25 to 40% yield loss from light to killing frost, respectively).



Source: Kansas State University Agricultural Experiment Station and Cooperative Extension Service MF3305 June 2016 Ignacio A. Ciampitti, Crop Production and Cropping Systems Specialist, Department of Agronomy, Kansas State University[X]

R5 – Dent: Most of the kernels are dented. Kernel moisture declines to approximately 55% (38 to 42 days after R1) as the starch content increases.

Management - Stress can reduce kernel weight. Silage harvest is approaching (at around 50% kernel milk).

R6 – Maturity: A black layer forms at the base of the kernel, blocking movement of dry matter and nutrients from the plant to the kernel (50 to 60 days after R1). Kernels achieve maximum dry weight (30 to 35% moisture) and are physiologically mature.
Management - Grain is not ready for safe storage. Frost or any biotic or abiotic stress does not impact yields after this development stage. Lodging from disease, insect damage, or hail can result in physical loss of yield. Harvest can proceed, but recommended moisture for long-term storage is 14.5%. Scout fields for ear-drop due to things such as European corn borer damage.

CORN USAGE

FEED

Historically, the major use for corn has been as the primary feed grain for animal and livestock production. Corn can supply all the energy and a large percentage of the protein in an animal's diet. Its low cost, high palatability, availability, storability and consistent nutrient content make it the feed ingredient of choice by livestock producers of every kind. This includes major sectors of beef, dairy, pork, and poultry.

In the United States, corn, barley, grain sorghum and oats all compete as feed grains that go into various livestock rations. However, corn makes up the vast majority of the final ration and represents up to 86% of the grain used as feed in the U.S. In addition, a number of other feed stuffs that are a co-product of the milling process, such as Distillers Grains, Corn Gluten Meal and Corn Gluten Feed also compete as ingredients into these feed rations.

Currently (2021/22) United States corn consumption as animal feed has averaged over 712 mmts over the last five years.[xi] In 2021/22 world feed and residual demand is forecast to exceed 750 mmts, or about 62% of total production.[xii] Projected growth of world demand for animal protein is expected to propel a growing need for corn well into the future.

ENERGY & INDUSTRIAL

While corn has been a valuable food and feed grain for thousands of years, its use as a widespread industrial product is much more recent.

Through the process of wet or dry milling, corn can be processed into a range of industrial products, primarily ethanol and its co-products. Since the early 2000's, rocketing demand for ethanol has introduced the energy sector as a strong market competitor for corn.

Through the milling process, each corn kernel is separated into three component parts: 1) **starch**, 2) the **germ**; and 3) the **hull**.

Products made from corn **starch** range from ethanol, high fructose corn syrup, as a stiffener for paper, textiles and food, paint, make-up, coatings, films and adhesives.

The primary industrial uses for corn starch are for ethanol (ethyl alcohol), fructose and industrial starch. As a common food ingredient, such as dextrose, corn becomes the principal ingredient of many processed foods, such as; peanut butter, hot dogs and baby food. In the textile industry it finds use, aside from starch, in absorbents, dyes and sizing. The packing industry uses biodegradable corn "peanuts," while ecologically friendly garbage bags are making their way into U.S. households.

Corn oil is extracted from the **germ** of the corn kernel, and has a variety of uses in cooking and non-cooking applications. For example, corn oil is used as an industrial cleaner and lubricant, as well as blended into fuels to power gasoline and diesel-powered engines. Other uses include corn oil in many cosmetic products, liquid soaps, and shampoos.

The **hull**, or bran, is combined with residue from these extraction processes to become corn gluten feed or corn gluten meal, which are both prized additions to livestock feed.

FOOD

Today, despite its predominant use for feed energy and industrial use, corn is still a staple food in many parts of the world. Corn is also processed into corn starch, dextrose, syrups, sweeteners, corn oil, beverages and alcohol for direct human consumption.

Sugar-rich varieties called sweet corn are usually grown for human consumption as kernels, while field corn varieties are used for animal feed, various corn-based human food uses (including grinding into cornmeal or masa, pressing into corn oil, and fermentation and distillation into alcoholic beverages like bourbon whiskey), and as chemical feedstocks.

Corn has already made significant inroads into every facet of U.S. leisure and business life. Extensive, ongoing research at the governmental, institutional, academic, and corporate levels ensures that the limitless resources of corn will continue to astound us in the future. This marvelous plant, which has been domesticated for 7,000 years, has only begun to demonstrate the broad range of applications it has in our daily lives.

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Barley, ***Hordeum vulgare***, is a member of the grass family and is a major cereal grain grown in temperate climates globally. After corn, wheat and rice, barley is the fourth largest grain crop produced in world. Barley is generally produced in areas where the growing season is relatively short and climatic conditions are cool and dry.

Barley was one of the first cultivated grains, particularly in Eurasia as early as 10,000 years ago. It has been used as animal feed and fodder, and as a source of fermentable grains in the production of beer and whisky. As a food grain, it has been used bread flours, portages, soups and stews of various cultures.

Barley

World average annual production of barley averages around 150 mmts, with 2020/21 world production estimated at 160 mmts. [xiii] Major producers of barley are Europe, the United Kingdom, Russia, the Ukraine, Australia, Canada, Argentina, Turkey and Iran.

Barley production in the United States is concentrated in the Northern Plains and the Pacific Northwest. Since reaching peak production in the United States in the mid 1980's of over 12.5 mmts, production has declined to less than 4 mmts.[xiv]

Both two-row and six-row barley is produced in the United States. Roughly 65% of the U.S. acreage is planted to six-row barley in the Northern Plains and Pacific Coast states. The balance, 35%, is planted to two-row barley in the Rocky Mountain states. Universities in the Northern Plains states maintain aggressive breeding programs that continue to produce new varieties that improve the agronomic, feed and malting qualities of U.S. barley.

Two-row barley, sometimes considered a separate species, ***Hordeum distichon***, generally has a lower protein content than six-row barley.
Preferably, malting barley has a lower protein content and a more fermentable sugar content making it more suitable for malting. High-protein barley is best suited for animal feed. Protein in the malt extract that can make beer cloudy. Malting barley also has a more uniform germination specification, which results in a shorter and more uniform steeping time.

U.S. barley producers are committed to improving the quality of barley production in the United States. Each practices strict varietal purity, preserving the identity of each different variety during seeding, harvest, storage and handling. This combination of innovation and efficiency enables the U.S. barley industry to satisfy the needs of any barley consumer, whether they are a livestock feeder, maltster or food retailer.

BARLEY PRODUCTION CYCLE: SEASONAL FACTORS

Barley is a widely adaptable cereal crop and is an important food and feed grain in many areas of the world not typically suited for maize production, especially in northern climates in northern and eastern Europe. Currently, it is a popular in temperate areas where it is grown as a summer crop and tropical areas where it is sown as a winter crop.

Barley grows under cool conditions, but is not particularly winter hardy, and is not as cold tolerant as the winter wheats, fall rye, or winter triticale. It can be found sown as a winter crop in warmer areas of Australia and Great Britain.

Barley is more tolerant of soil salinity than wheat, which might explain the increase of barley cultivation in Mesopotamia from the second millennium BCE onwards.

Barley has a short growing season and is also relatively drought tolerant. Its germination time is one to three days. For spring barley, the seed matures three to five months after planting.

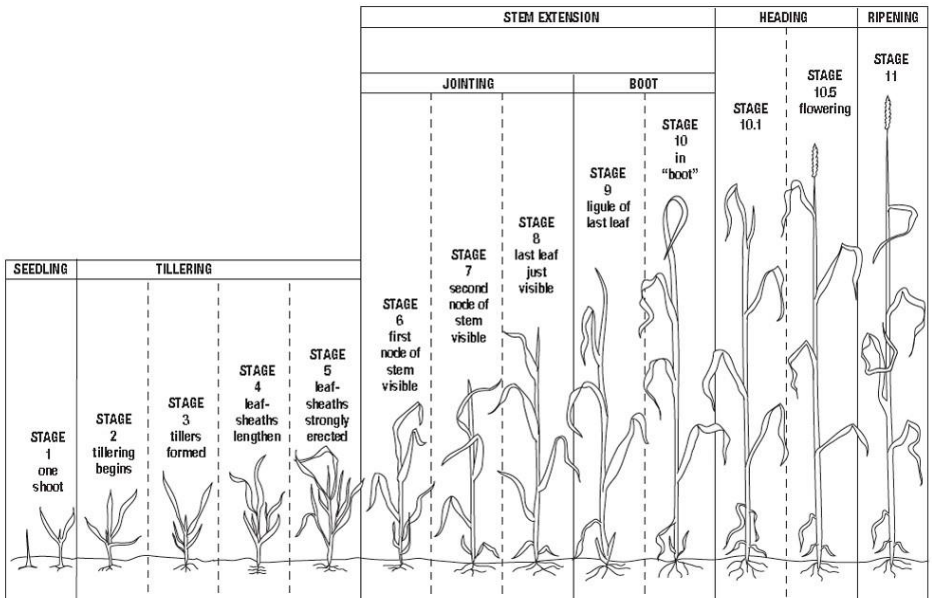
Growth of the barley plant is not restricted to the development of a single main stem, as with maize. Like most other small cereals grains, such as wheat and rice, barley produces several additional secondary stems known as tillers. These emerge from the crown of the primary stem a few weeks after emergence. The number of tillers that develop varies by variety and climatic conditions.

Barley is also classed by its requirement for cold temperatures. Winter barley seedlings must be exposed to cold temperatures (vernalization), which enables it to normally produce heads and grain later.

Winter barley is usually sown in the fall for exposure to low temperatures during the winter. It then completes development the following spring and summer. Spring barley doesn’t require exposure to winter temperatures and can be sown in spring. Winter types usually mature somewhat earlier than spring types.

Understanding crop staging helps in identifying various stages of crop development and to visually identify vegetative and reproductive stages in a crop's life cycle, as well as to understand what conditions can impact yields and productivity of the crop.

When staging barley and other cereal grains two common scales are used, the Zadoks[xv] scale and Feekes[xvi] scale. Both scales measure the maturity of the plant through vegetative and reproductive stages but differ slightly in their metric quantification. For this manual, and the following figure, the Feekes scale will be referenced.



Source: Anheuser-Busch "Smart Barley [xvii]

1 Emergence: Seedlings have germinated and begin breaking through the soil crust. During this time, it is important to check for uniformity across the plant stand and determine if it is necessary for future application of herbicides for control of weeds. The main shoot and early leaves are present during this stage.

2-3 Tillering: Stages two and three describe a plant which has begun to tiller, meaning the plant is putting auxiliary or side shoots. At the end of stage three the plant will have completed tillering. During this time, it is important to continue to monitor for disease and pest pressures and to take precautionary action as needed. Early fungicides sprays may also be needed at this time.

4-5 Green Up: During the "green up" phases the plant begins to grow upright gaining plant mass above and below ground.

6-7 Jointing: At Feekes stage six, the first node a, swollen bump will be visible at the base of the shoot. Nodes are areas of active cell division from which leaves and tillers arise. In Feekes stage seven, a second and possibly a third node will be visible approximately six inches above the soil surface.

8 Flag Leaf: Approximately five to ten days after the plant has reached Feekes stage seven the flag leaf will emerge signifying that is has transitioned to Feekes stage eight. The flag leaf is the last leaf to emerge and signals the change between vegetative and reproductive growth.

9-10 Boot: At Feekes stage nine the flag leaf's ligule is visible. The ligule is a membrane on the inside of the leaf that connects the leaf to the sheath. During this stage, the flag leaf is fully emerged.

During this time, the head will still be encased in the sheath and will begin to swell. Once the head is visible in the leaf sheath directly below the flag leaf the plant has entered Feekes stage ten. Feekes stage ten uses a decimal scale within the stage to describe milestone developments within the boot stage. These subdivisions should be assigned when approximately 50% of the field has reached the decimal designation.
10.1 awns visible, heads emerging
10.3 heading half complete
10.5 heading complete, flowering has taken place in the boot
Optimum timing for fungicides to protect against Fusarium Head Blight is in the early stages of Feekes stage ten.

11 Ripening: Once flowering begins, pollination will be completed in four or five days. When pollination is complete ripening will begin. Again, in this stage a decimal system is used to distinguish milestone developments.
11 formation of kernels, early milk
11.1 kernels full size, medium milk
11.2 kernel content starchy and readily crushed, leaves drying, glumes yellowing
11.3 kernels semi-hard, leaves dry, nodes yellow
11.4 kernels hard, plant dry

As barley enters its reproductive phase, the stems of some of the tillers, called culms, elongate upward. Barley's flowering structure is known as the spike, ear, or head. It is borne upward, emerging from the "boot," which is the sheath of the uppermost "flag" leaf on the culm. The spike consists of a large number of individual flowers called florets, which are present in individual spikelets that are attached to a central stemlike structure called the rachis. Spikelets are attached in groups of three on opposite sides of the rachis. Barley is predominantly self-pollinating producing between twenty-five and sixty seeds per spike.

The barley "type" can be distinguished by its differences in the head as it is classified based upon the fertility of the florets on the spike. In a six-rowed barley, three kernels form at each node of the head, while in a two-rowed type, only a single kernel forms at each node. In six-row barleys, all of the florets are fertile, leading to six vertical rows of seeds on the spike. Six-row barley is predominately used for feed. In two-row types only the central floret of the three at each node is fertile, and thus just two rows of seeds develop on opposite sides of the rachis. Two-row barley is predominately used for malting.

The barley seed consists of the embryo, a series of outer layers of cells called the pericarp, and the endosperm. The principal compound found in the endosperm is starch, which represents about 65% of the mass of the seed. This starch serves as an energy source for the seedling. The second largest component of the barley endosperm is protein. The amount of protein present is generally inversely proportional to the amount of starch. This protein provides a source of amino acids that can be used for protein synthesis by the seedling. The amount of protein present in a seed is positively correlated with the amount of nitrogen fertilizer applied when the parent plant is being grown.

When the barley crop is mature, harvesting is facilitated by either direct combining, or by first swathing and then harvesting. Technology for harvesting ranges from a simple sickle in developing countries to sophisticated mechanical combines or headers that cut the culms above the soil, move the harvested plants between a concave and a rotating cylinder to dislodge grain; it then passes over a set of screens, separating the grain from the straw and chaff, and collecting the grain into a bin. Once the grain is harvested, it may either be stored in bins on the farm, or delivered to a local grain elevator where it is purchased from the producer.

BARLEY USAGE

Barley is a versatile and useful crop with historical applications ranging from feed and food production to beverage manufacturing.

When we analyze current barley usage we break it down into three sectors: 1) Feed, 2) Malting and 3) Food.

FEED

Barley's primary use is as a feed grain used in animal feed. In Canada, Europe, and in the northern United States, as well as in many areas of the world that are not suited for maize production barley is an important feed grain. Over half of barley production is used as livestock feed.

Though barley is not as efficient an energy converter as corn, it does have a higher protein content which reduces the need for protein supplements in a compound feed. Consequently, barley competes very effectively with both corn, sorghum and other cereals as a feed grain.

MALTING

The most noted barley product consumed by humans is beer. Beer is produced and drunk in large quantities worldwide. Although a variety of grains can be used for brewing and malting, barley has become the preferred grain for beer and malting. The malting process creates certain enzymes required for modifying starches into sugars.

The decline in barely production in the United States has now left the largest portion of barley production now contracted for malting purposes. Barley that does not meet quality specifications for malting is subsequently used as livestock feed.

The production of malt beverages in the United States has stabilized over the past decade. The brewing industry uses a mixture of two-row and six-row barley in the production of malt beverages. Two-row barley should be a minimum of 85 percent plump, a maximum of 3 percent thin and 11.5 to 13.5 percent protein. U.S. maltsters prefer six-row barley with a minimum of 70 percent plump, a maximum of 3 percent thin and protein levels of 12 to 14 percent. Germination is very important and that of U.S. barley is consistently high. The efficient U.S. handling system ensures that skinned and broken kernels, which reduce germination counts and malt yield, are kept low.

Though two-row varieties are higher in test weight and kernel production plumpness, six-row barley has superior enzyme systems which are crucial to the value of malt in beverage production. Brewers evaluate malt on the basis of total protein, soluble protein extract, fine/coarse difference, diastatic power and alpha amylase. The very high diastatic power and alpha amylase levels in six-row barley make U.S. malt very efficient in the brew house.

FOOD

In some regions of the world, where other grains do not grow well, barley has been historically grown for human consumption. Today, only a minor volume of barley is actually consumed for human food consumption. It can be used in soups, as an extender for vegetable proteins and is occasionally milled into flour.

When the barley grain is consumed directly for food, it is generally used absence of the hull to make it more palatable. “Pearled Barley” has had the outer hull and layers of the seed mechanically removed, followed by processing to produce small, rounded, pieces of the endosperm. Barley can also be dehulled, milled, and polished to remove the bran layers, to produce a rice-like product. Pearled and polished barley are used in porridges and soups and as rice substitutes.

Other food uses include barley flakes, flour for baking purposes to produce breads and crackers, grits, breakfast cereals, pilaf, noodles, and baby foods.

Lastly, some barley is used for the production of distilled spirits such as whiskey, vodka, and gin, and for making vinegar and malted beverages.

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GRAIN SORGHUM (Milo) (Sorghum bicolor)

Sorghum is in the subfamily ***Panicoideae*** and the tribe ***Andropogoneae*** (This is the same tribe as big bluestem and sugarcane). Within the genus of Sorghum is about 25 species of flowering plants in the grass family ***Poaceae***. Some of these species are grown as cereals for human consumption and some in pastures for animals.

Grain Sorghum

One species, ***Sorghum bicolor***, was originally domesticated in Africa and has since spread throughout the globe.[xviii] The earliest known record of sorghum comes from an archaeological dig at Nabta Playa, near the Egyptian-Sudanese border and had been dated at 8,000 B.C. From here, domestic cultivation spread throughout Africa. Along the way, the underlying genetic diversity of sorghum allowed the crop to adapt to a wide range of environments, from the highlands of Ethiopia to the semi-arid Sahel. [xix]

The spread of five different races of sorghum can, in many cases, be attributed to the movement of various tribal groups in Africa. Sorghum then spread to India and China and eventually worked its way to Australia.

Sorghum is justly renowned for its ability to survive on limited moisture and on marginal land subject to lower rainfall and periods of drought. Versatility as a food and feed grain, underpin its importance in the lives of millions of people throughout the world.

The first known record of sorghum in the United States comes from Ben Franklin in 1757, who wrote about its application in producing brooms.

"Because of its versatility and adaptation, "sorghum is one of the really indispensable crops" required for the survival of humankind." – Jack Harlan, 1971

The hybridization of sorghum commenced much later than other crops such as maize. It was not until the 1950's when a hybridized variety of sorghum of uniform, short stem height became commercially available.

Currently there are no genetically modified (GM) varieties of grain sorghum, making it attractive to consumers who prefer that trait.

Sorghum promises a steady, less spectacular return than corn for feed grains producers. Consequently, it is grown primarily in arid areas of the plains where corn production must be irrigated to be profitable.

Currently, U.S. sorghum production is concentrated in drier cropping areas of the Central and Southern Plains. The states of Kansas, Texas, Nebraska and Missouri produce approximately 80 percent of the U.S. crop.

SORGHUM PRODUCTION CYCLE: SEASONAL FACTORS

Sorghum's growth habit is similar to that of maize, but with more side shoots and a more extensively branched root system. The root system is very fibrous, and can extend to a depth of up to 1.2 m. The plant finds 75% of its water in the top meter of soil, and because of this, in dry areas, the plant's production can be severely affected by the water holding capacity of the soil. The plants require up to 70–100 mm of moisture every 10 days in early stages of growth, and as sorghum progresses through growth stages and the roots penetrate more deeply into the soil to tap into hidden water reserves, the plant needs progressively less water. By the time the seed heads are filling, optimum water conditions are down to about 50 mm every 10 days. Compacted soil or shallow topsoil can limit the plant's ability to deal with drought by limiting its root system. Since these plants have evolved to grow in hot, dry areas, it is essential to keep the soil from compacting and to grow on land with ample cultivated topsoil.

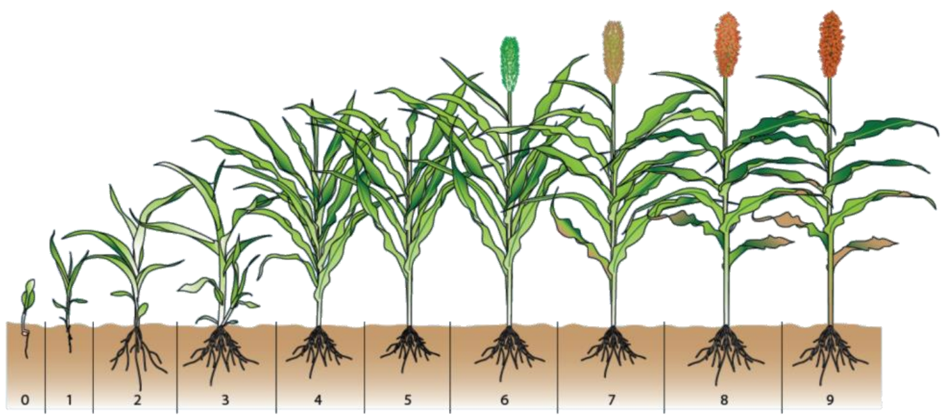
Sorghum requires an average temperature of at least 25 °C to produce maximum grain yields in a given year. Maximum photosynthesis is achieved at daytime temperatures of at least 30 °C. Night time temperatures below 13 °C for more than a few days can severely reduce the plants' potential grain production. Sorghum cannot be planted until soil temperatures have reached 17 °C. The long growing season, usually 90–120 days, causes yields to be severely decreased if plants are not in the ground early enough.

Wild species of sorghum tend to grow to a height of 1.5–2 m; however, due to problems this height created when the grain was being harvested, in recent years, cultivars with genes for dwarfism have been selected, resulting in sorghum that grows to between 60 and 120 cm tall.

Grain sorghum is usually planted with a commercial corn seeder at a depth of 2 to 5 cm, depending on the soil type. The objective is to achieve a plant population of 50,000 to 300,000 plants per hectare. With an expected average emergence rate of 75%, sorghum should be planted at a rate of 2 to12 kg of seed per hectare.

Yields have been found to be boosted by 10–15% when optimum use of moisture and sunlight are available, by planting in 25 cm rows instead of the conventional 1-meter rows.

Sorghum, in general, is a very competitive crop, and does well in competition with weeds in narrow rows. Sorghum produces a chemical compound called sorgoleone, which the plant uses to combat weeds. The chemical is so effective in preventing the growth of weeds it sometime prohibits the growth of other crops harvested on the same field. To address this problem, researchers at the Agricultural Research Service found two gene sequences believed to be responsible for the enzymes that secrete the chemical compound sorgoleone.[xx] The discovery of these gene sequences will help researchers one day in developing sorghum varieties that cause less soil toxicity and potentially target gene sequences in other crops to increase their natural pesticide capabilities, as well. [xxi]



Sorghum Development Stages

Source: Kansas State University Agricultural Experiment Station and Cooperative Extension Service MF3234 October 2015 Ignacio A. Ciampitti, Crop Production and Cropping Systems Specialist, Department of Agronomy, Kansas State University[xxii]

Stage 0 Emergence: The plant breaks through the soil surface; early growth usually is slow. The time between planting and emergence depends on soil temperature, residue cover and distribution, soil moisture, planting depth, and seed vigor. Adjust planting time so emergence occurs in favorable conditions.

Stage 1 Three-leaf stage: Three leaves are fully expanded with a visible collar (leaf tissue at the junction of the leaf blade and sheath). The growing point is under the soil surface. This stage occurs 10 to 20 days after emergence, depending on soil temperature and moisture.

Stage 2 Five-leaf stage: Five leaves are fully expanded with a visible collar. The growing point is below the soil surface. The plant begins a rapid growth and nutrient accumulation phase. The root system is expanding rapidly. Minimize weed competition from planting through this growth stage. This stage occurs 20 to 25 days after emergence.

Stage 3 Growing point differentiation: Potential leaf number is defined 30 to 40 days after emergence. Maximum plant growth and nutrient uptake rates are achieved. The growing point is above the surface and changes from producing leaves to forming heads.

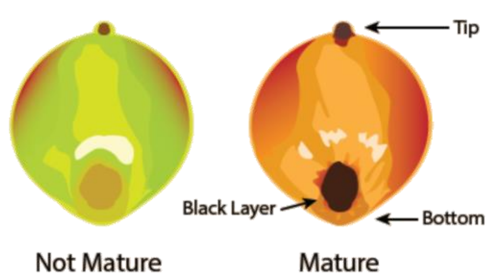
Stage 4 Flag leaf visible: Rapid stem elongation and increases in leaf area occur at this stage. The final leaf, the "flag leaf," is visible in the whorl. Potassium uptake is >40%, nitrogen >30%, phosphorus >20%, and total growth is about 20% complete relative to final nutrient content.

Stage 5 Boot stage: Maximum leaf area has been achieved. Maximum potential head size and seed number has been set. The upper stalk, known as the "peduncle," begins to elongate. Final size of the peduncle varies with the genotype. This stage occurs 50 to 60 days after emergence.

Stage 6 Half-bloom: Full exsertion of the head occurs at this stage and 50% of the plants in the field are in some stage of bloom. For an individual plant, this stage is when the flowering reaches 50% of the head. Total growth is 50% complete. Compared to final nutrient content, nutrient accumulation is 60% for phosphorus, 70% for nitrogen, and >80% for potassium.

Stage 7 Soft-dough: Grain formation begins immediately after flowering and the grain fills rapidly (50% of dry weight). The stem losses weight due to a remobilization process (from stem to grain). Grains are the main priority for the plant; thus, without a good balance between leaves (source) and grain (sink), the duration of grain filling can be shortened. A severe stress at this growth stage can produce lighter and chaffy grains.

Stage 9 Physiological maturity: Grain achieves its maximum dry weight. Mature grain is identified by looking for the dark spot, the black layer, on the bottom of the kernel. Grain moisture ranges from 25 to 35%. The time to harvest depends on the environmental conditions. Artificial drying can be promoted by the use of desiccants without affecting yield when applied after maturity. [xxiii]



Insect and diseases are not prevalent in sorghum crops. Birds, however, can be a major source of yield loss. Hybrids with higher tannin content and growing the crop in large field blocks are solutions used to combat the birds. The crop may also be attacked by corn earworms, aphids, and some Lepidoptera larvae, including turnip moths.

Sorghum demands high amounts of nitrogen. An average hectare producing 6.3 tonnes of grain yield requires 110 kg of nitrogen, but relatively small amounts of phosphorus and potassium (15 kg of each).

Sorghum's yields are not affected by short periods of drought as severely as other crops such as maize, because it develops its seed heads over longer periods of time, and short periods of water stress do not usually have the ability to prevent kernel development. Even in a long drought severe enough to hamper sorghum production, it will still usually produce some seed on smaller and fewer seed heads. Rarely will one find a kernelless season for sorghum, even under the most adverse water conditions. Sorghum's ability to thrive with less water than maize may be due to its ability to hold water in its foliage better than maize. Sorghum has a waxy coating on its leaves and stems which helps to keep water in the plant, even in intense heat.

GRAIN SORGHUM USAGE

Grain sorghum has multiple uses as feed, fodder, fuel and food. In addition to these, many other industrial applications such as health, pharmaceutical diagnosis, packing, synthesis of organic molecules, and utility items have been in place.

Sorghum has a very hard kernel. This makes it resistant to disease and damage but also requires further processing to enhance its feeding efficiency. Sorghum is ground, cracked, steam flaked, roasted, micronized or reconstituted. Such processing will enhance the nutritional value of sorghum by 12 to 14 percent.

An important component global sorghum usage is in the production of Chinese Baijiu. Baijiu is a clear liquid usually distilled from fermented sorghum that is between 35% and 60% alcohol by volume. Each type of baijiu uses a distinct type of fermentation unique to the distillery for the distinct and characteristic flavor profile.

A resurgence in global demand for sorghum began to increase dramatically between 2014 and 2016, when China began purchasing US sorghum crops to use in both Baijiu production, as well as livestock feed. It is the demand for Chinese Baijiu production that frequently adds a significant premium to the market price.

FEED

Sorghum is a competitive feed ingredient in many feed rations. In the United States, Mexico, South America and Australia, grain sorghum is a principal feed ingredient for both cattle and poultry rations. Due to a number of its unique characterizes, grain sorghum is also included in the formulation of pet feed for dogs, fish, etc.

In the U.S., the swine industry is not a significant consumer of grain sorghum as the production of pigs is geographically located closer to the major corn producing areas of the Corn Belt.

Historically, sorghum was prized for its tannin content because high-tannin sorghum is not palatable to wild birds. Tannin, an acidic complex found in sorghum, can affect both the palatability and nutritional value. Such sorghum may still be grown in areas of the world where birds are a threat to the crop. However, in the United States, sorghum has long been bred to reduce the tannin content. Today, tannin content in U.S. grain sorghum is no longer a concern.

ENERGY AND INUSTRIAL

Sorghum can also be utilized in the energy and industrial sectors, being processed into ethanol and related co-products. Sorghum is directly substituted for corn as a feed stock in the milling process.

Depending on relative price relationships to corn, grain sorghum will often price itself into the ethanol grind for many corn processers.

See the following section on the Milling Process for more information…

FOOD

Sorghum is an important food crop, especially for subsistence farmers in arid, less developed regions of the world. It can be used to make such foods as sorghum flour, couscous, porridge and molasses.

Popcorn (for size comparison) left, and popped sorghum seeds, right
In South Africa, sorghum meal is often eaten as a stiff porridge much like pap. In Ethiopia, sorghum is fermented to make injera flatbread, and in Sudan it is fermented to make kisra[xxiv]. In India, dosa[xxv] is sometimes made with a sorghum-grain mixture. In Arab cuisine, the unmilled grain is often cooked to make couscous, porridges, soups, and cakes.

Sorghum is a non-GMO, gluten free, ancient grain that is gaining popularity food grain for people residing in Asia and Africa. Because of sorghum’s gluten free properties, it has become a whole grain alternative for those who deal with gluten intolerance or celiac disease.

As there are currently no genetically modified (GM) varieties of grain sorghum, the grain has become increasingly attractive to consumers who prefer these traits.

A major use of grain sorghum can be found in China, where sorghum is an important ingredient for the production of distilled beverages, such as baijiu, maotai and kaoliang wine.

Baijiu (Chinese: 白酒), also known as shaojiu, is a colorless white liquor usually distilled from fermented sorghum, although other grains may be used. The liquor id typically between 35% and 60% alcohol by volume. [xxvi]

Baijiu is comparable to whisky in terms of variation, complexity of flavor and sensation. Each type of baijiu uses a distinct type of “qū" (曲/麴) *(a type of East Asian dried fermentation starter grown on a solid medium and used in the production of traditional Chinese alcoholic beverages)* for fermentation that produces distinct characteristics and a unique flavor profile. The qū starter culture used in the production of baijiu is usually made from pulverized grain. [xxvii]

PRODUCTS OF THE MILLING PROCESS

Both dry-milling and wet-milling processing methods can be use in the production of ethanol, resulting in a variety of economically valuable coproducts. Three important animal feed products coming from the corn milling process include:

- Distillers Grains
- Corn Gluten Meal
- Corn Gluten Feed

Distillers Grains – Cereal byproducts of the distillation process. There resulting feed values and quality analysis is influences by the type of feed stock, whether that be corn, barley, grain sorghum, rice or wheat, or other grains, as well as the underlying milling process. The products are created by the milling process of distillation, and is subsequently sold for a variety of purposes, usually as a feed stuff for the livestock sector, especially ruminants.

There are two main sources of these grains. The traditional sources were from brewers. Brewer's spent grain usually refers to barley produced as a byproduct of brewing. More recently, the ethanol biofuel industry is now the primary source of these products as a byproduct of corn and/or grain sorghum. The mash left over from the process contains nutrients, such as protein, fiber, germ, vitamins, and minerals.

Corn-based distillers grains from the ethanol industry are commonly sold as a high protein livestock feed that increases efficiency and lowers the risk of subacute acidosis in beef cattle.

Wet Distillers Grains (**WDG**) – contains primarily unfermented grain residues (protein, fiber, fat and up to 70% moisture). Quality and analysis can vary significantly by supplier. WDG has a shelf life of four to five days. Due to the water content, WDG transport is usually economically viable within 200 km of the ethanol production facility.

Dried Distillers Grains with Solubles (**DDGS**) – is WDG that has been dried with the concentrated thin stillage to 10–12% moisture. Quality and analysis can vary significantly by supplier. DDGS have an almost indefinite shelf life and may be shipped to any market regardless of its proximity to an ethanol plant. Drying is costly, as it requires further energy input. In the US, it is packaged and traded as a commodity that competes with other protein feed stuffs.

Corn Gluten Meal – is a byproduct of corn processing that has historically been used as an animal feed. Despite the name, corn gluten does not contain true gluten, which is formed by the interaction of gliadin and gluten in proteins. The meal is a combination of bran fibers and the corn oil cake left from the extraction of corn oil, has protein content in excess of 60% and is a low-cost alternative to soybean meal or other expensive protein sources.

Corn gluten meal is commonly used as livestock feed containing about 65% crude protein. It can be a source of protein, energy, and pigments for livestock, and is used in pet foods for digestibility. [xxviii] Quality and analysis can vary significantly by supplier.

Poultry feeders particularly value corn gluten meal because of the presence of xanthophyll, a pro-vitamin which determines corn’s pigmentation and enriches the yellow color in a chicken’s skin and eggs.

Corn Gluten Feed – is a result of gluten, removed from the heavier starch, being combined with bran from the hull to make a feed ingredient that dairy cattle and sheep find particularly palatable.

Corn gluten feed has approximately 22% crude protein and is a mixture of bran, steep liquor, and maize germ oil from the milling process. Quality and analysis can vary significantly by supplier.

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[xiv] USDA FAS PS&D Online “Production, Supply & Demand” Market and Trade Data Website: https://apps.fas.usda.gov/psdonline/app/index.html#/app/compositeViz Accessed 31 December 2021

[xv] The Zadoks Growth Scale is a a 0-99 scale of development that is recognized internationally for research, advisory work and farm practice, particularly to time the application of chemicals and fertilizers.

[xvi] The Feekes Growth Scale is a numbering system 1 through 11 with each number representative of a new growth event in cereal grains. Each number may be further divided by using decimals to further describe a given stage.

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[xxiii] Kansas State University Agricultural Experiment Station and Cooperative Extension Service MF3234 October 2015 Ignacio A. Ciampitti, Crop Production and Cropping Systems Specialist, Department of Agronomy, Kansas State University

[xxiv] Kisra is a popular thin fermented bread made in Chad, Sudan and South Sudan. There are two different forms of kisra: thin baked sheets, known as kisra rhaheeefa, which is similar to injera; and a porridge known as kisra aseeda or aceda.

[xxv] A dosa is a thin pancake or crepe originating from South India, made from a fermented batter predominantly consisting of lentils and rice. It is somewhat similar to a crepe in appearance, although savoury flavours are generally emphasized

[xxvi] "The World's Most Consumed Alcohol Is One You Might Not Have Tried. But It's Coming to a Bar Near You" Accessed 20 January 2022

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