13 Crops – Cereals

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13.1 Introduction

Cereal grains, such as corn, wheat, rice, and sorghum, are grown and processed into a wide variety of ingredients for animal and human food uses. The focus of this chapter will be on corn and wheat, but other cereals have significance in global processing and human nutrition. For example, rice is grown throughout Asia and the Pacific Rim and is primarily consumed with the endosperm intact. Rice production requires large amounts of water during a relatively long growing season and therefore is grown in warm, moist climates. In contrast, grain sorghum (or milo) is processed to recover its endosperm with reduced particle size to be used in many foods throughout Africa and arid regions. Relative to other cereal crops, sorghum species are more frugal with water utilization at higher temperatures (above approximately 30°C), making them better suited to hot and dry growing conditions such as the western plains of the US and sub-Saharan Africa. Many processing techniques used with grain sorghum have strong similarities to those used for processing corn. In this chapter, however, we chose to focus on corn and wheat processing technologies, especially wet processing of these two cereals for food, feed, and industrial purposes.

13.2 Industrial corn processing for food uses

Corn, known as maize outside the US, is a high-yielding and genetically diverse crop grown for grain in many regions of the world. In the US, corn was grown as an ingredient in animal diets, but use for direct human consumption has increased during the past several decades. The US produced 32.1% of the world’s corn production for the period 2012–2013 and was the largest global producer (Capehart et al., 2013). Corn has been used for centuries as a food product. Archeological evidence suggests corn was cultivated 7000 years ago in Mexico before being cultivated elsewhere in North and South America (Farnham et al., 2003).

Industrial processing of corn started in the 1800s to optimize production of starch from corn kernels to be used in human food products as well as for industrial starches (e.g. adhesives, paper, and cardboard). Later, other corn components (oil, fiber, and protein) were also recovered as co-products. In 2010, US corn producers produced 12.45 billion bushels of corn, averaging 153 bushels per acre (NCGA, 2011). US corn usage totaled 11.3 billion bushels in 2012, consisting of feed and residual (4.45 billion bushels), exports (0.95 billion bushels) and food, seed, and industrial uses (3.47 billion bushels). Corn used for fuel ethanol production was 3.5 billion bushels (30.7% of corn use); corn used for syrups, sweeteners, and starch products was 1.0 billion bushels (8.9% of use in 2012); corn used for cereals, snacks, and beverage alcohol totaled 0.337 billion bushels, while seed use was 0.025 billion bushels (0.2%) (Capehart et al., 2013). It should be noted that these figures are for overall corn use, and do not reflect that industrial processes co-produce animal food ingredients (distillers dried grains with solubles, corn germ meal, corn gluten feed, and corn gluten meal) as 30–40% of their output. Sweetcorn grown for freezing and canning purposes is a very small fraction of the overall corn crop.

There are four major segments of the corn processing industry: corn wet milling, corn dry milling, dry grind ethanol, and masa. Wet milling, dry milling, and masa are used for producing food products from corn for human consumption and will be discussed in this chapter. Dry grind is the fastest growing segment of the corn processing industry and is primarily used for fuel ethanol production.
13.2.1 Corn kernel composition

Structurally, the corn kernel has four main parts: tip cap, pericarp, germ, and endosperm. Watson (2003) gave the percentage component parts and the composition of these parts of dent corn kernels. The tip cap is the location where the kernel is attached to the corn cob and where most of the water enters the kernel during process steps such as tempering and steeping. The pericarp is formed of plant tissues that surround the kernel and protect it during growth and maturation in the field as well as during harvest, storage, and handling. The germ comprises 83% of the fat and 26% of the protein in the corn kernel. The solubles in corn kernels are mostly proteins in the corn germ and monomeric sugars that leach out from the corn kernel when soaked in water. Most of the phytic acid in the corn kernel is in the germ fraction. The endosperm consists of starch, protein, and endosperm fiber and forms about 82% of the kernel weight. Two kinds of fiber are derived from two regions of the kernel: pericarp and endosperm. Pericarp fiber constitutes 50% of the fiber in the corn kernel. Endosperm fiber is the fiber fraction composed of cellular material from the endosperm interior. Depending on processing technique, different corn structural components will end up in various final products (Figure 13.1).

Because of its genetic diversity and relative ease of creating new hybrids, corn can have various colors, endosperm hardness, germ sizes, and overall kernel composition. Major classifications of commercially grown corn include regular dent, waxy, high amylose, flint, high oil, popcorn, and sweetcorn. In the US, regular dent is the primary crop. The endosperm of dent corn contains soft (characterized by spherical starch granules) and hard (characterized by polygonal granules) regions. As the corn kernel matures and begins to dry in the field, the softer regions of the endosperm lose moisture and shrink, causing the top end of the kernel (the portion on the outer part of the ear) to form a dimple or dent. Regular dent corn is a relatively broad classification; some dent varieties are well suited for wet milling but not for dry milling, and vice versa. Waxy (nearly 100% amylopectin starch in the kernel) and high-amylose (30–70% amylose starch) types are typically grown under contract and are channeled to wet milling facilities that produce specialty starch products. Flint corn is more common in South America and has primarily hard or vitreous endosperm.

Figure 13.1 Fractionation of corn components into different co-products based on processing technologies.
Due to the hard endosperm, this type of corn does not form a dent at the top of the kernel as with other softer varieties. Flint corn is difficult to steep if wet milled and can be too hard to be desirable for dry milling, but is less susceptible to breakage during storage, handling, and transportation. High-oil corn has oil contents from 6% to as high as 12% by increasing the size of the germ or concentration of the oil in the germ. This crop is typically grown under contract for animal diets near large animal feeding operations. Popcorn is a niche snack product, which has small, hard kernels that will pop when heated properly. Sweetcorn hybrids have high sugar contents and are harvested prior to kernel maturity and sold with kernels still attached to the ear, or processed into canned or frozen products. Even though highly visible to the average consumer, popcorn and sweetcorn consumption forms less than 1% of the total US corn crop. In the US and in most of the rest of the world, regular dent corn is used for industrial processing due to its availability as a commodity crop and its high starch content.

### 13.2.2 The corn wet milling process

In the wet milling process, corn is fractionated into individual components of starch, protein, fiber, germ, and solubles in an aqueous medium (Blanchard, 1992; Johnson & May, 2003). The industrial corn wet milling industry started when the Thomas Kingsford starch factory was established in 1848 in Oswego, New York. By 1879, about 140 corn wet milling companies had been established to produce starch as food ingredients and as a laundry aid (Peckham, 2000). In the 19th century, corn syrups were beginning to be used in the candy, baking, brewing, and vinegar industries (Peckham, 2000). Purified starch, the primary co-product of wet milling, can be modified for food and industrial uses, hydrolyzed to produce syrups and sweeteners, or converted to produce ethanol, lysine, polylactic acid, and other biochemicals. Present-day corn wet milling fractions are used in more than 1000 commercial products. Currently there are eight wet milling companies with 27 plants operating in the US; the major US wet milling companies include Archer Daniels Midland, Cargill, Corn Products International, Grain Processing Corporation, Roquette America, and Tate and Lyle Ingredients America. Most of the corn wet milling plants are located in the US Midwest region, which is also the highest corn-producing region in the country.

The first step in the corn wet milling process involves hydration of corn kernels in 0.1–0.2% SO₂ at 48–52°C. This process of hydration is called steeping and is conducted for 24–36 h (Figure 13.2). During steeping, the SO₂ reacts with the disulfide bonds in the endosperm, allowing subsequent separation of the starch granules from the other corn components. After steeping, corn is ground using attrition mills (specific to corn), which open the kernels and release germ. Germ is recovered by density separation using hydrocyclones. The remaining slurry is passed over a set of screens to recover fiber (pericarp and endosperm) and washed to recover residual starch and protein from fiber. After fiber recovery, starch and protein slurries are processed through a system of centrifuges to separate starch and protein (called gluten) and to recover a concentrated protein (corn gluten meal, CGM) fraction. Starch is further washed using hydrocyclones to remove residual protein and achieve 99.5% db purity. The starch is further processed to produce many different food and industrial products. Fiber, solubles (concentrated steepwater) and sometimes germ meal are mixed together to produce corn gluten feed (CGF). Wet milled germ is used for the extraction of corn oil for human food uses. CGM and CGF are used as ingredients in animal diets. The terms CGM and CGF are misnomers, even though they are used commercially as official names for these coproducts; the corn kernel does not contain gluten protein.

From the corn wet milling process, starch and corn oil are two major products produced for human consumption.

### 13.2.2.1 Starch from corn wet milling

The primary objective of corn wet milling is the recovery of high-purity starch to be further processed into many products. Starch accounts for 60–75% of the weight of the corn kernel, and is used in several food and industrial applications. Starch is a polymer of six-carbon sugar (D-glucopyranose) molecules linked by α,1,4 and α,1,6 glycosidic bonds. There are two polymers: amylose and amylopectin. Amylose is a smaller linear polymer of glucose molecules attached by α,1,4 bonds. Amylopectin is a larger branched glucose polymer using α,1,4 bonds and α,1,6 bonds; the branching of amylopectin is due to α,1,6 bonds. The molecular size of the starch polymers (degree of polymerization) is 1500 to 6000 (from 1500 to 6000 glucose molecules) for amylose and 300,000 to 3,000,000 for amylopectin. Dent corn typically has 23–25% amylose and 75–77% amylopectin. Waxy corn has less than 1% amylose and more than 99% amylopectin. High-amylose corn has 55–70% amylose and 30–45% amylopectin.
Depending upon the final use, starch can be used unmodified or modified (chemically or physically) to impart certain functional characteristics. Dry, unmodified corn starches are used as thickening and gelling agents, dry mixes for gravies and puddings, batters, and other food applications. Chemically modified starches (cross-linked, substituted, acid-thinned, oxidized, and dextrinized) are produced for food applications that require retaining viscosity, improving stability, gelling, adhesion or emulsification properties. Chemical modification improves the visual appearance of final food products, stabilizes texture, makes food product preparation more convenient, or improves shelf stability of the food product. Modified starches have many applications and uses in a range of food and industrial products relative to unmodified counterparts. Cross-linked starches have improved shear and temperature stability in food processing systems; substituted starches have improved stability during temperature cycling (e.g. freeze-thaw stability) and reduced gelatinization temperatures; acid-thinned starches can have reduced viscosity in high solids systems; oxidized starches have adhesive characteristics needed for batters and coatings; dextrins can be used in adhesives and coatings.

Starch can also be hydrolyzed into glucose or short polymers using acid, enzyme or a combination to produce products that are classified based on their dextrose equivalent (DE). DE is a measure of the total reducing sugars in a product. Hydrolyzed starch food products consist of maltodextrins (5–20 DE), low-DE corn syrups (22–30 DE), and high-DE corn syrups (above 60 DE). A low-DE syrup can be used in applications that require body, cohesiveness, foam stability, prevention of sucrose crystallization, and viscosity whereas a high-DE syrup is used when browning, fermentability, enhanced flavor, lowering of freezing point, increased osmotic pressure, and sweetness are required (Table 13.1) (Hull, 2010).

13.2.2 Oil from corn wet milling

Corn oil ranks third in the world production of edible plant oils, with an annual production of 2.4 million tons (Moreau, 2008). The corn kernel contains typically 4.0% oil in commercial corn hybrids. Most of this oil (≈85%) is located in the corn germ (corn germ oil). A small amount of oil (6–7%) is also located in the fiber fraction (corn fiber oil). On a commercial scale, corn oil is recovered
from the germ which has been separated during the corn wet milling process. Corn wet-milled germ is composed of 40–50% oil by weight. This oil is usually removed by either hexane extraction or mechanical prepressing followed by hexane extraction (Moreau, 2011). Crude corn oil contains 96% triacylglycerols, 0.3–1.7% free fatty acids, 1% phytosterols and 1% phospholipids (Moreau et al., 1999b; Orthoefer & Sinram, 1987). Currently all refined corn oil for human use is produced from corn germ; however, oil can also be recovered from corn fiber (corn fiber oil) or from the entire corn kernel (corn kernel oil). Processes have been developed to recover corn from the whole corn kernel (Hojilla-Evangelista et al., 1992) or from the fiber fraction (Singh et al., 1999, 2005). Modifications in conventional corn wet milling (Johnston & Singh, 2001) have been implemented that could potentially allow recovery of pericarp and endosperm fiber fractions for recovery of corn fiber oil and other components for food applications (Doner et al., 2001).

Depending upon the solvent used (i.e. ethanol, methylene chloride, chloroform/methanol), corn kernel oil was shown to contain higher levels of three phytosterol lipid classes (Moreau et al., 1996) as well as the yellow pigments lutein and xanthophylls (Moreau et al., 2007), compared to hexane-extracted corn germ oil. Corn fiber oil is rich in phytosterol esters and can be extracted from different corn fiber fractions (Moreau et al., 1996, 1998). Corn fiber oil has been found to contain the highest levels of natural phytosterols and phytostanols of any known plant extracts (Hicks & Moreau, 2001). In clinical studies, phytosterols have been shown to reduce serum cholesterol (Hendriks et al., 1999; Liu, 2007; Miettinen et al., 1995; Moreau et al., 1999a). Major food uses of corn oil are in cooking, salad oil, margarines, and spreads (Moreau, 2011).

### 13.2.3 The corn dry milling process

In the dry milling process, corn is dry fractionated into grits (endosperm), germ, pericarp fiber, and flour (Duensing et al., 2003). The most common commercial-scale dry milling process consists of a tempering-degerming milling process (Figure 13.3). Cleaned corn is tempered (with steam or hot water) to increase its moisture content from 15% to about 22% (weight basis, wb). Tempering facilitates the removal of germ and bran (pericarp). The tempering moisture is rapidly absorbed by the pericarp and germ, causing differential swelling between these tissues and the endosperm; tempering is terminated before moisture is evenly distributed throughout the kernel, facilitating separation of kernel components. The moistened pericarp and germ become more resilient and resist breakage during subsequent milling steps. Tempered corn is passed through a degerminator. Several commercial degerminator systems, such as Beall, Buhler, Satake, and Ocrim, use a combination of abrasion, shear and crushing forces to break the tempered kernel.
13.2.3.1 Flaking and smaller grits

Flaking and smaller grits are mainly used in food applications. Flaking grits are used to make corn flakes and are valued for their large size; each corn flake is made from a single grit (Fast, 2003). Brewers grits, corn meal, and corn cones are smaller endosperm grit materials that are used in a wide variety of snack, baking, and breakfast products. Typical composition of degemmed corn products, granulation and uses are listed in Table 13.2 (Duensing et al., 2003). Dry-milled germ, bran, low-grade flour (standard meal), and broken corn are mixed together to make hominy feed, which is sold mainly as an ingredient for ruminant animal diets.

13.2.3.2 Dry milled corn oil

In dry milling, all corn components are dry fractionated; therefore, separation of germ from endosperm is not complete, resulting in small pieces of endosperm and pericarp adhering to germ. Consequently, the oil content in dry-milled germ is about 18–22% (Johnston et al., 2005). Starch content of dry-milled germ is twice that of wet-milled germ and dry-milled germ value is half that of wet-milled germ (Johnston et al., 2005). Moreau et al. (1999b) compared the composition of laboratory wet- and dry-milled germ. They found that dry-milled germ had lower diacylglycerols and γ-tocopherols but had higher phytosterol compounds compared to wet-milled germ. The composition of free fatty acids and triacylglycerols was similar (Moreau et al., 1999b). Dry millers are unable to sell their germ to corn oil
extraction facilities due to low oil and high starch contents of germ. Some dry millers will mechanically expel and/or solvent extract their germ for producing corn oil. Crude corn oil that has been expelled from dry-milled germ can be sold into specialty niche food markets since expelling without solvents has supposed advantages over hexane-extracted oil.

13.2.3.3 Dry-milled corn bran

Bran can be aspirated from the thrus process stream (see Figure 13.3) based on its particle size and density differences. This bran is high in total dietary fiber (TDF) (Burge & Duensing, 1989) and can be cleaned to remove adhering endosperm pieces and processed further (ground) and used to increase the fiber content of food products. Coarse ground bran is used in ready-to-eat cereals and extruded products and finely ground bran is used in high-fiber baked products (Duensing et al., 2003).

13.2.4 The corn masa process

Corn masa processing or nixtamalization is a process of cooking corn in a 1% lime (wb) solution to form eventually a unique dough called masa (Serna-Saldivar, 2010a). Cooking is done typically at 85–110 °C for 15–60 min to loosen pericarp from the kernel. After cooking, corn is steeped for 8–16 h at temperatures above 68 °C (Figure 13.4). Cooked/steeped corn is washed with water to remove pericarp and lime to recover a product called nejayote. The washed corn (nixtamal) is stone ground to produce the masa dough. This dough is used to make a variety of corn-based products including tortillas, snack chips, and other food items. Masa can be pressed to form sheets, cut and baked to produce table tortillas or fried to produce tortilla chips or taco shells. Masa can also be extruded and fried to produce corn chips. Process parameters (cooking and steeping times and temperatures, lime concentrations, and agitation) and equipment used for cooking, steeping, and grinding (direct steam injected or jacketed kettles, cooker, volcanic

Figure 13.4 The corn masa process.
or synthetic stones with different groove designs, cutters, mills) is varied depending upon the final product and cultural preferences. The masa dough can be used directly or dried and ground to produce shelf-stable packaged flour. Several sources in the literature (Maya-Cortes et al., 2010; Rooney & Serna-Saldivar, 2003; Serna-Saldivar, 2010b; Serna-Saldivar et al., 1990) report without providing specific detail that nixtamalization has beneficial effects on the nutritional value of nixtamal proteins by improving the essential amino acid profile and leads to assimilation of calcium ions (originating from the lime in the cooking step) into the masa material. However, the washing process that recovers the nejayote also removes protein and other valuable nutrients.

### 13.3 Industrial wheat processing for food uses

For thousands of years, wheat has been ground into flour to make bread of various types all over the world. During the 20th century, the flour production process was developed to remove wheat kernel pericarp (bran) and germ, resulting in a lighter colored flour that was more shelf stable and gave bread a whiter appearance. As protein research progressed, scientists identified the protein that gave quality wheat bread a desirable volume and texture during mass production of bread: wheat gluten. It was discovered that quality gluten, or vital gluten, would improve the bread loaf characteristics of many bread formulations, since gluten was elastic and would allow the bread dough to rise uniformly during the proofing stage and remain stable during baking. Vital gluten became a commodity in demand for commercial bread making. Wheat starch was co-produced with vital wheat gluten and markets for this co-product were developed.

#### 13.3.1 Wheat kernel composition

For commercial processing, wheat is classified by its hardness (soft, hard, and durum), its protein content and its color (white and red). Soft, hard, and durum varieties have protein content ranges of 8.5–9.5%, 11.5–15%, and 14–15%, respectively (Delcour & Hoseney, 2010b). Soft varieties are used in baking of cakes, biscuits, cookies, and pastries; hard wheat is used for bread making; durum wheat is used to produce semolina and pasta. The wheat kernel (35 mg) is approximately one-tenth the weight of a corn kernel. The major components of the kernel are the endosperm, germ, and pericarp, comprising 90%, 2–3.5% and 5% of the kernel, respectively. Other components of lesser importance are the brush hairs at the kernel tip and the crease, which runs along the longitudinal axis of the kernel. The starch granules present in the endosperm have two size groupings: large granules (about 40 micron diameter) called A starch and small granules (2–8 microns) called B starch.

#### 13.3.2 The wheat flour process

Wheat flour production has some similarities to corn dry milling, but due to the differences in process objectives and in wheat and corn kernel morphologies, there are distinct differences in process strategies and technologies.

The flour production process begins with whole, cleaned kernels of wheat being subjected to a tempering process (Figure 13.5). Unlike corn tempering, the objective of wheat tempering is to increase the kernel moisture uniformly so the bran layer does not shatter during further processing and to prepare the endosperm for milling. In contrast to corn dry milling, moisture is allowed sufficient time (5–24 h) to fully penetrate the wheat kernel. The amount of moisture and the length of tempering time are increased as kernel hardness increases. Wheat bran layers do not provide a barrier to moisture transfer as in the corn kernel. Tempered kernels are sent to break rolls, which crush and shear the kernels to separate bran and germ components from the endosperm. Break rolls, arranged in pairs, are corrugated and rotate at differential speeds to generate the shear needed. The shearing action avoids breaking the bran component into smaller fragments and making subsequent separation more difficult (Delcour & Hoseney, 2010a).

Following the break rolls, the fractured kernel components are sifted through a series of screening cloths to classify the particles by size. The smallest fragments, those passing through a 10XX cloth (132 micron openings), are considered to be flour. The largest particles, classified as bran, are abraded in the scalper reels in an attempt to remove endosperm particles from pericarp. The small particles are sent along with other small particles from the classifier to the reduction rolls. These rolls do not have corrugations and are used to reduce particle size. The material leaving the reduction rolls is classified again, separating material into reduction flour, shorts (small endosperm particles with bran attached), bran and a low-grade flour called red dog. Germ is typically recovered with the shorts fraction. Shorts, bran, red dog and sometimes germ are blended to form the millfeed...
co-product. Germ may be recovered separately, dried or toasted to deactivate enzymes that oxidize the fat and sold separately for specialty food ingredients or oil extraction. Germ yields are much lower than those for corn, typically 0.5–1.0% of total mill production.

Several grades of flour are produced. For whole wheat flour, all kernel components are present in the flour (bran, germ, and endosperm), but this type of flour will have shortened shelf life due to the higher fat content unless preservatives are added. Most flours have had the bran and germ removed to improve shelf life and lighten the appearance of bakery products. Flours are blended based on their ash content since this is an indication of baking characteristics (Delcour & Hoseney, 2010a). A flour miller will adjust flour composition based on customer requirements and market prices. Straight grade flour includes all flour-sized particles from the endosperm. Long patent flour originates from the break rolls, is one of the highest quality flours produced and is typically 65% of total products made by the mill. Short patent flour has the lowest ash content of all the flours and is about 45% of total mill production. Low-grade or red dog flour is about 7% of production and has a high ash content and dark color; usually, red dog is not used for bread making but is blended with the millfeed co-product, which consists of endosperm particles that have bran attached along with wheat bran and germ.

13.3.3 The wet wheat milling process

Wheat or wheat flour can be wet milled to produce vital wheat gluten and wheat starch. Wet wheat milling is practiced in many countries primarily for the vital gluten to be used in baking and meat products, but also to recover starch in regions and conditions where corn starch cannot be economically produced.

Many plants begin with wheat flour, rather than producing flour within the facility or processing whole kernels. There are many versions of the wet milling process for wheat, but the most common is the Martin process (Serna-Saldivar, 2010c), shown in Figure 13.6. Unlike corn endosperm, which requires a lengthy acidic steeping process for starch-protein separation, in the wheat endosperm, starch and gluten particles are separated by addition of water and agitation. Water is mixed with flour to form a dough or batter and allowed to rest. The addition of water, mixing and rest initiates agglomeration of the gluten protein particles, which makes separation possible. The mixture is sent to an extractor, which is a rotating screen that allows starch granules to pass through and gluten to remain on top. The extractor sends the wet gluten to dewatering rolls and a ring dryer to produce dry, vital wheat gluten. The gluten protein must be dewatered and dried in such a manner as to preserve its functionality in baking and other products. If the functionality is lost,
the non-vital gluten is sold as a lower valued co-product for use in animal diets, aquaculture, and pet food.

The starch stream is further refined to recover gluten particles, centrifuged and dried to make a high-value starch product as well as other co-products (see Figure 13.6). The A starch fraction can be recovered using hydrocyclone technology and can be used, modified or converted in much the same way as corn starch can be utilized. The challenges in wet milling of wheat flour have been to recover small granule starch (B starch) in an economical fashion and reduce the amount of water and water-soluble components of wheat being discharged into the waste treatment stream. Due to their small diameter, B starch granules are more difficult to recover and yet have significant implications if discharged as a waste stream. Many developments have occurred to recover this fraction as a separate co-product that can be used in production of glucose as well as beverage and fuel ethanol.

13.4 Sustainability of corn and wheat processing

Processing of corn and wheat in industrialized countries and regions requires significant inputs of resources. These resources are transferred to the processing facility using a well-developed infrastructure to provide water, electricity, natural gas, coal, and petroleum. Processes using large amounts of water, specifically the corn wet milling and wheat wet milling processes, must properly treat waste water to comply with regulations and reduce the environmental footprint of the discharge from the facility. Because processing of cereal grains such as corn and wheat is carried out at a large scale (commonly 1000–10,000 tonnes per day), these processes must be operated in a sustainable manner.

Corn wet milling has improved its use of water so that the amount of water per bushel has decreased significantly, cutting costs for the processor but also reducing environmental implications. The process is still water intensive, using 10–12 gal per bushel (Johnson & May, 2003), with water use strongly correlated to energy use at the plant since much of the water must be evaporated, resulting in intensive energy use as well. However, challenges in water use remain because water usage is largely controlled by the amount needed to properly steep the corn. Johnson and May (2003) reported that wet milling operations require 1.48 million kilocalories per metric tonne corn, with about 20% of the total for electricity and the remainder for steam generation. Galitsky et al. (2003) reported that corn wet milling was the largest consumer of energy in the US food industry sector.

Wet processes used for the production of wheat gluten and starch have improved in their consumption of water and energy, but there are few publications quantifying specific water and energy use other than reports from European facilities. The Martin process, which is the oldest commercial process used to produce wheat starch and gluten, uses more than 10–15 parts fresh water per part wheat flour, resulting in large volumes of process water with low solids contents. This process water contains low levels of starch, protein and water-soluble components such as arabinoxylans and β-glucans. While these components could be of commercial value, typically the process water is considered effluent and treated as waste water. Other processes, such as the batter, Fesca and Raiso processes, were developed in part because they had
potential to use less water during gluten and starch production. Improvements in the Martin and batter processes reduced water consumption to 5–7 parts fresh water per part flour (Maningat et al., 2009; Zwitserloot, 1989). With the introduction of modern centrifuges into wet wheat processing, ratios were reduced to 4–5:1 (Meyer et al., 1999). In the context of a growing global population, the sustainability of these processes should also be concerned with process design innovations and the co-products made at a processing facility. Processes historically designed to produce pure starch have implicitly placed a lower value on cereal protein; conversely, processes designed to recover protein have typically recovered starch and other carbohydrates as an afterthought. Process improvements tend to focus on commodities from a business standpoint, or on regulatory compliance. As the global population grows, all cereal processes must continue to increase in their respective sophistication. Not only should water and energy resources be used sustainably, but the components of cereal grains should also.

References


