

1 **DIET COMPOSITION AND ILEITIS IN PIGS 1**

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3 **Effect of dietary inclusion of distiller's dried grains with solubles on the ability of**
4 **growing pigs to resist a *Lawsonia intracellularis* challenge¹**

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11 **ABSTRACT: An experiment was conducted to determine if including distiller's**
12 **dried grains with solubles (DDGS) in the diet for growing pigs reduces the incidence**
13 **and/or severity of infection after a *L. intracellularis* challenge. Eighty 17-d old**
14 **weaned pigs were blocked by sex and weight and randomly allotted to one of four**
15 **treatment groups: negative control (NC) - unchallenged, corn-soy diet; positive**
16 **control (PC) - challenged, corn-soy diet; 10% DDGS diet (10D) – challenged; and**
17 **20% DDGS diet (20D) - challenged. Challenged pigs were orally inoculated with 1.5**
18 **x 10⁹ *L. intracellularis* after a 4-wk pre-challenge feeding period. On d 21 post-**
19 **challenge, pigs were euthanized, lesions of intestinal mucosa were evaluated, and**
20 **ileal tissue samples were analyzed by immunohistochemistry to determine presence**

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1 and proliferation of *L. intracellularis*. Challenging pigs with *L. intracellularis*
2 reduced growth rate, feed intake, and feed efficiency ($P < 0.01$), and increased
3 gauntness ($P < 0.05$) and diarrhea ($P < 0.01$) compared to unchallenged pigs. Diet
4 did not affect growth performance post-challenge ($P > 0.40$). Feeding 10 or 20%
5 DDGS diets did not reduce lesion length, prevalence, proliferation of *L.*
6 *intracellularis*, or severity of lesions ($P > 0.10$). Dietary inclusion of DDGS may
7 provide some benefit to growing pigs subjected to a moderate ileitis challenge, but it
8 does not appear to reduce the incidence and severity of lesions under the conditions
9 of a severe *L. intracellularis* challenge used in this study.

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11 **Key Words:** Pig, Ileitis, Distiller's dried grains with solubles, Diet, Disease

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Introduction

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16 Ileitis, also known as porcine proliferative enteropathy (PPE), is an enteric
17 disease of the lower small intestine, and occasionally, the large intestine, that can
18 decrease feed intake, reduce growth rate, and increase mortality in swine. The
19 disease is caused by *Lawsonia intracellularis*, an intracellular microaerophilic
20 bacteria that infects immature epithelial cells located in the crypts of the villi of the
21 intestine. Cellular proliferation and thickening of the infected intestine occurs, and
22 may result in necrosis, ulceration, and (or) hemorrhaging of the epithelial surface.
23 Broonsvoort et al. (2001) estimated that *L. intracellularis* is present in approximately

1 75% of all U.S. swine herds. These infections increase cost of production from \$3 to
2 \$11 per pig, due to elevated feed cost and time to reach market weight (McOrist et
3 al., 1997).

4 Antibiotics and (or) antimicrobials have been used effectively against acute
5 outbreaks of *L. intracellularis* and prevention of the disease. Sub-therapeutic levels
6 of these antibiotics often fail to prevent the disease, while therapeutic levels of feed-
7 grade antibiotics are very expensive and can generally only be used for a limited
8 period of time. In addition, there has been increasing pressure to decrease the use
9 of antibiotics in livestock production because of the potential for development of
10 antibiotic resistant bacteria. Therefore, there is a significant need to identify
11 alternative approaches to disease control that would reduce antibiotic usage in
12 commercial pork production systems.

13 Data from informal field reports suggest that including distiller's dried grains
14 with solubles (DDGS) in grow-finish diets in commercial herds, may reduce or
15 eliminate the dependence on antibiotics to combat PPE (Goehl, 2001). Distiller's
16 dried grains with solubles is a co-product of the fuel ethanol industry and is often an
17 economical partial replacement for corn, soybean meal, and dicalcium phosphate in
18 commercial swine diets. The product contains approximately 10% crude fiber, and
19 the fiber composition is primarily insoluble (42.2%) versus soluble (0.7%) in nature
20 (Shurson et al., 2000). According to Hampson et al. (1999), feeding diets that are
21 low in soluble non-starch polysaccharides can reduce the proliferation of pathogenic
22 organisms in the gastrointestinal tract. Smith and Halls (1968) suggested that fiber
23 influences the secretory function of the epithelium, and this alteration may impair

1 bacterial adhesion. Fiber also has a “cleansing” effect in the gut as a result of
2 reducing the viscosity of digesta (Lawrence, 1972). The objective of this study was
3 to evaluate the effect of dietary inclusion of DDGS on the ability of growing pigs to
4 resist a challenge with *L. intracellularis*.

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Materials and Methods

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Animals and Allotment

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11 The experimental protocols used in this study were reviewed and approved by
12 the Institutional Animal Care and Use Committee at the University of Minnesota.
13 Eighty crossbred pigs (40 gilts and 40 barrows; 1/4 Landrace x 1/4 Large White x
14 1/2 Duroc) were obtained and transported from a commercial farrowing unit to
15 isolation barns located on the University of Minnesota (St. Paul) campus. The
16 source herd had no history or recorded cases of proliferative enteropathy, and was
17 serologically negative for *Lawsonia intracellularis*, porcine respiratory and
18 reproductive syndrome (PRRS), and *Actinobacillus pleuropneumonia*. Pigs were
19 also clinically negative for *Salmonella cholerasuis*, transmissible gastroenteritis
20 (TGE), and pathogenic *Brachyspira* species. Pigs, approximately 17 d of age, were
21 blocked by gender and weight and within each block pigs were allotted randomly to
22 one of four treatment groups: negative control (NC) corn-soybean meal diet fed
23 without disease challenge, positive control (PC) corn-soybean meal diet fed with

1 **disease challenge, 10% DDGS diet fed with disease challenge (10D), or 20% DDGS**
2 **diet fed with disease challenge (20D). The DDGS utilized for the study was obtained**
3 **from Al-Corn Clean Fuel (Claremont, MN). Animals were housed in isolation**
4 **rooms, with 10 pigs per room (7.25 m² per room, 8 rooms total) and 2 rooms per**
5 **treatment group.**

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7 *Experimental Diets*

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9 **All pigs were fed a common commercial pelleted Phase I nursery diet for the first**
10 **4 d of the experiment to encourage feed intake prior to initiation of dietary**
11 **treatments. After the initial 4-d acclimation period, animals were fed experimental**
12 **diets for the remainder of the 53-d study. Representative samples of each diet were**
13 **obtained and analyzed for dry matter, gross energy, crude protein, ash, ether**
14 **extract, crude fiber, calcium, phosphorus, and individual amino acid composition.**
15 **Experimental diets were formulated to contain equivalent energy (3390 kcal/kg**
16 **ME), calcium (0.80%), total phosphorus (0.70%), and apparent ileal digestible**
17 **lysine (1.15%). Diets were formulated based on recently determined DDGS nutrient**
18 **values for energy (Spiehs et al., 1999), total amino acid and mineral levels (Spiehs et**
19 **al., 2002), and apparent ileal amino acid digestibility coefficients (Whitney et al.,**
20 **2000). The ME value used for DDGS was 3350 kcal/kg on an as-fed basis, while**
21 **apparent ileal digestible lys, met + cys, thr, and trp levels were estimated at 0.39%,**
22 **0.57%, 0.55%, and 0.13%, respectively. All other nutrients were provided to meet**
23 **or exceed NRC (1998) recommendations. Digestible and metabolizable energy**

1 values were calculated based on proximate analysis values using the following
2 formulas from Noblet and Perez (1993):

3

4 $DE \text{ kcal/kg} = 4151 - (122 \times \% \text{ Ash}) + (23 \times \% \text{ CP}) + (38 \times \% \text{ EE}) - 64 \times \text{Crude}$
5 fiber)

6 $ME \text{ kcal/kg} = DE \times (1.003 - (0.0021 \times \% \text{ CP}))$

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8 *Disease Challenge*

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10 Four wks after experimental diets were initiated (d 32), pigs were manually
11 restrained and provided 60 ml of either saline (NC) or an inoculation of *L.*
12 *intracellularis* (PC, D10, and D20 treatments) via stomach tube (Winkelman, 1999).
13 The inoculate was prepared as a mucosal homogenate collected from the small
14 intestines of pigs previously infected with *Lawsonia intracellularis* and exhibiting
15 lesions consistent with ileitis. Mucosal material was collected by scraping the lumen
16 of the infected intestine, and then diluting it with a sucrose-phosphate-glutamate
17 buffer with the goal of obtaining a dosage rate of 1×10^8 *L. intracellularis* per pig. A
18 representative sample of the harvested intestinal material was submitted to the
19 University of Minnesota Veterinary Diagnostic Lab, and actual dosage rate of *L.*
20 *intracellularis* provided per pig was determined to be 1.56×10^9 . Additionally, the
21 material was screened and determined to be negative for other pathogens, including
22 spirochetes, viruses, parasite ova, B-hemolytic *E. coli* and *Salmonella* sp. Care was
23 taken to avoid cross-contaminating pigs from different rooms after the disease

1 challenge. Biosecurity procedures included the use of separate coveralls, boots, and
2 gloves for each room. In addition, cleaning and feeding schedules were developed
3 and implemented to ensure that movement between rooms was conducted in order
4 from non-infected (NC) to infected groups.

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6 *Data Collection*

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8 Growth rate and feed intake data were collected for both the pre- and post-
9 inoculation periods. Clinical observations for alertness, gauntness, and diarrhea
10 were scored 3 times/wk following challenge. Alertness was scored on animal
11 behavior characteristics, with 1 = normal, 2 = slightly depressed or listless, and 3 =
12 severely depressed or recumbent. Gauntness scores were based on body condition,
13 with 1 = normal, 2 = slightly to moderately gaunt, and 3 = severely gaunt. Diarrhea
14 was scored based on the following characteristics of feces: 1 = no diarrhea, 2 = semi-
15 solid feces without blood, 3 = watery feces without blood, 4 = blood-tinged feces that
16 was loose or formed, and 5 = profuse diarrhea with frank blood or dark tarry feces.
17 Fecal samples were collected on d 14 and d 20 post-inoculation, and sent to the
18 University of Minnesota Veterinary Diagnostic Laboratory for polymerase chain
19 reaction (PCR) evaluation of *L. intracellularis* presence, to determine if pigs were
20 shedding the organism. Bacterial DNA were extracted from fecal samples using a
21 Qiagen extraction kit (Qiagen, Valencia, CA) prior to PCR analysis using a
22 Quantitect kit (Qiagen, Valencia, CA) and following the procedures of Jones et al.
23 (1993).

1 **On d 20 or d 21 post-challenge, all pigs were euthanized and necropsies were**
2 **performed. Internal organ weights of the heart, empty stomach, liver, and empty**
3 **small and large intestine were determined. Representative samples of digesta from**
4 **the small and large intestines were collected and pH was measured. Length of the**
5 **small and large intestine was also measured and visual evaluation (scoring) of the**
6 **general condition of the intestine (lesion severity), length of observable lesions, and**
7 **location of lesions were recorded. Lesions were scored for severity based on the**
8 **following criteria: 0 = normal (no visual appearance of lesion), 1 = mild mesenteric**
9 **and intestinal wall edema and hyperemia, 2 = mild to moderate edema and**
10 **hyperemia of the mesentery and intestinal wall, and corrugated intestinal mucosa**
11 **(PIA), 3 = severe mesenteric and intestinal wall edema and hyperemia, and necrosis**
12 **of the mucosal surface with formation of pseudo-diphtheric membrane (necrotic**
13 **enteritis), and 4 = moderate to severe edema and hyperemia of the mesentery and**
14 **intestinal wall, thick and corrugated mucosa, and blood clots in the intestinal lumen**
15 **(PHE). A 10 cm tissue section of the distal ileum proximal to the ileal-cecal junction**
16 **was collected, along with adjacent lymph nodes, and were fixed by immersion in**
17 **10% neutral buffered formalin, embedded in paraffin, and analyzed by**
18 **immunohistochemistry (IHC) using a monoclonal antibody specific for L.**
19 **intracellularis (McOrist et al., 1987). The reaction to L. intracellularis antigen was**
20 **graded from 0 (no L. intracellularis positive antigen labeled) to 4 (100% of epithelial**
21 **cells in the crypts with positive antigen labeling) (Guedes et al., 2002a).**

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1 *Statistical Analysis*

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3 Analysis of variance was conducted on all data utilizing the GLM procedures of
4 SAS (1985). Growth performance data were analyzed by room using analysis of
5 variance (two replications per treatment). All other data were analyzed utilizing the
6 individual pig as the experimental unit, which provided 20 replications per
7 treatment. Least squares means were used to compare the negative and positive
8 control groups, and thereby, evaluate the effects of infecting pigs relative to the
9 response criteria measured. Analysis of variance was conducted to compare
10 response criteria among the disease challenge treatments (PC, D10, and D20). In
11 addition, least squares means comparisons were conducted among the challenged
12 treatments to identify differences due to dietary DDGS inclusion level.

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Results and Discussion

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17 *Diet Composition*

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19 Experimental diet composition and nutrient analysis are shown in Table 1.
20 Calculated metabolizable energy (ME) concentration was numerically lower in all
21 diets compared to formulated levels (3168 vs. 3390 kcal/kg), but was similar among
22 experimental diets (range = 3152 – 3197 kcal/kg ME). Calcium level tended to be
23 higher in the corn-soybean meal diet (0.89%), and the 10% and 20% DDGS diets

1 (0.86% and 0.85%, respectively), compared to the formulated level (0.80%), but was
2 within the permitted analytical range of 0.66% - 0.94% (AOAC, 1990). Analyzed
3 total phosphorus concentration was similar among dietary treatments, but lower
4 than the formulated level (0.58 vs. 0.70%) and outside of the permitted analytical
5 range of 0.61% - 0.79% (AOAC, 1990). Addition of DDGS to the diet increased
6 crude protein level, and tended to increase individual amino acid concentrations
7 with the exception of lysine, which was relatively constant among dietary
8 treatments. Nitrogen concentration and intake have been previously demonstrated
9 to increase with DDGS inclusion in the diet (Spiels et al., 1999).

11 *Growth Performance*

13 A summary of the growth performance data for the pre- and post-challenge
14 periods is provided in Table 2. Growth rate, feed intake, and feed conversion were
15 similar among dietary treatments during the pre-challenge period ($P \geq 0.15$).
16 Challenging pigs resulted in a 55% decrease in growth rate, 25% decrease in feed
17 consumption, and a 40% reduction in feed conversion ($P < 0.01$). Providing 10 or
18 20% DDGS in the diet did not significantly affect growth, feed intake, or feed
19 efficiency ($P > 0.40$).

20 The lack of change in growth performance when feeding the 10 and 20% DDGS
21 diets observed in this study supports results reported by Whitney and Shurson
22 (2004) utilizing the same source of DDGS. In that study, feeding up to 25% DDGS
23 in Phase 3 nursery diets resulted in comparable growth rate, feed intake, and feed

1 efficiency following a 2-wk acclimation period. Conversely, Wahlstrom and Libal
2 (1980) observed reduced growth rate with increasing level of DDGS from 0 to 30%
3 in the diet. However, although pigs were older (4 wks of age) and heavier (8.1 kg) at
4 the beginning of that 4-wk growth performance trial compared to the current study,
5 diets were formulated to be equivalent in total lysine, and not necessarily energy. A
6 reduction in dietary energy concentration and amino acid digestibility would be
7 expected with DDGS source used in the study, and may have partially explained the
8 reductions observed in growth rate. The authors also indicated that the DDGS
9 source used appeared to negatively affect palatability since feed intake was reduced.

10 The decrease in growth performance observed after challenging pigs with
11 *Lawsonia intracellularis* was expected, but was more severe than has typically been
12 documented in field and disease challenge situations. Using a similar ileitis
13 challenge model, but younger pigs (28 d of age at time of challenge), Winkelman et
14 al. (1998) observed a 15% decrease in growth rate during the first 3 wks post-
15 inoculation. Growth performance was most greatly affected during the third wk
16 after challenge, with *Lawsonia* inoculation reducing feed intake 14% and increasing
17 feed/gain by 23%.

18 19 *Alertness, Gauntness, and Fecal Scores*

20
21 Clinical gauntness and fecal scores are presented in Tables 3 and 4, respectively.
22 Pig behavior appeared normal throughout the trial, with only one pig exhibiting
23 slight depression during the final week of the study. Unchallenged pigs remained

1 healthy throughout the post-challenge period, as indicated by a lack of gauntness
2 and near-normal fecal scores. Infecting pigs resulted in increased incidence of
3 gauntness and diarrhea ($P < 0.10$). During the first wk post-challenge, infected pigs
4 fed the control corn-soybean meal diet tended to be more gaunt ($P < 0.10$) than pigs
5 fed the 20% DDGS diet. A similar increase in gauntness was observed on d 16 post-
6 challenge in pigs fed the control diet compared to pigs fed the 20% DDGS diet ($P <$
7 0.05). No other differences in gauntness score due to diet were noted during the
8 final two wks of the study ($P > 0.10$). Fecal scores were similar among dietary
9 treatments ($P > 0.10$) during the first two wks post-challenge. During the final wk of
10 the study, however, pigs fed either the 10% or 20% DDGS diets tended to exhibit
11 looser stools compared to positive control pigs ($P < 0.10$).

12 Guedes et al. (2002b) observed a high correlation between fecal consistency and
13 body condition or gauntness on d 21 post-challenge in pigs dosed with 3.4×10^9 L.
14 intracellularis from a mucosal homogenate challenge. In that study, gauntness was
15 not observed until the second wk post-challenge, and peaked at around 3 wks of age.
16 Fecal consistency started becoming semi-loose 1 wk after challenge, but was most
17 profuse and noticeable around the third wk post-challenge. In the present study,
18 pigs had noticeably looser stools within 3 d after challenge, perhaps indicating a
19 more severe disease challenge.

20 Although dietary treatment did not appear to greatly affect gauntness, dietary
21 DDGS appeared to increase the incidence of diarrhea observed after challenge. The
22 dietary fiber contained in DDGS is primarily insoluble (42.2%) versus soluble
23 (0.7%) in nature (Shurson et al., 2000). Corn and soybean meal, the two main

1 ingredients DDGS replaces in a typical grow-finish diet, contain much lower levels
2 of insoluble fiber (4.7% and 13.2%), but are greater in soluble fiber content (1.7%
3 and 1.6%), respectively (Shurson et al., 2000). Soluble non-starch polysaccharides
4 have been shown to increase the viscosity of digesta by increasing retention of water,
5 and thereby reducing the dry matter content of digesta, in the gastrointestinal tract.
6 Rainbird (1986) observed a 27% reduction in dry matter content of digesta after
7 including guar gum, a purified form of soluble fiber, in growing pig diets. However,
8 Pond et al. (1988) indicated a 19% reduction in digesta dry matter content after
9 feeding a diet containing 80% alfalfa meal. Alfalfa has approximately 4.3% soluble
10 fiber, but contains significantly more insoluble fiber (52.4%), suggesting that
11 insoluble fiber can also reduce digesta dry matter content in the pig. Including
12 high-fiber ingredients also has been shown to increase rate of passage through the
13 gastro-intestinal tract. Jorgensen et al. (1996) indicated that passage rate was
14 increased 5 – 6 fold through the terminal ileum when pigs were fed a diet high in
15 insoluble fiber (268 vs. 59 g/kg). The authors attributed an increase in peristaltic
16 action to the increased passage rate. Potkins et al. (1991) observed a 14 and 23%
17 increase in rate of passage of digesta by including wheat bran or oatmeal co-
18 products in the diet. Wheat bran and oat fiber are excellent sources of insoluble
19 fiber (Grieshop et al., 2001). Therefore, including higher fiber ingredients in the
20 diet, regardless of solubility, would be expected to increase looseness of stools in
21 pigs, as was observed when feeding diets containing DDGS in this study.

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2 *Body and Internal Organ Weights*

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4 **Body weights and internal organ data are summarized in Table 5. Initial body**
5 **weight, and body weight at the time of challenge were similar among dietary**
6 **treatment groups ($P > 0.10$). Infecting pigs with *L. intracellularis* reduced body**
7 **weight at the time of necropsy ($P < 0.001$). Heart and stomach weights, relative to**
8 **body weight, were unaffected by challenge ($P > 0.10$). Liver and small intestinal**
9 **weights, however, were increased relative to body weight when pigs were challenged**
10 **($P < 0.01$), while large intestine weight also tended to be increased ($P < 0.10$).**
11 **Intestinal length decreased in both the small ($P < 0.10$) and large ($P < 0.01$) intestine**
12 **when pigs were infected with ileitis. Challenged pigs also had more acidic digesta**
13 **collected from both the small and large intestines ($P < 0.05$).**

14 **Providing DDGS in the diet did not affect ending body weight ($P > 0.10$),**
15 **although increasing DDGS level in the diet numerically decreased final body weight.**
16 **Heart and liver weights, relative to bodyweight, were greater in 20D pigs compared**
17 **to PC pigs ($P < 0.05$). Large intestine weight also tended to be greater in 20D pigs**
18 **compared to PC or 10D pigs, relative to body weight ($P < 0.10$). Stomach and small**
19 **intestine weights were unaffected by dietary treatment. Providing 10% or 20%**
20 **DDGS decreased small intestine and total intestine length ($P < 0.05$), but did not**
21 **appreciably alter length of the large intestine ($P > 0.10$). Digesta pH was unaffected**
22 **by dietary treatment. No differences in body weight or internal organ weights were**
23 **observed for pigs fed diets containing 10% and 20% DDGS.**

1 **Results from several studies indicate that feeding diets high in insoluble fiber**
2 **increases the mass of the gastro-intestinal tract relative to overall body weight. Ma**
3 **et al. (2002) observed a 21% and 25% increase in small and large intestine weights,**
4 **respectively, relative to bodyweight when an insoluble fiber source (5% wheat bran)**
5 **was included in a corn-soybean meal based grower pig diet. Including a soluble**
6 **fiber source (5% sugar beet pulp), however, did not affect gastro-intestinal weight.**
7 **Jorgensen et al. (1996) noted an increase in stomach, cecum, and colon weights in**
8 **growing pigs fed high insoluble fiber diets. Experiments by Zebrowska et al. (1983)**
9 **indicated that feeding high fiber diets significantly increases the secretion of**
10 **endogenous fluids, including saliva, gastric juice, pancreatic juice, and bile. The**
11 **increase in dietary fiber content was accomplished mainly by increasing the soluble**
12 **fiber content by feeding barley and soybean meal. Wenk (2001) suggested that the**
13 **increased secretion of these fluids is associated with higher activity of secretory**
14 **organs, and therefore, may result in their enlargement. Because bactericidal**
15 **enzymes and antibacterial peptides are contained in endogenous fluids, increasing**
16 **secretion by these organs due to feeding diets containing significant amounts of fiber**
17 **may thereby provide additional protection against infection by enteric pathogens.**

18 **Feeding diets high in fiber has also been shown to affect other internal body**
19 **organ weights. Ma et al. (2002) observed a reduction in liver weight with inclusion**
20 **of wheat bran or sugar beet pulp. Pancreas weight was also reduced by adding 18%**
21 **wheat bran to the diet. Other studies, however, have indicated an increase in**
22 **internal organ weights in response to dietary fiber addition. Pond et al. (1988)**
23 **observed an increase in the liver and kidney weights relative to body weight when**

1 an 80% alfalfa meal diet was fed to mature barrows. In that study, feeding the 80%
2 alfalfa meal diet, which was high in insoluble fiber, increased organ weight, and was
3 correlated with an increase in basal metabolic rate. In the current study, inclusion
4 of DDGS in the diet as a source of insoluble fiber appeared to primarily increase
5 visceral organ weights relative to body weight, and may therefore, indirectly
6 increase the maintenance energy requirement of those pigs.

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8 *Clinical Lesion Evaluation*

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10 Clinical lesion evaluation results for the jejunum, ileum, cecum, and colon are
11 presented in Table 6. No lesions were observed in the intestinal tract of negative
12 control (NC) pigs, while lesions were observed in 63% of challenged pigs. Feeding
13 the 10% DDGS diet tended to increase the prevalence, severity, and length of lesions
14 in the jejunum compared to positive control (PC) pigs ($P < 0.10$). Feeding the 20%
15 DDGS diet tended to increase the severity of lesions in the jejunum compared to PC
16 pigs ($P < 0.10$), but lesion length was intermediate to the other challenged groups (P
17 > 0.10). Prevalence, severity, and length of lesions appeared unaffected by diet in
18 the ileum ($P > 0.10$). Pigs fed the 10% DDGS diet had increased prevalence, length,
19 and severity of lesions in the cecum compared to pigs fed either the 0 or 20% DDGS
20 diets ($P < 0.05$). Lesion severity was also greater in the colon for pigs fed the 10%
21 DDGS diet ($P < 0.10$), while lesion prevalence and length were unaffected by dietary
22 treatment. Overall, lesions were longer ($P < 0.05$) in pigs fed the 10% DDGS diet
23 compared to PC pigs, while lesion length in pigs fed the 20% DDGS diet was

1 intermediate. Number of pigs exhibiting lesions was unaffected by dietary
2 treatment ($P > 0.10$).

3 Winkelman (1999) reported that the length of lesions at necropsy is a useful
4 quantitative measure of the severity of ileitis infection in the pig and its impact on
5 growth performance. In that study, using a similar mucosal homogenate challenge
6 model, lesion length was found to be highly correlated with growth rate in a linear
7 fashion ($r^2 = 0.97$). Use of the current challenge model was highly successful in
8 initiating disease, with lesions consistent with ileitis infection observed in the
9 majority of challenged animals at the time of necropsy. Lesion prevalence in
10 challenged pigs was greatest in the ileum (58%), as expected, but was also quite high
11 in the jejunum (38%) and colon (18%). Lesions indicating proliferative enteropathy
12 most commonly occur in the ileum and distal jejunum, and less commonly in the
13 proximal colon (McOrist and Gebhart, 1999).

14 The severity of disease in this study appeared to be much greater than that
15 typically observed in commercial situations. Quantification of actual dosage rate
16 indicated an inoculation level of 1.56×10^9 *L. intracellularis* / pig was much higher
17 than the goal of 1×10^8 as originally planned. Therefore, the results of this study
18 may not be directly applicable to most situations typically observed for ileitis in
19 commercial swine operations. The target dosage level was difficult to achieve
20 because the inoculum was a mucosal homogenate harvested from infected tissues on
21 the day that pigs were challenged, and therefore, quantification of actual dosage
22 level was not possible prior to the disease challenge.

1

2 *PCR and IHC Analysis*

3

4 **Laboratory results are summarized for fecal polymerase chain reaction (PCR)**
5 **and ileal tissue immunohistochemistry (IHC) in Table 7. All pigs tested negative for**
6 **presence of *L. intracellularis* via the fecal PCR test prior to being inoculated.**

7 **Twenty percent of NC pigs tested positive for fecal shedding of the organism on d 14**
8 **post-challenge, and this value doubled by d 20 post-challenge, but was still less than**
9 **challenged pigs ($P < 0.01$). This indicates that cross-contamination occurred, and**
10 **the NC group was in the early stages of an ileitis infection by the end of the study.**
11 **Percentage of challenged pigs shedding *L. intracellularis* increased from 83% on d**
12 **14 to 92% on d 20 post-challenge. Feeding DDGS diets increased percentage of pigs**
13 **shedding on d 14 and d 20 compared to PC pigs ($P < 0.10$).**

14 **Immunohistochemistry results showed that 30% of NC pigs were infected with *L.***
15 ***intracellularis*, but this was much lower than the 95% of challenged pigs testing**
16 **positive ($P < 0.01$). Prevalence and proliferation of the organism in ileal tissue,**
17 **however, appeared unaffected by dietary treatment ($P > 0.10$).**

18 **Because a variety of other enteric diseases can appear grossly similar to the**
19 **chronic or acute forms of PPE, diagnostic confirmation must be conducted to**
20 **conclusively establish presence of PPE. Culturing of *L. intracellularis* has been**
21 **extremely difficult, and therefore a PCR assay has been developed to detect**
22 **presence of the organism in feces. Collection and analysis of fecal samples from**
23 **infected pigs allows monitoring of the prevalence of PPE in a herd without**

1 **sacrificing animals. However, the sensitivity of the assay does not generally allow**
2 **for diagnosis of all infections, and is likely due to the presence of inhibitors in feces**
3 **that reduce the ability to detect *L. intracellularis* (Lawson and Gebhart, 2000).**
4 **Microscopic examination of affected intestinal segments that have been fixed and**
5 **stained by immunohistochemical techniques results in a more definitive measure of**
6 **PPE infection. However, this procedure is expensive because animals must be**
7 **sacrificed to obtain the tissue samples (Guedes et al., 2002b).**

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Implications

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12 Results from this study showed no beneficial effect of feeding diets containing
13 distiller's dried grains with solubles (DDGS) on ability of growing pigs to resist an ileitis
14 challenge. However, the severity of the challenge induced in this study was much greater
15 than is commonly observed in commercial production situations, and therefore, may not
16 be reflective of typical conditions when an ileitis outbreak occurs. Ileitis infection
17 severely reduces feed intake, growth rate, and feed conversion. Feeding young growing
18 pigs a 10 or 20% DDGS diet results in similar growth performance compared to feeding
19 pigs a corn-soybean meal diet devoid of DDGS. Due to the severity of infection
20 observed in this study and beneficial effects of DDGS inclusion that have been observed
21 in commercial feeding situations, further evaluation is needed to determine the effect of
22 dietary DDGS inclusion during a more moderate ileitis challenge.

1 **Literature Cited**

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Table 1. Composition and analyzed nutrient content of experimental diets (as-fed basis)^a

Item	Dietary treatment ^b			
	NC	PC	10D	20D
Ingredient, %				
Corn	61.91	61.91	52.77	43.62
Soybean meal (47% CP)	32.62	32.62	31.77	30.92
DDGS ^c	0.00	0.00	10.00	20.00
Choice white grease	2.20	2.20	2.30	2.40
Dicalcium phosphate	1.67	1.67	1.37	1.07
Limestone	0.56	0.56	0.77	0.98
Vitamin/trace mineral premix ^d	0.45	0.45	0.45	0.45
Salt	0.40	0.40	0.40	0.40
L-Lysine	0.15	0.15	0.15	0.15
DL-Methionine	0.04	0.04	0.02	0.01
Nutrient analysis				
Crude protein, %	21.13	21.13	23.16	24.65
Lysine, % ^e	1.23	1.23	1.25	1.23
Methionine, %	0.33	0.33	0.35	0.36
Threonine, %	0.73	0.73	0.80	0.85
Tryptophan, %	0.23	0.23	0.24	0.26
ME, kcal/kg ^f	3152	3152	3171	3197
Calcium, %	0.89	0.89	0.86	0.85
Phosphorus, %	0.58	0.58	0.60	0.57

^a Diets were formulated to contain 3390 kcal/kg of ME, 1.15% apparent digestible lysine, 0.65% apparent digestible methionine & cystine, 0.80% Ca, and 0.70% total P.

^b NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^c Distiller's dried grains with solubles (AI-Corn Clean Fuel, Claremont, MN).

^d Amount supplied per kg of premix: 1,466,667 IU vitamin A as retinyl acetate, 246,400 IU vitamin D3, 6,138 IU vitamin E as dl- α -tocopherol acetate, 979 mg vitamin K as menadione dimethylpyrimidinol bisulfite, 1,467 mg riboflavin, 8,800 mg niacin, 5,867 mg pantothenic acid as d-calcium pantothenate, 6.6 mg vitamin B12, 141 mg iodine as EDDI, 99 mg selenium as sodium selenite, 59,840 mg zinc as zinc oxide, 59,840 mg iron as ferrous sulfate, 3,960 mg copper as copper sulfate, and 1,980 mg manganese as manganese oxide.

^e Amino acids are expressed on a total basis.

^f Calculated from equation by Noblet and Perez (1993):

$$\text{DE (kcal/kg)} = 4151 - (122 \times \% \text{ Ash}) + (23 \times \% \text{ CP}) + (38 \times \% \text{ EE}) - (64 \times \% \text{ Crude fiber})$$

$$\text{ME (kcal/kg)} = \text{DE} \times (1.003 - (0.0021 \times \% \text{ CP})).$$

Table 2. Effect of adding distiller's dried grains with solubles to the diet and ileitis challenge on growth rate, feed intake, and feed conversion efficiency

	Dietary treatment ^a				Challenged treatments	
	NC ^b	PC	10D	20D	SEM	Pr>F
<i>Pre-treatment (d 0 - 4)</i>						
# of pens	2	2	2	2		
Start wt, kg	5.73	5.73	5.73	5.74	0.09	0.99
<i>Pre-challenge (d 4 - 32)</i>						
Start wt, kg	6.80	6.88	6.91	6.83	0.13	0.81
ADG, g	353.7	379.0	389.2	360.3	6.3	0.15
ADFI, g	567.0	594.5	592.5	588.5	7.4	0.97
G/F	0.62	0.64	0.66	0.61	0.012	0.43
<i>Post-challenge (d 32 - 53)</i>						
Start wt, kg	16.70	17.49	17.81	16.92	0.31	0.51
ADG, g	599.5	311.0	258.9	245.3	25.9	0.67
ADFI, g	1363.0	990.0	1012.0	1066.5	31.4	0.70
G/F	0.44	0.31	0.26	0.23	0.023	0.43
End wt, kg	29.91	24.46	23.66	22.57	0.54	0.36

^a NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^b Significant difference between NC and PC groups for ADG, ADFI, and G/F during the post-challenge period ($P < 0.01$).

Table 3. Effect of adding distiller's dried grains with solubles to the diet and ileitis challenge on gauntness scores (1-3), post-challenge.

	Dietary treatment ^a				Challenged treatments ^b	
	NC ^c	PC	10D	20D	SEM	Pr>F
# of pigs	20	20	20	20		
<i>Week 1 post-challenge</i>						
Day 3	1.00	1.10	1.05	1.03	0.021	0.33
Day 5	1.00	1.13 ^d	1.05 ^{d,e}	1.03 ^e	0.022	0.16
Day 7	1.00	1.30 ^d	1.05 ^{d,e}	1.03 ^e	0.022	0.16
Average	1.00	1.10 ^d	1.05 ^{d,e}	1.03 ^e	0.023	0.21
<i>Week 2 post-challenge</i>						
Day 9	1.00	1.30	1.10	1.08	0.026	0.74
Day 11	1.03	1.30	1.10	1.08	0.026	0.74
Day 14	1.00	1.15	1.15	1.05	0.032	0.35
Average	1.01	1.25	1.12	1.07	0.028	0.63
<i>Week 3 post-challenge</i>						
Day 16	1.00	1.23 ^t	1.15 ^{t,g}	1.05 ^g	0.036	0.14
Day 18	1.00	1.18	1.20	1.05	0.040	0.26
Day 20	1.00	1.20	1.30	1.10	0.051	0.28
Average	1.00	1.20	1.22	1.07	0.044	0.21

^a NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^b Indicates a significant time effect ($P < 0.05$).

^c Significant difference between NC and PC groups for gauntness on d 9, d 14, d 16, d 18, d 20, and wk 3 average post-challenge ($P < 0.05$).

^{d,e} Within challenged treatment groups, means with different superscripts differ ($P < 0.10$).

^{f,g} Within challenged treatment groups, means with different superscripts differ ($P < 0.05$).

Table 4. Effect of adding distiller's dried grains with solubles to the diet and ileitis challenge on fecal scores (1-5), post-challenge

	Dietary treatment ^a				Challenged treatments ^b	
	NC ^c	PC	10D	20D	SEM	Pr>F
# of pigs	20	20	20	20		
<i>Week 1 post-challenge</i>						
Day 3	1.33	1.80	1.90	1.78	0.12	0.90
Day 5	1.20	1.85	2.03	1.88	0.09	0.69
Day 7	1.15	1.80	1.88	1.83	0.08	0.93
Average	1.23	1.82	1.94	1.83	0.09	0.76
<i>Week 2 post-challenge</i>						
Day 9	1.15	1.88	2.10	1.95	0.08	0.51
Day 11	1.15	2.00	2.10	2.10	0.09	0.88
Day 14	1.03	1.98	2.28	2.25	0.09	0.35
Average	1.11	1.95	2.16	2.10	0.08	0.47
<i>Week 3 post-challenge</i>						
Day 16	1.05	2.03 ^d	2.45 ^e	2.33 ^e	0.07	0.05
Day 18	1.03	2.10 ^f	2.53 ^g	2.38 ^{f,g}	0.08	0.09
Day 20	1.05	2.13 ^d	2.68 ^e	2.53 ^e	0.10	0.06
Average	1.06	2.09 ^d	2.55 ^e	2.41 ^e	0.08	0.06

^a NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^b Indicates a significant time effect ($P < 0.001$).

^c Significant difference between NC and PC groups for fecal scores throughout the post-challenge period ($P < 0.05$).

^{d,e} Within challenged treatment groups, means with different superscripts differ ($P < 0.10$).

^{f,g} Within challenged treatment groups, means with different superscripts differ ($P < 0.05$).

Table 5. Effect of adding dietary distiller's dried grains with solubles to the diet and ileitis challenge on body weight, internal organ weight (relative to body weight), intestinal length, and digesta pH

	Dietary treatment ^a				Challenged treatments	
	NC ^b	PC	10D	20D	SEM	Pr>F
# of pigs	20	20	20	20		
<i>Body weight, kg</i>						
Start wt	5.73	5.73	5.73	5.74	0.09	0.99
Challenge wt	16.71	17.49	17.81	16.92	0.31	0.51
End wt	29.91	24.46	23.66	22.57	0.54	0.36
<i>Internal organ weights, % of body weight</i>						
Heart	0.500	0.480 ^f	0.499 ^f	0.533 ^e	0.007	0.79
Stomach	0.839	0.860	0.844	0.865	0.013	0.11
Liver	2.666	2.995 ^{e,f}	2.908 ^f	3.159 ^e	0.049	0.40
Small intestine	3.961	4.709	4.336	4.571	0.113	0.17
Large intestine	2.191	2.459 ^d	2.435 ^d	2.742 ^c	0.074	0.32
Total intestine	6.152	7.169	6.771	7.313	0.151	0.29
<i>Intestinal lengths, cm</i>						
Small intestine	1501.3	1497.2 ^e	1357.9 ^f	1363.2 ^f	32.2	0.04
Large intestine	384.7	343.6	333.2	337.7	7.4	0.69
Total intestine	1886.0	1840.8 ^e	1691.1 ^f	1700.9 ^f	34.8	0.05
<i>Digesta pH</i>						
Small intestine	6.57	6.21	6.30	6.14	0.07	0.68
Large intestine	6.37	6.04	6.06	5.91	0.05	0.44

^a NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^b Significant difference between NC and PC groups for end wt, liver wt, small intestine wt, total intestine weight, large intestine length, total intestine length, small intestine digesta pH, and large intestine digesta pH ($P < 0.05$).

^{c,d} Within challenged treatment groups, means with different superscripts differ ($P < 0.10$).

^{e,f} Within challenged treatment groups, means with different superscripts differ ($P < 0.05$).

Table 6. Effect of adding distiller's dried grains with solubles to the diet and ileitis challenge on lesion length, severity, and prevalence

	Dietary treatment ^a				Challenged treatments	
	NC ^b	PC	10D	20D	SEM	Pr>F
# of pigs	20	20	20	20		
<i>Jejunum</i>						
Length, cm	0.00	14.95 ^c	54.40 ^d	31.90 ^{c,d}	8.47	0.16
Score (0-4)	0.00	0.40 ^c	1.10 ^d	1.20 ^d	0.16	0.08
Prevalence, %	0.00	20.00 ^c	50.00 ^d	45.00 ^d	6.33	0.12
<i>Ileum</i>						
Length, cm	0.00	7.45	11.75	11.05	1.37	0.39
Score (0-4)	0.00	0.85	1.45	1.50	0.17	0.22
Prevalence, %	0.00	50.00	65.00	60.00	6.41	0.63
<i>Cecum</i>						
Length, cm	0.00	0.00 ^e	1.45 ^f	0.15 ^e	0.27	0.05
Score (0-4)	0.00	0.00 ^e	0.50 ^f	0.05 ^e	0.08	0.03
Prevalence, %	0.00	0.00 ^e	20.00 ^f	5.00 ^e	3.60	0.06
<i>Colon</i>						
Length, cm	0.00	1.00	6.20	0.60	1.43	0.20
Score (0-4)	0.00	0.25 ^c	0.70 ^d	0.15 ^c	0.11	0.10
Prevalence, %	0.00	20.00	25.00	10.00	5.04	0.47
<i>Total</i>						
Length, cm	0.00	23.40 ^e	73.80 ^f	43.70 ^{e,f}	9.50	0.09
Prevalence, %	0.00	55.00	70.00	65.00	6.27	0.62

^a NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^b Significant difference between NC and PC groups for length, score, and prevalence in the jejunum and ileum, prevalence in the colon, and overall length and prevalence ($P < 0.05$).

^{c,d} Within challenged treatment groups, means with different superscripts differ ($P < 0.10$).

^{e,f} Within challenged treatment groups, means with different superscripts differ ($P < 0.05$).

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Table 7. Effect of adding distiller's dried grains with solubles to the diet and ileitis challenge on fecal PCR and ileum IHC

	Dietary treatment ^a				Challenged treatments	
	NC ^b	PC	10D	20D	SEM	Pr>F
# of pigs	20	20	20	20		
<i>Fecal PCR</i>						
Day 0	0.0	0.0	0.0	0.0	0.0	---
Day 14	20.0	70.0 ^c	90.0 ^d	90.0 ^d	4.9	0.15
Day 20	40.0	80.0 ^c	95.0 ^d	100.0 ^d	3.6	0.06
<i>IHC</i>						
Score (0-4)	0.55	2.00	2.15	2.25	0.12	0.71
Prevalence, %	30.0	100.0	90.0	95.0	2.8	0.36
Lamina propria, %	0.0	35.0 ^c	15.0 ^d	10.0 ^d	5.2	0.12
Ileocecal lymph node, %	5.0	50.0	55.0	65.0	6.5	0.63

^a NC = negative control, PC = positive control, 10D = 10% DDGS, and 20D = 20% DDGS diet.

^b Significant difference between NC and PC groups for all parameters ($P < 0.01$).

^{c,d} Within challenged treatment groups, means with different superscripts differ ($P < 0.10$).

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