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Increasing the Value of Hominy Feed as a Coproduct by Fermentation

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Abstract Hominy feed is a low value ($83.7/metric ton) coproduct of the corn dry milling process that accounts for nearly 35% of the starting corn quantity. The average composition of hominy feed on a dry basis is 56.9% starch, 25.2% neutral detergent fiber, 11.1% protein, and 5.3% fat. Starch in hominy feed can be fermented to ethanol thus increasing its levels of protein and fat. The increase in protein and fat percentages may increase the market competitiveness and price of hominy feed. Hydrolysis and fermentation were performed on nine hominy feed samples collected from three corn dry milling plants in the USA. The original hominy feed samples and postfermentation solids were analyzed for starch, protein, fat, and fiber content. Compared to the original hominy feed, the percentage increase in protein, fat and fiber in postfermentation solids of nine samples ranged from 10.4 to 21.3, 6.78 to 10.6, and 12.6 to 28.7% (dry basis), respectively. Ethanol yields varied from 271.7 to 380.2 l/metric ton for the nine hominy feed samples. These results indicate that the value of hominy feed as an animal feedstock can potentially be increased with fermentation and can produce more profit per metric ton than currently being derived by its sale as a low protein feed ingredient.

Keywords Animal feed · Corn dry milling · Ethanol · Hominy feed

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Introduction

Hominy feed is a low value ($83.7/ metric ton) coproduct of the corn dry milling process [1] and accounts for nearly 35% of the starting corn quantity. Hominy feed competes with similar corn by-products such as corn gluten feed and brewer's spent grain as ingredient for animal feed [2]. The corn dry milling industry uses 163 million bushels of corn per year [3] producing approximately 1.45 million metric ton of hominy feed. The steps in the corn dry milling process include tempering of the kernels with water and degermination followed by grinding, sifting, and aspiration provides the separation of corn kernel into germ, corn bran, and endosperm (Fig. 1). Germ oil is extracted and spent germ or germ cake becomes one of the by-product streams. The fines including tip caps and fine fiber are separated during sifting and aspiration and become by-product stream called standard meal. The corn bran, germ cake, standard meal, and/or broken corn are mixed dried, and ground to produce hominy feed [2]. Germ cake may be oil-extracted and added to hominy feed, making it a low fat hominy feed [4]. Hominy feed is widely used in ruminant diets because of its high level of fat, high available energy [5] and it is a good substitute for corn [6]. Larson [7] reported the composition of hominy feed as 56.9% starch, 25.2% neutral detergent fiber (NDF), 11.1% protein, and 5.3% fat.

The corn dry grind ethanol industry is growing at a fast pace in the USA and around the world. The US ethanol production has increased to 23.9 billion liters per year in June 2007, which is more than three times the ethanol production capacity in 2000 [8]. The US ethanol production capacity is projected to double in the next 4 to 5 years. Currently, 17% of US corn production is being utilized for ethanol production. Demand for corn and other feedstock for ethanol production will increase. Hominy feed, due to its high starch content can be potentially used as feedstock for ethanol production.

Hydrolysis and fermentation of hominy feed for ethanol production will utilize the starch in hominy feed thereby increasing compositional percentages of protein and fat. Animal diets and prices of animal feedstuffs are often determined based on protein and fat content. Higher protein content results in higher prices for animal feedstuffs [6, 9, 10]. Distillers dried grain and solubles (DDGS), a coproduct from corn dry grind process, with high fat (13%) and high protein (33%) is worth $5 to 20 per ton more than DDGS with lower fat (11%) and lower protein (28%) [9]. Hence, with increased compositional percentages of protein and fat content, hominy feed may demand a higher price per weight than present. However, the processing steps in a dry milling plant may affect the quantity and quality of

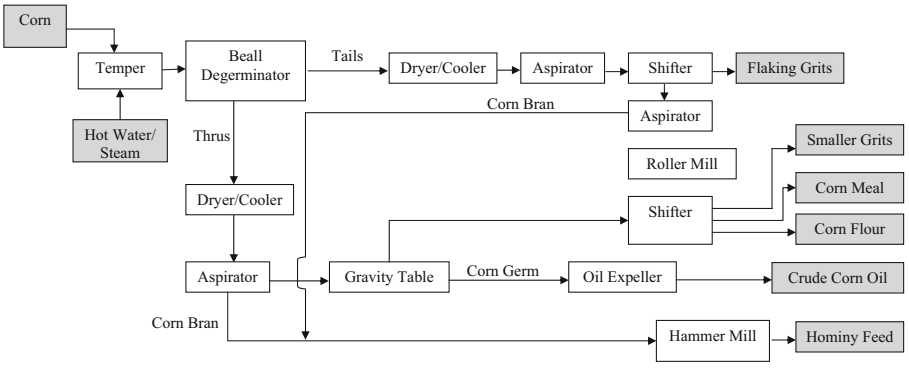

Fig. 1 Process flow diagram for the corn dry milling

starch in hominy feed and affect its conversion to ethanol. This work was designed to study the suitability of hominy feed for a combined hydrolysis and fermentation process to produce ethanol, similar to dry grind corn process, and to analyze the change in hominy feed composition. The specific objectives for this study were (1) to evaluate the fermentability of hominy feed for ethanol production, and (2) to analyze the composition of hominy feed before and after fermentation.

Materials and Methods

Experimental Material

Nine hominy feed samples were obtained from three corn dry milling plants in the Midwestern USA. All three plants were using no. 2 yellow dent corn as feedstock. Hominy feed samples included pericarp, germ cake, and standard meal in different proportions. The exact proportion of these three components in hominy feed varied from batch to batch depending upon the processing conditions and the specifications for flaking grits, brewer's grits or fine grits produced by the dry milling plant. Due to proprietary reasons, the exact methods for preparing hominy feed samples were not available. All hominy feed samples were analyzed for their starch, protein, fat, and fiber content. Granular starch hydrolyzing enzyme (GSHE) Stargen 001 and acid fungal protease GC106 were obtained from Genencor International (Palo Alto, CA, USA). GSHE contains α-amylase from *Aspergillus kawachi* and a glucoamylase from A*spergillus niger* and had an activity of ≥456 GSHU/g (GSHU, granular starch hydrolyzing units). *Saccharomyces cerevisia* yeast culture was prepared by dispersing 11 g of active dry yeast (Fleischmann's Yeast, Fenton, MO) and 1 g of yeast malt broth (Sigma, St. Louis, MO, USA) in 89 ml of distilled water and agitated at 50 rpm and 30°C for 20 min (C24 Incubator Shaker, New Brunswick, NJ, USA). Saccharomyces yeast culture had a viable cell count of 1.8×10^8 cells/ml using Petrifilm plates (3M, St. Paul, MN, USA). Sulfuric acid (10N) was obtained locally. Urea (U15–500, Fisher Scientific, Pittsburgh, PA, USA) was used as a source of free amino nitrogen for yeast growth.

Analytical Tests

Original hominy feed and post fermentation solids samples were analyzed in duplicate by Midwest Laboratories (Omaha, NE, USA). The samples were analyzed for crude protein (Method 990.03, AOAC [11]), crude fat (Method 920.39), and ash (Method 942.05). Protein was reported as 6.25×total nitrogen. NDF content was determined by the procedure outlined by Van Soest [12]. Total crude starch in hominy feed was measured by two stage hydrolysis of starch (Method AOAC 979.10, AOAC [13]). Sample moisture contents were determined using the two-stage convection oven method by drying the samples at 49°C for 24 h and further drying at 135°C for 2 h (Method 44–15A, AACC International [14]).

Fermentation

The process flowchart for hominy feed hydrolysis and fermentation is shown in Fig. 2. Hominy feed sample (50 g) was mixed with water at 35°C in a 500 ml Erlenmeyer flask (Bellco Biotechnology, Vineland, NJ, USA) to obtain 30% solid content in the slurry. Slurry temperature was increased to 48°C in a shaking water bath (MaxQ 7000, Lab-Line/

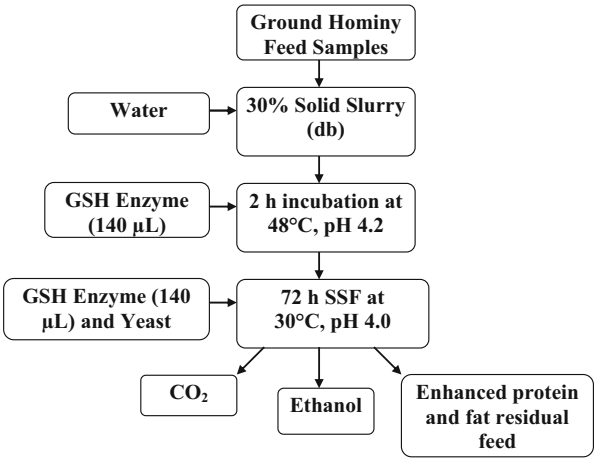

Fig. 2 Proposed process flow diagram for the fermentation of hominy feed

Barnstead International, Dubuque, IA). Slurry pH was adjusted to 4.2 using 10*N* sulfuric acid solution. GSHE (140 µl) and GC106 (30 µl) was added to the slurry which was then maintained at 48°C for 2 h with agitation at 120 rpm in a shaking water bath (MaxQ 7000, Lab-Line/Barnstead International, Dubuque, IA, USA) for the incubation. After incubation, simultaneous saccharification and fermentation (SSF) was conducted to produce ethanol. Incubated mash was cooled to 30°C and adjusted to pH 4.0 using 10*N* sulfuric acid solution. Active dry yeast (0.01 g/g of starch), urea (0.1% of slurry), 140 µl of GSHE and 30 µl of GC 106 were added to the mash. The mash was maintained at 30°C for 72 h at 100 rpm in shaking water bath (MaxQ 7000, Lab-Line/Barnstead International) for the SSF.

During fermentation, carbon dioxide is produced by the yeast and is vented, resulting in weight loss of fermentation mash ($C_6H_{12}O_6=2C_2H_5OH+2CO_2+$Energy). Carbon dioxide released during fermentation is stoichometrically equivalent to ethanol produced [15] and can be measured to monitor the fermentation process. The weight of fermentation vessel (flask and mash) was recorded at 0, 2, 4, 6, 8, 10, 12, 24, 48 and 72 h during SSF. Weight loss was calculated by subtracting the weight of empty fermentation flask from recorded weights during SSF. Mash samples (3 ml) were also drawn at 24 and 72 h for HPLC analysis. The weight to fermentation vessel was adjusted for the two 3 ml samples that were drawn for HPLC analysis.

For HPLC analysis, the mash samples (3 ml each) were split into two 1.5 ml samples and centrifuged for 2.5 min at 16,110×g (13,000 rpm; model 5415 D, Eppendorf, Westbury, NY, USA) to obtain clear supernatant liquid. Supernatant was passed through a 0.2 µm sterile syringe filter (Corning Inc., Corning, NY, USA) into 1 ml shell vials (Fisherbrand, Fisher Scientific, Pittsburgh, PA, USA). Filtered liquid was injected into an ion-moderated partition chromatography column (Aminex HPX-87H, Bio-Rad, Hercules, CA) maintained at 50°C. HPLC grade water containing 5 mM sulfuric acid was used as mobile phase. Elution rate was 0.6 ml/min. Separated components were detected with a refractive index detector (model 2414, Waters Corporation, Milford, MA). Data were processed using HPLC software (Waters Corporation). The HPLC was calibrated with standards containing all components of interest at known concentrations at beginning of each batch of samples, after every ten samples and at the end of the batch. Both samples were injected twice for HPLC analysis. The mean of two samples with two injections each was reported as component concentration. After fermentation, mash was heated at 90°C for

3 h to evaporate ethanol. To recover residual feed, the remaining materials were dried in a convection oven at 49°C for 72 h [16].

Estimating Animal Feedstuff Prices Based on Protein Content

Srinivasan [10] estimated the dependence of animal feedstuff prices on their protein content based on market prices of wheat middlings (16.5% protein), corn gluten feed (21% protein), DDGS (28% protein), cottonseed meal (41% protein), soybean meal (50% protein), and corn gluten meal (60% protein) for years 2004–05, 2003–04 and 2002–03 as reported by ERS [1]. Linear regression models (R^2=0.87 to 0.95) were developed by Srinivasan [10] to determine the animal feedstuff prices based on their protein content. Based on the model, the increase in animal feedstuff price for every percent increase in protein content was $4.44, 5.00 and 3.66/t for June, 2005, 2003–2004 and 2002–2003 prices, respectively. The regression model for June 2005 reported by Srinivasan [10] was used in this study to estimate prices of post fermentation solids.

Statistical Analyses

Each treatment hydrolysis/fermentation was performed with three replications (n=3). Analysis of variance and Tukey's test (SAS Institute, Cary, NC) were used to compare mean ethanol yield and weight loss at 24 and 72 h. Tukey's test was used for a conservative comparison of treatment mean. Statistical significance between hominy feed composition and ethanol yield was based on 95% confidence level ($p \leq 0.05$). For analytical tests each sample was measured twice (n=2) and relative percent difference (RPD) was calculated to determine precision, with acceptable limit for %RPD set at <15%.

Results and Discussion

Hominy Feed Composition

Starch, protein, fat and fiber content in the nine hominy feed samples were in the range of 37.5 to 55.2, 9.5 to 12.3, 5.9 to 8.3, and 8.6 to 23.1%, respectively (Table 1). There were

Table 1 The composition of hominy feed before and after fermentation (% RPD<15).

	Sample no.								
Composition	H1	H2	H3	H4	H5	H6	H7	H8	H9
Crude protein (%; BF)	11.9a	12.3a	10.3b	10.9b	9.62c	9.49c	9.72c	10.5b	10.2b
Crude protein (%; AF)	23.1c	25.2b	23.0c	21.3d	29.1a	30.8a	25.9b	22.9c	22.4c
Crude fat (%; BF)	7.72b	8.28a	7.57b	7.57b	5.87c	6.25c	6.23c	7.73b	7.46b
Crude fat (%; AF)	14.5c	15.5b	16.0a	14.4c	16.1a	16.8a	14.7c	15.7b	16.4a
Ash (%; BF)	3.06a	2.94a	2.67a	2.8a	1.74b	1.93b	1.9b	3.18a	2.36b
Ash (%; AF)	5.23a	5.52a	4.93b	5.0b	5.44a	5.69a	5.02b	5.48a	4.93b
Neutral detergent fiber (%; BF)	19.8b	17.0c	16.1c	23.1a	11.0d	8.6e	14.9c	18.2b	21.1a
Neutral detergent fiber (%; AF)	35.5b	33.6b	33.4b	38.6a	39.7a	21.2c	34.1b	35.3b	37.6a

Values in the same row followed by same letter are not different ($p \leq 0.05$). Each data point is mean of two replications (n=2)

BF, before fermentation; AF, after fermentation

significant differences in starch, protein, fat, and fiber content among nine hominy feed samples indicating the process variations among the three dry milling plants and sampling within the plants for hominy feed samples. Starch, protein, fat, and fiber composition of all hominy feed samples were within the range reported in the literature [6, 7].

Ethanol Yield

Ethanol yields of 271.7 to 380.2 l/ metric ton were obtained from the fermentation of hominy feed samples (Table 2). Differences in ethanol yields ($p \leq 0.05$) were observed after fermentation of the hominy feed samples (Table 2). The highest ethanol yields were achieved by samples H5 (377.1 l/metric ton) and H6 (380.2 l/metric ton) followed by sample H7 (344.2 l/metric ton; Table 2). The lowest ethanol yield was from sample H4 (271.7 l/ metric ton). The samples H5 and H6 also had the highest amount of starch content compared to other samples (Table 1). Final ethanol yields indicate that hominy may be a good feedstock for ethanol production. All samples, by 24 h of SSF, reached more than 77% of their respective final ethanol yield (Table 2), whereas sample H5 and H6 reached 86 to 92% of final ethanol yield and are indicative of high rate of fermentation. The high rate of fermentation for all samples shows that there was no lack of yeast nutrition. The processing steps (tempering, grinding, sieving, drying, cooling and aspiration) in a corn dry milling plant had no affect on hominy feed starch fermentability. The starch hydrolysis was fast, and the amount of ethanol produced was proportional ($R^2=0.97$) to hominy feed starch content, which shows that there are no other factors (starch damage or particle size) involved that may affect the starch fermentability. Dry milling plants could potentially identify the hominy feed streams only based on high starch content and process it further for hydrolysis and fermentation for high ethanol yields. The glucose content in the fermentation mash was undetectable after the first 24 h of SSF indicating rapid sugar utilization by yeast. Also, the glycerol, lactic and acetic acid concentration were below critical limit showing no infection and stress for yeast. Ethanol yield and rate of fermentation data based on weight loss (due to CO_2 production; not reported) was similar to HPLC ethanol data indicating highest weight loss observed was for samples H5 and H6 and lowest was for sample H4.

Table 2 Ethanol yield (l/metric ton) at 24 and 72 h.

Sample no.	Ethanol Yield (l/metric ton)		Percent of final ethanol value reached at 24 h
	24 h	72 h	
H1	222.30±0.33c[ab]	276.56±0.72c	83.71
H2	229.98±0.56c	288.01±0.27c	83.86
H3	229.35±0.60c	288.64±0.61c	77.40
H4	223.69±0.51c	271.65±0.03c	79.44
H5	298.34±0.36a	377.14±0.20a	86.53
H6	305.76±0.48a	380.16±0.03a	91.70
H7	259.31±0.62b	344.16±0.61b	85.90
H8	230.49±0.47c	301.99±0.56c	77.61
H9	219.54±0.21c	281.34±0.38c	81.70

[a] Mean ethanol ± standard deviation and values in the same column followed by same letter are not different ($p \leq 0.05$)

[b] Each data point is mean of three replications ($n=3$)

Organic Acids and Sugar Concentrations

Lactic acid, acetic acid and glycerol were measured as they are important parameters to monitor bacterial infection or yeast stress during fermentation [15, 17]. Lactic acid (<0.50% *w/v*), acetic acid (<0.10% *w/v*) and glycerol (<0.40% *w/v*) were below critical limits [17] at 24 and 72 h. *Saccharomyces* yeast shows a distinct pattern of sugar utilization. After glucose consumption, fructose is used, followed by maltose, and then maltotriose [16]. Higher sugars (DP4+) cannot be metabolized by yeast. For all nine hominy feed samples low DP4 + (<0.50% *w/v*) and lower fructose (<0.03% *w/v*), maltose (<0.04% *w/v*), and maltotriose (<0.04% *w/v*) concentrations in SSF were observed. Lower sugar concentrations in SSF are preferred as they exert less osmotic stress on yeast and hinder growth of other microorganism that may compete with yeast for glucose for growth.

Compositional Analysis of Residual/Fermented Hominy Feed

As starch was converted to ethanol through fermentation, the other components, protein, fat, NDF, and ash content increased in post fermentation solids. The increases in the levels of components in fermented hominy feed compared to original hominy feed were 10.4 to 21.3% for protein, 6.8 to 10.6% for fat, 12.6 to 28.7% for NDF and 2.2 to 3.8% for ash (Table 1). Based on these results, users of hominy feed can expect more protein and fat per ton of fermented hominy feed compared to the original hominy feed sample. ERS [1] reported the average price for hominy feed as $86.7/ metric ton for 2006. Rausch and Belyea [6] reported that the decision to use hominy feed in ruminant diets depends on market price; low protein content can reduce its competitiveness and result in low usage. After fermentation, the higher protein and fat content of fermented hominy feed would make it competitive with other feed ingredients such as DDGS (29.6% protein, Rausch and Belyea [6]) and corn gluten feed (21% protein, ERS [1]). Fermented hominy feed samples (H5 and H6) had comparable protein content (29.1 and 30.8%) and higher fat content (16.1 and 16.8%) compared to DDGS from the dry grind corn process, which was sold at average price of $122.77/metric ton in 2006 [1]. Other fermented hominy feed samples (H1, H2, H3, H4, H7, H8) had higher protein content compared to original sample but not as high as DDGS. However, these samples had comparable fat content compared to DDGS. This shows that there were significant differences in protein and fat content among fermented hominy feed content and selection of original hominy feed sample to be fermented will be an important factor in making the fermented hominy feed competitive with other animal feedstuffs. Hominy feed has traditionally been used almost exclusively in ruminant animal diets (due to its high fiber content) [2]. Since the fiber content further increases after fermentation, the use of fermented hominy feed will also be limited to ruminant animal diets.

Revenues Estimation

The average price of conventional hominy feed was $83.7/ metric ton (for January 2005 to May 2006, ERS [1]). Using the regression model [10] and the protein content of the hominy feed after fermentation (21.3%), the estimated price of fermented hominy would be $102.5 to 150.5/metric ton, based on 2005 prices.

Based on the average ethanol and fermented hominy feed yields from nine hominy feed samples, a metric ton of hominy feed will produce 311.77 l of ethanol and 0.75 metric ton of fermented hominy feed. The average ethanol prices for July 2006 to June 2007 were $2.21/gallon ($0.58/l, CBOT [18], May 2007) and the average price of fermented hominy

feed was $119.72/metric ton (calculated above). Thus, from one metric ton of original hominy feed, a total revenue of $270.6 ($180.8 for ethanol and $89.6 for fermented hominy feed) could potentially be achieved. In other words, using hominy feed as a feedstock for ethanol production can potentially increase revenues by $186.9/ metric ton. These prices however do not include the operating expense of producing ethanol, but they are still a conservative estimate because current ethanol prices ($2.3/gallon CBOT [18], May 2007) are higher than those used for estimating revenues. The higher protein and fat of the fermented hominy feed is also expected to increase its market demand, compared to conventional hominy feed [9, 10].

Conclusions

Fermentation was effective in increasing the nutritional and economic value of hominy feed. For residual hominy feed after fermentation, the levels of protein (21.3 to 30.8%), fat (14.4 to 16.8%), and fiber (21.2 to 39.7%) content increased (dry basis) compared to the levels in the original hominy feed, protein (9.49 to 12.3%), fat (5.67 to 8.28%), and fiber (8.6 to 23.1%) contents. The higher levels of protein will increase the value of hominy feed and make it competitive with other animal feedstuff products. Ethanol yields of 271.7 to 380.2 l/metric ton were achieved from nine hominy feed samples. In conclusion, the fermentation of hominy feed is a simple process that appears to increase the nutritional value of hominy fed and increase revenues.

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