Dry Grind Corn Processing – New Technologies

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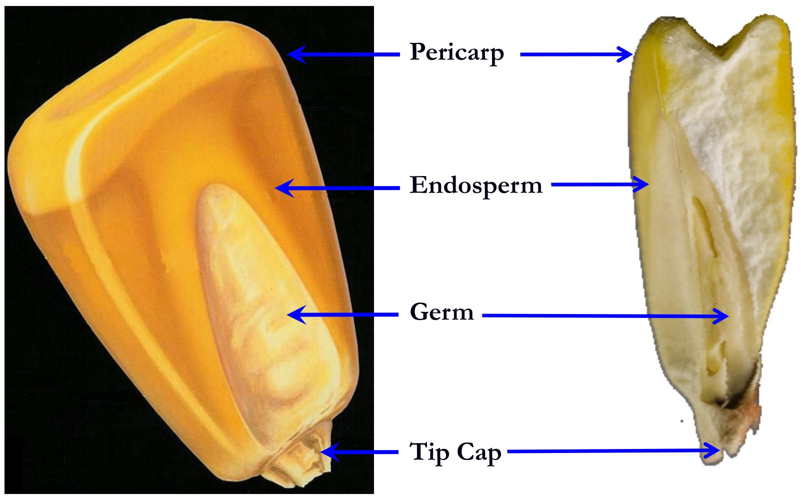
Presentation Outline

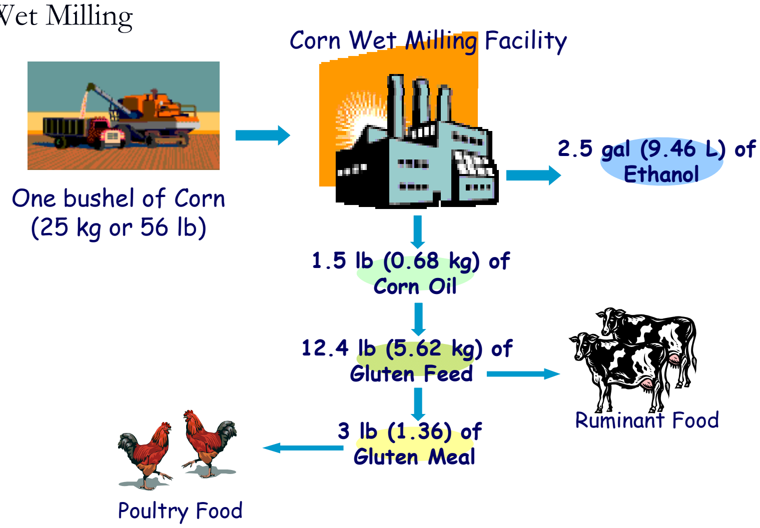
- Corn Kernel Composition
- Corn Processing Terminology
- Conventional Dry Grind Process
- New Technologies

Composition of Corn Kernel



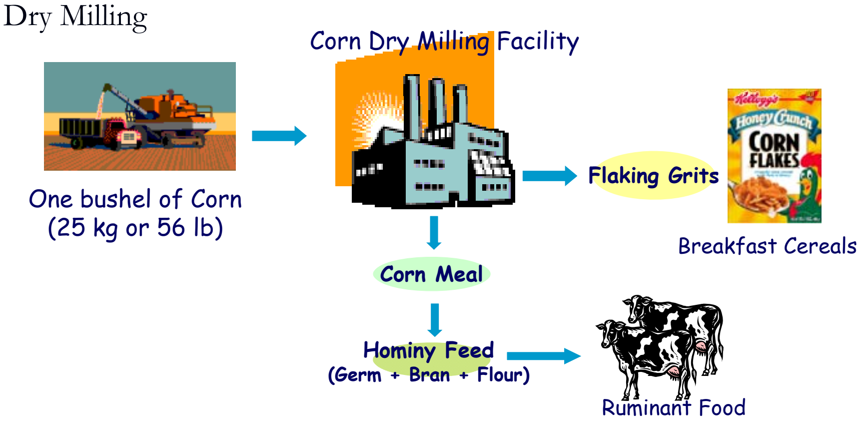
Corn Milling Processes

1. Wet Milling



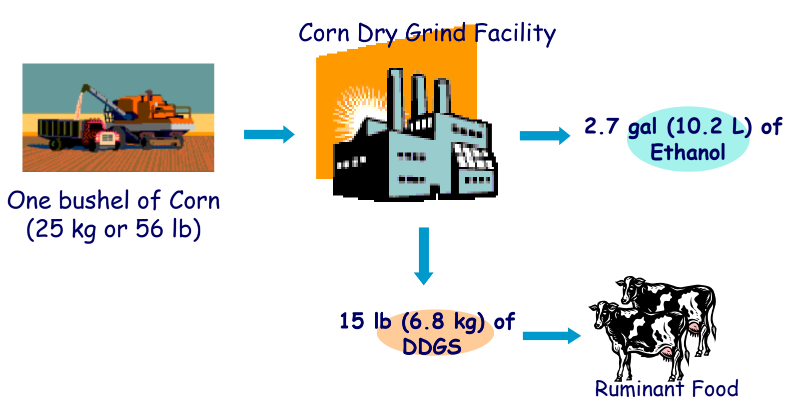
Corn Milling Processes (Cont.)

2. Dry Milling

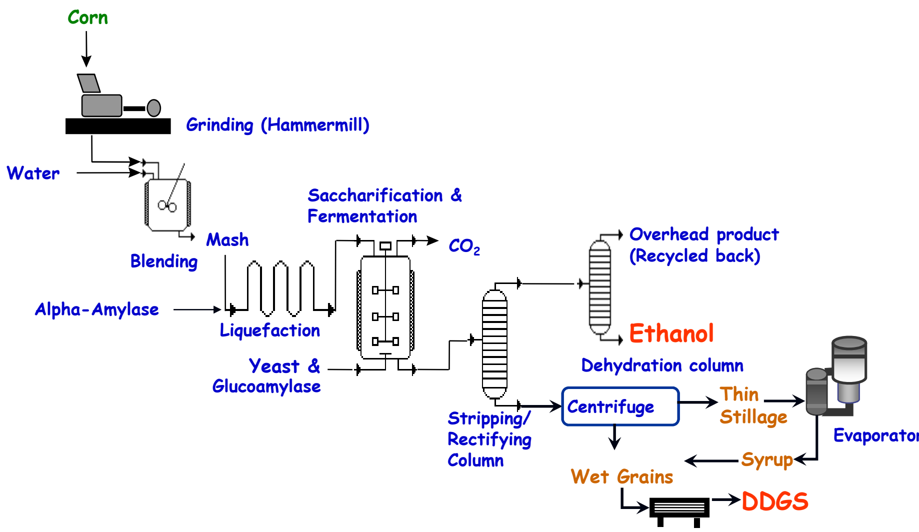


Corn Milling Processes (Cont.)

3. Dry Grind



Conventional Dry Grind Process



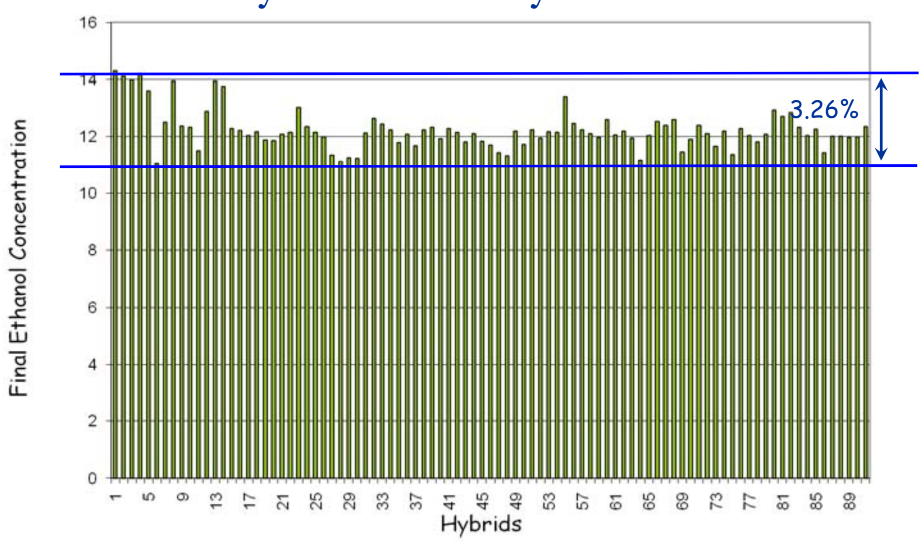
New Technologies in Dry Grind Ethanol Production:

Feedstock Development
Conventional Corn

High Fermentable Corn (HFC) Hybrids

- Typically Dry Grind Ethanol yield
  - 2.7 gallons/bushel
- Range
  - 2.65 to 2.75 gallons/bushel
  - 3-4% difference in ethanol yield

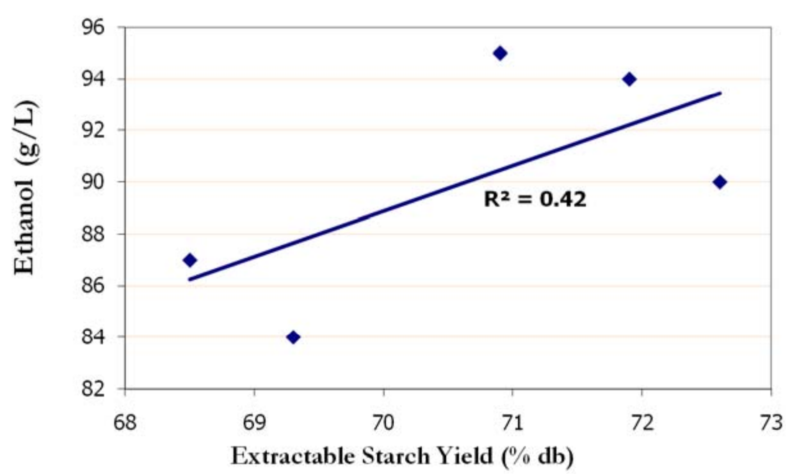
Effect of Hybrid Variability on Ethanol Yield



Singh, V. and Graeber, J.V. 2005. Effect of corn hybrid variability and planting location on ethanol yields. Trans. ASAE 48:709-714

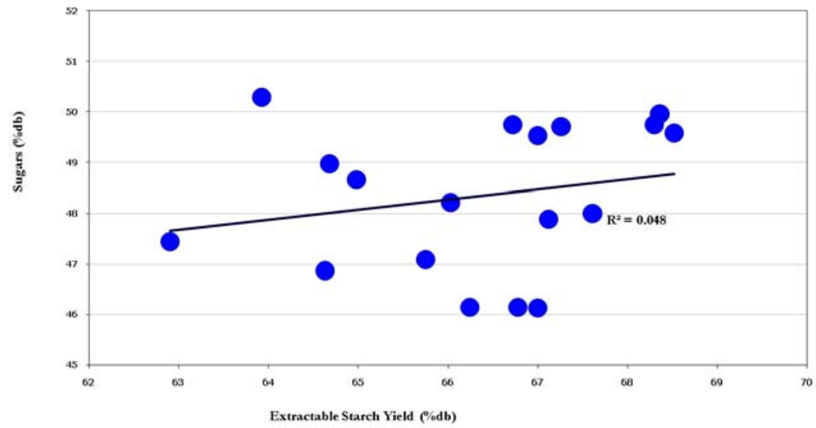
Correlation between Starch and Ethanol

Starch Yield and Ethanol (Dien et al 2002)



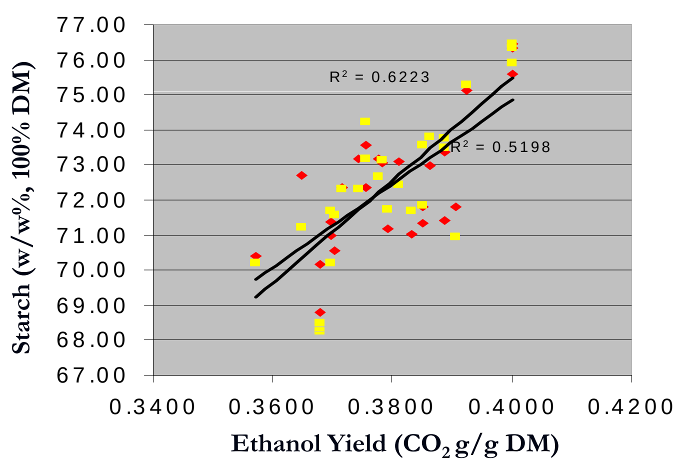
Dien, B.S., Bothast, R.J., Iten, L.B., Barrios, L. and Eckhoff, S.R. 2002. Fate of Bt protein and influence of corn hybrid on ethanol production. Cereal Chem. 79:582-585

Starch Yield and Sugars (Pruiett 2002)



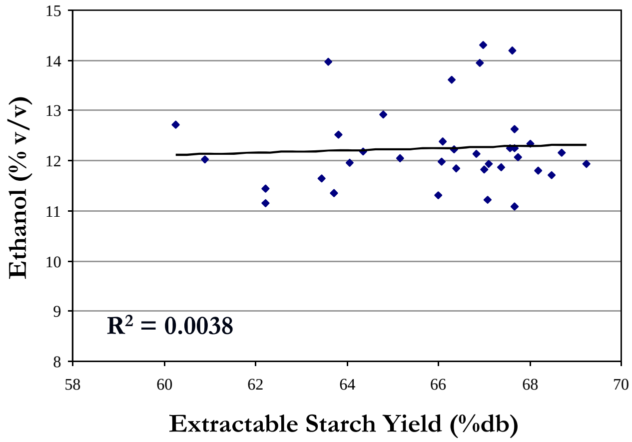
Pruiett, L. 2002. Unpublished Data. University of Illinois.

Starch Content and Ethanol Yield (Haefele et al 2004)



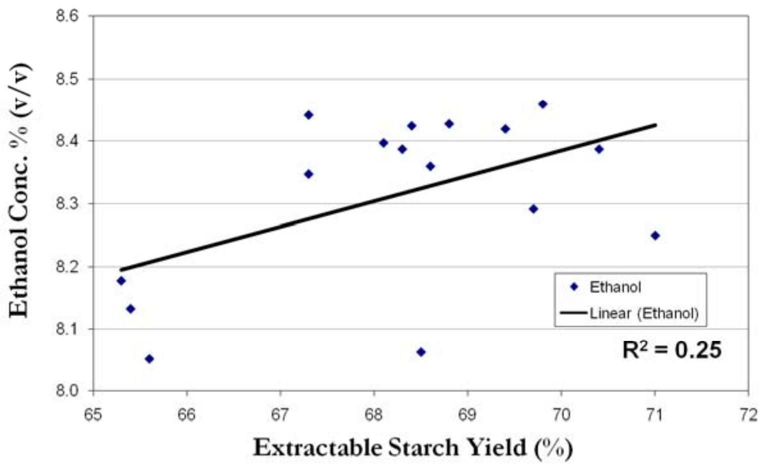
Haefele, D., Owens, F., O'Bryan, K. and Sevenich, D. 2004. Selection and optimization of corn hybrids for fuel ethanol production. 21 pp. Proc. Am. Seed Trade Assoc. 59th Annual Corn and Sorghum Research Conference, Chicago, IL.

Starch Yield and Ethanol Conc. (Singh and Graeber 2005)



Singh, V. and Graeber, J.V. 2005. Effect of corn hybrid variability and planting location on ethanol yields. Trans. ASAE 48:709-714

Starch Yield and Ethanol Conc. (Zhan et al, 2005) - Sorghum

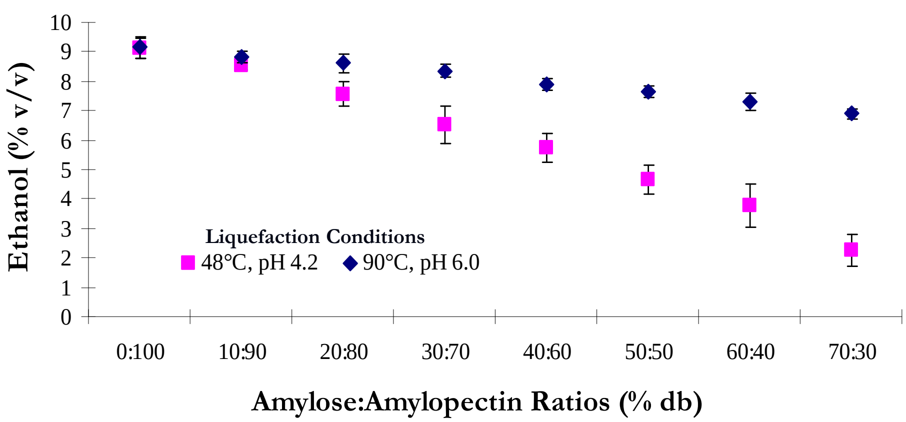


Zhan, X., Wang, D, Tuinstra, M.R., Bean, S., Sieb, P.A. and Sun, X.S. 2003. Ethanol and lactic acid production as affected by sorghum genotype and location. Industrial Crops and Products 18:245-255

Why Poor Correlation Between Starch and Ethanol?

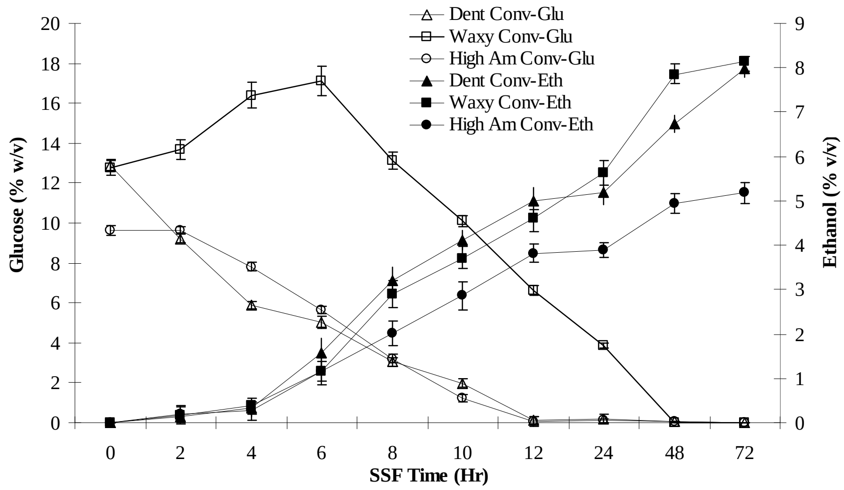
- Starch is very broad term
  - Amylose
  - Amylopectin
    - Are both amylose and amylopectin equally digestible?
  - Resistant Starch
    - Resistant starch (RS) is part of starch that is resistant to enzymatic hydrolysis
    - RS acts as fiber and is not hydrolyzed
- Corn contains other micronutrients that affect dry grind fermentation process

Effect of Amylose and Amylopectin Content in Starch on Ethanol Yield



Sharma, V., Rausch, K.D, Tumbleson, M.E. and Singh, V. 2007. Granular starch hydrolyzing and conventional enzyme comparison on maize starch hydrolysis with different amylose:amylopectin ratios. Starch/Starke 59:549-556.

Effect of Amylose and Amylopectin Content in Corn on Ethanol Yield



Sharma, V., Rausch, K.D, Tumbleson, M.E. and Singh, V. 2007. Granular starch hydrolyzing and conventional enzyme comparison on maize starch hydrolysis with different amylose:amylopectin ratios. Starch/Starke 59:549-556.

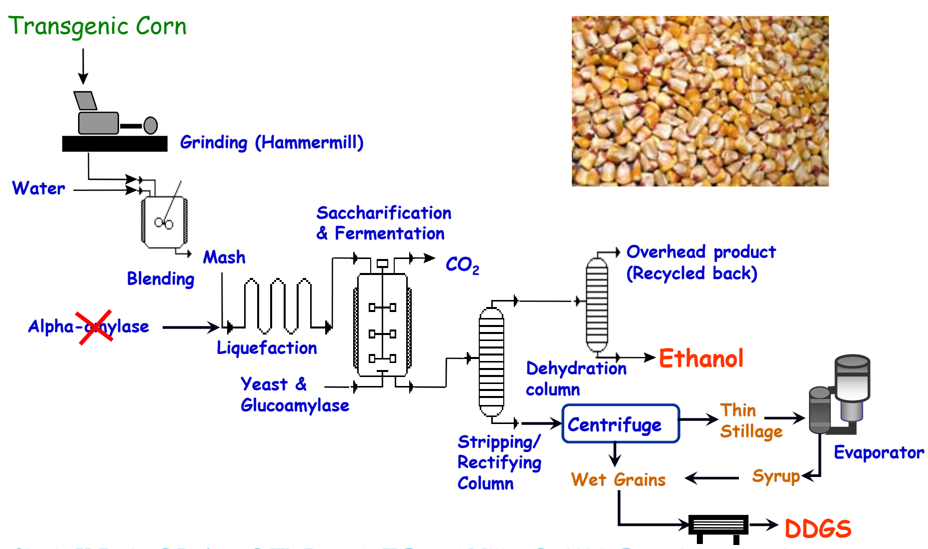
Feedstock Development: Conventional Corn

- Variation in ethanol potential among yellow dent corn hybrids
  - 3 to 4% variation between a high performing and low performing corn hybrids
- Ethanol potential cannot be predicted based on starch content alone
- Determination for ethanol potential of corn hybrids should be done based on fermentation assay

Emerging Technologies in Dry Grind Ethanol Production:

Feedstock Development of New Corn

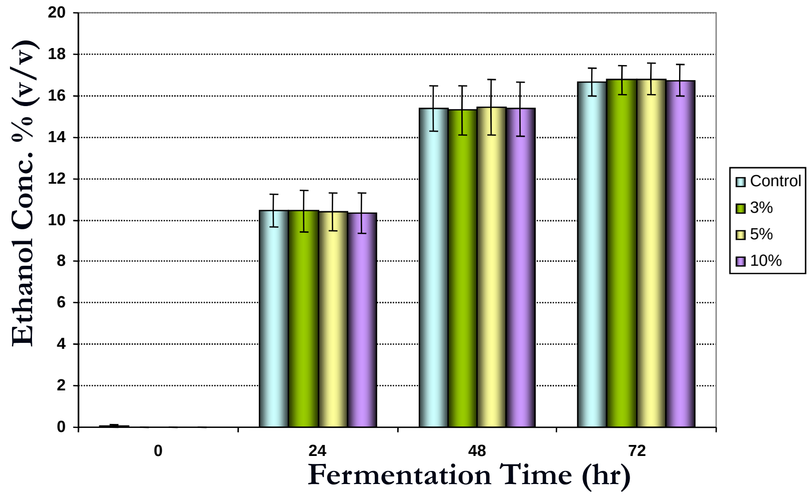
Transgenic Corn for Dry Grind Process



Singh, V, Batie, C.J., Aux, G.W., Rausch, K.D. and Miller, C. 2006. Dry grind processing of corn with endogenous liquefaction enzymes. Cereal Chem. 83:317-320.

500 ml Fermentations

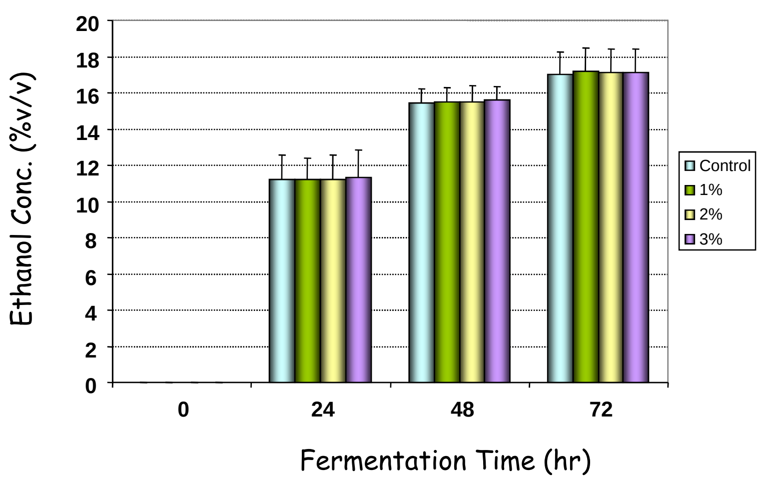
Control vs 3, 5 and 10% amylase corn addition



Singh, V, Batie, C.J., Aux, G.W., Rausch, K.D. and Miller, C. 2006. Dry grind Processing of corn with endogenous liquefaction enzymes. Cereal Chem. 83:317-320.

500 ml Fermentations

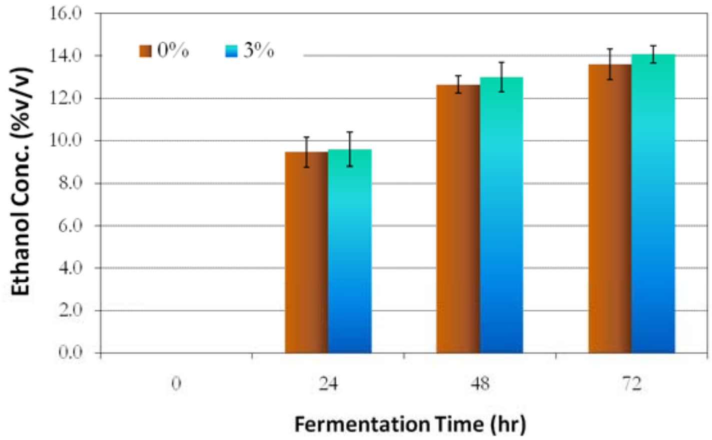
Control vs 1, 2 and 3% amylase corn addition



Singh, V, Batie, C.J., Aux, G.W., Rausch, K.D. and Miller, C. 2006. Dry grind Processing of corn with endogenous liquefaction enzymes. Cereal Chem. 83:317-320.

15 L Fermentations

Control vs 3% amylase corn addition



DDGS Composition

Components	3% amylase corn addition	Control Treatment
Crude Protein (%)	26.1 ± 0.2	25.8 ± 0.1
Crude Fat (%)	14.1 ± 0.1	13.6 ± 0.2
Crude Fiber (%)	6.6 ± 0.1	6.8 ± 0.1
Ash (%)	3.78 ± 0.1	3.35 ± 0.1

No significant difference in composition of DDGS for 3% amylase corn addition and control treatment

Singh, V, Batie, C.J., Aux, G.W., Rausch, K.D. and Miller, C. 2006. Dry grind Processing of corn with endogenous liquefaction enzymes. Cereal Chem. 83:317-320.

Dry Milling (1 kg Procedure)

Fractions	Control	0.1% Amy	1.0% Amy	10% Amy
+5(Large Grits)	31.42	33.23	30.59	28.73
-10+24 (Small Grits)	29.88	28.91	31.79	31.46
-24(Fines)	18.01	17.47	16.65	18.18
Germ	13.02	12.88	13.32	13.79
Pericarp	7.45	7.57	7.64	7.60
Total	99.78	100.06	99.98	99.76

Singh, V, Batie, C.J., Rausch, K.D. and Miller, C. 2006. Wet and dry milling properties of dent corn with addition of amylase corn. Cereal Chem 83:321-323

Wet Milling (1 kg Procedure)

Fractions	Control	0.1% Amy	1.0% Amy	10% Amy
Solubles (%)	4.52	4.40	4.38	4.82
Germ (%)	6.21	6.35	6.43	6.74
Fiber (%)	12.36	11.72	11.98	11.90
Starch (%)	67.24	67.66	67.33	66.19
Gluten (%)	10.25	10.18	10.16	10.65
Total (%)	100.59	100.31	100.29	100.30

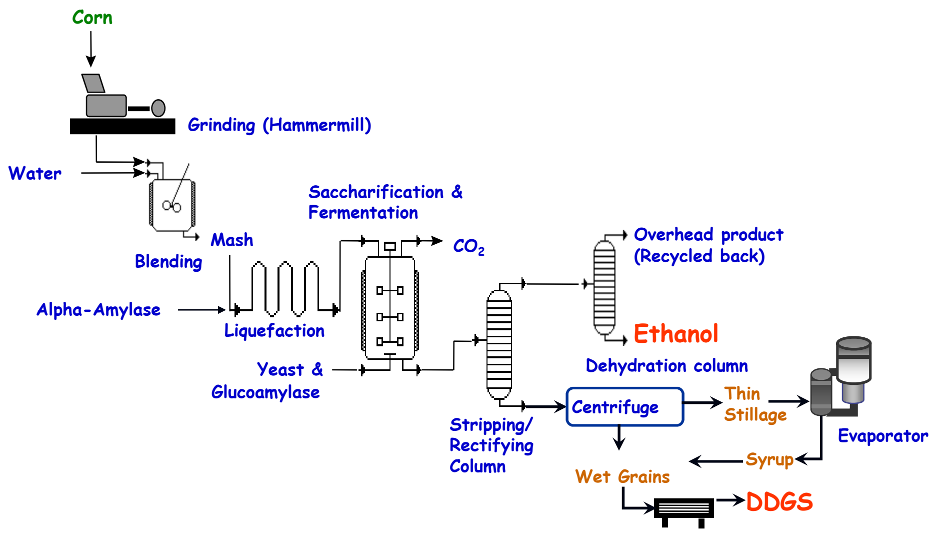
Singh, V, Batie, C.J., Rausch, K.D. and Miller, C. 2006. Wet and dry milling properties of dent corn with addition of amylase corn. Cereal Chem 83:321-323

Feedstock Development: Transgenic Corn

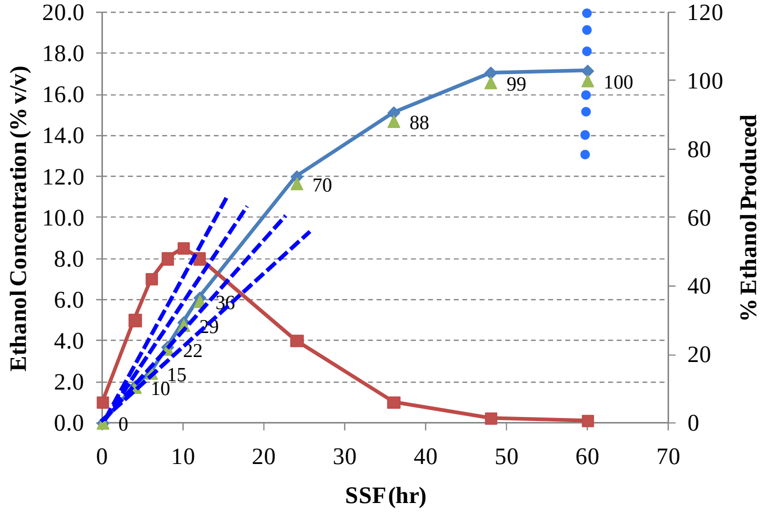
- Reduces requirement of exogenous alpha amylase
- Only 3% amylase corn addition is required with dent corn for complete liquefaction
- No differences in DDGS composition between 3% amylase corn treatment and conventional treatment

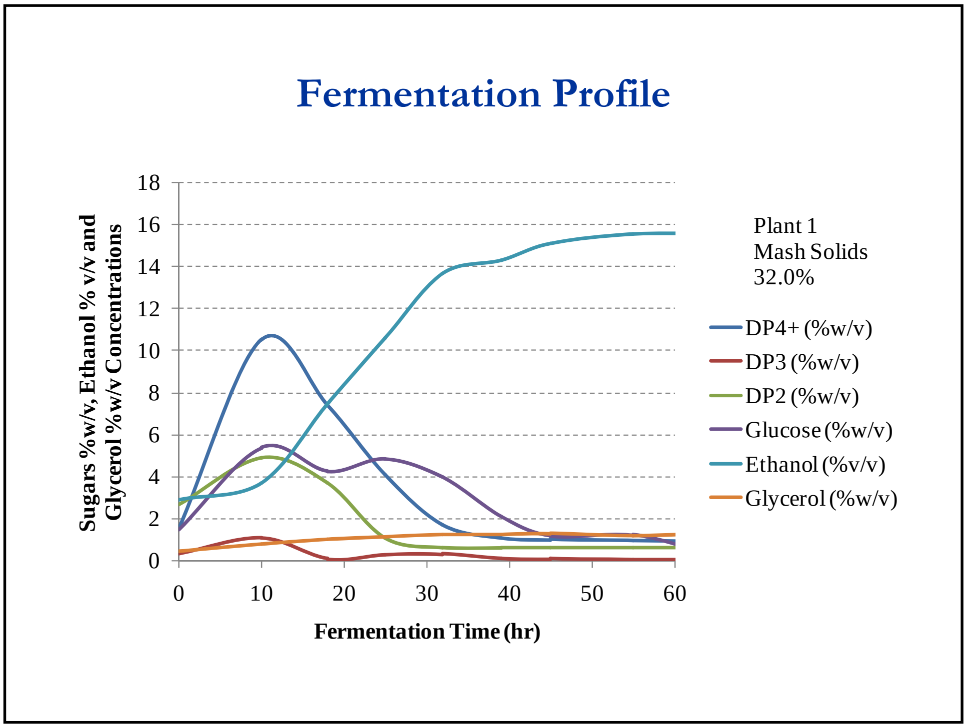
New Technologies that Affect Dry Grind Ethanol Fermentation

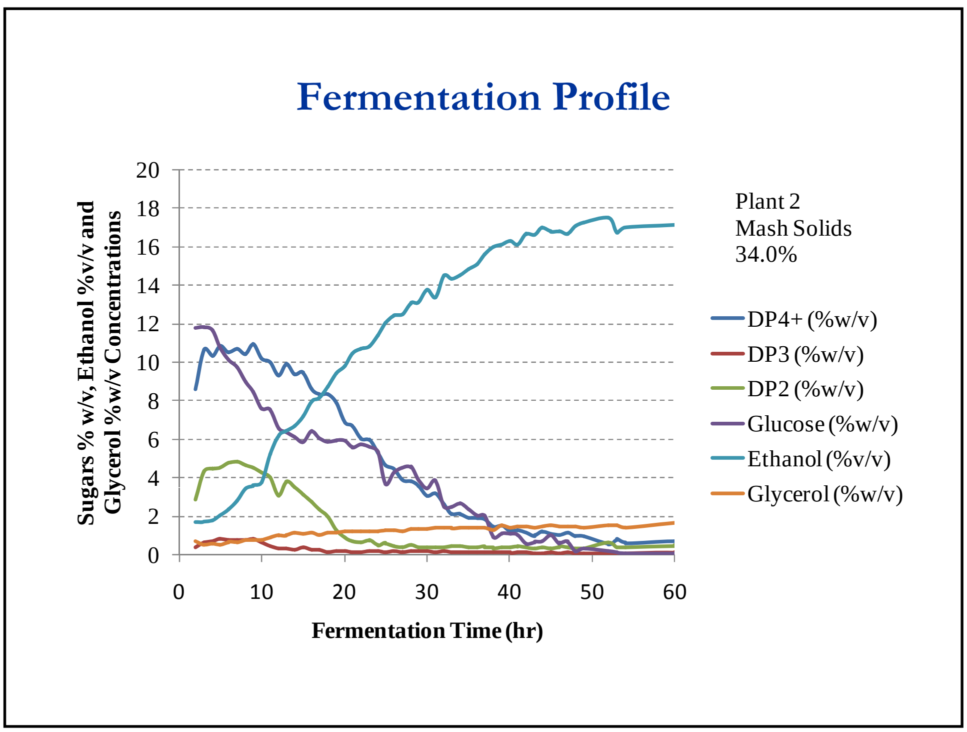
Conventional Dry Grind Process



Fermentation Profile




Fermentation Profile
Sugars %w/v, Ethanol % v/v and Glycerol %w/v Concentrations
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Fermentation Time (hr)
Plant 1
Mash Solids
32.0%
DP4+ (%w/v)
DP3 (%w/v)
DP2 (%w/v)
Glucose (%w/v)
Ethanol (%v/v)
Glycerol (%w/v)

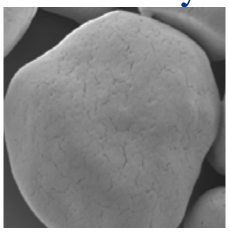

Fermentation Profile
Sugars % w/v, Ethanol %v/v and Glycerol %w/v Concentrations
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Fermentation Time (hr)
Plant 2
Mash Solids
34.0%
DP4+ (%w/v)
DP3 (%w/v)
DP2 (%w/v)
Glucose (%w/v)
Ethanol (%v/v)
Glycerol (%w/v)

New Technology:
Granular Starch Hydrolyzing Enzymes

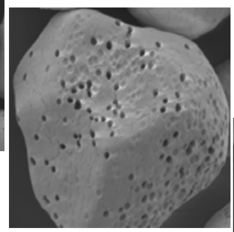
Granular Starch Hydrolyzing (GSH) Enzymes

- These enzymes have high granular starch (raw starch or native starch) hydrolyzing activity
  - Blend of alpha and glucoamylases
- Can liquefy and saccharify starch into glucose at low temperature (< 48°C)
  - Stargen 001, Genencor International
  - BPX, Novozymes NA
- These enzymes can be used for all cereal grains

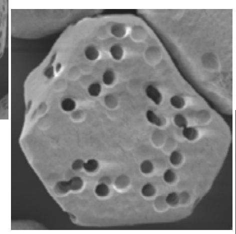
Corn Starch Treated with Granular Starch Hydrolyzing Alpha and Glucoamylase pH 4.5, 32°C



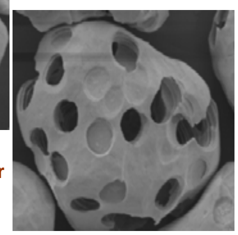
Granular Starch



Granular Starch Incubated with GSHE, 2 hr



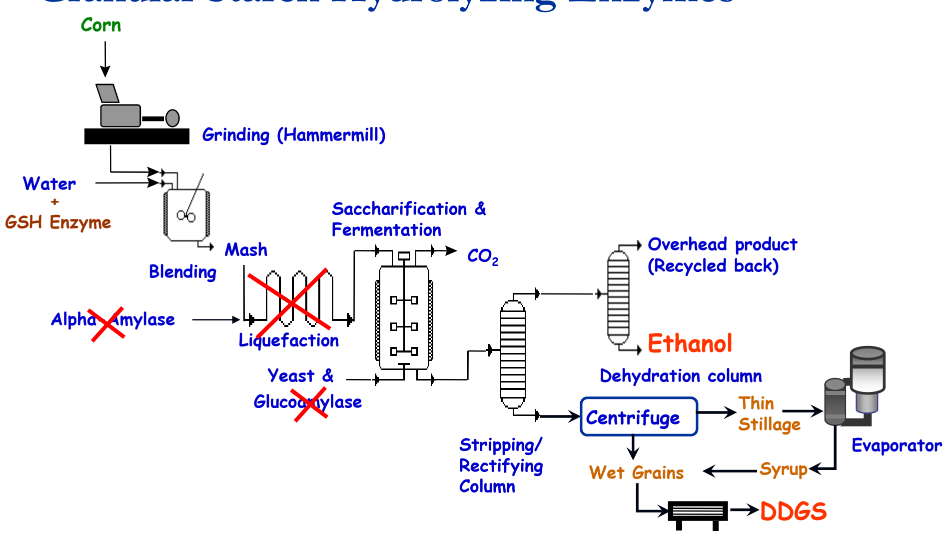
Granular Starch Incubated with GSHE, 4 hr



Granular Starch Incubated with GSHE, 8 hr

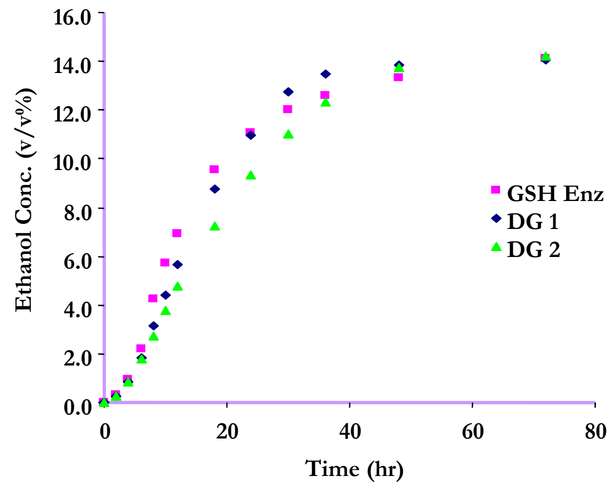
Source: USDA/ARS/ERRC and Genencor International

Granular Starch Hydrolyzing Enzymes



Wang, P., Singh, V., Xue, H., Johnston, D.B., Rausch, K.D. and Tumbleson, M.E. 2006. Comparison of raw starch hydrolyzing enzyme with conventional liquefaction and saccharification enzymes in dry grind corn processing. Cereal Chem. 84(1):10-14.

Results: Ethanol Concentration



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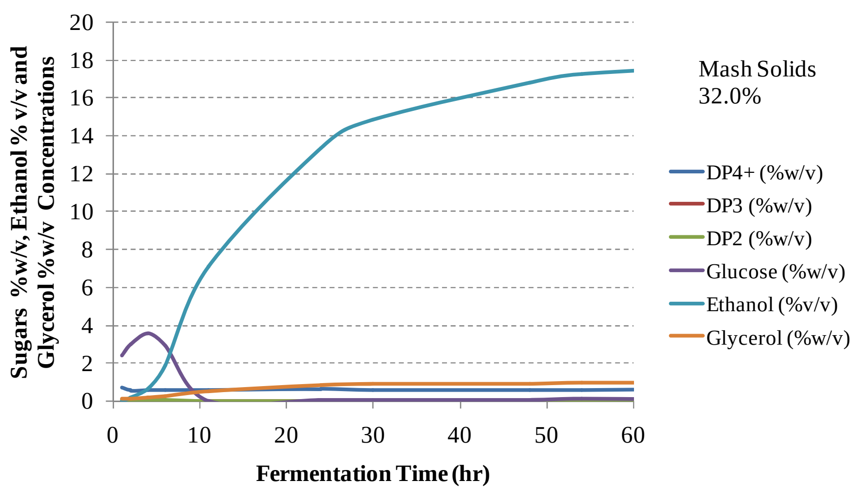
Fermentation Profiles with GSH Enzymes



Granular Starch Hydrolyzing Enzymes

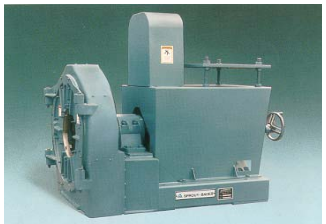
- Final ethanol yield with GSH enzymes is comparable to conventional enzymes
- Glucose, maltose and maltotriose concentrations are consistently low with GSH enzymes throughout fermentation
- GSH enzymes work at same temperature conditions as conventional SSF
  - With GSH enzymes simultaneous liquefaction, saccharification and fermentation can be conducted
- GSH enzymes are commercially being used
  - Corn ethanol production in US
  - Rye, wheat, broken rice ethanol production in Europe and Asia

New Technology: Corn Fractionation

Corn Wet Fractionation

- **Involves soaking of corn or other cereal grains (wheat, sorghum) in water and separation of coproducts in aqueous medium**
- **Uses wet grinding mills, hydrocyclones and screens for separation**
  - Quick Germ Process, Univ. of Illinois (UIUC)
  - Quick Germ Quick Fiber Process, UIUC (Licensed to MPI Inc.)
  - **Enzymatic Dry Grind Process, UIUC & US Dept. of Ag.**
  - Hydromilling Process, CVP, LLC (Joint venture between AMG Inc, Centrisys Corporation and QTI)

Wet Fractionation Equipment

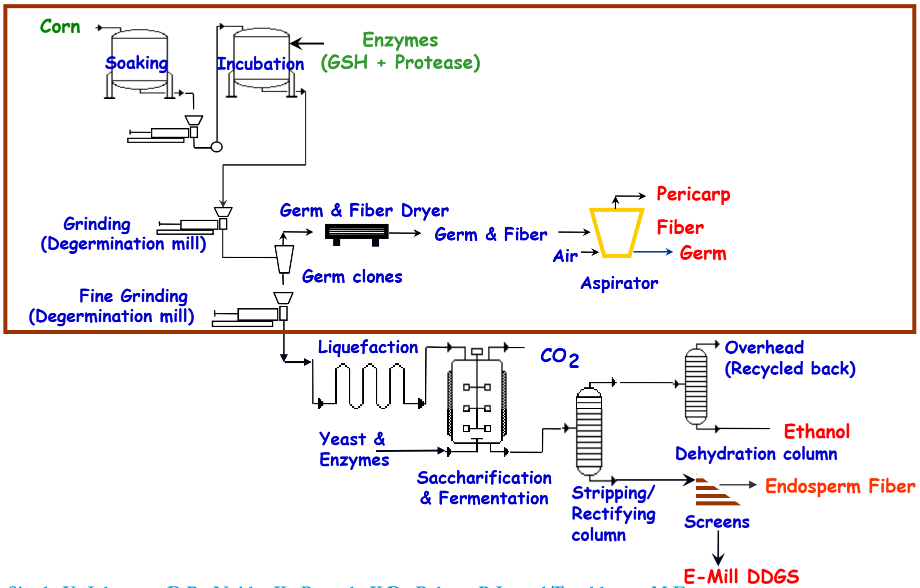


Wet Degermination Mill

Hydrocyclones

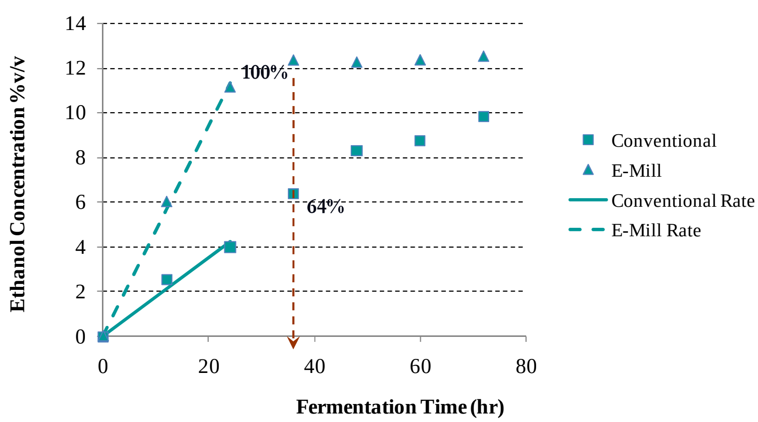
Screens

Enzymatic Dry Grind Corn Process (E-Mill)



Singh, V., Johnston, D.B., Naidu, K., Rausch, K.D., Belyea, R.L. and Tumbleson, M.E. 2005. Comparison of modified dry grind corn processes for fermentation characteristics and DDGS composition. Cereal Chem. 82:187-190.

Fermentation Profiles: Conventional and E-Mill Processes



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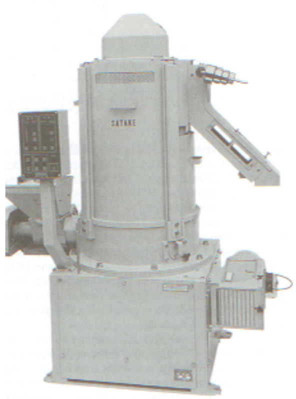
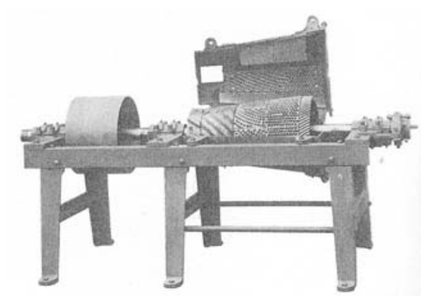
Corn Dry Fractionation

- **Involves tempering of corn or other cereal grains (wheat, sorghum) with steam or hot water and dry separation of coproducts**
- **Uses dry degerminators, gravity tables and sifters for separation**
  - **Dry Degerm Defiber Process (3D process), UIUC**
  - FWS Process, FWS Technologies, Winnipeg, MB, Canada
  - BFrac Process, Poet
  - CTP Process, Cereal Process Technologies, LLC
  - Extrax Process, Renessen LLC
  - Mor Technology Inc.
  - DTS, Delta-T Corporation
  - Applied Milling System, ICM Inc.

Dry Fractionation Equipment



Satake Degerminator

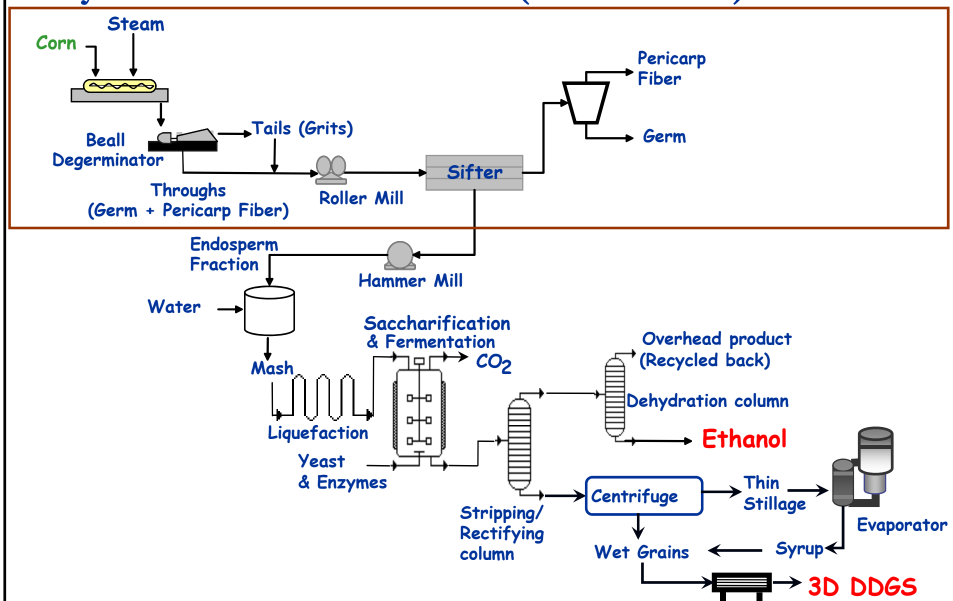


Beall Degerminator

Dry Degermination Mills

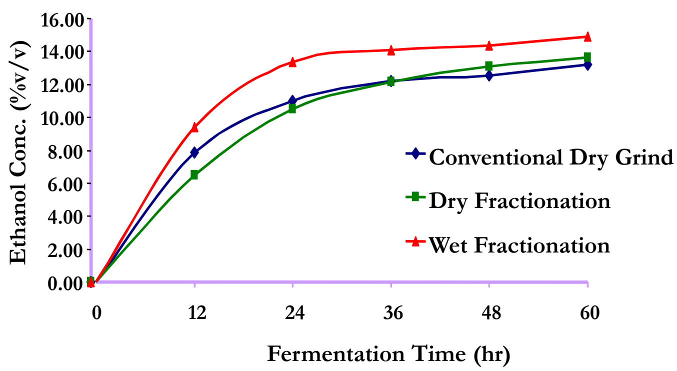
(Duensing et al. 2003, Corn Dry Milling, Corn Chemistry and Technology Book)

Dry Fractionation Process (3D Process)



Murthy, G.S., Singh, V., Johnston, D.B., Rausch, K.D. and Tumbleson, M.E. 2006. Evaluation and strategies to improve fermentation characteristics of modified dry grind corn processes. Cereal Chem. 83:455-459.

Comparison of Wet and Dry Fractionation: Fermentation Profiles



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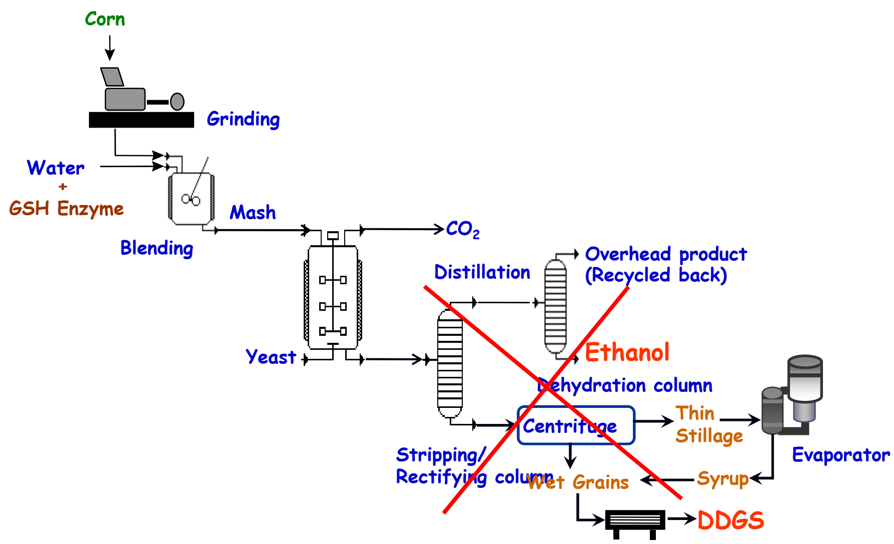
Corn Fractionation Processes

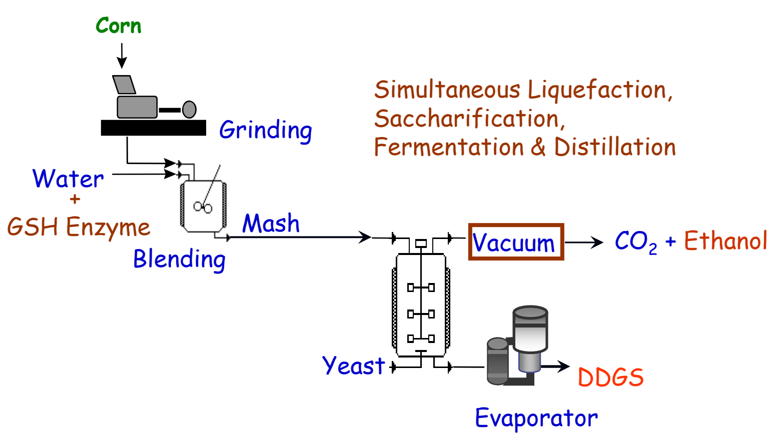
- Corn fractionation (wet or dry) prior to fermentation
  - Reduces volume of DDGS produced
  - Recovers germ and fiber as valuable coproducts
  - Increases final ethanol concentration
- Wet fractionation process compared to dry fractionation process
  - Has higher rate of fermentation
  - Has higher final ethanol concentration

New Technology:
Simultaneous Liquefaction, Saccharification, Fermentation and Distillation (SLSFD)

SLSFD Process

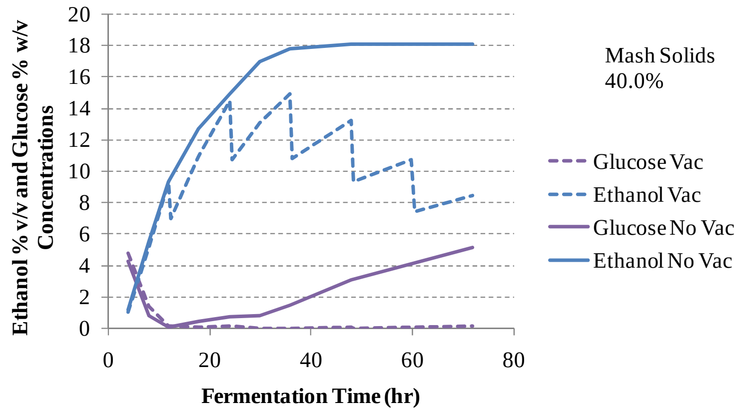


SLSFD Process



Shihadeh, J.K., Rausch K.D., Tumbleson, M.E. and Singh, V. 2007. Vacuum fermentation for in situ removal of ethanol during simultaneous liquefaction, saccharification, and fermentation. Proc. American Association of Cereal Chemists. Abstract No. 52:A28. San Antonio, TX.

SLSFD Process



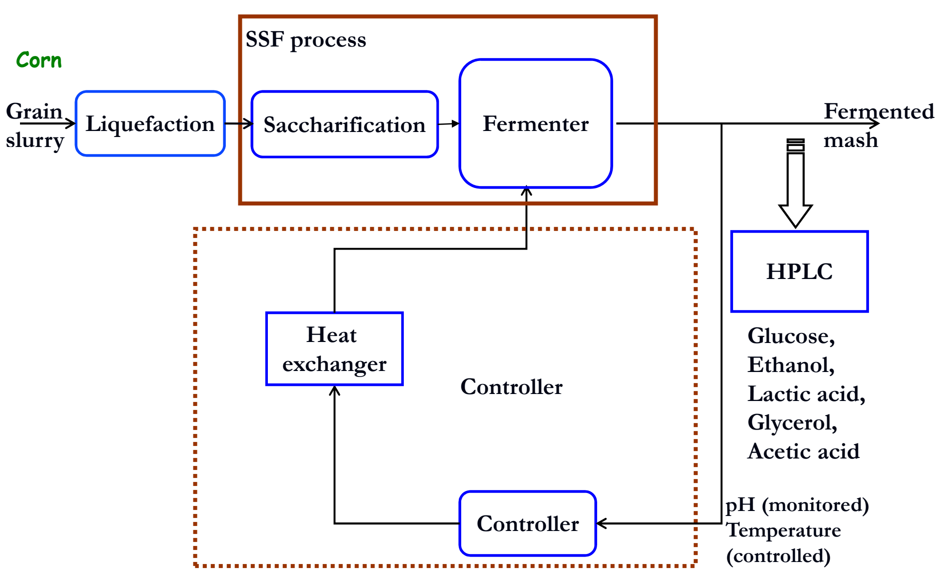
Shihadeh, J.K., Rausch K.D., Tumbleson, M.E. and Singh, V. 2007. Vacuum fermentation for in situ removal of ethanol during simultaneous liquefaction, saccharification, and fermentation. Proc. American Association of Cereal Chemists. Abstract No. 52:A28. San Antonio, TX.

SLSFD Process

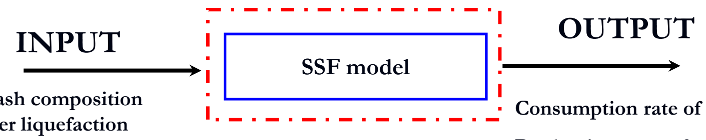
- Slurry solids as high as 40 to 45% can be used
- No substrate or product inhibition
- Less water use in process
- No whole stillage processing required
  - No thin stillage generation
- Higher ethanol productivity

New Technology:
Optimal Control of SSF Process

Conventional Controller Schematic



SSF Model: Input and Output



Mash composition after liquefaction

Enzyme dosage

Enzyme activity

Yeast dosage

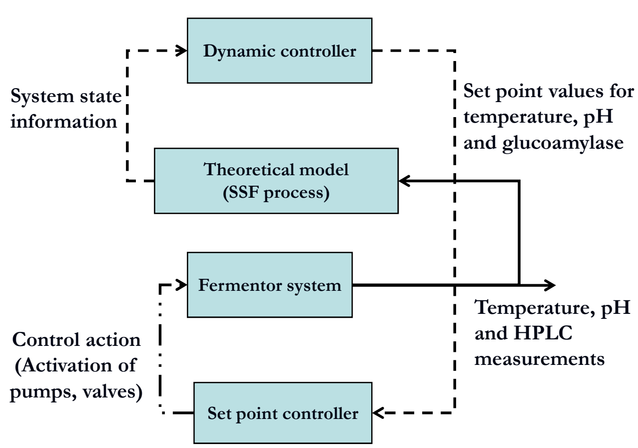
Temperature, pH of fermentor

Consumption rate of glucose

Production rates of ethanol, yeast cell mass, acetic acid, lactic acid and glycerol

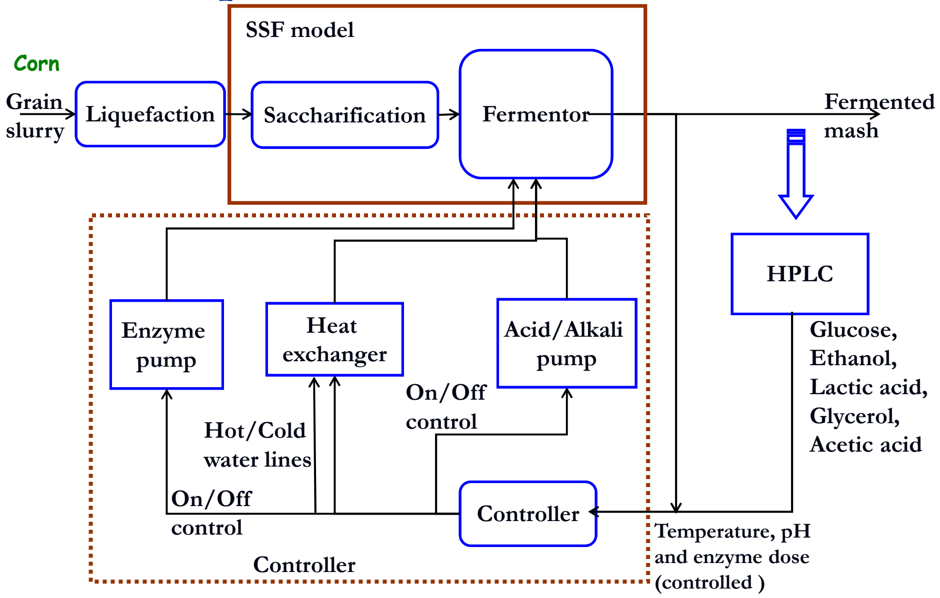
Murthy, G.S. 2006. Development of a controller for fermentation in the dry grind corn process. PhD. Thesis, University of Illinois at Urbana-Champaign, Urbana, IL.

Overall Control System Architecture



Murthy, G.S. 2006. Development of a controller for fermentation in the dry grind corn process. PhD. Thesis, University of Illinois at Urbana-Champaign, Urbana, IL.

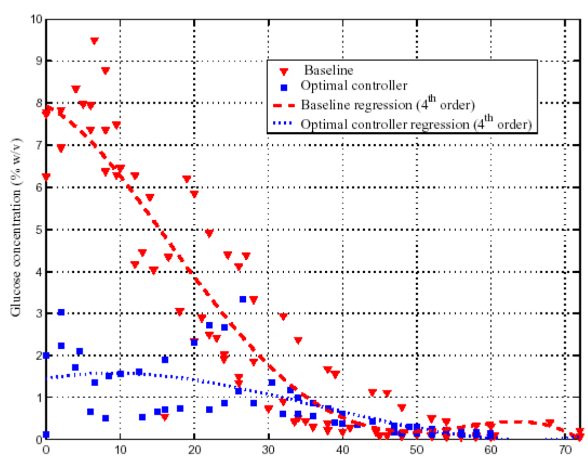
Optimal Controller Schematic



Murthy, G.S. 2006. PhD. Thesis

Optimal Controller: Lab Results

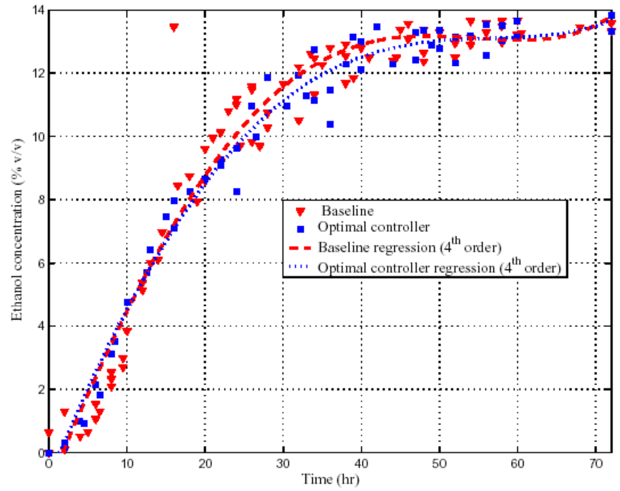
- 50% reduction in glucoamylase dose in a conventional dry grind ethanol plant with optimal controller



Murthy, G.S. 2006. Development of a controller for fermentation in the dry grind corn process. PhD. Thesis, University of Illinois at Urbana-Champaign, Urbana, IL.

Optimal Controller: Lab Results

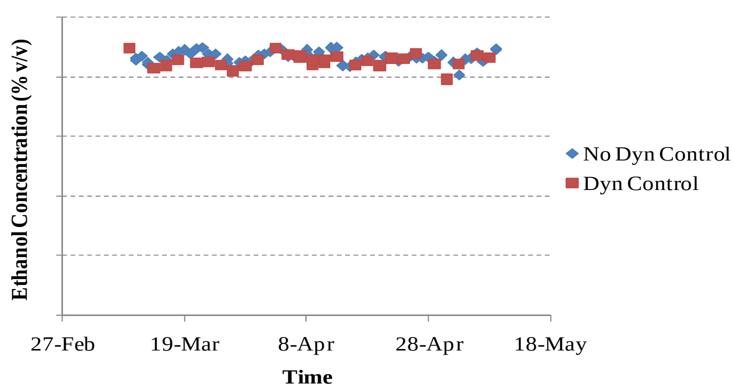
- No difference in ethanol profile between baseline and optimal controller



Murthy, G.S. 2006. Development of a controller for fermentation in the dry grind corn process. PhD. Thesis, University of Illinois at Urbana-Champaign, Urbana, IL.

Optimal Controller: Plant Results

- 35% reduction in glucoamylase dose in a conventional dry grind ethanol plant

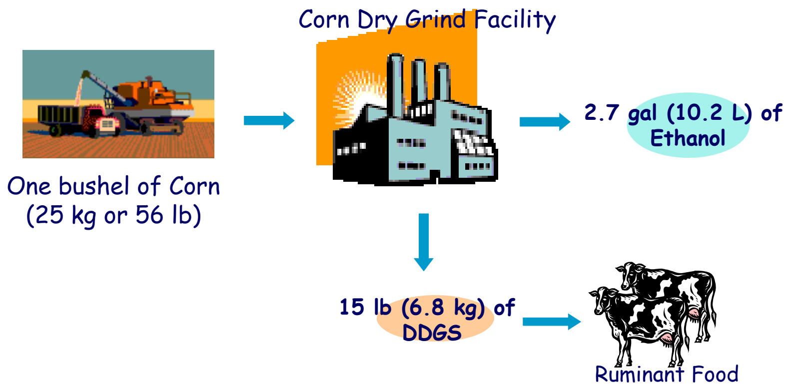


Optimal Controller for SSF

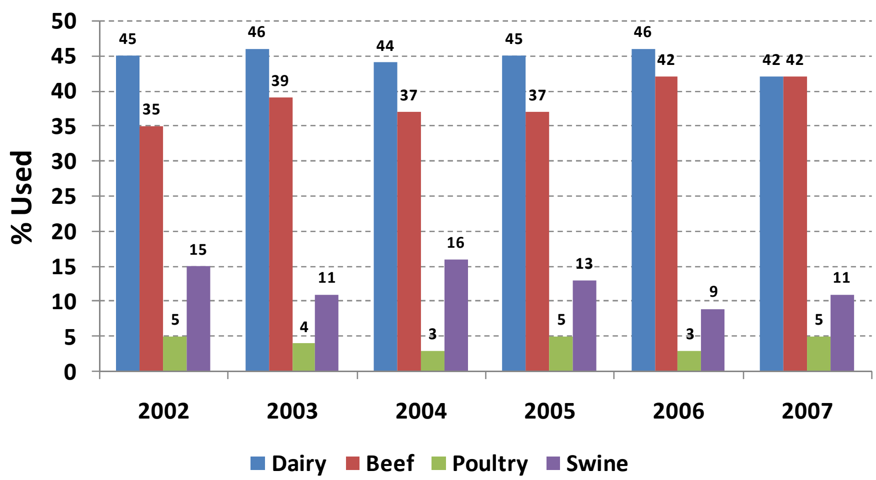
- Lower concentration of glucose during SSF
- Less glucoamylase requirement during SSF
- Similar of higher final ethanol concentration

New Technologies that Affect DDGS Volume and/or Composition and Allow Recovery of Other Coproducts

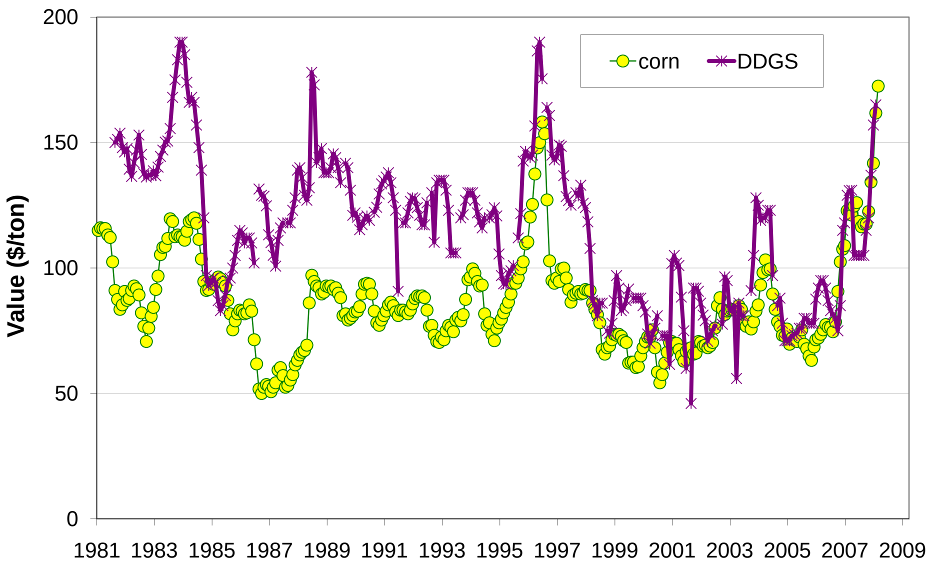
Conventional Dry Grind Process



DDGS Utilization



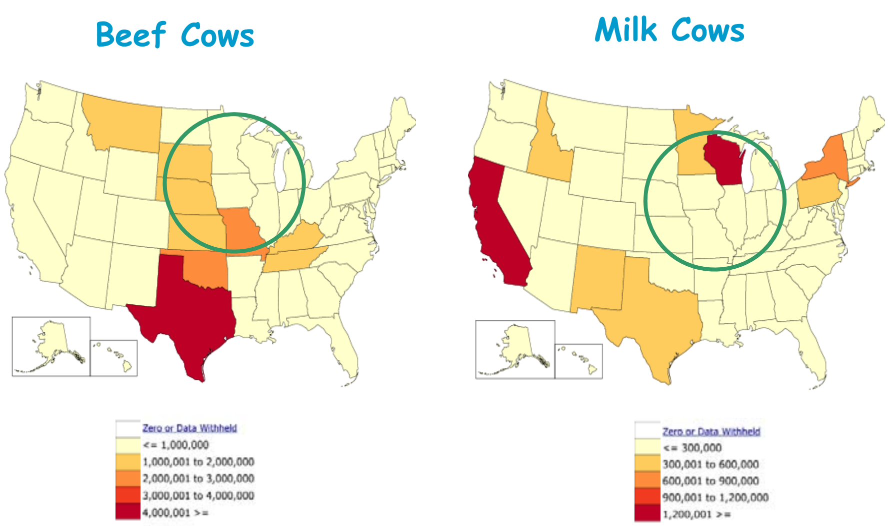
ILLINOIS



http://www.ers.usda.gov/Data/feedgrains/FeedGrainsQueriable.aspx

Cattle and Calves Inventory

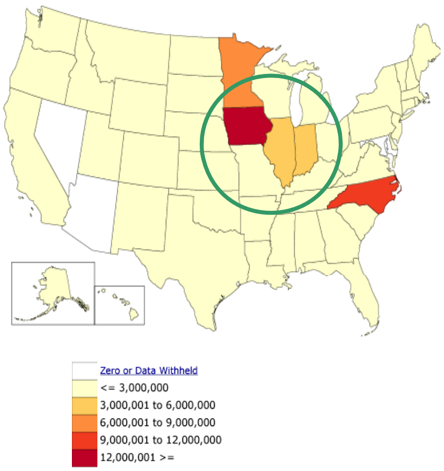
Source: USDA-NASS 2002 Census of Agriculture



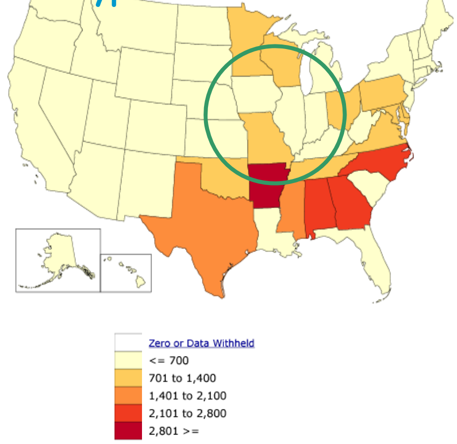
Poultry and Swine Inventory

Source: USDA-NASS 2002 Census of Agriculture

Pigs

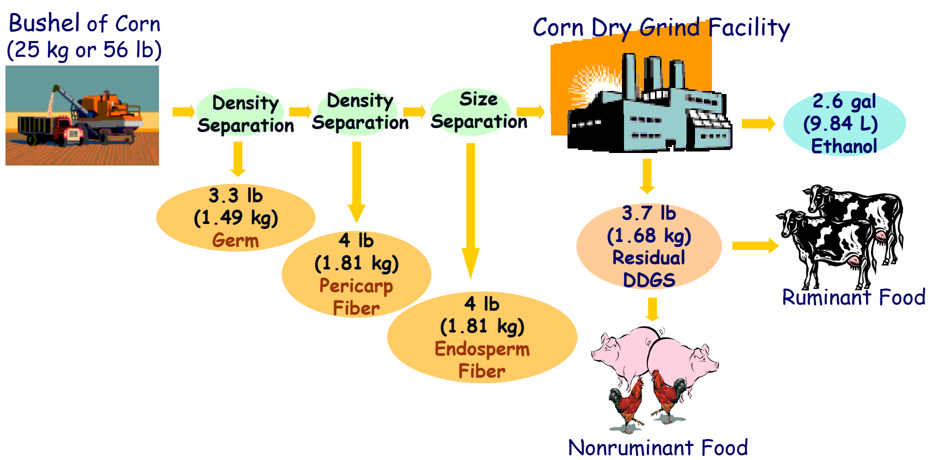


Broiler and Other Meat Type Chicken



New Technology: Corn Fractionation

Corn Wet Fractionation:
Enzymatic Dry Grind Corn Process (E-Mill)



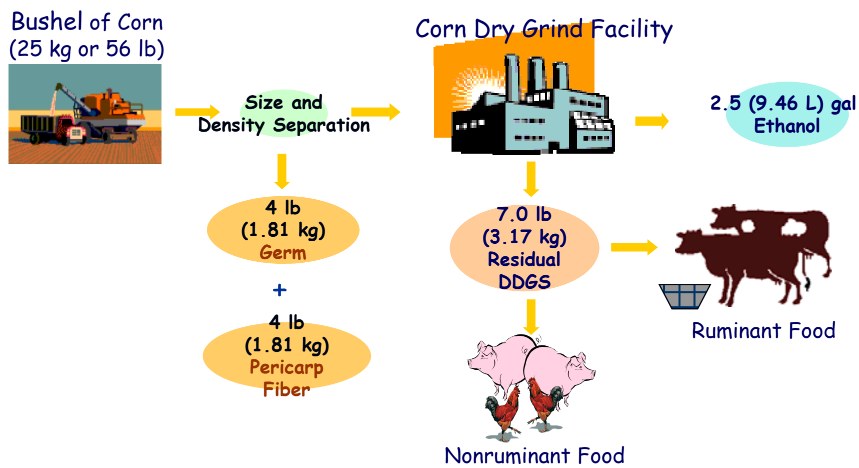
Singh, V., Johnston, D.B., Naidu, K., Rausch, K.D., Belyea, R.L. and Tumbleson, M.E. 2005. Comparison of modified dry grind corn processes for fermentation characteristics and DDGS composition. Cereal Chem. 82:187-190.

DDGS Composition: Corn Wet Fractionation (E-Mill Process)

	Conv.	E-Mill	Soy Meal	CGM
Crude Prot. (%)	28.50	58.50	53.90	66.70
Crude Fat (%)	12.70	4.53	1.11	2.77
Ash (%)	3.61	3.24	----	----
Acid Det. Fiber (%)	10.8	2.03	5.95	6.88

Singh, V., Johnston, D.B., Naidu, K., Rausch, K.D., Belyea, R.L. and Tumbleson, M.E. 2005. Comparison of modified dry grind corn processes for fermentation characteristics and DDGS composition. Cereal Chem. 82:187-190.

Corn Dry Fractionation:
Dry Degerm Defiber Process (3D Process)



Murthy, G.S., Singh, V., Johnston, D.B., Rausch, K.D. and Tumbleson, M.E. 2006. Evaluation and strategies to improve fermentation characteristics of modified dry grind corn processes. Cereal Chem. 83:455-459.

Comparison of Wet and Dry Fractionation: DDGS Nutrient Content

Component	Conventional Dry grind	Dry Fractionation	Wet Fractionation
Protein (%)	21	25	28
Fat (%)	14	9	5.4
Fiber (TDF)(%)	36	28	25
Lysine (%)	0.73	0.63	0.91
Lys, % of CP	3.4	2.5	3.3
Phosphorus (%)	0.78	0.47	1.12

Martinez-Amezcua, C., Parsons, C.M., Singh, V. Murthy, G.S. and Srinivasan, R. 2007. Nutritional characteristics of corn distillers dried grains with solubles as affected by amounts of grains versus solubles and different processing techniques. Poultry Sci. 86:2624-2630.

Corn Fractionation Processes: Effect on DDGS

- Corn fractionation (wet or dry) prior to fermentation
  - Reduces volume of DDGS produced
  - Increased protein and reduces fiber content of DDG
- Wet fractionation process compared to dry fractionation process
  - Better nutritional quality of DDGS

Other Benefits of Fractionation Processes: Recovery of Valuable Coproducts

- Recovery of germ, pericarp and endosperm fiber as valuable coproducts
  - Germ
    - Corn Germ Oil
  - Pericarp and Endosperm Fiber
    - Corn Fiber Oil
    - Corn Fiber Gum
    - Ethanol

Singh, V., Johnston, D.B., Naidu, K., Rausch, K.D., Belyea, R.L. and Tumbleson, M.E. 2005. Comparison of modified dry grind corn processes for fermentation characteristics and DDGS composition. Cereal Chem. 82:187-190.
Dien, B.S., Johnston, D.B., Hicks, K.B., Cotta, M.A. and Singh, V. 2005. Hydrolysis and fermentation of pericarp and endosperm fiber recovered from enzymatic corn dry grind process. Cereal Chem. 82:616-620.

Comparison of Wet and Dry Fractionation: Germ Composition

Milling Process	Oil (%)	Protein (%)	Starch (%)	Ash (%)	Yield (%)
Commercial Wet Milling A	40.89	14.03	8.00	2.20	7.50
Commercial Wet Milling B	36.39	13.09	6.90	1.43	7.50
Laboratory Wet Milling	38.77	18.38	11.60	2.30	7.51
Wet Fractionation	36.43	21.36	6.20	ND	6.50
Commercial Dry Milled	23.00	15.35	19.81	ND	12.00
Dry Fractionation	18.06	17.46	21.20	ND	13.86

Johnston, D.B., McAloon, A.J., Moreau, R.A., Hicks, K.B. and Singh, V. 2005. Composition and economic comparison of germ fractions derived from modified corn processing technologies. J. Am. Oil Chem. Soc. 82:603-608.

Lipids in Refined Vegetable Oils

- Sponifiables (>99%)
  - Acyl Lipids
  - Triacylglycerols (TAG)
- Nonsaponifiables
  - **Phytosterols**
    - Free
    - Acyl esters
    - OH-cinnamate esters
  - Tocols
    - Tocopherols (Vitamin E)
    - Tocotrienols
  - Carotenoids
- Others (squalene, phospholipids, glycolipids)

(OH-cinnamate esters, Tocols, Tocopherols (Vitamin E), Tocotrienols, Carotenoids } Antioxidants)

Why are Phytosterols Valuable

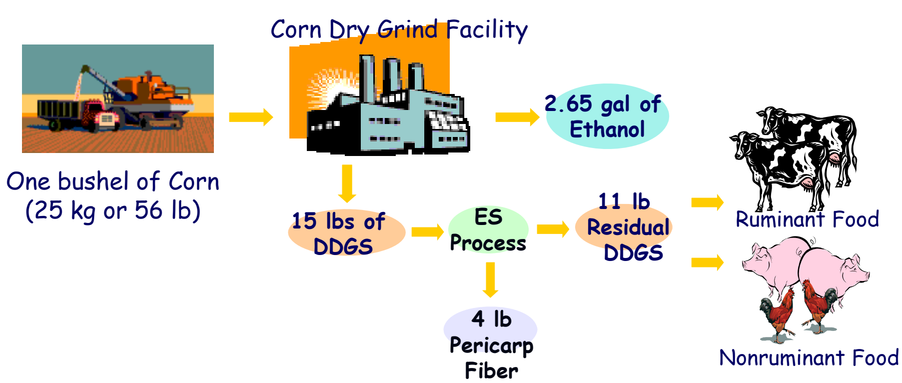
- When consumed, Phytosterols can lower LDL-Cholesterol levels by 15-20% without the use of "statin" drugs
- This is estimated to reduce the risk of heart disease by 20-40%
- Recent NIH guidelines regarding the need to lower LDL-Cholesterol levels points to increasing demand for phytosterols

Corn Fractionation Processes: Recovery of Additional Coproducts

- Corn fractionation (wet or dry) prior to fermentation
  - Recover germ, pericarp fiber and endosperm fiber as additional coproducts
  - Fibers can be used as feedstock for recovery of other valuable corpdoucts
    - Corn fiber oil
    - Corn fiber gum
- Wet fractionation process compared to dry fractionation process
  - Recovers germ with better composition

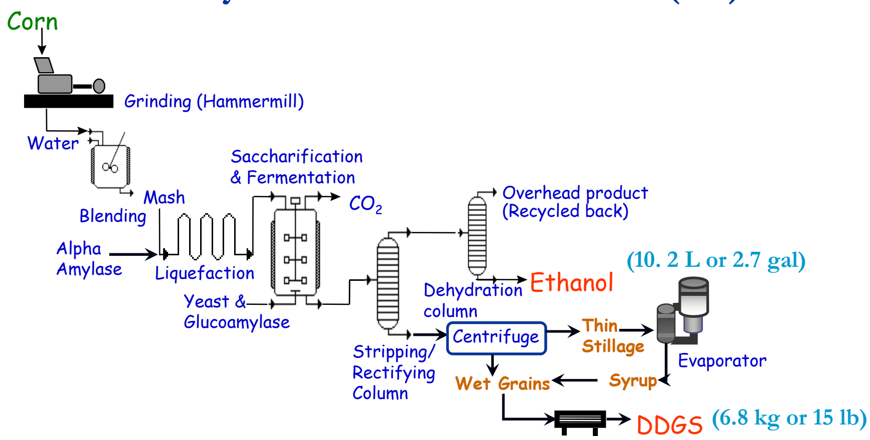
New Technology: DDGS Fractionation

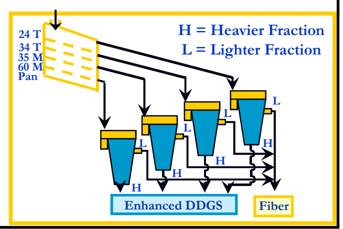
DDGS Fractionation: Elusieve (ES) Process



Srinivasan, R., Moreau, R.A., Rausch, K.D., Belyea, R.L., Tumbleson, M.E. and Singh,V. 2005. Separation of fiber from distillers dried grains with solubles (DDGS) using sieving and elutriation. Cereal Chem. 82:528-533.

Modified Dry Grind Process: Elusieve (ES) Process





Srinivasan, R., Singh, V., Belyea, R.L., Rausch, K.D., Moreau, R.A. and Tumbleson, M.E. 2006. Economics of fiber separation from distillers dried grains with solubles (DDGS) using sieving and elutriation. Cereal Chem. 83:324-330.

Sieving Results

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

NDF – Neutral Detergent Fiber

Srinivasan, R., Singh, V., Belyea, R.L., Rausch, K.D., Moreau, R.A. and Tumbleson, M.E. 2006. Economics of fiber separation from distillers dried grains with solubles (DDGS) using sieving and elutriation. Cereal Chem. 83:324-330.

Elutriation Results

24T, Air Velocity = 3.35 m/s, Yield (Lighter) = 27.8%

Fraction	NDF %	Protein %	Fat %
Lighter	53.3	19.3	7.05
Bulk	33.4	29.3	12.5
Heavier	32.6	35.6	14.2

34T, Air Velocity = 2.55 m/s, Yield (Lighter) = 33.4%

Fraction	NDF %	Protein %	Fat %
Lighter	58.7	15.5	6.5
Bulk	37.8	26.9	11.3
Heavier	32.4	33.1	13.8

35M, Air Velocity = 1.84 m/s, Yield (Lighter) = 19.3%

Fraction	NDF %	Protein %	Fat %
Lighter	56.0	16.5	8.5
Bulk	33.6	31.2	10.9
Heavier	27.6	35.4	13.1

Srinivasan et al. 2005. Cereal Chemistry 82:528-533.

DDGS Fractionation Process

- DDGS fractionation
  - Modified DDGS with high protein, high fat and low fiber content compared to conventional DDGS
  - Depending upon separation parameters DDGS can be produced with
    - Protein content, 42%
    - NDF, 19%
  - Cost of retrofitting a 45 Mil gallon/yr is less than $1.0 M
  - Payback period is less than 2 years

Srinivasan, R., Singh, V., Belyea, R.L., Rausch, K.D., Moreau, R.A. and Tumbleson, M.E. 2006. Economics of fiber separation from distillers dried grains with solubles (DDGS) using sieving and elutriation. Cereal Chem. 83:324-330.