PROCESS AND ENGINEERING EFFECTS ON DDGS PRODUCTS – PRESENT AND FUTURE

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Summary

In a conventional dry grind process, corn is processed to produce ethanol and a low valued animal food coproduct called distillers dried grains with solubles (DDGS). Approximately 33% of corn in dry grind ethanol plant becomes DDGS. Due to its high fiber content DDGS has traditionally being sold as ruminant foodstuffs. New fractionation technologies are being implemented to recovery valuable coproducts, reduce amount of DDGS produced and improve fermentation efficiency in conventional dry grind ethanol plants. These technologies include corn fractionation as well as DDGS fractionation. Corn fractionation can be broadly classified as wet and dry technologies. Wet fractionation involves a short soaking of corn followed by milling to recover germ, pericarp fiber and/or endosperm fiber in an aqueous medium prior to fermentation of degermed defibered slurry. In dry fractionation, a dry degerm defiber process is used to separate germ and pericarp fiber prior to fermentation of the endosperm fraction. Both wet and dry processes reduce the total amount of DDGS produced, increase it protein content and reduce its fiber content. Depending upon the modified process used, the amount of DDGS produced can be reduced by 70% and its protein content can be increased to 58%. DDGS fractionation involves sieving and elutriation (aspiration) to separate fiber from DDGS. This process recovers fiber as a coproduct, increases protein and fat content of residual DDGS and reduces the fiber content of residual DDGS. Depending upon the parameters used this process increased protein and fat contents of residual DDGS from 28 to 41% and 12 to 14%, respectively. A reduction in fiber content and increase in protein content of DDGS could allow increased use of DDGS as nonruminant foodstuffs.

Introduction

Dry grind ethanol production from corn is growing at fast pace in the US. In last 4 years ethanol production has increased 126% (RFA, 2006). This increase in dry grind ethanol production is expected to continue for next several years and it is estimated to reach 12 billion gallons by 2012. Most of this increase in ethanol production will come from construction of new dry grind ethanol plants. In a conventional dry grind process, corn is ground and mixed with water to produce slurry. The slurry is cooked; slurry starch is liquefied, saccharified and fermented to produce ethanol. The remaining nonfermentables (germ, fiber and protein) are recovered together at the end of the dry grind process as an animal food coproduct called distillers dried grains with solubles (DDGS). With increase in ethanol production, the amount of DDGS will increase concomitantly. DDGS due to its high fiber content is mainly used as foodstuffs in ruminant (dairy and beef cattle) diets and is a low valued coproduct. There is a need to recover valuable coproducts, reduce volume of DDGS and improve its nutritional characteristics for increasing use in non ruminant (poultry and swine) diets.

Composition of Corn

A corn kernel has four main parts: 1) tip cap, 2) pericarp, 3) germ and 4) endosperm. Watson (2003) gave the percent component parts and the composition of these parts of dent corn kernels, as shown in Table 1. There are four kinds of protein in corn kernel based on their solubility. Osborne (1924) classified corn protein as: albumins-proteins soluble in water; globulins-proteins soluble in dilute salt solutions; prolamins-proteins soluble in 70% alcohol solution; and glutelins-proteins soluble in dilute acid or based. Lawton and Wilson (2003) reviewed the corn protein composition for dent corn reported in literature (Table 2). Albumins and globulins are physiologically active protein (enzymes) and are concentrated in germ, aleurone and pericarp fractions. Small amounts of albumins and globulins (5% of total endosperm protein) are found in endosperm fraction (Hoseney 1994). Albumins and globulins have good amino acid balance and are high in Lysine, Tryptophan and Methionine. Prolamins and glutelins are classified as storage proteins and constitute 72% of total endosperm protein. Prolamins and glutelins are deficient in Lysine, Tryptophan and Methionine. Germ comprises of 83% of the fat and 26% of the protein in the corn kernel (Table 2). Most of the phytic acid in corn kernel is in the germ fraction. There are two kinds of fiber in corn kernel: pericarp fiber and endosperm fiber. Pericarp fiber is coarse fiber fraction comprising of dead cell wall material surrounding the corn kernel. Pericarp fiber constitutes 50% of the fiber in the corn kernel. Endosperm fiber is fine fiber fraction comprising of cellular material inside the corn endosperm.

Table 1. Whole corn kernel composition and composition of its fractions (endosperm, germ, pericarp and tip cap)[1].

	% (db) Composition of Whole Kernel					
	Starch	Fat	Protein	Ash	Sugar	Fiber
Whole Kernel	73.4	4.4	9.1	1.4	1.9	9.5
Kernel Fractions	Percent of Total Indicated Constituents in Kernel Fraction					
Endosperm	98.1	15.4	73.8	17.9	28.6	27
Germ	1.5	82.6	26.2	78.4	69.3	16
Pericarp	0.6	1.3	2.6	2.9	1.2	51
Tip Cap	0.1	0.8	0.9	1	0.8	0.01

[1] Data from Watson (2003).

Table 2. Distribution of corn endosperm protein in dent corn[1]

	Corn 1	Corn 2	Corn 3	Corn 4
Albumin	7.8	12.4	7.8	4.7
Globulin	0	0	0	3.5
Prolamin	50	33.9	37.6	45.8
Glutelins	38.2	36.8	43.6	38
Residue	4	16.9	11	9

[1] Data from Lawton and Wilson (2003).

CONVENTIONAL DRY GRIND PROCESS

A schematic of the dry grind process is shown in Figure 1. In the conventional dry grind process, the kernel is ground using a hammermill. Dry granular material is mixed with water to form slurry, which is cooked at approximately 160°C using pressurized steam to break down the crystalline structure of starch granules. Alpha-amylase is added to break down starch polymers into short chain molecules, called dextrins, to form mash. The mash is held at an elevated temperature (~70°C) for a short period of time, cooled to 32°C and transferred into a fermentation vessel. Glucoamylase and yeast are added for simultaneous saccharification and fermentation. In the mash, glucoamylase breaks down dextrins into mono or disaccharides, such as glucose and maltose, while yeast ferment these saccharides into ethanol. At the end of fermentation, the resulting beer is transferred to a holding tank called a beer well. From the beer well, the beer is transferred to a stripper/rectifier column to remove ethanol. Overflow from the stripper/rectifier column is an ethanol and water mixture and underflow from the column is whole stillage (nonfermentable components of corn, yeast and water). The ethanol and water mixture is processed further through a distillation column and molecular sieves to remove remaining water from the ethanol.

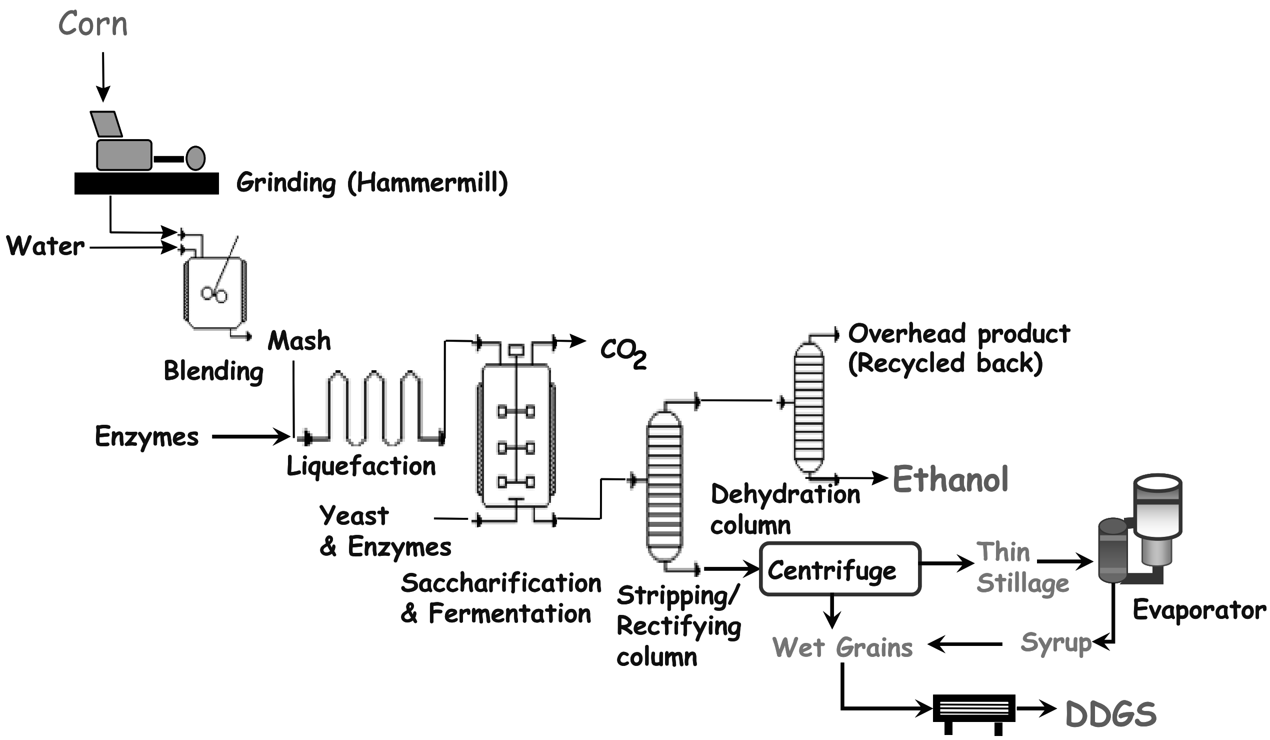

Figure 1. Conventional corn dry grind process.

Whole stillage (WS) is centrifuged to produce thin stillage (water and soluble solids) and wet grains (suspended solids). Using an evaporator, thin stillage (TS) is concentrated into syrup and mixed with the wet grains (WG), which is dried to produce a coproduct with 12% moisture content. This coproduct is marketed as DDGS.

Modified Dry Grind Corn Processes

Wet fractionation of corn prior to fermentation: enzymatic dry grind corn process

A modified dry grind process which involves corn fractionation in an aqueous medium to recover germ, pericarp fiber and endosperm fiber as valuable coproducts has been developed (Figure 2) (Singh *et al*., 2005). This modified dry grind ethanol process is known as the enzymatic dry grind (E-Mill) corn process. The E-Mill process involves soaking corn kernels in water for a short period of time (6 to 12 hr) followed by coarse grinding and incubating with protease and starch degrading enzymes for 2 to 4 hr (Figure 2). Protease and starch degrading enzymes increase specific gravity of the slurry and aid in separation of individual corn components. Germ and pericarp fiber are recovered by floatation (hydrocylcones) (Singh and Eckhoff 1996; Singh *et al*., 1999; Wahjudi *et al*., 2001). Endosperm fiber can be recovered by use of screens (200 mesh or 0.074 mm opening) either prior to fermentation (Singh *et al*., 2005) or after fermentation (Wang *et al*., 2005). Recovery of endosperm fiber after fermentation reduces the loss of starch in fiber fraction and increases ethanol yield. Rest of the ground corn slurry is processed for ethanol production. E-Mill process benefits dry grind ethanol production in three ways: 1) by adding valuable coproducts (corn germ, pericarp fiber and endosperm fiber) to the process, 2) by increasing the plant capacity and 3) by increasing the amount of protein and reducing the amount of fiber in DDGS. Currently in the US there are two dry grind corn plants using E-Mill process.

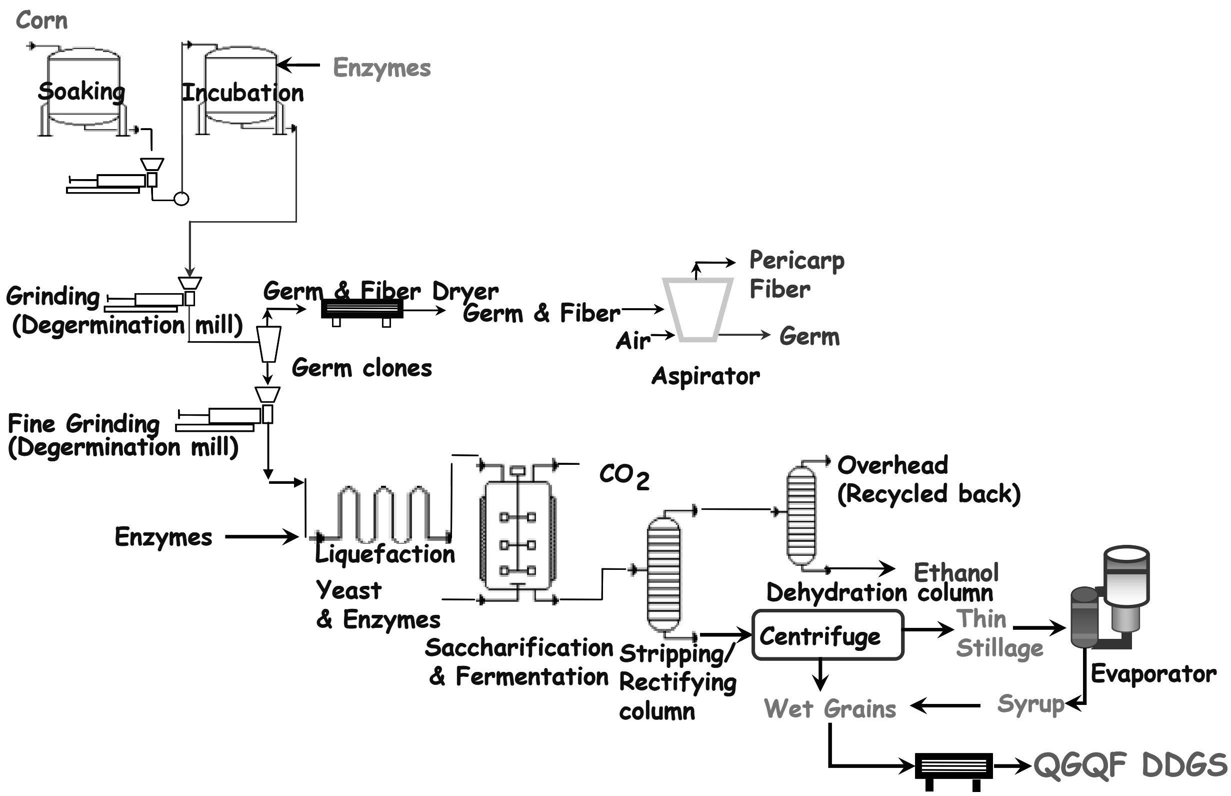

Figure 2. Enzymatic (E-Mill) dry grind corn process.

Comparison of DDDG from E-Mill and Conventional Dry Grind Processes

DDGS protein content was 28 and 58% for conventional and E-Mill processes, respectively (Table 3). Protein content of DDGS for the E-Mill process was higher than protein content of other high protein foodstuffs such as soybean meal (54%). Fat contents of DDGS materials were 12.7 and 4.5% for conventional and E-Mill processes, respectively. No differences were observed in ash contents of DDGS. Due to process modification, DDGS acid detergent fiber (ADF) content was reduced. Compared to conventional DDGS, ADF content was reduced from 10.8 to 2.0% for the E-Mill process (Table 3).

E-Mill process reduces the volume of the DDGS by approximately 70%, increases the protein content and reduced the fiber content compared to the conventional dry grind process. Higher protein and lower fiber content can diversify DDGS as a more valuable foodstuff for nonruminant animals. This is important because the predicted growth in ethanol industry could lead to over production of conventional DDGS and limited market demand as ruminant foodstuffs.

Table 3. Distiller dried grains with solubles (DDGS) composition of conventional (Conv.) and enzymatic milling (E-Mill) dry grind ethanol processes[1].

	Conv.	E-Mill	CGM*	SBM
Crude Protein (%)	28.5	58.5	66.7	53.9
Crude Fat (%)	12.7	4.5	2.8	1.1
Ash (%)	3.6	3.2	--	--
Acid Detergent Fiber (%)	10.8	2.0	6.9	5.9

[1] Data form Singh *et al*. (2005).
[2] CGM: corn gluten meal; SBM: soybean meal.

Dry Fractionation of Corn Prior to Fermentation: Dry Degerm Defiber Process

Another modified dry grind process uses corn dry fractionation to recovery germ and pericarp fiber as valuable coproducts prior to fermentation (Figure 3) (Murthy *et al*., 2006). This process is called dry degerm defiber (3D) process. In 3D process, corn is tempered with hot water or steam for short period of time (5 to 10 min) and ground in a degerminator to remove germ and pericarp from corn endosperm (Duensing *et al*., 2003). During grinding corn endosperm is broken into smaller pieces (grits). Germ is separated from grits with the help of gravity tables (density separation) and fiber is removed from grits by aspiration. Grits are further ground to reduce particle size and processed using conventional dry grind ethanol methods to produce ethanol and DDGS. Endosperm fiber is not recovered in 3D process. Currently in the US there are three dry grind corn plants using 3D process.

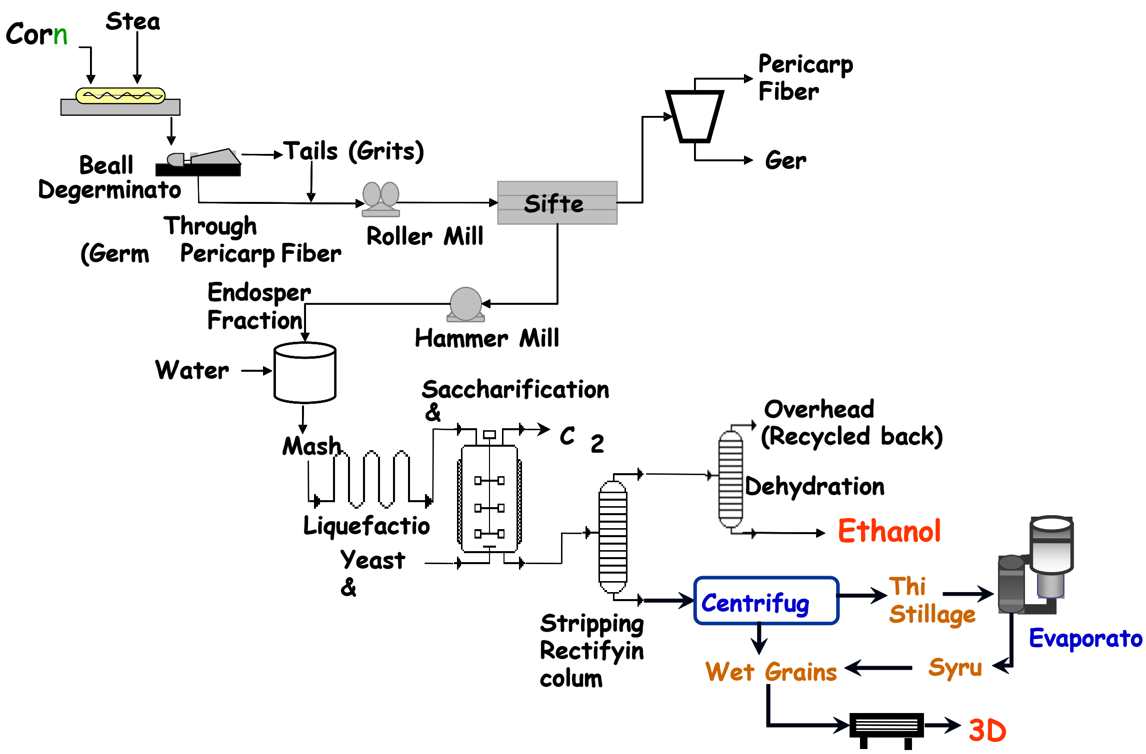

Figure 3. The dry degerm defiber (3D) process.

Comparison of DDGS from Wet and Dry Fractionation Processes

Martinez-Amezcua (2005) evaluated nutrient composition of DDGS samples produced using laboratory wet and dry fractionation processes. In dry fractionation process (3D process) endosperm fiber is not recovered and proteases are not used in the process. To allow comparison of dry fractionation with wet fractionation process, endosperm fiber recovery and use of protease were eliminated from wet fractionation process. The modified wet fractionation process was called quick germ quick fiber (QGQF process). The DDGS from wet and dry fractionation processes were compared to DDGS produced using laboratory conventional dry grind process (Table 4).

Table 4. Distiller dried grains with solubles (DDGS) composition of conventional (Conv.), dry degerm defiber (3D) and quick germ quick fiber (QGQF) dry grind ethanol processes[1]

	Conv.	3D	QGQF
Crude Protein (%)	21.2	23.8	28.0
Crude Fat (%)	13.9	8.7	12.6
Fiber (TDF)	36.4	28.0	25.3
Lysine (%)	0.73	0.63	0.91
Lys, % of CP	3.4	2.5	3.3
Total phosphorus (%)	0.78	0.47	1.12

[1] Data from Martinez-Amezcua (2005).

Crude protein (CP) of both wet and dry fractionation processes was higher than CP of conventional DDGS. This increase in CP was expected because germ and fiber dilute the protein content in conventional DDGS and their removal will result in higher protein content. Among the two fractionation process, CP of wet process (QGQF process) was higher than dry process (3D process). The higher CP of the QGQF DDGS was possibly due to cleaner separation of germ and fiber from endosperm (less loss of protein) and due to leaching of soluble proteins during the soaking process; the water soluble fraction was used in fermentation process and was concentrated in the final DDGS. Water soluble proteins (albumins and globulins) leach out of germ during soaking in wet fractionation process and get concentrated in DDGS. Whereas in dry fractionation process these protein are lost with the germ fraction and are not recovered in DDGS. That is why the lysine content of QGQF DDGS was higher than 3D or Conventional DDGS. The DDGS produced by the 3D and QGQF processes had lower concentrations of fat than the conventional DDGS. The lower fat was due to the removal of germ. Total dietary fiber was reduced from 36% in the conventional DDGS sample to 28 and 25% by the 3D and QGQF methods. The P content of DDGS was reduced by the 3D process but was increased by the QGQF process. A reduction for 3D was expected since much of the germ is removed and almost 90% of the phytic acid is present in the germ of corn (Ravindran *et al*., 1995; Rebollar and Mateos, 1999). The increase in P for the QGQF was unexpected and may have been due to leaching of P during the 12 hr soaking process.

Removal of Fiber from DDGS: Elusieve Process

A process called elusieve has been developed to separate fiber from distillers dried grains with solubles (DDGS). Separation of fiber from DDGS in a dry grind ethanol plant increases protein and fat content and reduces fiber content in the resulting DDGS. Fiber produced from the elusive process can be used for recovery of other value added coproducts. The elusieve process uses sieving and elutriation to separate fiber from DDGS (Figure 4).

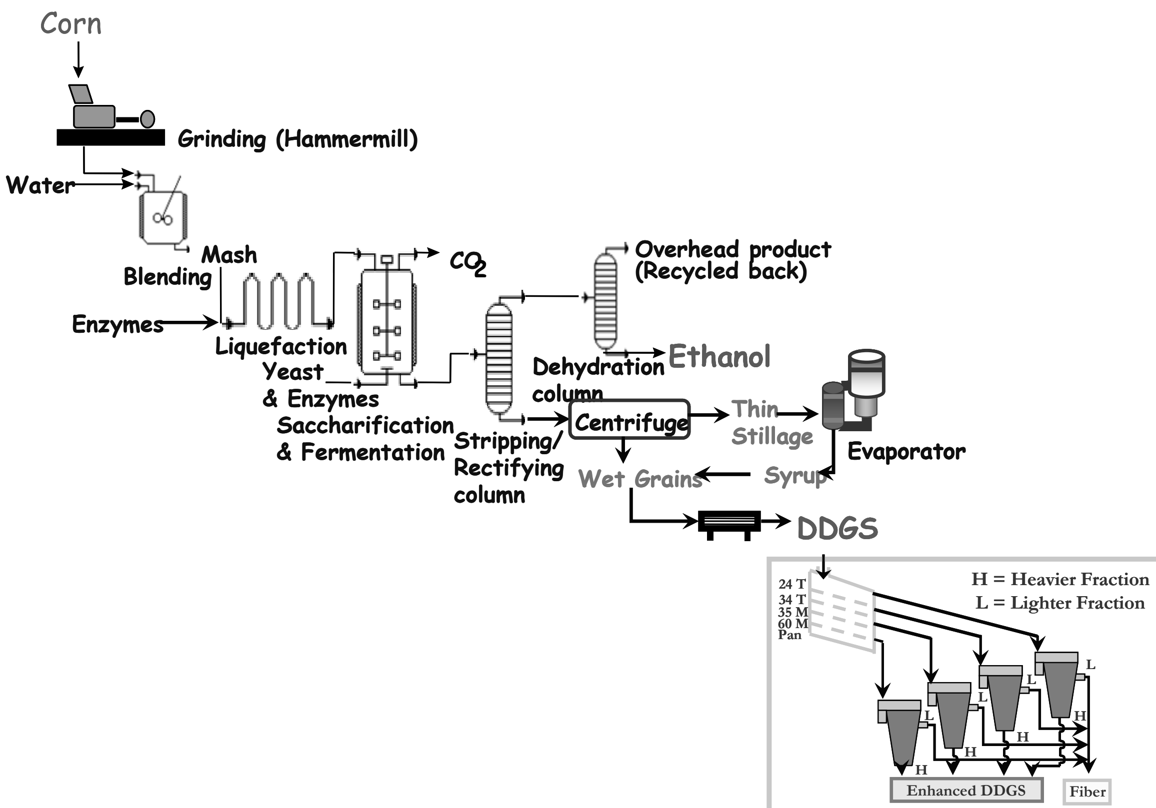

Figure 4. Elusieve process to remove fiber from DDGS.

Material carried to the top of the elutriation column is called "lighter fraction" or "fiber fraction" and material that settled to the bottom of the column is called "heavier fraction" or "enhanced DDGS". Conventional DDGS samples, obtained from dry grind corn plants, were processed using elusive technology. By adjusting process parameters, elusive processing increased protein and fat contents of enhanced DDGS from 28 to 41% and 12 to 14%, respectively, and reduced neutral detergent fiber content from 32 to 19%, compared to the original DDGS (Table 5 and 6.) (Srinivasan *et al.*, 2005). Elusive process is low cost solution to the reduce fiber content of conventional DDGS. The payback period for elusieve process for a dry grind ethanol plant producing 40 million gallons per year was estimated to be less than two years (Srinivasan *et al.*, 2006).

Table 5. Composition of different size materials after sieving of commercial DDGS sample[1].

Size Category	Nominal Particle Size (Microns)	% (w/w) Retained on Screen	Protein (%)	Fat (%)	Neutral Detergent Fiber (%)
Original DDGS	All	100	33.6	12.5	32.5
Material on 24T[2]	>869	27	29.3	12.5	33.4
Material on 34T	582 to 869	19.4	26.9	11.3	37.8
Material on 35M	447 to 582	13.3	31.2	10.9	33.6
Material on 60M	234 to 447	20.1	37.5	11.3	29.3
Material in Pan	<234	20.2	42.2	12.9	19.0

[1] Data from Srinivasan *et al*. (2005).
[2] Screen size, M and T refer to market grade cloth and tensil bolt cloth.

Table 6. Elutriation (aspiration) of fiber from material on 24T screen[1].

Fraction	Neutral Detergent Fiber (%)	Protein (%)	Fat (%)
Lighter Fraction	53.3	19.3	7.05
Material on 24T	33.4	29.3	12.5
Enhanced DDGS	32.6	35.6	14.2

[1] Data from Srinivasan *et al.* (2005).

Conclusions

Modified dry grind processes have been developed that involve fractionation of corn at the beginning of the dry grind process and recovery of nonfermentable components (germ, pericarp and endosperm fiber) prior to fermentation. Other modified processes involve fractionation of conventional DDGS recover fiber as a coproduct. These technologies reduce the amount of DDGS produced in a dry grind ethanol plant and improve its nutritional composition.

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