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Effect of fiber removal from ground corn, distillers dried grains with solubles, and soybean meal using the Elusieve process on broiler performance and processing yield

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Primary Audience: Nutritionists, Plant Managers, Researchers, Feed Mill Managers

SUMMARY

The Elusieve process, a combination of sieving and elutriation (air classification), has been found to be effective in separating fiber from ground corn, distillers dried grains with solubles (DDGS), and soybean meal (SBM). The objective of this study was to determine the effect of removing fiber from ground corn, DDGS, and SBM on broiler live performance during the 42-d experimental period and assess the economic effect. A total of 6 dietary treatments were evaluated in which 3 treatments incorporated an additional nonstarch polysaccharide (NSP) enzyme corresponding to the following 3 treatments: regular diet, direct substituted enhanced diet, and an isocaloric, isonitrogenous enhanced diet. The study consisted of 48 pens with 45 male broiler chicks per pen. Elusieve processing increased starch content of corn by 7.8% and increased protein content of DDGS and SBM by 2.3 and 0.9%, respectively. Enhanced diets resulted in birds with 4.6 to 5.0% higher BW gain, higher breast weight by 7.1 to 11.3% and feed conversion improvement by 4 to 6 percentage points (2.4 to 3.2%) compared with regular diet. There was no effect of NSP enzyme on performance and feed consumption. Interaction effect (between NSP enzyme and dietary type) was observed only in 2 of a total of 12 performance indicators. The increase in profit due to implementation of the Elusieve process in a 1,000 t/d feed mill is estimated to be $0.5 to 2.5 million/yr, which is 0.8 to 4.3 cents/bird produced. The payback period is estimated to be 0.9 to 4.7 yr.

Key words: fiber removal, Elusieve, broiler, nutrition

2013 J. Appl. Poult. Res. 22:177–189
http://dx.doi.org/10.3382/japr.2012-00544

DESCRIPTION OF PROBLEM

Ground corn has been used across the world for centuries to feed poultry and swine. Poultry and swine, being nonruminants, do not digest fiber well. The removal of fiber from corn would increase its nutritional value for nonruminants; however, there has not been a simple or inexpen-

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sive method of removing fiber from corn. Recently, the Elusieve process, a combination of sieving and elutriation (air classification), was found to be effective in fiber separation from ground corn [1, 2].

Soybean meal (**SBM**) is the most commonly used protein source in diets. Recently, increases in fuel ethanol production from corn have created increased amounts of distillers dried grains with solubles (**DDGS**), which is a coproduct of ethanol production. Due to decreased availability and increased prices of corn, DDGS has become a major feed ingredient for poultry and swine. The Elusieve process results in effective separation of fiber from both DDGS and SBM [3, 4]. The ingredient remaining after separating fiber is called enhanced material. In the Elusieve process, the feed ingredient is sieved into 4 sizes (large, medium, small, and pan) and the 3 biggest sizes (large, medium, and small) are individually air classified using aspirators to blow away fiber predominantly into the lighter fraction (Figure 1). The heavier fractions from the 3 size fractions and the pan size fraction are combined as enhanced material.

A pilot plant for continuous operation has been built and is operating for Elusieve processing of ground corn, DDGS, and SBM [5]. It is envisioned that the Elusieve process will be implemented in feed mills that supply feeds to swine and poultry farms. Feed mills grind whole corn kernels and then mix various other feed ingredients such as DDGS, SBM, and micronutrients. The Elusieve process would be implemented to separate fiber from the ingredients before mixing. The separated fiber is expected to be used as a feed ingredient in diets for breeders, layer chickens, sows, cattle and others. Nutrient composition of separated fiber is similar to wheat middlings and soy hulls.

The use of feedstuffs enhanced by the Elusieve process has been shown to increase ME for pigs and poultry. Feeding trials with grow-finish pigs have shown that enhanced DDGS had higher digestible energy, ME, and ME_n contents by 240, 183, and 209 kcal/kg, respectively, compared with regular DDGS [6]. True ME for enhanced DDGS was 3.0% higher than for conventionally processed DDGS, based on precision-feeding of cecectomized roosters [7]. Broilers (21-d study) fed diets containing enhanced corn had 4.3% higher BW gain and feed conversion was improved by 3 percentage points compared with diets with regular corn [8]. Elusieve processing did not have any effect on the amino acid profile of DDGS [7, 9]. The use of Elusieve indicates an increase in nutritional value for corn and DDGS in poultry and swine diets.

There is a need to determine the nutritional value of poultry diets that incorporate enhanced materials from all 3 major ingredients: corn, DDGS, and SBM. The first objective of this study was to determine the effect of removing fiber from ground corn, DDGS, and soybean meal on broiler live performance from 0 to 42 d and carcass and breast yield. The second objective was to assess the economic effect of Elusieve processing on an integrated broiler facility served by a feed mill processing 1,000 t/d of feed.

MATERIALS AND METHODS

Elusieve Processing

Elusieve processing of feed ingredients was carried out using the pilot plant facility at Mississippi State University [5]. In this study, we used a conveyor belt to continuously discharge the heavier fractions and the pan size fraction directly into the enhanced material bulk bag, instead of collecting the fractions into barrels and then mixing. The use of a conveyor belt was made possible by suitably aligning the aspirators and using sheet metal channels to direct the fractions into the conveyor belt. The lighter fractions were collected in barrels and were dispatched for feeding cattle.

Ground yellow dent corn was procured from Ware Milling [10]. The screen opening used in the hammer mill was chosen to produce the desired size distribution of ground corn that produces best fiber separation [2]. The screens used in the pilot plant's sifter were 16M (1,184 µm), 28M (710 µm), and 40M (470 µm; Table 1). The rate of material flow into the sifter was 453 kg/h (0.5 t/h), which was controlled by timing the manual feeding of 50-lb bags. The large, medium, small, and pan size fractions comprised 25.9, 21.9, 15.3, and 36.8 weight by percent of the regular ground corn, respectively. The 3 size fractions (large, medium, and small) were air

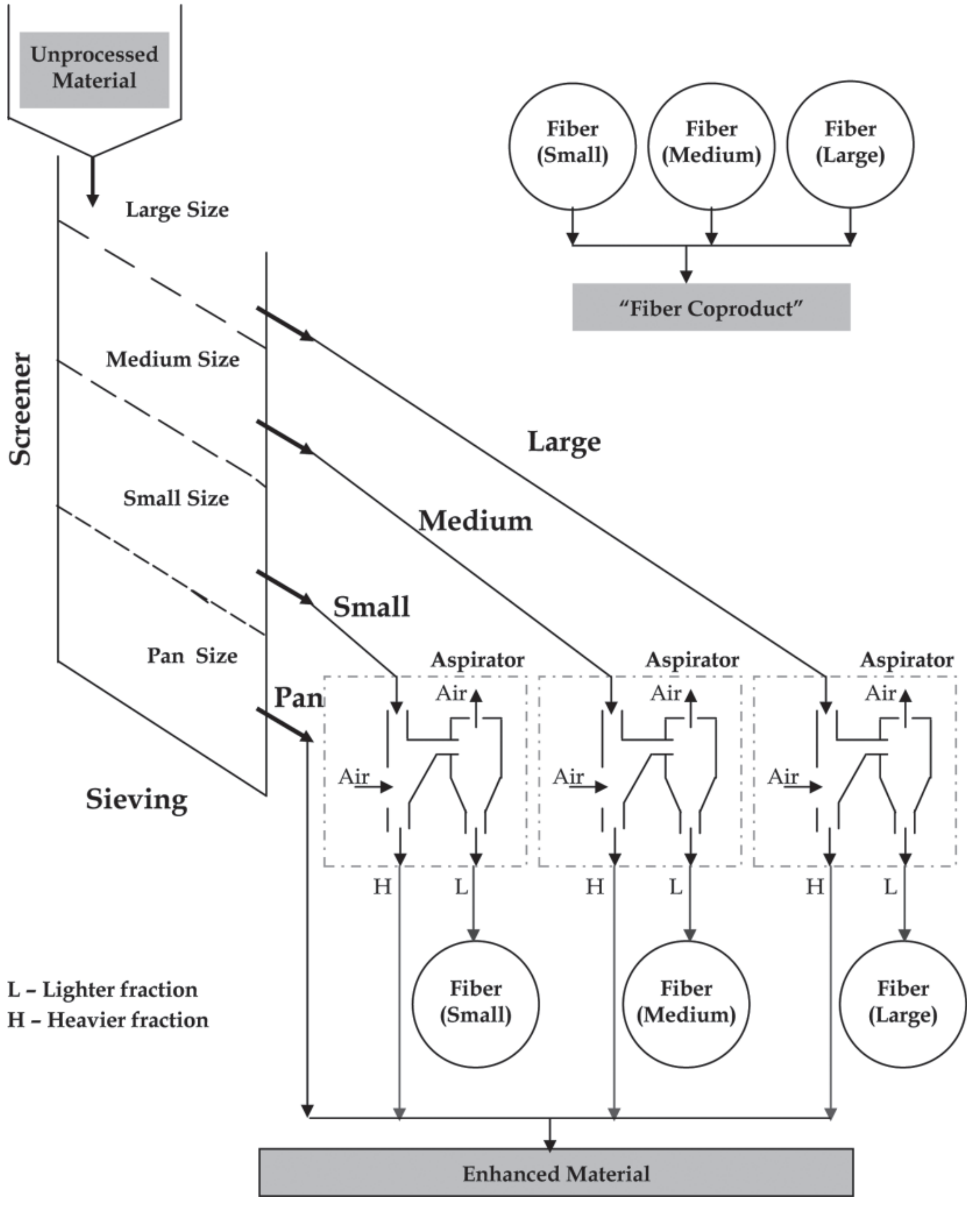

Figure 1. Schematic diagram of Elusieve processing.

classified using multiaspirators [11] to separate out 20 to 30 weight by percent of each size fraction as a lighter fraction. The weight by percent of material separated as fiber coproduct was 15.6% of the original corn (Table 1). The quantity of fiber coproduct separated (15.6%) was chosen to be higher in the pilot plant facility than what would be used in an industrial-scale facility (10%) because of the separation inefficiencies of the pilot plant's sifter and aspirators. The sifter in the pilot plant was used equipment that was procured and customized for the Elusieve

Table 1. Elusieve processing details for ground corn, soybean meal (SBM), and distillers dried grains and solubles (DDGS)

Material	Screen openings (μm) used for sieving			Weight by percent of size fractions				Processed quantity (kg)	Fiber separated (weight by percent of processed material)	Fiber that would be typically separated in an industrial scale (weight by percent)
	Screen 1	Screen 2	Screen 3	Large	Medium	Small	Pan			
Ground corn	1,184	710	470	25.9	21.9	15.3	36.8	9,072	15.6	10
SBM	1,484	868	582	41.6	26.0	16.1	16.3	2,654	14.0	5 to 8
DDGS	1,042	710	470	16.9	28.7	25	29.4	1,809	43.3	15

process. The sifter does not have change of flow direction when the material flows to the next screen and, hence, the size separations are not very efficient. Also, the aspirators supplied were scaled down by the manufacturer to accommodate the lower capacities of the pilot plant, which results in inefficiency in separation during air classification.

Soybean meal was procured from Ware Milling [10]. The 3 size fractions (large, medium, and small) were air classified to separate out 10 to 25 weight by percent of each size fraction as lighter fraction. The weight by percent of material separated as fiber coproduct was 14.0% of the original SBM (Table 1). The quantity of fiber coproduct separated (14.0%) was chosen to be higher in the pilot plant facility than what would be used in an industrial-scale facility (5 to 8%) because of the separation inefficiencies of the pilot plant's sifter and aspirators.

The DDGS was procured from Ware Milling [10], who sourced the material from Green Renewable Energy [12]. Due to an operational error, the 3 size fractions were air classified to separate out 50 to 60 weight by percent of each size fraction as lighter fraction. The weight by percent of material separated as fiber coproduct was 43.3% of the original DDGS (Table 1). The quantity of fiber coproduct separated in and industrial-scale implementation would typically be 15%. It is estimated that this operational error would not have a major effect on the overall results because the inclusion level of DDGS in the diets is low (6 to 8%) compared with other ingredients.

Composition Determination for Feed Ingredients

Six samples were collected for compositional determination from each type of feed ingredient. Samples were collected from regular and enhanced materials of ground corn, DDGS, and SBM. Thus, 36 ingredient samples were analyzed for composition. The samples were ground to a fine powder using a coffee grinder before analysis to avoid particle segregation. Compositional analysis was done at a commercial analytical laboratory [13].

The NDF content was determined using the procedure of Van Soest et al. [14]. Samples were analyzed for total N (method 990.03) [15]. Crude protein content was calculated as total N × 6.25. Samples were also analyzed for crude fat (method 920.39) [15] and ash (method 942.05) [15]. Starch content was determined using the glucoamylase procedure (method 77–11) [16]. Moisture content was determined using the 2-stage convection oven method (method 44–18) [16].

Broiler Performance Study

Broiler performance studies were conducted by Southern Poultry Research Inc. All procedures were approved by the University of Georgia committee on Laboratory Animal Care. The experiment consisted of 48 pens. One-day-old male Cobb × Cobb 500 chicks were randomized to 45 male broiler chicks per pen. A total of 2,160 birds were used; the average initial weight of the chicks was 41 g. All feeds were manufactured at the University of Georgia Feed Mill. Robenz (30 g/t), an anticoccidial drug, was added to all starter and grower feeds; BMD 50, an antibiotic, was added to all feeds [17]. Each batch of feed was mixed and bagged separately. Feeds were fed in crumbled form in the starter phase and in pellet form in the grower and finisher phases.

Floor Pen Description and Management. The floor pen house is a modified poultry house with concrete floors and curtain sidewalls. The pens were prepared for use in the study according to the Southern Poultry Research Inc. standard operating procedure. The experimental house is divided into pens of equal size, arranged along a central aisle. Pens measured 1.22 × 3.66 m and contained 45 chicks per pen. Fresh wood shavings were used as bedding with a thickness of approximately 0.1 m. The stocking density, after subtracting out for equipment, was 0.09 m^2 per bird. Each pen had 0.6 m side walls with mesh wire to prevent bird migration. The temperature of the building was monitored daily and maintained appropriate to the age of the animals. Illumination was provided by incandescent bulbs placed above the pens with 24 h of light per day for the duration of the study. Lighting for 24 h per day is not common in commercial settings, but each company and breed of bird has different lighting programs; however, 24 h lighting is common in the research setting. The diets were provided ad libitum in one tube-type feeder per pen. From d 1 to 7, feed was also supplied on feeder trays, placed on the litter. Diets were provided water ad libitum from a one-nipple drinking line. Body weight was measured at 0, 21, 35, and 42 d of age. Feed intake was measured at 21, 35, and 42 d of age. Weight gain and FCR were calculated at 21, 35, and 42 d. At the occurrence of mortality, feed intake was adjusted based on bird days on feed.

Carcass Analysis. Upon completion of the growth study, 5 birds per pen were randomly selected for processing, double wing tag numbered for identification, and individually weighed. There were a total of 40 birds selected to be processed per treatment. All birds were taken off feed approximately 10 h before processing, at which point they were transported to the University of Georgia processing facility. Birds were slaughtered and eviscerated. During the slaughtering process, steps were performed similar to those in the industry but scaled down. The scalding method used was a hard scald at 134°F. Carcass weights were determined without giblets and abdominal fat. Carcasses were then placed on ice for 5 h.

Treatments and Experiment Design. The experiment design was a randomized complete block design of 6 treatments in 8 blocks throughout the house, with the pen being the experimental unit. Six feed formulation treatments (**trt 1**–**6**) were used for each growing period (starter from d 0 to 21, grower from d 21 to 35, and finisher from d 35 to 42). The formulations and the expected nutrient composition are reported in Table 2 for trt2, trt4, and trt6. Treatments 1 and 2 were commercial grade diets (ME of 3.183, 3.220, and 3.265 Mcal/kg and CP of 23.6, 22.0, and 20.6% for starter, grower, and finisher, respectively) composed of all regular feed ingredients. The only difference was that trt1 did not contain a nonstarch polysaccharide (**NSP**) enzyme. Treatments 3 and 4 (ME of 3.205, 3.245, and 3.291 Mcal/kg and CP of 23.3, 21.7, and 20.2% for the starter, grower, and finisher, respectively) comprise equal inclusion levels of all enhanced feed ingredients. The only difference was that trt3 did not contain the NSP enzyme. Treatments 3 and 4 have same inclusion levels of feed ingredients as trt1 and trt2,

Table 2. Dietary formulations, expected nutrient compositions, and ME for treatments based on formulation

Item	Ingredient or nutrient	Starter[1,2]			Grower[1,2]			Finisher[1]		
		Trt2	Trt4	Trt6	Trt2	Trt4	Trt6	Trt2	Trt4	Trt6
Dietary inclusion (%)	Corn	57.34	57.34	57.97	60.94	60.94	60.07	65.09	65.09	63.60
	Soybean meal	31.05	31.05	31.12	26.16	26.16	26.83	22.31	22.31	23.67
	Distillers dried grains and solubles	6.00	6.00	6.00	8.00	8.00	8.00	8.00	8.00	8.00
	Calcium carbonate	1.72	1.72	1.39	1.44	1.44	1.50	1.41	1.41	1.37
	Fat (animal)	1.67	1.67	1.02	1.43	1.43	1.29	1.33	1.33	1.22
	Dicalcium phosphate	1.21	1.21	1.20	1.18	1.18	1.18	1.02	1.02	1.01
	DL-Met	0.25	0.26	0.27	0.23	0.23	0.25	0.25	0.25	0.26
	Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	Salt, plain (NaCl)	0.22	0.22	0.41	0.20	0.20	0.40	0.19	0.19	0.40
	L-Lys	0.14	0.14	0.22	0.03	0.03	0.09	0.02	0.02	0.07
	Trace mineral[4]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	BMD 50[5]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Phytase[6]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	NSP enzyme[7]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	DM	88.22	88.22	88.14	88.20	88.20	88.24	88.13	88.13	88.16
	CP	23.60	23.31	23.50	22.00	21.67	22.00	20.58	20.17	20.77
	Crude fat	4.50	4.19	3.57	4.50	4.16	4.00	4.50	4.13	4.00
	NDF	11.10	7.50	7.60	11.80	8.00	8.00	12.00	8.00	8.00
Expected nutrient compositions (%) and ME (kcal/kg) based on calculations	Calcium	1.10	1.08	0.95	0.98	0.96	0.98	0.93	0.90	0.89
	Phosphorus (total)	0.67	0.65	0.65	0.66	0.64	0.64	0.62	0.60	0.60
	Phosphorus (available)	0.46	0.46	0.46	0.46	0.46	0.46	0.43	0.43	0.43
	ME poultry	3,183	3,205	3,182	3,220	3,245	3,221	3,265	3,291	3,265
	Met	0.63	0.61	0.63	0.59	0.57	0.59	0.59	0.57	0.59
	Lys	1.34	1.26	1.33	1.13	1.05	1.12	1.03	0.94	1.01
	Sodium	0.20	0.13	0.20	0.20	0.12	0.20	0.20	0.12	0.20
	Potassium	0.82	0.82	0.83	0.76	0.76	0.77	0.70	0.70	0.72
	Chloride	0.22	0.22	0.34	0.21	0.21	0.33	0.20	0.21	0.34
	Digestible Met	0.60	0.58	0.60	0.56	0.54	0.56	0.56	0.54	0.56
	Digestible Cys	0.31	0.30	0.30	0.30	0.29	0.29	0.28	0.27	0.28
	Digestible Lys	1.20	1.14	1.20	1.00	0.93	1.00	0.90	0.83	0.90

Continued

Table 2 (Continued). Dietary formulations, expected nutrient compositions, and ME for treatments based on formulation

[1]Treatment (Trt) 1 and Trt2 are similar, except that Trt1 does not contain the NSP enzyme; Trt3 and Trt4 are similar, except that Trt3 does not contain the NSP enzyme; Trt5 and Trt6 are similar, except that Trt5 does not contain the NSP enzyme.

[2]Robenz (30 g/t) [17] was added to all starter and grower feeds.

[3]Vitamin premix provided the following (per kg of diet): 2.4 mg of thiamin mononitrate; 44 mg of nicotinic acid; 4.4 mg of riboflavin; 12 mg of D-Ca pantothenate; 12.0 μg of vitamin B_{12} (cobalamin); 4.7 mg of pyridoxine HCl; 0.11 mg of D-biotin; 5.5 mg of folic acid; 3.34 mg of menadione sodium bisulfite complex; 220 mg of choline chloride; 27.5 μg of cholecalciferol; 1,892 μg of trans-retinyl acetate; 11 mg of all-*rac*-α-tocopheryl acetate; 125 mg of ethoxyquin.

[4]Trace mineral mix provided the following (per kg of diet): 60 mg of manganese ($MnSO_4$-H_2O); 30 mg of iron ($FeSO_4$-$7H_2O$); 50 mg of zinc (ZnO); 5 mg of copper ($CuSO_4$-$5H_2O$); 0.15 mg of iodine (ethylene diamine dihydroiodide); 0.3 mg of selenium ($NaSeO_3$).

[5]Manufactured by Pfizer Animal Health [17].

[6]Phytase enzyme is a commercial product that supplied 500 phytase units (per kg of diet).

[7]Nonstarch polysaccharide (NSP) enzyme is a commercial product added at the recommended level. As the enzyme products were not cleared with the companies, we are not permitted to report trademarked names.

except that trt3 and trt4 incorporate enhanced materials (corn, SBM, and DDGS), whereas trt1 and trt2 incorporate regular materials. Treatments 5 and 6 were formulated to be isocaloric and isonitrogenous with tr1 and trt2 while being composed of all enhanced feed ingredients. The only difference was that trt5 did not contain the NSP enzyme. Thus, 3 dietary types (regular, enhanced, and isocaloric) were each evaluated in the presence and absence of the NSP enzyme. The ME, CP, and amino acid values for regular corn, DDGS, and SBM were estimated based on previously published values [18].

Statistical Analyses

Factorial analysis (3 × 2) with dietary type (regular, enhanced, and enhanced-isocaloric) and NSP enzyme (with and without) as factors was used to determine effects on broiler performance using the GLM method of SAS [19]. Duncan's test was used to identify statistical differences. Statistical significance level used was $P < 0.05$.

RESULTS AND DISCUSSION

Compositions of Feed Ingredients and Diets

As anticipated, compositional analysis showed that enhanced materials had lower fiber content (NDF) and lower ash contents than the corresponding regular materials due to fiber removal (Table 3). Elusieve processing increased starch content of corn by 7.8% and decreased NDF by 5.2%. Enhanced DDGS had higher protein by 2.3% and lower NDF by 3.4% compared with regular DDGS. Enhanced SBM had higher protein by 0.9% and lower NDF by 1.4% compared with regular SBM.

Starch content of regular corn (53.2%) was lower than usually observed (58–60%); the reason for this anomaly is not known. The CP content of enhanced corn was lower than for regular corn, which was not expected and has not been observed in any other processing runs of ground corn in the Elusieve pilot plant facility. We suspect that errors in compositional analysis could have caused the anomaly of lower protein content in enhanced corn compared with regular corn. Coefficient of variation for compositional

Table 3. Nutrient compositions of feed ingredients[1]

Material (%)	Moisture	CP	Crude fat	Ash	NDF	Starch
Regular corn[2]	11.0	10.9	3.3	2.4	12.0	53.2
Regular DDGS[2]	9.8	26.2	8.1	4.8	30.2	NM[3]
Regular SBM[2]	12.0	48.7	1.2	6.2	7.8	NM
Enhanced corn	11.7	9.7	3.1	1.7	6.8	61.0
Enhanced DDGS	10.0	28.5	8.1	5.1	26.8	NM
Enhanced SBM	11.8	49.6	1.3	6.3	6.4	NM
Corn fiber[4]	11.0	5.3	2.3	1.2	43.3	22.4
DDGS fiber[4]	12.1	11.2	4.6	5.2	56.8	NM
SBM fiber[4]	11.2	21.5	0.5	5.0	44.7	NM

[1]Values are means of results from analysis of 6 replicates.

[2]For corn, CV were less than 10%, except for NDF content, which had CV less than 20%; for soybean meal (SBM) and distillers dried grains and solubles (DDGS), CV were less than 5% except for fat content, which had CV less than 10%.

[3]NM = not measured.

[4]Not determined in this study. Typical values from previous studies on Elusieve process.

results of corn were higher than coefficient of variation for compositional results of SBM and DDGS (Table 3).

The enhanced diets (trt3, trt4, trt5, and trt6) were formulated to have protein content within 0.5% or same as regular diets (trt1 and trt2; Table 2). However, the measured protein contents of enhanced diets were found to be 1.0 to 2.0% higher than regular diets (Table 4). Formulation of diets was based on the lower protein content of enhanced corn compared with regular corn and we suspect that this could have resulted in higher protein contents in enhanced diets.

Broiler Performance

There was a significant interaction effect (dietary type and enzyme) only for 2 out of the 12 performance indicators: (1) feed conversion at 35 d and (2) live weight of processed birds (Table 5). The interaction effect of live weight was not considered important because weight gain at d 42, which had a bigger sample than live weight, did not show any interaction effect. Nonstarch polysaccharide enzyme decreased feed conversion at d 35 for enhanced diet, whereas there was no effect of NSP enzyme on feed conver-

Table 4. Measured nutrient compositions of diets (%)

Dietary phase	Treatment	CP	CF	Total fat	Ash	Moisture
Starter	Treatment 1	22.8	2.3	4.2	5.2	11.0
	Treatment 2	21.9	2.5	4.5	5.2	10.8
	Treatment 3	22.6	1.9	4.7	5.7	10.5
	Treatment 4	23.3	2.0	4.7	5.2	11.3
	Treatment 5	24.5	2.0	4.0	5.3	10.9
	Treatment 6	22.2	1.8	4.1	5.5	10.8
Grower	Treatment 1	19.3	2.2	4.6	5.1	12.7
	Treatment 2	20.0	2.4	4.7	5.1	12.5
	Treatment 3	21.3	2.0	3.5	5.8	12.6
	Treatment 4	22.2	2.3	4.8	5.8	12.5
	Treatment 5	22.2	2.2	4.5	6.2	12.7
	Treatment 6	22.8	2.4	4.7	6.2	12.7
Finisher	Treatment 1	19.2	2.1	4.3	4.9	11.7
	Treatment 2	18.6	2.3	4.2	4.6	11.5
	Treatment 3	21.5	2.2	4.2	5.4	11.1
	Treatment 4	21.5	2.2	4.6	5.4	11.4
	Treatment 5	21.3	2.3	4.2	5.6	11.3
	Treatment 6	21.8	2.1	4.5	6.0	11.4

Table 5. Broiler performance for different treatments

Item	Adjusted feed consumption per bird (kg)			Adjusted feed conversion			Weight gain (kg)			Carcass yield[1] (%)	Breast yield[1] (%)	Live weight[1] (kg)
	0 to 21 d	0 to 35 d	0 to 42 d	d 21	d 35	d 42	d 21	d 35	d 42			
Dietary type												
Without enzyme												
Regular (treatment 1)	1.259	3.381	4.496	1.377	1.642^{ab}	1.759	0.914	2.059	2.556	74.65	20.08	2.671^{ab}
Enhanced (treatment 3)	1.240	3.532	4.602	1.336	1.649^{ab}	1.745	0.928	2.142	2.637	75.69	20.51	2.646^{ab}
Enhanced, isocaloric (treatment 5)	1.276	3.549	4.655	1.338	1.622^{bc}	1.752	0.954	2.188	2.657	74.73	21.45	2.682^{a}
With enzyme												
Regular (treatment 2)	1.234	3.470	4.594	1.353	1.696^{a}	1.801	0.912	2.046	2.551	74.40	19.93	2.579^{b}
Enhanced (treatment 4)	1.226	3.440	4.592	1.318	1.565^{c}	1.699	0.930	2.198	2.703	74.57	20.51	2.734^{a}
Enhanced, isocaloric (treatment 6)	1.244	3.461	4.661	1.319	1.574^{c}	1.723	0.943	2.199	2.705	74.35	21.01	2.717^{a}
P-value												
Dietary type	0.436	0.814	0.913	0.010	0.003	0.016	0.003	<0.0001	0.004	0.190	<0.0001	0.041
Enzyme	0.133	0.162	0.680	0.206	0.147	0.496	0.667	0.461	0.265	0.061	0.362	0.694
Interaction	0.434	0.114	0.243	0.779	0.007	0.078	0.805	0.483	0.644	0.468	0.716	0.016
CV (%)	4.4	5.0	3.8	3.2	3.7	3.2	2.9	3.8	4.2	3.2	8.5	7.6
Main effect												
Dietary type												
Regular	1.246	3.426	4.542	1.365^{a}	1.669	1.779^{a}	0.913^{b}	2.053^{b}	2.553^{b}	74.52	20.01^{b}	2.625
Enhanced	1.224	3.486	4.598	1.319^{b}	1.607	1.722^{b}	0.928^{b}	2.169^{a}	2.670^{a}	75.13	20.51^{b}	2.689
Isocaloric	1.259	3.506	4.657	1.328^{b}	1.598	1.737^{b}	0.948^{a}	2.194^{a}	2.681^{a}	74.54	21.23^{a}	2.699
Enzyme												
Without	1.254	3.517	4.648	1.345	1.638	1.752	0.932	2.147	2.653	75.02	20.69	2.666
With	1.233	3.434	4.556	1.329	1.612	1.741	0.928	2.130	2.617	74.44	20.48	2.676

$^{a–c}$Within a column, values followed by the same letter are not different ($P < 0.05$).
[1]Mean for processed birds.

sion at d 35 for regular and enhanced-isocaloric diets (Table 5). For the treatments without NSP enzyme, there was no effect of diets on feed conversion at d 35. For the treatments with NSP enzyme, enhanced diets had lower feed conversion at d 35 compared with the regular diet (Table 5).

Chicks fed enhanced diets had improved performance in terms of weight gain, breast yield, and feed conversion compared with regular diets (Table 5). There were no differences in feed consumption and carcass yield between enhanced and regular diets. There was no effect of NSP enzyme on performance and feed consumption. The use of exogenous enzymes in wheat- and barley-based diets is known to improve performance, but the results for corn-based diets have been variable [20–22]. Earlier works have reported inconsistent performance when xylanase was used independent of other enzymes, such as phytase, protease, and amylase in corn-soy diets [22].

Enhanced diets resulted in birds with 4.6 to 5.0% higher BW gain, higher breast weight by 7.1 to 11.3% and feed conversion improvement by 4 to 6 points (2.4 to 3.2%) compared with regular diet (Table 5). There was no effect of dietary type on carcass yield. The higher breast yield for enhanced diets compared with regular diet is perhaps because the lower fiber content of enhanced diets facilitates higher protein digestibility. Thus, Elusieve processing had a beneficial effect on diets by increasing BW gain, lowering feed conversion, and increasing breast yield. There was no difference ($P > 0.05$) in mortality among the treatments.

Implementation Strategies for Enhanced Diets and Economic Analysis

The poultry industry could take advantage of higher BW gain from enhanced feeds by either growing the birds to a heavier final weight using the same growth period (42 d) as existing practice or by shortening the growth period to 40 d (or 41 d) to obtain same weight as in existing practice. Mean BW gain of birds in the last week (d 35 to 42) was 72 g/d (Table 5). Considering the rate of BW gain decreased as age increased and the BW for enhanced diets was higher than regular diet by 117 to 128 g, the 40-d growth period for birds with enhanced diets should be achievable without substantial change in target BW. Annual broiler production and increase in annual broiler production were calculated on the basis that stoppage between cycles was 25% of total time, which corresponds to 274 d of broiler production per year.

The capital investment required for implementing the Elusieve process in a 1,000 t/d feed mill is estimated to be $2.3 million, which is based on 3.25 times the equipment cost ($720,000; Table 6). The operating cost would be $72,332/yr based on 100 hp electricity consumption and a labor requirement of 2 man-hours per day (Table 6). The total operating cost, inclusive of depreciation cost (assuming a plant life of 15 yr), would be $0.65/t.

Costs and revenues were estimated for poultry farms implementing enhanced diets based on experimental results for main effects and

Table 6. Estimated costs for implementation of the Elusieve process in a feed mill producing 1,000 t/d, which corresponds to a broiler processing capacity of nearly 210 birds/min

Cost type	Category	Value
Fixed costs	Sifters	$300,000
	Aspirators	$260,000
	Instruments	$80,000
	Conveyor bins	$80,000
	Total equipment cost	$720,000
	Capital investment	$2,300,000
Equipment operating costs	Electricity requirement	100 horsepower (74.6 kW)
	Electricity cost/yr (at $0.05/kW per h)	$31,332
	Labor/yr (at 2 man-hours/d and $30/man-hour)	$21,000
	Maintenance cost/yr	$20,000
	Total operating cost/yr	$72,332
Total	Total operating cost per tonne of feed processed (inclusive of depreciation cost and based on a plant life of 15 yr)	$0.65/t

Table 7. Comparison of costs and revenues for regular, enhanced, and enhanced-isolacaloric, isonitrogenous diets[1]

		Enhanced diet			Enhanced, isocaloric, isonitrogenous		
Category	Regular diet, 42-d growth	d 42 (higher weight)	41-d growth	40-d growth	d 42 (higher weight)	41-d growth	40-d growth
FCR	1.779	1.722	1.722	1.722	1.737	1.737	1.737
Weight gain (kg)	2.553	2.67	2.553	2.553	2.681	2.553	2.553
Carcass yield (%)	74.52	75.13	75.13	75.13	74.54	74.54	74.54
Breast yield (%)	20.01	20.51	20.51	20.51	21.23	21.23	21.23
Broiler weight (t/yr)	157,949	165,073	161,802	165,847	165,743	161,802	165,847
Broiler no./yr	55,238,400	55,238,400	56,585,678	58,000,320	55,238,400	56,585,678	58,000,320
Broiler revenue/yr	$132,500,000	$140,100,00	$137,300,000	$140,700,000	$140,700,000	$137,400,000	$140,800,000
Increase in broiler revenue due to Elusieve	0	$7,600,000	$4,800,000	$8,200,000	$8,300,000	$4,900,000	$8,300,000
Feed consumed by chicks (t/yr)	280,992	284,256	278,622	285,588	287,896	281,050	288,076
Feed processed in feed mill (t/yr)	280,992	334,419	327,791	335,986	338,701	330,646	338,913
Fiber removed (t/yr)	0	50,163	49,169	50,398	50,805	49,597	50,837
Feed materials (cost/yr = Cost for feed processed in feed mill – Revenue from fiber)	$75,867,768	$81,013,081	$79,407,411	$81,392,596	$82,050,347	$80,099,113	$82,101,591
Feed expenditure due to Elusieve	0	−$5,100,000	−$3,500,000	−$5,500,000	−$6,200,000	−$4,200,000	−$6,200,000
Elusieve operating cost/yr	$0	−$72,332	−$72,332	−$72,332	−$72,332	−$72,332	−$72,332
Depreciation cost/yr	0	−$148,747	−$146,971	−$149,164	−$149,886	−$147,737	−$149,942
Profit due to Elusieve/yr	0	$2,200,000	$1,000,000	$2,500,000	$1,900,000	$500,000	$1,900,000
Payback period (yr)	NA[2]	1.0	2.1	0.9	1.2	4.7	1.2

[1]Based on 274 operating days per year (based on 25% off time between cycles) for a processing plant at 210 bird/min for current practice. Feed mill capacity of 1,000 t/d and 350 operating days per year would satisfy requirements for all of the above scenarios.

[2]Not applicable.

compared with regular diets representing current industry practice (Table 7). The results are reported for 3 implementation scenarios: (1) production to achieve a heavier final weight, (2) reducing the growth period to 41 d, and (3) reducing the growth period to 40 d. The final weights for birds with enhanced diets were assumed to be the same (2.594 kg) as that for the 2 scenarios of shortened growth period on the regular diet. The wholesale prices for the breast and the rest of the bird used in this study were $0.87/lb and $0.42/lb, calculated based on USDA price listing [23]. The wholesale broiler composite price for September, 2011, was $0.74/lb and was conservatively used in this study as $0.70/lb. The retail prices of broiler composite, breast (bone-in), and whole broiler were $1.77, $2.20, and $1.29/lb, respectively, for September, 2011 [23]. The wholesale price for breast was calculated from the retail breast price by multiplying with the ratio of wholesale composite to retail composite prices. Similarly, the wholesale price of whole broilers was calculated from the retail whole broiler price by multiplying with the ratio of wholesale composite to retail composite prices. The economics estimates are based on feed price of $270/t and fiber price of $185/t (price of wheat middlings).

Broiler production increased by 3,852 to 7,897 t/yr for farms implementing enhanced diets (Table 7). The increase in feed requirement due to higher broiler production was partially offset by lower feed conversion for the enhanced diets. Savings from lower feed conversion were partially offset by the lower value for fiber coproducts relative to feed in Elusieve implemented feed mills. Feed material costs for enhanced diets would be higher by $3.5 to $6.2 million/yr (Table 7). The increase in broiler revenue in farms implementing enhanced diets would be $4.8 to $8.3 million/yr. The overall increase in profit due to implementation of the Elusieve process in a 1,000 t/d feed mill is estimated to be $0.5 to $2.5 million/yr, which is 0.8 to 4.3 cents per bird produced. The payback period is estimated to be 0.9 to 4.7 yr.

CONCLUSIONS AND APPLICATIONS

1. Elusieve processing increased starch content of corn by 7.8% and increased protein contents of DDGS and SBM by 2.3 and 0.9%, respectively. Elusieve processing decreased NDF content of corn, DDGS, and SBM by 5.2, 3.4, and 1.4%, respectively.
2. Chicks fed enhanced diets had improved performance compared with regular diets. Enhanced diets resulted in birds with 4.6 to 5.0% higher BW gain, 7.1 to 11.3% higher breast weight, and 4 to 6 percentage points (2.4 to 3.2%) improvement in feed conversion compared with a regular diet. No effect on carcass yield was observed.
3. There was no effect of NSP enzyme on performance and feed consumption. Interaction effect (between NSP enzyme and dietary type) was observed only in 2 of a total of 12 performance indicators.
4. The profit due to the implementation of Elusieve process in a 1,000 t/d feed mill is estimated to be $0.5 to 2.5 million/yr, which is 0.8 to 4.3 cents per bird produced. The payback period is estimated to be 0.9 to 4.7 yr.

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Acknowledgments

Thanks to Dennis Rowe (Mississippi State University) for guidance in statistical analysis. Thanks to Chance Ervin, Tejas Pandya, Aditya Samala, Brianna Smith, Kaleb Smith, and Courtney Paige Thompson of Mississippi State University for help in Elusieve processing of feed ingredients. Thanks to Richard Ware of Ware Milling (Houston, MS) for custom grinding the corn. Thanks to Greg Mathis of Southern Poultry Research for valuable guidance.