# NUTRITIONAL EVALUATION OF RICE COPRODUCTS FED TO PIGS

BY

GLORIA AMPARO CASAS BEDOYA

DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Animal Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2018

Urbana, Illinois

Doctoral Committee:

Professor Hans H. Stein, Chair
Professor Emeritus George C. Fahey, Jr.
Professor Michael Ellis
Dr. Pedro E. Urriola, University of Minnesota
Dr. Scott N. Carr, Elanco Animal Health

## ABSTRACT

Seven experiments were conducted to determine the nutritional value of rice coproducts fed to pigs. In Exp. 1, the objective was to determine the carbohydrate composition and the *in vitro* total tract digestibility of DM in 5 rice coproducts and to test the hypothesis that *in vitro* digestibility of DM is negatively correlated with the concentration of non-starch polysaccharides (NSP). Results indicated that broken rice and brown rice contain more starch than full fat rice bran (FFRB) and defatted rice bran (DFRB), whereas rice mill feed had the least concentration of starch. The concentration of soluble dietary fiber (SDF) was between 0.1% in brown rice and 1.9% in rice mill feed. The concentration of insoluble dietary fiber (IDF) was 1.5% in broken rice and 52.9% in rice mill feed. Arabinose and xylose were the main monosaccharides in the fiber fraction of all rice coproducts, but the concentration of these monosaccharides varied among ingredients. The *in vitro* DM digestibility decreased ($P < 0.05$) as the concentration of total NSP increased in the ingredients. In Exp. 2, digestibility values of CP and AA in rice coproducts were determined. Results indicated that the SID of CP and Lys in broken rice was greater ($P < 0.05$) than in other rice coproducts, but the concentration of digestible Lys in DFRB was greater ($P < 0.05$) than in broken rice and FFRB. In Exp. 3, the hypothesis that the apparent total tract digestibility (ATTD) of nutrients and GE by starter pigs and the concentration of DE and ME in FFRB, DFRB, brown rice, and broken rice is improved if microbial xylanase is added to the diet was tested. Results indicated that concentrations of DE and ME (DM basis) in FFRB and DFRB increased ($P < 0.05$) if xylanase was used. Broken rice had a greater ($P < 0.05$) concentration of DE and ME than FFRB and DFRB if no xylanase was added to the diets, but if xylanase was used, no differences in ME among FFRB, brown rice, and broken rice were observed. The ATTD of DM was greater ($P < 0.05$) in ingredients with xylanase than in

ingredients without xylanase. The ATTD of NDF in FFRB was greater ($P < 0.05$) if xylanase was added to the diet than if no xylanase was used. Experiment 4 was designed to test the hypothesis that the ATTD of GE and nutrients in FFRB and DFRB determined in gestating sows is greater if feed is provided at 1.5 × the ME required for maintenance than at 3.5 × the ME requirement. The second objective of this experiment was to test the hypothesis that the ATTD of GE and nutrients and the concentrations of DE and ME in FFRB and DFRB is not different between growing gilts and gestating sows if both groups of animals are fed 3.5 × the maintenance requirement for ME. Results indicate that there were no effects of level of feed intake of sows on ATTD of GE, DM, OM, or NDF, or on concentrations of DE and ME in FFRB or DFRB. The ATTD of GE, OM, and NDF of FFRB or DRFB was greater ($P < 0.05$) in gestating sows than in growing gilts. Concentrations of DE and ME in diets were also greater ($P < 0.05$) if determined in gestating sows than in growing gilts. Concentrations of DE and ME were greater ($P < 0.05$) in FFRB than in DFRB regardless of feed intake level or the physiological stage of the animals. In Exp. 5, ATTD and standardized total tract digestibility (STTD) of P of 5 rice coproducts were determined. Among the rice coproducts, the greatest ($P < 0.05$) ATTD and STTD of P was observed for broken rice regardless of inclusion of phytase. If no microbial phytase was used, values for STTD of P in brown rice, FFRB, DFRB, and rice mill feed were not different, but if microbial phytase was included in the diet, ATTD and STTD of P in brown rice was greater ($P < 0.05$) than in FFRB, DFRB, and rice mill feed. The STTD of P in brown rice, FFRB, and rice mill feed was greater ($P < 0.05$) if microbial phytase was used than if no microbial phytase was used. Experiments 6 and 7 were designed to test the hypothesis that increasing inclusion levels of FFRB or DFRB does not affect growth performance of weanling pigs or growing-finishing pigs, respectively, if diets are formulated based on values for SID of

AA, STTD of P, and ME in all ingredients. In both experiments, a control diet without rice bran and diets containing 10, 20 or 30% FFRB or DFRB were formulated. In nursery pigs, the ADG increased at 10% inclusion of FFRB and decreased at 20 or 30% (quadratic, $P < 0.05$). The G:F ratio was not affected by inclusion of DFRB, but increased from 0.643 in the control diet 0.682 at 20% inclusion of FFRB in the diet (quadratic, $P < 0.05$) and the G:F was greater ($P < 0.05$) in pigs fed diets containing FFRB than in pigs fed diets containing DFRB. In growing-finishing pigs, for the overall experimental period, the ADFI decreased (linear, $P < 0.05$) and G:F increased linearly ($P < 0.05$) for pigs fed diets with increasing concentrations of FFRB. The ADFI of pigs fed diets containing DFRB increased linearly ($P < 0.05$), but G:F decreased (linear, $P < 0.05$). There were no effects of dietary treatments on carcass or loin quality. The concentration of saturated fatty acids (SFA) in adipose tissue of pigs fed diets containing FFRB decreased (linear, $P < 0.05$), whereas the concentration of poly unsaturated fatty acids (PUFA) increased (linear, $P < 0.05$). In conclusion, rice coproducts are sources of energy and AA that may be used in diets for pigs; however, the ATTD of DM and GE may vary among different physiological stages of the animals. Addition of phytase reduced the output of P and improve the STTD of P in rice coproducts. Full fat rice bran and DFRB may be included in diets of weanling or growing-finishing pigs at 10 to 30% without affecting growth performance, and carcass and meat quality also is not affected with the exception that inclusion of FFRB diets for finishing pigs will increase concentrations of PUFA in belly fat of pigs.

## ACKNOWLEDGEMENTS

I express my deepest gratitude to my advisor, Professor Hans H. Stein, who guided and supported me in this process. Thanks Dr. Stein for giving me this opportunity. Thanks for your patience, your time and your optimism. I am so fortunate to have you as an advisor and mentor for my Ph.D.

I thank my committee members, Dr. George C. Fahey, Jr., Dr. Michael Ellis, Dr. Pedro E. Urriola, Dr. Scott N. Carr, and Dr. James Eugene Pettigrew for their time and all your suggestions.

My sincere thanks to the Universidad Nacional de Colombia, Sede Bogotá, and to my colleagues in the Department of Animal Sciences for allowing me to take 3.5 years off to complete my PhD. Also, thanks to Colciencias-Colfuturo for the financial support during this time.

I also thank the professors and students from other Laboratories, the farm crew, and special thanks to HiDee Ekstrom for being willing and ready to help when I needed it.

I thank the former and current members of the Stein Monogastric Nutrition Laboratory, for all your help and support. It has been an honor to belong to this team.

A special thanks to my family. All of you have been there for me. Most importantly, I wish to thank my supportive husband, German, and my adorable kids, Ana Sofia and Juan. Thanks for your support; you are the motivation for all my pursuits.

*To My Family*

**TABLE OF CONTENTS**

# CHAPTER 1: INTRODUCTION

Use of cereal coproducts to formulate swine diets is increasing as a result of the high costs of conventional feed ingredients. Rice is ranked second after corn in world cereal production and represents the main staple food for half of the global population, mainly in developing countries (Muthayya et al., 2014). In 2017, the production of paddy rice was approximately 756 million tonnes (FAO, 2017). Rice coproducts are produced in the rice milling process in which 65% of paddy rice becomes polished rice for human consumption, and 35% is represented in coproducts potentially available for animal feeding (Singh et al., 2014). Rice coproducts include rice hulls, rice bran or rice polish, and broken rice (Serna-Saldivar, 2010; Hossain et al., 2012). However, rice oil can be extracted from the rice bran and defatted rice bran is obtained (Hargrove, 1994). Blends of the main rice coproducts can be made to prepare other feed ingredients such as rice mill feed (mixture of rice bran and rice hulls) or polishing rice (mix of rice bran and broken rice), which also can be included in diets for pigs (Stacey and Rankins, 2004; Kaufmann et al., 2005; Ofogo et al., 2008).

Rice bran and broken rice are the coproducts most studied as ingredients for weanling and growing pigs (Warren and Farrell, 1990; Chae and Lee, 2002; de Campos et al., 2006; Mateos et al., 2007; Herfel et al., 2013). The high content of dietary fiber (Shi et al., 2015) and the low digestibility of P have limited the use of rice coproducts in diets for pigs (Sauvant et al., 2004; Agudelo et al., 2010). Effects of inclusion of rice bran in diets for weanling and growing pigs are inconclusive, and there is no information related to the nutritional value of defatted rice bran in these phases of production or about the effects of supplementation with enzymes to increase the nutritional value of rice coproducts. Likewise, there are no values reported for

apparent total tract digestibility (ATTD) of gross energy (GE) and nutrients or for concentrations of digestible energy (DE) and metabolizable energy (ME) in rice coproducts for sows.

Therefore, the objectives of this dissertation were to determine the composition of rice coproducts and the digestibility of amino acids, GE, P, and other nutrients in rice coproducts fed to pigs in different physiological stages. Additional objectives included evaluation of effects of supplementation with phytase and xylanase on the digestibility of P and GE, respectively; and to test the hypothesis that increasing inclusion levels of FFRB and DFRB is not detrimental for growth performance of weanling pigs or growing-finishing pigs or for the quality of meat or fat in pigs.

## LITERATURE CITED

Agudelo, J. H., M. D. Lindemann, and G. L. Cromwell. 2010. Phosphorus utilization in growing pigs fed a phosphorus deficient diet supplemented with a rice bran product and amended with phytase. Rev. Colomb. Cienc. Pecu. 23:429-443.

Chae, B. J., and S. K. Lee. 2002. Rancid rice bran affects growth performance and pork quality in finishing pigs. Asian-Australas. J. Anim. Sci. 15:94-101. doi:10.5713/ajas.2002.94

de Campos, R. M. L., E. Hierro, J. A. Ordoñez, T. M. Bertol, and L. Hoz. 2006. A note on partial replacement of maize with rice bran in the pig diet on meat and backfat fatty acids. J. Anim. Feed Sci. 15:427-433. doi:10.22358/jafs/66913/2006

FAO. 2017. Rice market monitor. In: Food and Agriculture Organization of the United Nations. Accessed 12 January 2018, http://www.fao.org/3/I8317EN/I8317EN.pdf.

Hargrove, K. L. J. 1994. Processing and utilization of rice bran in the United States. In: W. E. Marshall and J. I. Wadsworth, editors, Rice, science and technology. Marcel Dekker, NY. p. 381-404.

Herfel, T., S. Jacobi, X. Lin, E. Heugten, V. Fellner, and J. Odle. 2013. Stabilized rice bran improves weaning performance via a prebiotic mechanism. J. Anim. Sci. 91:907-913, doi:10.2527/jas.2012-5287

Hossain, M. E., S. Sultaba, S. M. S. Shahriar, and M. M. Khatun. 2012. Nutritive value of rice polish. Online J. Anim. Feed Res. 3:235-239.

Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. He, M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. Can. J. Anim. Sci. 85:355-363. doi:10.4141/A04-084

Mateos, G. G., F. Martín, M. A. Latorre, B. Vicente, and R. Lázaro. 2007. Inclusion of oat hulls in diets for young pigs based on cooked maize or cooked rice. Anim. Sci. 82:57-63. doi:10.1079/ASC20053

Muthayya, S., J. D. Sugimoto, S. Montgomery, and G. F. Maberly. 2014. An overview of global rice production, supply, trade, and consumption. Ann. N.Y. Acad. Sci. 1324:7-14. doi:10.1111/nyas.12540

Ofogo, S. T., S. Kehraus, E. A. Iyayi, and K. H. Sudekem. 2008. Rice mill feed: an agro-industrial by-product wih potential for rural development. In: Conference on International Research of Food Security, Rural Resoruce Management and Rural Development, University of Hohenheim, Germany http://www.researchgate.net/publication (Accessed 15 July 2014).

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Shi, C. X., Z. Y. Liu, M. Shi, P. Li, Z. K. Zeng, L. Liu, C. F. Huang, Z. P. Zhu, and D. F. Li. 2015. Prediction of digestible and metabolizable energy content of rice bran fed to growing pigs. Asian-Australas. J. Anim. Sci. 28:654-661. doi:10.5713/ajas.14.0507

Singh, A., M. Das, S. Bal, and R. Banerjee. 2014. Rice processing. In: R. P. Ferrerira-Guiné and P. M. dois-Reis-Correia, editors, Engineering aspects of cereal and cereal-based products. CRC Press, Boca Raton, FL. p. 71-96.

Stacey, W. N., and D. L. Rankins. 2004. Rice mill feed as a replacement for broiler litter in diets for growing beef cattle. J. Anim. Sci. 82:2193-2199. doi:10.2527/2004.8272193x

Warren, B. E., and D. J. Farrell. 1990. The nutritive value of full-fat and defatted Australian rice bran. II. Growth studies with chickens, rats and pigs. Anim. Feed Sci. Technol. 27:229-246. doi:10.1016/0377-8401(90)90085-m

# CHAPTER 2: COMPOSITION OF RICE COPRODUCTS AND THEIR UTILIZATION IN SWINE FEEDING

## INTRODUCTION

In 2017, the global production of paddy rice was approximately 756 million tonnes (502 million tonnes, milled basis; FAO, 2017). China and India are the main producers of rice with annual production of approximately 208 million and 152 million tonnes, respectively (FAO, 2017). The United States produces approximately 8 million tonnes of rice annually. The states in the U. S. that produce the most are Arkansas, California, Louisiana, Mississippi, Missouri, and Texas (USDA, 2017).

There are several species of rice, but *Oryza sativa* and *O. glaberrimma* are the most common species used for human consumption. *Oryza sativa* is widely distributed around the world, whereas *O. glaberrimma* is cultivated mainly in Africa (Muthayya et al., 2014). Rice usually is processed before consumption to obtain a product with increased palatability and improved properties in various forms of food preparations. A small amount of rice is consumed as brown rice, which contains the bran and germ, but polished white rice is the principal food staple of more than 2 billion people worldwide (Saunders, 1985). Polished rice contains the endosperm of the rice whereas the outer fractions consisting of the hull and the bran have been removed.

The main processes for rice are drying and milling. The coproducts that are used in animal feeding are obtained after milling, which includes separation of the outer tissues from the endosperm. The commercial milling process involves dehulling, whitening, polishing, and separation of the fractions into polished rice and bran (Fig 2.1). The edible portion of polished rice makes up 65 to 72% of the total weight, with the remaining 28 to 35% are coproducts and

waste (Singh et al., 2014). The percentages of the individual coproducts produced depend on milling rate, type of rice, and other factors. On average, the proportions are: hulls, 20%; bran, 10%; polishings, 3%; and broken rice, 1 to 17% (Heuzé and Tran, 2015).

## RICE PROCESSING

Intact rice with the hull is called "paddy" or "rough" rice. Rice processing is aimed at producing unbroken rice with a specific size, color, and shelf life. The process consists mainly of drying, grain cleaning, dehulling, decortication, polishing, and sizing. Concentration of moisture between 11 to 13% is required for prolonged storage and milling. The paddy rice must be cleaned to remove light contaminants to improve quality of end-products (Serna-Saldivar, 2010).

### *Rice Dehulling*

The hull is removed by pressure and shear force when the rough rice is passed between 2 rubber-coated rolls that turn in opposite directions. The pressure and shear remove the hulls. The pressure exerted by the rolls can be varied according to the rice variety. After separation, the hull is removed by aspiration and the remaining rough rice is separated by a technique based on bulk density on a gravity separator. The separated paddy is returned for another pass through the sheller. Products produced after these steps are 20% hulls, and 80% brown rice (Delcour and Hoseney, 1994).

### *Brown Rice Milling*

Milling of brown rice results in removal of the bran by milling to produce white rice. In the peeler or milling machine, some rice breakage occurs (1 to 17%). In some cultivars of rice, the bran is more difficult to remove than in other cultivars. In such cases, a small amount of water can be added to soften the bran layers before milling. Dry calcium carbonate

(approximately 3.3 g/kg) is added to the brown rice to improve the efficiency of milling because it acts as an abrasive that contributes in removing the bran (Serna-Saldivar, 2010). The objective of the milling process is to increase the yield of head rice (unbroken milled kernels) and to minimize the quantities of broken rice. After milling, the loose bran is removed by an aspirator, and the milled rice can be polished. The polisher consists of a rotating vertical cylinder to which straps of leather are attached. The milled rice passes downward between the rotating cylinder and the surrounding wire screen. An additional amount of bran is removed by the polisher. After being polished, the head rice is separated from broken rice by screening or by disk separators. The products obtained after these steps are head rice, broken rice, rice bran, and rice polishings (Delcour and Hoseney, 1994).

The level of broken rice depends on the rice cultivar, the milling scheme, and the skills of the miller. The broken rice is used in brewing or as a raw material for industrial rice starch isolation. However, broken rice can also be used in animal feeding (Serna-Saldivar, 2010).

## RICE COPRODUCTS: COMPOSITION AND UTILIZATION

### *Rice Hulls*

The hulls constitute about 20% of the weight of rough rice. Rice hulls cover and protect the grain during its growth, and consist of an outer epidermis coated with a thick cuticle layer of highly silicified cells, and the sclerenchyma with thick lignified and silicified walls. The hulls are high in cellulose (25%), lignin (30%), arabinoxylans (15%), and ash (21%). Hulls also contain fats, gums, alkaloids, resins, essential oils, and other cytoplasmic components. The ash is composed mainly of silica (80 to 90%), but also of $K_2O$, $P_2O_5$ (5%), CaO (0.4 to 1.2%), and small amounts of Mg, Fe, and Na. The complex chemical composition of rice hulls represents a

barrier for the release of cellulose (Dagnino et al., 2013). The high concentrations of lignin and silica result in rice hulls being of low value both nutritionally and commercially (Delcour and Hoseney, 1994), and the gross composition of rice hulls makes this coproduct unattractive as a food or feed ingredient (Serna-Saldivar, 2010).

### *Broken Rice*

In the United States market, rice is classified according to the size and shape of the grains and is sold as long (> 3:1 length to width ratio), medium (2.0 to 2.9:1 length to width ratio) or short rice (< 2:1 length to width ratio; USA-Rice-Federation, 2011). Most often, the whole kernels or head rice are used for direct consumption as a food (FAO, 2017), but some kernels are broken in the milling process, and rice that is less than 50% of the length of whole kernel is called "second heads". These second heads may be used "as is" for a variety of products or ground for rice flour. Kernels that are 25% or less the original length of grain are called broken rice or brewer's rice and they are used for brewing and other fermented products, or for animal feeding, especially in pet foods (USA-Rice-Federation, 2011). Composition of broken rice and other rice coproducts is shown in Table 2.1.

***Carbohydrates in Broken Rice***. Broken rice is high in starch (77%), but contains only 1.1% crude fiber and 5% NDF, which results in high digestibility of energy when fed to pigs (Sauvant et al., 2004). Starch is located in the kernel endosperm in smaller granules compared with other cereals, and the granules are evenly distributed in the endosperm. Rice varieties differ in the proportion of amylose and amylopectin in the starch. Amylose concentration varies from a low of 0 to 2% in waxy rice to approximately 25% in non-waxy rice. The proportion of amylose affects the cooking characteristics, texture, water absorption ability, stickiness, volume expansion, hardness, and whiteness of the rice (Zhou et al., 2002). Starch digestibility in rice

varieties is inversely related to amylose content and granule size, but rice starch is less resistant to enzymatic hydrolysis and more digestible by pigs than starch from other cereals (Vicente et al., 2008b; Cervantes-Pahm et al., 2014a). Heat processing may improve starch gelatinization and, therefore, improve nutrient availability and pig performance, but the degree of gelatinization depends on the proportion of amylose. However, an excess of heat may increase the proportion of resistant starch, and reduce nutrient digestibility and piglet growth (Vicente et al., 2008b).

***Lipids in Broken Rice***. The concentration of lipids in broken rice is low, because most lipids in brown rice are located in the bran, which is removed in the milling process. The content of ether extract ranges from 0.61 to 1.3% (Sauvant et al., 2004; NRC, 2012), and the most important fatty acids are oleic acid (40.2%), linoleic acid (35.1%), and palmitic acid (18.1%). Most lipids in broken rice are associated with the starch granules, which may prevent the formation of resistant starch; therefore, if the lipids are removed, the concentration of resistant starch increases (Zhou et al., 2002).

***Proteins and Amino Acids in Broken Rice***. Broken rice contains 6.6 to 7.3% CP, but the concentration may decrease during the milling process because most CP is included in rice bran. Proteins in rice contain 9.7 to 14.2% albumin, 13.5 to 18.9% globulin, 3.0 to 5.4% prolamin, and 63.8 to 73.4% glutein (Zhou et al., 2002). The glutein in rice has a better balanced AA profile than the CP in many others cereals that store most protein as prolamine, which has a less favorable AA profile compared with the requirement of pigs (Hamaker, 1994). The protein and AA in rice are better digested than protein and AA in other cereal grains (Cervantes-Pahm et al., 2014b).

***Minerals and Vitamins in Broken Rice.*** Rice contains 2.1 g/kg of P, but 55% is bound to phytate, and 44, 16, and 14 mg/kg of Fe, Zn, and Mn, respectively. Rice also contains 3.1 g/kg of

K and 1.5 g/kg of Mg, but the concentrations of Ca (0.5 g/kg), Cl (0.4 g/kg), and Na (0.04 g/kg) are low (Sauvant et al., 2004). Broken rice contains more vitamin $B_6$ (14 mg/kg) than corn.

***Nutritional Value of Broken Rice***. The concentration of GE in broken rice is 4,290 kcal/kg, DE is 3,565 kcal/kg, ME is 3,511 kcal/kg, and NE is 2,778 kcal/kg (NRC, 2012). These data concur with those reported by Robles and Ewan (1982) determined in pigs of 38 d (GE, 4,380; DE 3,700, ME 3,580 and NE 2,510 kcal/kg; as-is basis). The NE value of rice is 70.1 to 79.1% of the ME value, and the efficiency of utilization of ME is comparable to that of other cereals such as corn, wheat, or milo (Cervantes-Pahm et al., 2014a). The apparent total tract digestibility (**ATTD**) of GE in un-cooked rice fed to weanling pigs is between 91.3 and 92.8% (Robles and Ewan, 1982; Cervantes-Pahm et al., 2014a).

The ATTD of OM, GE, ether extract, and CP in uncooked rice is 93, 91, 80, and 86%, while the apparent ileal digestibility (**AID**) of OM, GE, CP, and starch is 89, 87, 83, and 95%, respectively (Menoyo et al., 2011). If the rice is steam cooked, the ATTD of OM and GE increases by 1 and 4%, respectively, whereas the AID for OM, GE, and CP increases 2, 1, and 1%, respectively. However, starch digestibility is not affected by heat processing (Menoyo et al., 2011). The ATTD of CP, DM, OM, and GE in cooked rice is 82.5, 84.8, 87.7, and 86.1%, respectively (Parera et al., 2010). Likewise, ATTD of GE in extruded rice is 90.4% in weaned pigs and 93% in growing pigs (Kim et al., 2007). The ATTD of GE, OM, DM, and ether extract in pigs from 21 to 41 d of age is greater in pigs fed rice diets than in pigs fed diets based on corn (Mateos et al., 2007). The reason for this increase may be that the rice diet contains less NSP compared with the corn diet and differences in the degree of encapsulation of the starch may also contribute to the increased ATTD of nutrients (Mateos et al., 2007). Similar values were reported by Vicente et al. (2008a) for ATTD in diets with raw ground rice, cooked ground rice, and

cooked flaked rice. Heat processing of rice improved ATTD of dietary components only at d 29, but not at d 39 or 53. The ATTD of GE, DM, and CP tended to decrease with heat processing in pigs at 29 d of age, but the ATTD of all nutrients increased with age. This effect was more pronounced in pigs fed rice that was cooked and flaked than for pigs fed rice that was uncooked and ground (Vicente et al., 2008a).

***Growth Performance of Pigs Fed Diets Containing Broken Rice***. Rice has been used in weanling pig diets to minimize stress and improve digestive functions. Feeding raw rice or cooked rice improved the structure and functionality of the mucosa of the small intestine, reduced enteric bacterial infections, and improved growth performance of weanling pigs (Vicente et al., 2008b). It has been observed that diets based on white rice improve the resistance of piglets to an *Escherichia coli* infection and diets with this cereal have been proposed as a way to control post-weaning diarrhea in piglets (Solà-Oriol et al., 2009). Responses to inclusion of rice in diets fed to weanling pigs are summarized in Table 2.2.

Mateos et al. (2006) reported improved ADG (447 vs. 418 g/d) and ADFI (659 vs. 623 g/d), but no change in G:F ratio, in piglets from d 21 to 54 that were fed a diet containing cooked rice compared with pigs fed a diet containing cooked corn. Comparable results were reported by Vicente et al. (2008a); however, a tendency for improved G:F and an increased incidence of diarrhea in pigs fed a diet containing raw rice or cooked rice compared with pigs fed diets containing cooked or flaked corn was observed. No differences in ADG of pigs (21 to 47 d of age) were reported when pigs were fed diets containing raw rice or heat processed rice compared with pigs fed corn diets, but ADFI by pigs fed the rice diet increased 3.6% (Menoyo et al., 2011).

Che et al. (2012) reported greater ADG and ADFI (337 vs. 331g and 504 vs. 462 g) by pigs fed diets containing rice than by pigs fed diets containing barley, but pigs fed diets

containing rolled oats during 6 weeks after weaning had an ADG that was not different from that of pigs fed rice diets. Pigs fed rice diets during 4 weeks post-weaning had a greater G:F than pigs fed the corn diet only from 14 to 28 d post-weaning. When rice replaced corn in Phase 1 diets, a tendency for reduced overall removal rate was observed, but differences in growth rate were not observed. Pigs consuming rice-based diets had a greater carcass weight percentage than pigs fed diets based on wheat, barley, and lupins, which reflects the lower visceral weights of pigs eating rice and greater digesta contents in pigs fed diet containing other cereals (Pluske et al., 2007).

***Rice Bran***

Rice bran is the outer brown layer of rice that includes several sub-layers within the pericarp and aleurone layer, but some sub-aleurone and endosperm material and breakage from white rice usually is included in the bran fraction and can make up 20 to 25% of the bran (Prakash and Ramaswamy, 1996). The final physical characteristics and chemical composition of rice bran depend on rice variety, treatment of the grain prior to milling, type of milling system, degree of milling, and the fractionation processes used during milling (Saunders, 1985). Parboiling the rice prevents endosperm breakage during milling, resulting in a reduced starch concentration in parboiled rice bran. Adulteration with rice hulls, which have low nutritive value, and other chemical components may make the use of rice bran as an animal feed challenging (Warren and Farrell, 1990a).

Two categories of rice bran have been described: food grade and feed grade. The feed grade bran composition is variable and depends on the mill design, dehulling and paddy separation efficiencies, and whether or not calcium carbonate is used as a milling aid. In contrast, in food grade rice bran, mixing with other coproducts is minimized and this product is less variable in composition. Rice bran can be further categorized as full fat stabilized rice bran or

parboiled, defatted, or partially defatted rice bran (Hargrove, 1994). An additional category of rice bran is obtained when the starchy endosperm is removed from the rice kernel and is called polished rice bran (Kaufmann et al., 2005).

***Carbohydrates in Rice Bran***. The composition of carbohydrates in rice bran depends on the amount of breakage and the degree of milling. The average content of starch is 27.4% in full fat rice bran and 30.2% in defatted rice bran, but concentration and ratios of amylose and amylopectin depend on the rice variety (Sauvant et al., 2004). The concentration of NDF in full fat rice bran is 20.5% whereas defatted rice bran contains 24.1% NDF (Sauvant et al., 2004). Kaufmann et al. (2005) reported contents of NDF ranging from 25.5 to 34.3% in full fat and extruded full fat rice bran samples, and 2.1% in polished rice bran. Total dietary fiber and soluble dietary fiber are greater in defatted bran (24 to 51% and 2 to 2.9%, respectively) than in full fat rice bran (20 to 25% and 1.8 to 2.0%, respectively; Hargrove, 1994; NRC, 2012).

The concentration of hemicelluloses may be 8.7 to 11.4% in rice bran, cellulose may range from 9.6 to 12.8%, and beta-glucans are present at less than 1%, whereas sugar concentration, mainly sucrose, ranges from 3.0 to 8.0% (Hargrove, 1994).

***Lipids in Rice Bran***. The oil in full fat rice bran may be removed using hydraulic pressing or solvent extraction and defatted rice bran, crude rice bran oil, wax, and soaps of fatty acids are produced. Usually, defatted rice bran is pelleted and in that way is easier to conserve, but its nutritional value is less than that of full fat rice bran (de Blas et al., 2010). Kaufmann et al. (2005) reported concentrations of crude fat ranging from 20.7 to 24.4% in full fat rice bran and from of 4.1 to 5.4% in defatted rice bran and polished rice bran. Values for ether extract in full fat rice bran of 14 to 17% and 3 to 4% for defatted rice bran have been reported by other authors (Sauvant et al., 2004; de Blas et al., 2010; NRC, 2012). Oleic acid represents approximately

40% of the fatty acids in rice bran and linoleic acid and palmitic acid contribute approximately 35.9 and 18.0%, respectively (Sauvant et al., 2004). If the bran is removed from the rice kernel lipids in milled bran, the lipase enzyme present in the bran is liberated, resulting in hydrolysis of oil to glycerol and free fatty acids. If rice bran is not immediately stabilized, free fatty acids will be produced within a few hours, which will result in peroxidation of rice bran (McCaskill and Orthoefer, 1994; Prakash and Ramaswamy, 1996). However, stabilization of rice bran prevents these problems and improves the quality of bran and oil extracted from it. Although there are several potential methods of accomplishing stabilization, most of them are associated with some type of heating process such as dry heat, moist heat, or extrusion (McCaskill and Orthoefer, 1994). The heat destroys lipase, but may destroy other compounds such as antioxidants, and excessive heat may initiate Maillard reactions. Therefore, extrusion at lower temperatures is preferred (Hargrove, 1994). Other methods to remove the oil, such as extraction with an organic solvent, or ethanolic denaturation of bran lipases, or use of lipase-producing bacteria, have been developed for stabilizing brown rice (Champagne, 1994).

***Proteins and Amino Acids in Rice Bran***. The concentration of CP is greatest in defatted and extruded rice bran (18.1 and 21.0%, respectively) and lowest in full fat rice bran and polished rice bran (15.6 and 15.8%, respectively; Kaufmann et al., 2005). These values are in agreement with those reported by Warren and Farrell (1990a). The distribution of soluble protein fractions in rice bran is: albumin, 37 to 40%; globulin, 21 to 36%; prolamine, 3 to 5%; and glutelin, 22 to 36% (Saunders, 1985; Prakash and Ramaswamy, 1996). The relatively high concentrations of albumins and globulins make rice bran protein a high quality protein because those fractions have a more favorable AA profile than many other cereals that store most protein as prolamine, which has a less favorable AA profile compared with the requirement of pigs (Hamaker, 1994).

***Minerals in Rice Bran***. The content of ash in full fat and defatted rice bran is 9 to 11%. The total concentration of P in rice bran is 17.7 g/kg, but 80 to 85% is bound as phytic acid (Sauvant et al., 2004), which makes that P unavailable to pigs. However, microbial phytase may be used to improve phytate P utilization and to reduce P excretion (Agudelo et al., 2010).

***Nutritional Value of Rice Bran***. Full fat rice bran contains 4,772 kcal/kg of GE, 3,100 kcal/kg DE, 2,997 kcal/kg ME, and 2,281 kcal/kg NE, whereas defatted rice bran contains 4,056 kcal/kg GE, 2,199 kcal/kg DE, 2,081 kcal/kg ME, and 1,553 kcal/kg NE (NRC, 2012). The NE value of full fat rice bran represents 76% of the ME value, whereas the NE value of defatted rice bran is 74% of the ME. Lower values for energy content were reported in rice bran containing 10.8% ether extract and 32.8% NDF, but the efficiency of utilization of ME from that rice bran is similar to that of other cereal grains (Robles and Ewan, 1982).

The ATTD of DM in defatted rice bran is 66% and the ATTD of GE is 72% (Warren and Farrell, 1990c). The main reason for the low digestibility of DM and GE is the high concentration of NDF in rice bran (Warren and Farrell, 1990c). Values for AID of DM range between 43.0 and 49.7% for full fat rice and is 35.8% for defatted rice bran, whereas AID of GE is 60 to 62% for full fat rice bran and 64% for defatted rice bran, but these values are greater for extruded rice bran (Kaufmann et al., 2005).

The nutritional value of rice bran protein is high; protein efficiency ratio values range from 1.59 to 2.04 and that of rice protein concentrate range from 1.99 to 2.19 (Prakash and Ramaswamy, 1996). The average AID of CP in full fat rice bran is 57% (NRC, 2012), but the AID of protein may range between 38.3% in defatted rice bran and 67.3% in extruded rice bran (Kaufmann et al., 2005). The AID for AA is between 72.7 and 82.2% for Lys; 66.9 and 76.0% for Met; 73.8 and 82.8% for Thr, and 69.7 and 82.6% for Trp in full fat rice bran. These values

were greater in samples with less NDF than in samples with greater concentrations of NDF (Kaufmann et al., 2005).

***Antinutritional Factors in Rice Bran***. Rice bran contains some anti-nutritional factors that may limit its use in livestock feeding. Lipases and enzyme inhibitors such as trypsin inhibitors and pepsin inhibitors are the main anti-nutritional factors. Other deleterious components in rice bran include hemaglutinin, antithiamin factors, and estrogenic compounds (Saunders, 1985).

Lipase activity produces rancid fat in rice bran, which can result in reduced palatability, feed intake and growth, and cause digestive disorders. The oxidative stability also is decreased in pork meat from pigs fed diets containing rancid rice bran (Chae and Lee, 2002).

Hemaglutinin-lectin is a growth depressant at lower concentrations in feeds and tends to be toxic at high concentrations. The rice bran lectins may bind to specific carbohydrate receptors in the intestinal wall, and thereby reduce nutrient absorption, but the activity of lectins may be decreased with thermal treatments (Khan et al., 2009).

Trypsin inhibitors impair trypsin activity in the digestive tract. However, heat treatment inactives trypsin inhibitors and the concentration of trypsin inhibitors can, therefore, be used as an indicator of correct heat treatment and stabilization of rice bran (Khan et al., 2009).

***Growth Performance of Pigs fed Diets Containing Rice Bran***. Inclusion of 10, 20, or 30% defatted rice bran improved feed intake and growth, but not G:F, of pigs from 15 to19 kg; however, 10 or 20% inclusion is recommended to obtain optimum consumption (Warren and Farrell, 1990b). Improved growth performance by pigs from 50 to 105 kg of BW was reported with inclusion of 20% full fat rice bran compared with 20% defatted rice bran. However, performance may be reduced if the full fat rice bran has been oxidized due to inadequate stabilization (Chae and Lee, 2002). In contrast, feeding diets containing 30% full fat rice bran

and 49.6% corn reduced ADFI (9.3%), ADG (13.4%), and G:F (4.83%) compared with pigs fed a diet based on only corn (de Campos et al., 2006).

Inclusion of 10% stabilized full fat rice bran improved feed efficiency in weanling pigs (21 to 49 d) if diets without antibiotic growth promoters were used, and increased the concentration of colonic bifidobacteria, indicating that stabilized rice bran may have prebiotic properties (Herfel et al., 2013). Growth performance of pigs fed diets containing rice is summarized in Table 2.3.

***Bioactive Food Components and Health Properties of Rice Bran***. Bioactive food components in rice bran may include gamma-orizanol, tocopherols, tocotrienol, phenols (feluric acid, salicylic, caffeic, and coumaric acids), phytosterols (beta-sitosterol, campesterol, and stigmasterol), and carotenoids (alpha-carotene, beta-carotene, lycopene, lutein, and zeazanthin). Gamma-orizanol is marketed for enhancing energy, improving muscle condition, and healing athletic stress in dogs, and for its ability to reduce cholesterol absorption and decrease early atherosclerosis, inhibit platelet aggregation, and increase excretion of fecal bile acids (Ryan, 2011).

### *Rice mill feed*

Rice mill feed is a blend of 65% ground rice hulls and 34% rice bran and is commonly used to feed beef cattle (Stacey and Rankins, 2004). This rice coproduct contains 5.13 to 6.7% CP, 5.9% ether extract, 54 to 71% NDF, 40 to 50% ADF, 49% cellulose, 21.6% ash, and 0.53% P (Stacey and Rankins, 2004; Ofogo et al., 2008). The high content of fiber in this ingredient limits its utilization as an ingredient for pig feeding. However, previous experiments conducted in broilers showed increased nutritional value of this rice coproduct with the addition of NSP-degrading enzymes and phytase (Ofogo et al., 2008).

## USE OF ENZYMES IN RICE COPRODUCTS

Exogenous enzymes in pig diets have been used to improve the nutritional value of feed ingredients, increasing the efficiency of digestion, reducing nutrient excretion, and allowing greater inclusion of ingredients of low nutritional value in diets fed to pigs (Adeola and Cowieson, 2011). The most common enzymes used in grains and coproducts are carbohydrases (xylanase, β-glucanase) and phytase (Barletta, 2010). Xylanases and β-glucanases reduce the molecular weight of NSP and use of these enzymes may result in improved ADG of pigs fed diets based on wheat, corn, barley, or rye. The addition of carbohydrases in diets of younger pigs is essential due to the limited capacity of the digestive tract and lower ability to digest ingredients high in fiber (Adeola and Cowieson, 2011).

Xylans are substrate for xylanases and are a major component of hemicelluloses and the second most abundant polysaccharide, after cellulose, in nature (Bach Knudsen, 2014). Xylans are polymers of 120 to 200 units of D-xylopyranose linked by β1-4 bonds, with some substituents groups attached to xylose. The number of substituents varies with the sources and defines the physical-chemical properties of xylan. L-arabinose is the monosaccharide linked to the D-xylose backbone to make arabinoxylans that are present in the cell walls of cereals (Paloheimo et al., 2010). Using diets based on rough rice and supplemented with an enzyme complex containing xylanase, beta-glucanase, and cellulase resulted in an increase in the ADG of growing pigs by 10% and the G:F by 9.4% compared with diets without enzymes (Wang et al., 2008). However, there is no information about the effects of carbohydrases on nutritional value of other rice coproducts.

Phytase dephosphorylates phytic acid to orthophosphate and inositol phosphate. Feed ingredients have variable concentrations of phytate-P because phytate-bound P serves as a P reservoir during seed germination (Selle and Ravindran, 2008). The concentration of phytate-P is approximately 1.88 g/kg in corn and 14.17 g/kg in rice bran (NRC, 2012). Phytate-P is poorly utilized by monograstric animals and has been described as an anti-nutritional factor because of its capacity to reduce the availability of nutrients like Ca, Zn, Fe, and Cu. Phytate-P also has potential to bind AA and may depress AA and energy digestibility (Selle et al., 2010). Undigested phytate-bound P is excreted in the manure and may contribute to pollution of water and ecosystems (Agudelo et al., 2010).

Microbial phytase degrades approximately 50% of the phytate bonds in diets, reducing the pollutant and anti-nutritional effects (Selle et al., 2010). A reduction in excretion of P and increase in the ATTD of P have been observed in diets based on corn, hominy feed, bakery meal, and DDGS supplemented with phytase (Rojas et al., 2013). Microbial phytase also reduced fecal output of P and increased the standardized total tract digestibility (**STTD**) of P in oilseed products such as canola, cottonseed, and sunflower meals (Rodríguez et al., 2013). Likewise, greater digestibility of P was observed in diets containing 30% full fat rice bran and supplemented with phytase compared with similar diets that were not supplemented with phytase (Agudelo et al., 2010).

In conclusion, the production of rice is mainly for human consumption; however, there are approximately 100 million tonnes of rice coproducts available annually for animal feeding. Full fat rice bran, defatted rice bran, and broken rice are the rice coproducts most commonly used in animal feeding, but brown rice and rice mill feed also are available. The proximal composition of rice coproducts reported in the literature indicates that it may be included in diets

for pigs as a replacement for traditional cereals. However, those data are based on limited numbers of observations. Inclusion of broken rice in weanling pigs has positive effects on growth performance and gut health. However, information about effects of inclusion of other rice coproducts and supplementation with enzymes in diets for pigs in different physiological stages is inconclusive.

## FIGURES

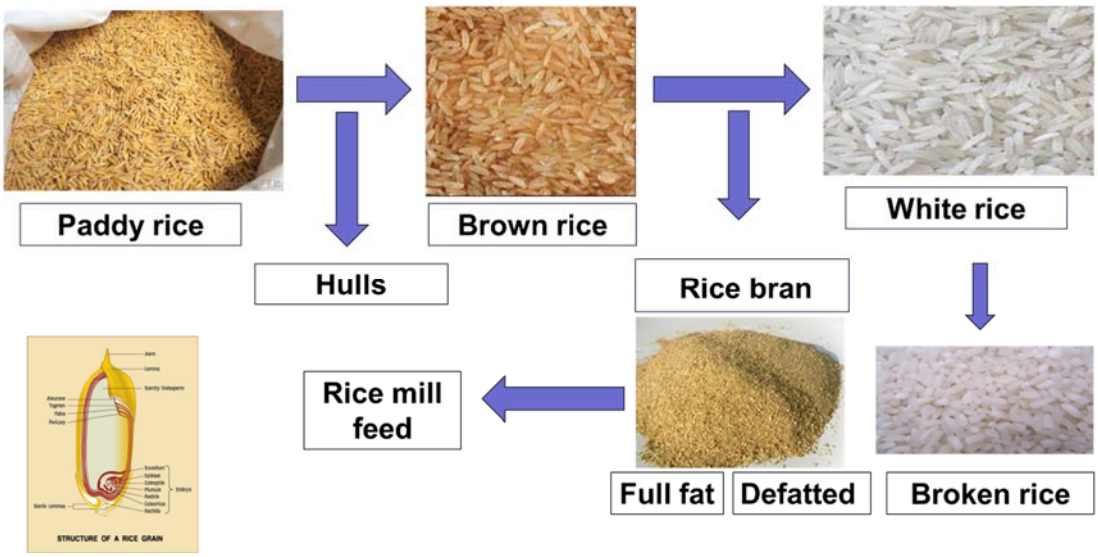


**Figure 2.1.** Rice Processing (http://www.intlcorn.com/seedsiteblog/?p=1141)

## TABLES

**Table 2.1.** Composition of rice coproducts.

| Items | Rice[1] | Broken rice[2] | Rice hulls[3] | Full fat rice bran[1] | Rice bran defatted[1] |
|---|---|---|---|---|---|
| DM% | 87.8 | 87.4 | 91.9 | 91.6 | 91.3 |
| CP, % | 7.8 | 7.7 | 3.7 | 15.1 | 17.3 |
| Crude fiber, % | 0.52 | 1.1 | 42.6 | 8.0 - 12.0[3] | 10.0 - 15.0[3] |
| Ether extract, % | 1.2 | 1.2 | 1.5 | 13.8 - 17.1[4] | 3.5 |
| Ash, % | 1.71 | 0.9 | 17.5 | 14.8 | 11.5 |
| Starch, % | 75.2 | 77.1 | 5.3 | 27.0 | 26.2 |
| NDF, % | 1.8 | 5.2 | 67.8 | 20.5[2] | 24.1[2] |
| ADF, % | 0.64 | 1.3 | 51.7 | 8.9[2] | 11.3[2] |
| GE, kcal/kg | 3,723 | 3,776 | 3,895 | 4,772 | 4,056 |
| DE, kcal/kg | 3,681 | 3,539 | - | 3,100 | 2,199 |
| ME, kcal/kg | 3,627 | 3,468 | - | 2,997 | 2,081 |
| NE, kcal/kg | 2,881 | 2,822 | - | 2,281 | 1,553 |

[1]NRC, 2012.

[2]Sauvant et al., 2004.

[3]Heuzé and G. Tran. 2015.

[4]de Blas et al., 2010.

**Table 2.2**. Differences in growth performance responses when uncooked, cooked or brown rice was included in diets for pigs

| Ingredient | Control | Age, d | ADG, g | ADFI, g | G:F | Reference |
|---|---|---|---|---|---|---|
| Rice uncooked | Corn cooked-flaked | 25 - 53 | 52.00 | 62.00 | 0.009 | Vicente et al., 2008 |
| | Corn uncooked | 23 - 47 | 47.00 | 37.00 | 0.03 | Menoyo et al., 2011 |
| | Corn heating | 23 - 47 | 42.00 | 70.00 | -0.02 | Menoyo et al., 2011 |
| | Corn | 21 - 63 | 6.00 | 9.00 | 0.001 | Che et al., 2012 |
| | Barley | 21 - 63 | 30.00 | 42.00 | 0.003 | Che et al., 2012 |
| | Rolled oats | 21 - 63 | 14.00 | 15.00 | 0.006 | Che et al., 2012 |
| Rice cooked | Corn cooked-flaked | 25 - 53 | 26.00 | 8.00 | 0.039 | Vicente et al., 2008a |
| | Corn cooked | 21 - 54 | 29.00 | -2.00 | 0.01 | Mateos et al., 2006 |
| | Corn raw | 23 - 47 | 11.00 | -31.00 | 0.06 | Menoyo et al., 2011 |
| | Corn heating | 23 - 47 | 6.00 | 0.39 | 0.01 | Menoyo et al., 2011 |
| | Uncooked rice | 23 - 47 | -36.00 | -68.00 | 0.03 | Menoyo et al., 2011 |
| Rice cooked, flaked | Corn cooked | 25 - 53 | 49.00 | 54.00 | 0.018 | Vicente et al., 2008a |
| Brown rice | Corn 100% | 31 - 59 | -10.00 | -50.00 | 0.036 | Li et al., 2002 |
| | Corn 50% | 31 - 59 | -50.00 | -60.00 | -0.019 | Li et al., 2002 |

**Table 2.3**. Change (%) in growth performance variables in weanling or growing-finishing pigs fed diets containing full fat rice bran (FFRB) or defatted rice bran (DDFB)

| Ingredient | Weight, kg | Control | ADG | ADFI, % | G:F | Dressing | BF[1] | Reference |
|---|---|---|---|---|---|---|---|---|
| Fresh FFRB, 20% | 51.12 - 105 | DFRB[3] (20%) | 15.87 | 4.85 | 10.49 | 0.24 | -7.78 | Chae and Lee, 2002 |
| Rancid FFRB,[2] 20% | 51.12 - 105 | DFRB (20%) | 2.67 | 0.33 | -4.01 | -1.80 | -0.52 | Chae and Lee, 2002 |
| FFRB, 30% | 25 - 120 | Corn | -13.4 | -9.3 | -4.8 | - | - | de Campos et al., 2006 |
| FFRB, 10% stabilized | 6 - 9.5 | Corn | 2.80 | -5.69 | 9.5 | N.A.[4] | N.A. | Herfel et al., 2013 |
| DFRB, 10% | 19 - 45 | Sorghum + wheat | 1.87 | 2.5 | 0 | N.A. | N.A. | Warren and Farrell, 1990b |
| DFRB, 20% | 19 - 45 | Sorghum + wheat | 9.92 | 8.78 | 0 | N.A. | N.A. | Warren and Farrell, 1990b |
| DFRB, 30% | 19 - 45 | Sorghum + wheat | 6.92 | 11.34 | -7.5 | N.A. | N.A. | Warren and Farrell, 1990b |

[1]BF = backfat.

[2]FFRB = full fat rice bran.

[3]DFRB = defatted rice bran.

[4]N.A. = No Apply.

## LITERATURE CITED

Adeola, O., and A. J. Cowieson. 2011. Board-invited review: Opportunities and challenges in using exogenous enzymes to improve nonruminant animal production. J. Anim. Sci. 89:3189-3218. doi:10.2527/jas.2010-3715

Agudelo, J. H., M. D. Lindemann, and G. L. Cromwell. 2010. Phosphorus utilization in growing pigs fed a phosphorus deficient diet supplemented with a rice bran product and amended with phytase. Rev. Colomb. Cienc. Pecu. 23:429-443.

Bach Knudsen, K. E. 2014. Fiber and nonstarch polysaccharide content and variation in common crops used in broiler diets. Poult. Sci. 93:2380-2393. doi:10.3382/ps.2014-03902

Barletta, A. 2010. Introduction: Current market and expected developments. In: M. Bedford and G. Partridge, editors, Enzymes in farm animal Nutrition. CAB International, Boston, MA. p. 1-11.

Cervantes-Pahm, S. K., Y. Liu, and H. H. Stein. 2014a. Comparative digestibility of energy and nutrients and fermentability of dietary fiber in eight cereal grains fed to pigs. J. Sci. Food Agric. 94:841-849. doi:10.1002/jsfa.6405

Cervantes-Pahm, S. K., Y. Liu, and H. H. Stein. 2014b. Digestible indispensable amino acid score and digestible amino acids in eight cereal grains. Br. J. Nutr. 111:1663-1672. doi:10.1017/S0007114513004273

Chae, B. J., and S. K. Lee. 2002. Rancid rice bran affects growth performance and pork quality in finishing pigs. Asian-Australas. J. Anim. Sci. 15:94-101. doi:10.5713/ajas.2002.94

Champagne, E. T. 1994. Brown rice stabilization. In: G. F. Maberly and J. I. Wadsworth, editors, Rice science and technology. Marcel Dekker, NY. p. 17-35.

Che, T. M., V. G. Perez, M. Song, and J. E. Pettigrew. 2012. Effect of rice and other cereal grains on growth performance, pig removal, and antibiotic treatment of weaned pigs under commercial conditions. J. Anim. Sci. 90:4916-4924. doi:10.2527/jas.2011-4916

Dagnino, E. P., E. R. Chamorro, S. D. Romano, F. E. Felissia, and M. C. Area. 2013. Optimization of the acid pretreatment of rice hulls to obtain fermentable sugars for bioethanol production. Ind. Crops Prod. 42:363-368. doi:10.1016/j.indcrop.2012.06.019

de Blas, C., G. G. Mateos, and P. García-Rebollar. 2010. Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos. (In spanish). 3rd. ed. Fund. Esp. Desarrollo Nutr. Anim., Madrid, Spain.

de Campos, R. M. L., E. Hierro, J. A. Ordoñez, T. M. Bertol, and L. Hoz. 2006. A note on partial replacement of maize with rice bran in the pig diet on meat and backfat fatty acids. J. Anim. Feed Sci. 15:427-433. doi:10.22358/jafs/66913/2006

Delcour, J. A., and R. C. Hoseney. 1994. Rice and out processing. In: R. C. Hoseney, editor, Principles of cereal science and technology. American Association of Cereal Chemists, St. Paul, MN. p. 149-160.

FAO. 2017. Rice market monitor. In: Food and Agriculture Orgranization of the United Nations. Accessed 12 January 2018, http://www.fao.org/3/I8317EN/I8317EN.pdf.

Hamaker, B. R. 1994. The influence of rice protein on rice quality. In: W. E. Marshall and J. I. Wadsworth, editors, Rice science and technology. Marcel Decker, NY. p. 177-193.

Hargrove, K. L. J. 1994. Processing and utilization of rice bran in the United States. In: W. E. Marshall and J. I. Wadsworth, editors, Rice science and technology. Marcel Dekker, NY. p. 381-404.

Herfel, T., S. Jacobi, X. Lin, E. Heugten, V. Fellner, and J. Odle. 2013. Stabilized rice bran improves weaning performance via a prebiotic mechanism. J. Anim. Sci. 91:907-913. doi:10.2527/jas.2012-5287

Heuzé, V., and G. Tran. 2015. Rice bran and other rice by-products. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/750 Last updated on October 5, 2015, 11:03

Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. He, M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. Can. J. Anim. Sci. 85:355-363. doi:10.4141/A04-084

Khan, S. H., M. S. Butt, F. M. Anjum, and A. Jamil. 2009. Antinutritional appraisal and protein extraction from differently stabilized rice bran. Pak. J. Nutr. 8:1281-1286. doi:10.3923/pjn.2009.1281.1286

Kim, J. C., B. P. Mullan, D. J. Hampson, M. M. J. A. Rijnen, and J. R. Pluske. 2007. The digestible energy and net energy content of two varieties of processed rice in pigs of different body weight. Anim. Feed Sci. Technol. 134:316-325. doi:10.1016/j.anifeedsci.2006.09.016

Li, D., D. F. Zhang, X. S. Piao, I. K. Han, C. J. Yang, J. B. Li, and J. H. Lee. 2002. Effects of replacing corn with Chinese brown rice on growth performance and apparent fecal digestibility of nutrients in weanling pigs. Asian-Australas. J. Anim. Sci. 15:1191-1197. doi:10.5713/ajas.2002.1191

Mateos, G. G., F. Martín, M. A. Latorre, B. Vicente, and R. Lázaro. 2006. Inclusion of oat hulls in diets for young pigs based on cooked maize or cooked rice. Anim. Sci. 82:57-63. doi:10.1079/ASC20053

McCaskill, D. R., and F. T. Orthoefer. 1994. Storage stability of extrusion stabilized and parboiled rice bran. In: W. E. Marshall and J. I. Wadsworth, editors, Rice science and technology. Marcel Dekker, NY. p. 37-47.

Menoyo, D., M. P. Serrano, V. Barrios, D. G. Valencia, R. Lazaro, J. Argente, and G. G. Mateos. 2011. Cereal type and heat processing of the cereal affect nutrient digestibility and dynamics of serum insulin and ghrelin in weanling pigs. J. Anim. Sci. 89: 2793-2800. doi:10.2527/jas.2010-3475

Muthayya, S., J. D. Sugimoto, S. Montgomery, and G. F. Maberly. 2014. An overview of global rice production, supply, trade, and consumption. Ann. N.Y. Acad. Sci. 1324:7-14. doi:10.1111/nyas.12540

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Ofogo, S. T., S. Kehraus, E. A. Iyayi, and K. H. Sudekem. 2008. Rice mill feed: an agro-industrial by-product with potential for rural development. In: Conference on International Research of Food Security, Rural Resoruce Management and Rural Development, University of Hohenheim, Germany http://www.researchgate.net/publication (Accessed 15 July 2014).

Paloheimo, M., J. Piironen, and J. Vehmaanperä. 2010. Xylanases and cellulases as feed additives. In: M. Bedford and G. Partridge, editors, Enzymes in farm animal nutrition. CAB International, Boston, MA. p. 12-53.

Parera, N., R. P. Lázaro, M. P. Serrano, D. G. Valencia, and G. G. Mateos. 2010. Influence of the inclusion of cooked cereals and pea starch in diets based on soy or pea protein concentrate on nutrient digestibility and performance of young pigs. J. Anim. Sci. 88:671-679. doi:10.2527/jas.2009-2202

Pluske, J. R., L. Montagne, F. S. Cavaney, B. P. Mullan, D. W. Pethick, and D. J. Hampson. 2007. Feeding different types of cooked white rice to piglets after weaning influences starch digestion, digesta and fermentation characteristics and the faecal shedding of β-haemolytic *Escherichia coli*. Br. J. Nutr. 97:298-306. doi:10.1017/S0007114507332534

Prakash, J., and H. S. Ramaswamy. 1996. Rice bran proteins: Properties and food uses. Crit. Rev. Food Sci. Nutr. 36:537-552. doi:10.1080/10408399609527738

Robles, A., and R. C. Ewan. 1982. Utilization of energy of rice and rice bran by young pigs. J. Anim. Sci. 55:572-577. doi:10.2527/jas1982.553572x

Rodríguez, D. A., R. C. Sulabo, J. C. González-Vega, and H. H. Stein. 2013. Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs. Can. J. Anim. Sci. 93:493-503. doi:10.4141/cjas2013-020

Rojas, O. J., Y. Liu, and H. H. Stein. 2013. Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 91:5326-5335. doi:10.2527/jas.2013-6324

Ryan, E. P. 2011. Bioactive food components and health properties of rice bran. J. Am. Vet. Med. Assoc. 238:593-600. doi:10.2460/javma.238.5.593

Saunders, R. M. 1985. Rice bran: Composition and potential food uses. Food Rev. Int. 1:465-495. doi:10.1080/87559128509540780

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Selle, P. H., and V. Ravindran. 2008. Phytate-degrading enzymes in pig nutrition. Livest. Sci. 113:99-122. doi:10.1016/j.livsci.2007.05.014

Selle, P. H., V. Ravindran, A. J. Cowieson, and M. R. Bedford. 2010. Phytate and phytase. In: M. Bedford and G. Partridge, editors, Enzymes in farm animal nutrition. CAB International, Boston, MA. p. 160-205.

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Singh, A., M. Das, S. Bal, and R. Banerjee. 2014. Rice processing. In: R. P. Ferrerira-Guiné and P. M. dois-Reis-Correia, editors, Engineering aspects of cereal and cereal-based proudcts. CRC Press, Boca Raton, FL. p. 71-96.

Solà-Oriol, D., E. Roura, and D. Torrallardona. 2009. Feed preference in pigs: Effect of cereal sources at different inclusion rates. J. Anim. Sci. 87:562-570. doi:10.2527/jas.2008-0949

Stacey, W. N., and D. L. Rankins. 2004. Rice mill feed as a replacement for broiler litter in diets for growing beef cattle. J. Anim. Sci. 82:2193-2199. doi:10.2527/2004.8272193x

USA-Rice-Federation. 2011. Rice technical information kit. The complete guide for using U. S. rice as an ingredient. https://www.usarice.com (Acceseed 21 January 2013).

USDA. 2017. Rice yearbook, https://www.ers.usda.gov. (Accessed 18 January 2018).

Vicente, B., D. G. Valencia, M. Pérez-Serrano, R. Lázaro, and G. G. Mateos. 2008a. The effects of feeding rice in substitution of corn and the degree of starch gelatinization of rice on the digestibility of dietary components and productive performance of young pigs. J. Anim. Sci. 86:119-126. doi:10.2527/jas.2006-697

Vicente, B., D. G. Valencia, M. P. Serrano, R. Lázaro, and G. G. Mateos. 2008b. Effects of feeding rice and the degree of starch gelatinisation of rice on nutrient digestibility and ileal morphology of young pigs. Br. J. Nutr. 101:1278-1281. doi:10.1017/S0007114508060789

Wang, M. Q., Z. R. Xu, J. Y. Sun, and B. G. Kim. 2008. Effects of enzyme supplementation on growth, intestinal content viscosity, and digestive enzyme activities in growing pigs fed rough rice-based diet. Asian-Australas. J. Anim. Sci. 21:270-276. doi:10.5713/ajas.2008.70289

Warren, B. E., and D. J. Farrell. 1990a. The nutritive value of full-fat and defatted Australian rice bran. I. Chemical composition. Anim. Feed Sci. Technol. 27:219-228. doi:10.1016/0377-8401(90)90084-L

Warren, B. E., and D. J. Farrell. 1990b. The nutritive value of full-fat and defatted Australian rice bran. II. Growth studies with chickens, rats and pigs. Anim. Feed Sci. Technol. 27:229-246. doi:10.1016/0377-8401(90)90085-m

Warren, B. E., and D. J. Farrell. 1990c. The nutritive value of full-fat and defatted Australian rice bran. III. The apparent digestible energy content of defatted rice bran in rats and pigs and the metabolisability of energy and nutrients in defatted and full-fat bran in chickens and adult cockerels. Anim. Feed Sci. Technol. 27:247-257. doi:10.1016/0377-8401(90)90086-N

Zhou, Z., K. Robards, S. Helliwell, and C. Blanchard. 2002. Composition and functional properties of rice. Int. J. Food Sci. Technol. 37:849-868. doi:10.1046/j.1365-2621.2002.00625.x

# CHAPTER 3: NUTRIENT COMPOSITION AND *IN VITRO* DIGESTIBILITY OF RICE COPRODUCTS

**ABSTRACT:** The objectives of these experiments were (1) to determine the carbohydrate composition and the *in vitro* DM and OM digestibility of brown rice, broken rice, full fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed; and (2) to test the hypotheses that (a) *in vitro* digestibility of DM (IVDMD) may be used to predict *in vivo* apparent total tract digestibility (ATTD) of DM, and (b) the ATTD of DM is negatively correlated with the concentration of non-starch polysaccharides (NSP) in rice coproducts. Three samples of broken rice, brown rice, FFRB, DFRB, and rice mill feed were used. Each sample was analyzed in duplicate for GE, DM, ash, NDF, ADF, ADL, CP, and acid hydrolyzed ether extract (AEE). Non-starch polysaccharides in the 5 rice coproducts were quantified and total NSP (T-NSP), non-cellulosic polysaccharides (NCP), and insoluble NSP were determined. Uronic acids and Klason lignin also were measured. Apparent total tract digestibility of broken rice, brown rice, FFRB, and DFRB was determined in a previous experiment using 80 pigs (13.6 ± 0.8 kg initial BW). The IVDMD and *in vitro* total tract digestibility of OM (IVOMD) were determined in 3 samples of each ingredient using a 3 step procedure. Results indicate that broken rice and brown rice contain more than 80.0% starch, rice mill feed contains 11.2%, starch, and both FFRB and DFRB contain 26.7% starch. The concentration of soluble dietary fiber (SDF) or soluble-non cellulosic polysaccharides (S-NCP) was between 0.1% in brown rice and 1.9% in rice mill feed, but insoluble dietary fiber (IDF) was 1.5% in broken rice and 52.9% in rice mill feed. The I-NCP fraction in all rice coproducts consisted mainly of arabinose and xylose. The A:X ratio was between 0.98 and 1.37 in all rice coproducts except rice mill feed. Broken rice and brown rice

had greater ($P < 0.05$) IVDMD and IVOMD than the other rice coproducts. There was a linear relationship ($P < 0.05$) between IVDMD and *in vivo* ATTD of DM, and there was a tendency ($P = 0.09$) for a linear relationship between *in vivo* ATTD of OM and IVOMD. There was a negative linear relationship ($P < 0.05$) between the T-NSP concentration and IVDMD. In conclusion, arabinoxylans are the main polysaccharides in the NSP fraction of rice coproducts. Arabinoxylans in broken rice, brown rice, FFRB, and DFRB have a different structure and are more soluble than arabinoxylans in rice mill feed. *In vitro* digestibility of DM may be used to predict ATTD *in vivo* of rice coproducts, but IVDMD in rice coproducts is reduced as the concentration of NSP is increased.

## INTRODUCTION

Dry milling of paddy rice usually involves removal of hulls, which have high concentrations of lignin and silica and is indigestible and unfermentable by monogastric animals (Serna-Saldivar, 2010). In the milling process of rice to obtain white rice, which is the endosperm, the aleurone layer and some external fractions of the grains also are removed and remain in a coproduct known as rice bran or rice polish (Hossain et al., 2012; Bhosale and Vijayalakshmi, 2015). The fiber fraction in cereal coproducts consists mainly of complex carbohydrates such as cellulose, arabinoxylans, mixed-linked β-glucans, and smaller quantities of other carbohydrates (Jaworski et al., 2015). By definition, fiber is not digested by the enzymes of the small intestine of animals, but may be digested by enzymes produced by microbes in the cecum or colon (Bach Knudsen, 2014). The concentration of fiber in corn and wheat coproducts is negatively correlated with *in vitro* total tract digestibility of DM (**IVDMD**; Jaworski et al., 2015). *In vivo* digestibility of DM and GE is less in rice coproducts with a high concentration of NDF compared with coproducts that have a low concentration of NDF (Casas and Stein, 2016).

Full fat rice bran (**FFRB**) contains approximately 20.5% NDF, and 8.9% ADF and defatted rice bran (**DFRB**) contains 24.1% NDF and 11.3% ADF (Sauvant et al., 2004). However, there is a lack data for the concentrations of individual sugars and fiber components in rice coproducts and effects of these components on the digestibility of DM.

Therefore, the objective of this experiment was to determine the carbohydrate composition and **IVDMD** and the *in vitro* digestibility of OM (**IVOMD**) of brown rice, broken rice, FFRB, DFRB, and rice mill feed. The second objective was to test the hypothesis that IVDMD may be used to predict *in vivo* apparent total tract digestibility (**ATTD**) of DM and that the IVDMD of rice coproducts is negatively correlated with the concentration of non-starch polysaccharides (**NSP**) in the rice coproducts.

## MATERIALS AND METHODS

Five rice coproducts were evaluated: broken rice, brown rice, FFRB, DFRB, and rice mill feed (Table 3.1). Broken rice was sourced from Consumers Supply Distributing, North Sioux City, SD; brown rice was sourced from Augason Farms, Salt Lake City, UT; FFRB and DFRB were sourced from Harvest Rice, Inc., McGehee, AR, and Rice Bran Technologies, Scotsdale, AR, respectively; and rice mill feed was sourced from Crescent Feed Co., Springfield, MO.

### *Nutrient Composition*

Three different samples of each ingredient were collected. Each sample was analyzed in duplicate for GE using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL) with benzoic acid as the standard for calibration (Table 3.1). Samples also were analyzed for DM (Method 930.05; AOAC Int., 2007), ash (Method 942.05, AOAC Int., 2007), and for NDF and ADF using Ankom Technology (method 12 and 13), respectively (Ankom 2000 Fiber

Analyzer; Ankom Technology, Macedon, NY). Acid detergent lignin was determined using Ankom Technology method 9 (Daisy$^{II}$ Incubator, Ankom Technology, Macedon, NY). Nitrogen was analyzed using the Kjeldahl method (Method 984.13; AOAC Int., 2007) on a KjeltecTM 8400 apparatus (FOSS Inc., Eden Prairie, MN). Crude protein was calculated as N × 6.25. Samples also were analyzed for acid hydrolyzed ether extract (**AEE**) by acid hydrolysis using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by fat extraction (Ankom XT-15 Extractor, Ankom Technology, Macedon, NY).

***Carbohydrate Composition***

One sample of each rice coproduct was used to determine carbohydrate composition. Starch was analyzed using an enzymatic colorimetric method as described by Bach Knudsen (1997). Non-starch polysaccharides in the 5 rice coproducts were quantified by adding the monosaccharide components in their anhydrous form, which were measured using a 3-parallel run extraction procedure: total NSP (**T-NSP**), non-cellulosic polysaccharides (**NCP**), and insoluble non-starch polysaccharides (Theander and Åman, 1979; Theander and Westerlund, 1986; Bach Knudsen, 1997). After hydrolysis, neutral sugars were quantified using gas chromatography, and uronic acids were determined using a colorimetric method (Englyst et al., 1994; Bach Knudsen, 1997). Klason lignin was determined as the insoluble residue after treatment with 12*M* $H_2SO_4$ (Bach Knudsen, 1997).

***In Vitro Total Tract Digestibility of DM and OM***

The in-vitro total tract digestibility of DM was determined in 3 samples of each ingredient and in triplicate using the procedure described by Boisen and Fernández (1997) with the modifications reported by Jaworski et al. (2015). In this procedure, 0.5 g of sample was used.

The first step of the procedure simulated the stomach digestion by adding pepsin and HCl to adjust the pH to 2 by adding 1*M* HCl or 1*M* NaOH, and the sample was incubated for 2 h at 39ºC. In the second step, pH was adjusted to 6.8 using 1*M* HCl or 1*M* NaOH; pancreatin solution was added, and samples were incubated at 39ºC for 4 h to simulate the small intestine digestion. The third step simulated fermentation in the large intestine and acetic acid was used to adjust the pH to 4.8 using a 30% acetic acid solution, and Viscozyme (Sigma-Aldrich, St. Louis, MO) was added to initiate fermentation. Incubation time for this step was 18 h at 39ºC. In the fourth step, the residue obtained by filtration was dried for 2 h in an oven at 135ºC to determine DM disappearance, and then ashed in a furnace at 600ºC for 2.5 h to determine OM disappearance (Jaworski et al., 2015).

***In-Vivo Apparent Total Tract Digestibility***

Apparent total tract digestibility of broken rice, brown rice, FFRB, and DFRB was determined in a previous experiment using 80 pigs (13.6 ± 0.8 kg initial BW; Casas and Stein, 2016). Pigs were individually housed in metabolism crates, which allowed for total collection of feces and urine. Pigs were randomly allotted to 10 diets. Experimental diets consisted of 1 basal diet based on corn and soybean meal and 4 diets that contained 50% brown rice, broken rice, FFRB, or DFRB. Five additional diets with the same ingredient composition also were formulated, and 16,000 units of microbial xylanase (Econase XT-25; AB Vista, Marlborough, UK) were added to these diets. However, only the data from diets without xylanase were used to evaluate the relationship between *in vivo* ATTD of DM and OM and values for IVDMD and IVOMD. The ATTD of DM and OM of the diets was calculated using the direct procedure, but the ATTD of DM and OM in each ingredient was calculated by difference (Casas and Stein,

2016). The samples of rice coproducts that were used to determine IVDMD and IVOMD were obtained from the same batches as those used to determine the *in vivo* ATTD of DM and OM.

***Calculations and Statistical Analysis***

Values for soluble dietary fiber (**SDF**), insoluble dietary fiber (**IDF**), and total dietary fiber (**TDF**) were calculated from the carbohydrate composition of ingredients. Soluble dietary fiber was calculated as the sum of individual monosaccharides in the S-NCP fraction, whereas values for IDF were calculated as the sum of all analyzed monosaccharides in the insoluble NCP (**I-NCP**), cellulose, and Klason lignin. Total dietary fiber was the sum of IDF and SDF.

*In vitro* total tract digestibility of DM and IVOMD for each ingredient were calculated using the following equation (Boisen and Fernández, 1997):

$$\text{IVDMD or IVOMD} = [(W_1 - (W_2 - \text{Blank}))]/W_1] \times 100$$

where $W_1$ is the weight of sample multiplied by percent DM or OM; $W_2$ is the weight of the residue after drying or after ashing.

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The fixed effect was the ingredient and the least squares mean statement was used to calculate ingredient means. The experimental unit was the sample. The REG procedure of SAS was used to evaluate the relationship between the concentration of total NSP and IVDMD or IVOMD. Equations to predict the ATTD of DM or OM of rice coproducts based on IVDMD or IVOMD were established using the REG procedure.

## RESULTS

Full fat rice bran had the greatest ($P < 0.05$) concentration of GE and AEE compared with the other rice coproducts (Table 3.1). Broken rice and brown rice had lower ($P < 0.05$)

concentrations of NDF, ADF, ADL, and ash than FFRB, DFRB, and rice feed mill. In contrast, rice mill feed had the greatest ($P < 0.05$) concentration of NDF, ADF, ADL, and ash among the rice coproducts. Rice mill feed contained less ($P < 0.05$) concentration of CP than the other rice coproducts.

The concentration of starch was more than 80.0% in broken rice and brown rice, but ranged between 11.2% in rice mill feed and 26.7% in FFRB and DFRB (Table 3.2). In contrast, rice mill feed contained more dietary fiber than the other ingredients. The content of S-NCP was low in all rice coproducts. Concentrations of arabinose, xylose, mannose, galactose, glucose, and uronic acids in the S-NCP fraction were 0.1% or not detectable in brown rice and broken rice. Defatted rice bran contained more arabinose and uronic acids than the other ingredients, but rice mill feed contained mostly xylose. In contrast, xylose was not detected in the S-NCP fraction of FFRB.

Insoluble dietary fiber was the main fraction of dietary fiber in all rice coproducts, but broken rice and brown rice contained less I-NCP than FFRB, DFRB, and rice mill feed. The I-NCP fraction in all rice coproducts consisted of arabinose and xylose, but the concentration of these 2 monosaccharides varied among ingredients. Thus, concentrations of arabinose and xylose were low in broken rice and brown rice, intermediate in FFRB and DFRB, and greater in rice mill feed. The A:X ratio was between 0.98 and 1.37 in all rice coproducts except in rice mill feed, which had an A:X ratio of 0.26. Likewise, among the rice coproducts, rice mill feed contained more NSP than did DFRB and FFRB, but most of the NSP in rice mill feed consisted of cellulose, whereas most of the NSP in FFRB and DFRB were I-NCP. Rice mill feed, FFRB and DFRB contained more NSP, IDF, Klason lignin, and dietary fiber than brown rice and broken rice.

Broken rice and brown rice had greater ($P < 0.05$) IVDMD and IVOMD than the other rice coproducts, followed by FFRB, DFRB, and rice mill feed (Table 3). The *in vivo* ATTD of DM and OM were 95.3 and 96.0% in broken rice, 94.6 and 96.2% in brown rice, 72.8 and 73.7% in FFRB, and 72.9 and 77.0% in DFRB (Casas and Stein, 2016). There was a linear relationship ($P < 0.05$) between the IVDMD and *in vivo* ATTD of DM (Fig. 3.1), and there was a tendency ($P = 0.09$) for a linear relationship between IVOMD and *in vivo* ATTD of OM (Fig. 2). There was a negative linear relationship ($P < 0.05$) between the T-NSP concentration and IVDMD (Fig. 3.3), and IVDMD was reduced ($P < 0.05$) as the concentration of T-NSP increased in the ingredients.

## DISCUSSION

As in other cereal grains, variation in the chemical composition of different samples of rice coproducts is expected due to differences among varieties, growing conditions, harvesting time, and milling quality (Angold, 1983; Serna-Saldivar, 2010). Formulation of diets for pigs requires accurate information about the composition of ingredients. However, composition values for rice coproducts in reference tables are most often based on a limited number of observations.

The concentration of starch in broken rice and brown rice was greater than reported values (Sauvant et al., 2004; Ohtsubo et al., 2005; Cervantes-Pahm et al., 2014; NRC, 2012), but in agreement with the values reported by Reed et al. (2013). The concentration of SDF in FFRB and DFRB was less than reported by Kahlon et al. (1990) and Aoe et al. (1993), but the concentration of total dietary fiber concurs with previous data (Kahlon et al., 1990).

Differences in chemical composition among rice coproducts are expected because different parts of the grain are separated in the milling process. Broken rice and brown rice contain more starch because these rice coproducts contain most of the endosperm of the grain. Certain varieties of rice, such as Japonica and Indica, contain more starch than other varieties such as Black, Arborio, or Basmati (Dhital et al., 2015). However, brown rice contains the aleurone layer and the germ, which contains most of the lipids and CP in the grain. Therefore, it is expected that brown rice has a greater concentration of these nutrients than broken rice (Juliano, 1983). Likewise, the carbohydrate composition of the tissues in rice grain may differ (Selvendran et al., 1988) and the grade of milling may affect the composition of white rice and rice coproducts (Saunders, 1985; Rosniyana et al., 2007; Rosniyana et al., 2009).

Regular analysis of feed ingredients often determines concentrations of crude fiber, NDF, ADF, and ADL. However, these fractions provide limited information about the carbohydrate composition and properties of the fiber (Bach Knudsen, 2014). In contrast, the enzymatic-chemical method (Englyst et al., 1994; Bach Knudsen, 1997) allows for separation of fiber into cellulose and NCP, and for estimation of the composition of the NCP fraction in terms of monosaccharide sugar residues. This may provide more information about the structure of complex carbohydrates in feed ingredients (Bach Knudsen, 2014).

The NSP analysis of the rice coproducts used in this study indicates that the fiber fraction of rice coproducts contains more NCP than cellulose, except for rice mill feed, which contains more cellulose than NCP. Also, the concentration of monosaccharides in the NCP fraction indicates that arabinoxylan is the main complex polysaccharide in this fraction. However, based on the A:X ratio, it is concluded that arabinoxylans in broken rice, brown rice, FFRB, and DFRB, which have an A:X ratio close to 1, have a different structure and probably are more

soluble than arabinoxylans in rice mill feed (Ebringerová, 2006). The high A:X ratio in broken rice and brown rice compared with the A:X ratio in FFRB, DFRB, and rice mill feed concur with previous data indicating that arabinoxylans from the endosperm have a greater A:X ratio than arabinoxylans from the aleurone layer (Bach Knudsen, 2014).

*In vitro* digestibility values are usually greater than *in vivo* ATTD values (Huang et al., 2003; Regmi et al., 2008). However, in this study, digestibility values for DM and OM in brown rice, broken rice, and DFRB were greater *in vivo* than *in vitro*, whereas the digestibility values for DM and OM in FFRB were greater *in vitro* than *in vivo*. It is likely that the digestion of starch, which is the main component in broken rice and brown rice, is more efficient *in vivo* than *in vitro*. The greater concentration of dietary fiber in FFRB may also increase the endogenous loss of DM and OM in FFRB, which may explain the lower values for ATTD observed *in vivo* compared with *in vitro* values (Regmi et al., 2008). In contrast, the lower *in vitro* digestibility in DFRB compared with *in vivo* values may be due to the fact that this sample was particularly powdery compared with the other ingredients, which may cause loss of particles in the filtration step of the *in vitro* procedure (Regmi et al., 2008).

The $r^2$ values obtained in this experiment indicate that IVDMD and IVOMD may be used to predict the ATTD of DM and OM obtained *in vivo*. This result concurs with previous experiments where *in vitro* digestibility of DM of wheat was a good predictor of ATTD of energy *in vivo* (Regmi et al., 2009). The negative relationship between the concentration of NSP and the IVDMD that was observed in this experiment is in agreement with data indicating that ingredients with greater concentrations of NSP had reduced IVDMD (Jaworski et al., 2015). This observation also concurs with previous experiments that demonstrated a reduced ATTD of DM and nutrients when the concentration of insoluble NSP increased in the ingredients (Zhang

et al., 2013). It is likely that differences in the concentration of starch and the complex composition and structure of arabinoxylans in rice mill, FFRB, and DFRB compared with the arabinoxylans in broken rice and brown rice is the reason for the lower IVDMD of those ingredients (de Vries et al., 2012; Bach Knudsen, 2014)

In conclusion, arabinoxylans are the main polysaccharides in the fiber fraction of rice coproducts except for rice mill feed in which the main fraction was cellulose. Arabinoxylans in broken rice, brown rice, FFRB, and DFRB have a different structure and probably are more soluble than arabinoxylans in rice mill feed. *In vitro* digestibility of DM is a good predictor of ATTD of DM *in vivo*, but the IVDMD in rice coproducts is reduced as the concentration of NSP is increased.

## FIGURES

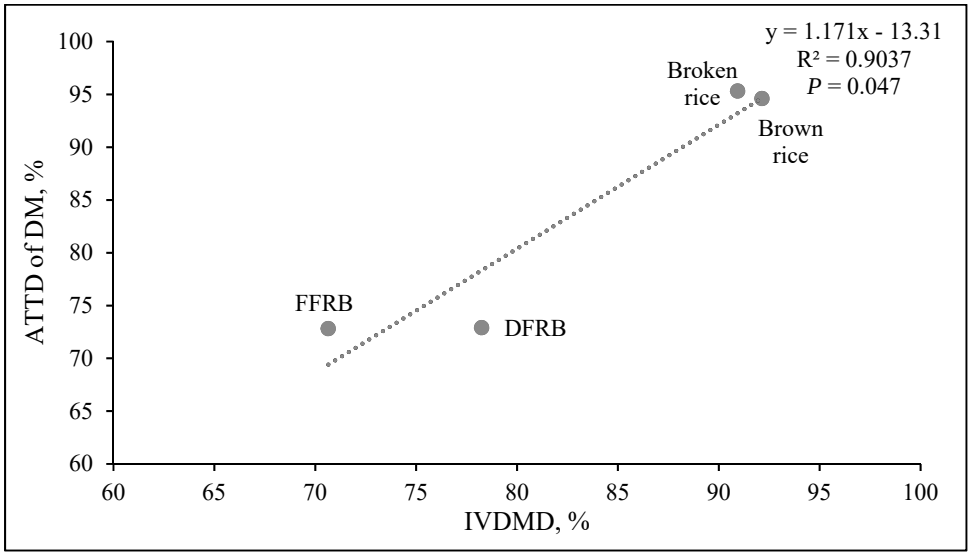


**Figure 3.1.** *In vitro* DM digestibility (IVDMD) versus *in vivo* ATTD of DM in broken rice, brown rice, full fat rice bran (FFRB), and defatted rice bran (DFRB).

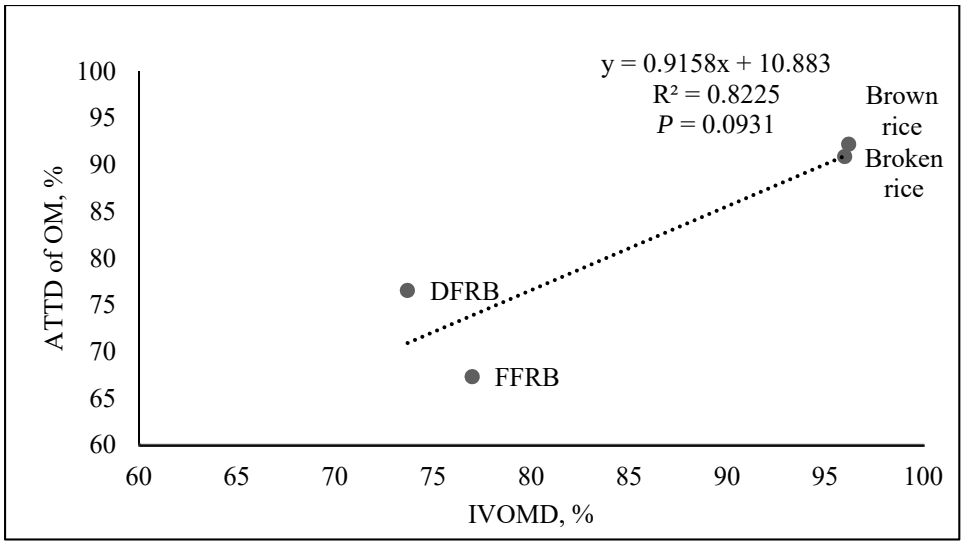


**Figure 3.2**. *In vitro* OM digestibility (IVOMD) versus *in vivo* ATTD of OM in broken rice, brown rice, full fat rice bran (FFRB), and defatted rice bran (DFRB).

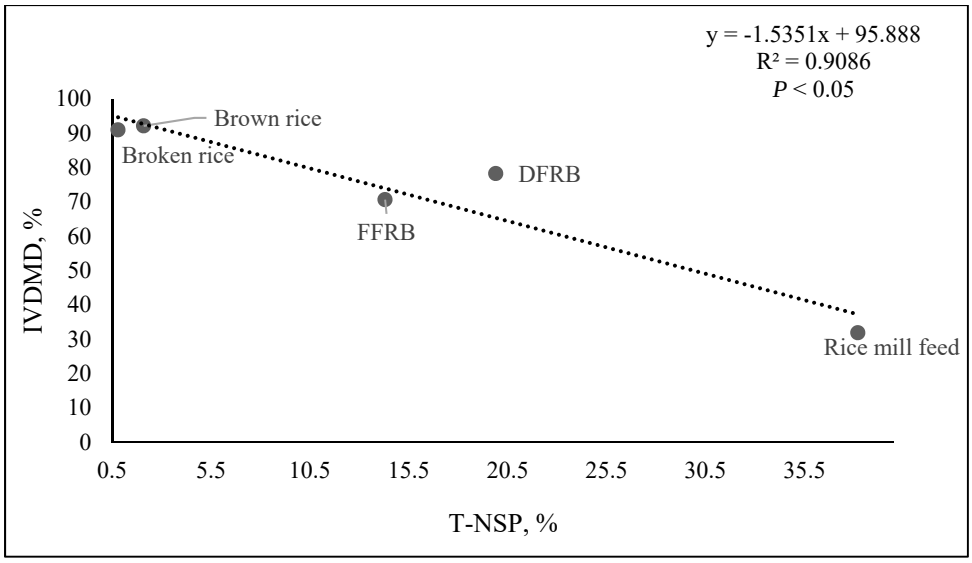


**Figure 3.3**. Relationship between total non-starch polysaccharides (T-NSP) and *in vitro* DM digestibility (IVDMD).

## TABLES

**Table 3.1.** Analyzed composition of broken rice, brown rice, full fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed, DM basis[1]

| Item | Broken rice | Brown rice | FFRB | DFRB | Rice mill feed | SEM | *P*-value |
|---|---|---|---|---|---|---|---|
| GE, kcal/kg | 4,266[c] | 4,404[b] | 5,232[a] | 4,095[e] | 4,176[d] | 7.392 | < 0.001 |
| DM, % | 87.40[d] | 87.55[d] | 93.47[a] | 88.66[c] | 90.01[b] | 0.12 | < 0.001 |
| Ash, % | 0.40[e] | 1.41[d] | 9.14[c] | 13.97[b] | 16.37[a] | 0.05 | < 0.001 |
| CP, % | 8.48[d] | 10.27[c] | 15.47[b] | 18.63[a] | 7.57[e] | 0.061 | < 0.001 |
| AEE[2], % | 1.13[d] | 3.74[b] | 19.58[a] | 2.73[c] | 4.16[b] | 0.218 | < 0.001 |
| ADF, % | 0.70[d] | 1.54[d] | 7.98[c] | 12.37[b] | 46.38[a] | 0.462 | < 0.001 |
| NDF, % | 0.63[e] | 5.41[d] | 17.17[c] | 25.09[b] | 51.33[a] | 0.849 | < 0.001 |
| ADL, % | 0.32[d] | 0.64[d] | 3.26[c] | 5.20[b] | 20.05[a] | 0.358 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 3 observations for all ingredients.

[2]AEE = acid hydrolyzed ether extract.

**Table 3.2**. Carbohydrate composition of broken rice, brown rice, full fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed, DM basis[1]

| Item,% | Broken rice | Brown rice | FFRB | DFRB | Rice mill feed |
|---|---|---|---|---|---|
| Starch | 86.64 | 80.87 | 26.58 | 26.67 | 11.16 |
| S-NCP[2] | 0.28 | 0.16 | 0.87 | 1.46 | 1.82 |
| Arabinose | 0.02 | N.D.9 | 0.2 | 0.49 | 0.39 |
| Xylose | 0.01 | N.D. | 0.01 | 0.23 | 0.52 |
| Mannose | 0.07 | 0.02 | 0.05 | 0.05 | 0.11 |
| Galactose | 0.08 | 0.05 | 0.22 | 0.23 | 0.27 |
| Glucose | 0.04 | 0.03 | 0.17 | N.D. | 0.2 |
| Uronic acids | 0.06 | 0.06 | 0.22 | 0.46 | 0.33 |
| I-NCP[3] | 0.43 | 1.9 | 8.98 | 11.6 | 15.07 |
| Arabinose | 0.14 | 0.46 | 3.13 | 4.02 | 2.16 |
| Xylose | 0.10 | 0.42 | 3.37 | 4.38 | 9.40 |
| Mannose | 0.05 | 0.08 | 0.28 | 0.20 | 0.19 |
| Galactose | N.D | 0.08 | 0.80 | 1.12 | 0.88 |
| Glucose | 0.12 | 0.74 | 0.60 | 0.89 | 1.63 |
| Uronic acids | 0.02 | 0.12 | 0.80 | 0.99 | 0.81 |
| Cellulose | 0.22 | 0.11 | 4.39 | 6.78 | 21.80 |
| Total NSP[4] | 0.93 | 2.17 | 14.24 | 19.84 | 38.39 |
| Klason lignin | 0.90 | 1.29 | 5.84 | 6.08 | 16.33 |
| Soluble dietary fiber[5] | 0.28 | 0.16 | 0.87 | 1.46 | 1.82 |
| Insoluble dietary fiber[6] | 1.55 | 3.30 | 19.21 | 24.46 | 52.90 |

**Table 3.2.** Cont.

| Item,% | Broken rice | Brown rice | FFRB | DFRB | Rice mill feed |
|---|---|---|---|---|---|
| Dietary Fiber[7] | 1.83 | 3.46 | 20.08 | 25.92 | 54.72 |
| A:X[8] | 1.37 | 1.14 | 0.98 | 0.98 | 0.26 |

[1]Total rhamnose and fucose in all ingredients range from N.D to 0.1% and thus was excluded from the table.

[2]Soluble non-cellulosic polysaccharides.

[3]Insoluble non-cellulosic polysaccharides.

[4]Total NSP = S-NCP + I-NCP + cellulose.

[5]Soluble dietary = S-NCP.

[6]Insoluble dietary fiber = I-NCP + cellulose + Klason lignin.

[7]Dietary fiber = soluble fiber + insoluble fiber.

[8]A:X = ratio arabinose:xylose.

[9]N.D. = not detectable.

**Table 3.3.** *In vitro* digestibility of DM (IVDMD) and of OM (IVOMD) of broken rice, brown rice, full fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed[1]

| Item, % | Broken rice | Brown rice | FFRB | DFRB | Rice mill feed | SEM | *P*-value |
|---|---|---|---|---|---|---|---|
| IVDMD | 90.94[a] | 92.15[a] | 78.25[b] | 70.65[c] | 31.86[d] | 0.554 | < 0.001 |
| IVOMD | 90.87[a] | 92.18[a] | 76.54[b] | 67.31[c] | 33.89[d] | 0.551 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are LSmeans of 3 observations per ingredient.

## LITERATURE CITED


Angold, R. E. 1983. The structure of the cereal grain. In: P. J. Barnes, editor, Lipids in cereal technology. Academic Press, London. p. 1-10. doi:10.1016/B978-0-12-079020-3.50007-6

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

Aoe, S., T. Oda, K. Tatsumi, M. Yamauchi, and Y. Ayano. 1993. Extraction of soluble dietary fibers from defatted rice bran. Cereal Chem. 70:423-425.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67:319-338. doi:10.1016/S0377-8401(97)00009-6

Bach Knudsen, K. E. 2014. Fiber and nonstarch polysaccharide content and variation in common crops used in broiler diets. Poult. Sci. 93:2380-2393. doi:10.3382/ps.2014-03902

Bhosale, S., and D. Vijayalakshmi. 2015. Processing and nutritional composition of rice bran. Curr. Res. Nutr. Food Sci. 3:74-80. doi:10.12944/CRNFSJ.3.1.08

Boisen, S., and J. A. Fernández. 1997. Prediction of the total tract digestibility of energy in feedstuffs and pig diets by *in vitro* analyses. Anim. Feed Sci. Technol. 68:277-286. doi:10.1016/S0377-8401(97)00058-8

Casas, G. A., and H. H. Stein. 2016. Effects of microbial xylanase on digestibility of dry matter, organic matter, neutral detergent fiber, and energy and the concentrations of digestible and metabolizable energy in rice coproducts fed to weanling pigs. J. Anim. Sci. 94:1933-1939. doi:10.2527/jas2015-0064

Cervantes-Pahm, S. K., Y. Liu, and H. H. Stein. 2014. Comparative digestibility of energy and nutrients and fermentability of dietary fiber in eight cereal grains fed to pigs. J. Sci. Food Agric. 94:841-849. doi:10.1002/jsfa.6405

de Vries, S., A. M. Pustjens, H. A. Schols, W. H. Hendriks, and W. J. J. Gerrits. 2012. Improving digestive utilization of fiber-rich feedstuffs in pigs and poultry by processing and enzyme technologies: A review. Anim. Feed Sci. Technol. 178:123-138. doi:10.1016/j.anifeedsci.2012.10.004

Dhital, S., L. Dabit, B. Zhang, B. Flanagan, and A. K. Shrestha. 2015. *In vitro* digestibility and physicochemical properties of milled rice. Food Chem. 172:757-765. doi:10.1016/j.foodchem.2014.09.138

Ebringerová, A. 2006. Structural diversity and application potential of hemicelluloses. Macromolecular Symposia. 232:1-12. doi:10.1002/masy.200551401

Englyst, H. N., M. E. Quigley, and G. J. Hudson. 1994. Determination of dietary fibre as non-starch polysaccharides with gas-liquid chromatographic, high-performance liquid chromatographic or spectrophotometric measurement of constituent sugars. Analyst. 119:1497-1509. doi:10.1039/AN9941901497

Hossain, M. E., S. Sultaba, S. M. S. Shahriar, and M. M. Khatun. 2012. Nutritive value of rice polish. Online J. Anim. Feed Res. 3:235-239.

Huang, G., W. C. Sauer, J. He, J. Hwangbo, and X. Wang. 2003. The nutritive value of hulled and hulless barley for growing pigs. 1. Determination of energy and protein digestibility with the *in vivo* and *in vitro* method. J. Anim. Feed Sci. 12:759-769 journal article. doi:10.22358/jafs/67771/2003

Jaworski, N. W., H. N. Lærke, K. E. Bach Knudsen, and H. H. Stein. 2015. Carbohydrate composition and *in vitro* digestibility of dry matter and nonstarch polysaccharides in corn, sorghum, and wheat and coproducts from these grains. J. Anim. Sci. 93:1103-1113. doi:10.2527/jas.2014-8147

Juliano, B. O. 1983. Lipid in rice and rice processing. In: P. J. Barnes, editor, Lipids in cereal technology. Academic Press, London. p. 305-330.

Kahlon, T. S., R. M. Saunders, F. I. Chow, M. M. Chiu, and A. A. Betschart. 1990. Influence of rice bran, oat bran, and wheat bran on cholesterol and triglycerides in hamsters. Cereal Chem. 67:439-443.

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Ohtsubo, K., K. Suzuki, Y. Yasui, and T. Kasumi. 2005. Bio-functional components in the processed pre-germinated brown rice by a twin-screw extruder. J. Food Compost. Anal. 18:303-316. doi:10.1016/j.jfca.2004.10.003

Reed, M. O., Y. Ai, J. L. Leutcher, and J. Jane. 2013. Effects of cooking methods and starch structures on starch hydrolysis rates of rice. J. Food Sci. 78:H1076-H1081. doi:10.1111/1750-3841.12165

Regmi, P. R., N. S. Ferguson, and R. T. Zijlstra. 2009. *In vitro* digestibility techniques to predict apparent total tract energy digestibility of wheat in grower pigs. J. Anim. Sci. 87:3620-3629. doi:10.2527/jas.2008-1739

Regmi, P. R., W. C. Sauer, and R. T. Zijlstra. 2008. Prediction of *in vivo* apparent total tract energy digestibility of barley in grower pigs using an *in vitro* digestibility technique. J. Anim. Sci. 86:2619-2626. doi:10.2527/jas.2008-1058

Rosniyana, A., M. A. Hashifah, and S. A. Shariffah-Norin. 2009. Nutritional content and storage stability of stabilised rice bran – MR 220. J. Trop. Agric. Food Sc. 37:163-170.

Rosniyana, A., M. A. Hashifah, and S. A. Sharuffah-Norin. 2007. The physico-chemical properties and nutritional composition of rice bran produced at different milling degrees of rice. J. Trop. Agric. Food Sc. 35:99-105.

Saunders, R. M. 1985. Rice bran: Composition and potential food uses. Food Rev. Intl. 1:465-495. doi:10.1080/87559128509540780

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Selvendran, R. R., B. J. H. Stevens, and M. S. Du Pont. 1988. Dietary fiber: Chemistry, analysis, and properties. In: C. O. Chichester, E. M. Mrak and B. S. Schweigert, editors, Adv. Food Res. No. 31. Academic Press. p. 117-209. doi:10.1016/S0065-2628(08)60167-6

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Theander, O., and P. Åman. 1979. Studies on dietary fibre. 1. Analysis and chemical characterization of water-soluble and water-insoluble dietary fibres. Swed. J. Agric. Res. 9:97-106.

Theander, O., and E. A. Westerlund. 1986. Studies on dietary fiber. 3. Improved procedures for analysis of dietary fiber. J. Agric. Food Chem. 34:330-336. doi:10.1021/jf00068a045

Zhang, W., D. Li, L. Liu, J. Zang, Q. Duan, W. Yang, and L. Zhang. 2013. The effects of dietary fiber level on nutrient digestibility in growing pigs. J. Anim. Sci. Biotechnol. 4:1-7 journal article. doi:10.1186/2049-1891-4-17

# CHAPTER 4: AMINO ACID DIGESTIBILITY IN RICE COPRODUCTS FED TO GROWING PIGS

**ABSTRACT:** The objective of this experiment was to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA in 2 sources of full fat rice bran (FFRB), 1 source of defatted rice bran (DFRB), and in broken rice when fed to growing pigs. Seven finishing pigs with an average initial BW of 70.1 ± 6.3 kg were used. Pigs were surgically fitted with a T-cannula in the distal ileum. Animals were allotted to a 7 × 7 Latin square design with 7 diets and 7 periods. Seven diets were prepared, but 1 diet was unrelated to this experiment; therefore only 6 diets were used in this experiment. One diet was based on bakery meal, and 1 diet was based on broken rice. Three additional diets were formulated by mixing bakery meal and each of the 2 sources of FFRB (FFRB-1 and FFRB-2) or DFRB. The last diet was an N-free that was used to estimate the basal ileal endogenous losses of CP and AA. The AID of CP and AA in bakery meal and broken rice was calculated using the direct procedure, but the AID of CP and AA in both sources of FFRB and in DFRB, was calculated using the difference procedure. The AID and SID of CP and AA in broken rice were greater ($P < 0.05$) than the AID and SID of CP and AA in all other ingredients. The AID of Leu, Lys, Cys, and Ser in FFRB-1was greater ($P < 0.05$) than in FFRB-2, but no differences were observed for CP or other AA between these 2 ingredients. The AID of CP and AA was greater ($P < 0.05$) in both sources of FFRB than in DFRB except for Arg, Lys, Phe, Thr, Trp, Asp, Glu, and Cys. The AID of the average of indispensable AA was greater ($P < 0.05$) for broken rice, and less ($P < 0.05$) for DFRB, than for the 2 sources of FFRB. The SID of CP, His, Lys, Met, Asp, and Gly was greater ($P < 0.05$) in FFRB-1 than in FFRB-2, but the SID of all other AA was not different between the 2 sources of FFRB. The SID of AA was greater ($P < 0.05$) in both sources of FFRB

than in DFRB, except for Lys, Thr, Trp, Val, and Gly. The SID for the average of indispensable, dispensable AA, and total AA in broken rice was greater than in the other ingredients, but there were no differences between the 2 the sources of FFRB, and the average SID of AA in DFRB was less ($P < 0.05$) than in the other ingredients. The concentrations of SID CP and indispensable AA in DFRB were greater ($P < 0.05$) than in all other ingredients. There were no differences in concentrations of SID CP and AA between the 2 sources of FFRB except for Lys, Trp, and Ala, in which the concentrations were greater ($P < 0.05$) in FFRB-1, and Ile and Leu, in which the values were greater ($P < 0.05$) in FFRB-2. There were no differences in the concentration of all SID dispensable AA between the 2 sources of FFRB and DFRB. In conclusion, the AID and SID of CP and AA in broken rice was greater than in FFRB and DFRB, but the greater concentration of CP and AA in FFRB and DFRB result in greater concentrations of SID CP and AA in FFRB and DFRB than in broken rice.

## INTRODUCTION

Rice is the main source of carbohydrates for humans worldwide, but its use in pig feeding is limited because of relatively high price and limited availability (Vicente et al., 2008). The global production of rice is approximately 756 million tonnes (FAO, 2017), and the majority is used for production of polished rice. When rice is milled, 65 to 72% of the grain is recovered as polished rice, which is used for human consumption, but the remaining 28 to 35% are coproducts, which may be used in animal feeding. The coproducts include rice hulls, rice bran, and broken rice (Singh et al., 2014). Rice hulls constitute about 20% of the weight of the rough rice, but contain large quantities of lignin and silica and have low nutritional value (Serna-Saldivar, 2010). Broken rice or brewers rice, are kernels that are 25% or less than the original

length of the grain and are used for brewing or other fermented products or for animal feeding (USA-Rice-Federation, 2011). Broken rice is high in starch, low in fiber, fat, and CP, and has been used in diets for nursery pigs without detrimental effects on growth performance, but improved intestinal health has been reported (Vicente et al., 2008). Rice bran is the brown layer of dehulled rice that includes several sub layers within the pericarp and aleurone layers. Commonly, rice bran is categorized as full fat rice bran (**FFRB**) or defatted rice bran (**DFRB**) that contains approximately 14.0% and 3.5% ether extract, respectively. The concentration of CP ranges from 15% in FFRB to 17.3% in DFRB (NRC, 2012). Different procedures used in rice milling may negatively affect the digestibility and availability of AA and CP by growing pigs (Kaufmann et al., 2005), but there is limited information about the ileal digestibility of AA in rice coproducts. Therefore, the objective of this research was to determine the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of CP and AA in 2 sources of (FFRB), 1 source of DFRB, and in broken rice when fed to growing pigs.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Four rice coproducts were evaluated: 2 sources of FFRB, 1 source of DFRB, and broken rice (Table 4.1).

### *Animals and Housing*

Seven finishing pigs that were the offspring of F-25 females that were mated to G-Performer males (Genetiporc, Alexandria, MN) with an average initial BW of 70.1 ± 6.3 kg were used. Pigs were surgically fitted with a T-cannula in the distal ileum (Stein et al., 1998) when they had a BW of approximately 25 kg, and all pigs had been used in another experiment before

being assigned to this experiment. Animals were allotted to a 7 × 7 Latin square design with 7 diets and 7 periods. Pigs were housed in individual pens (1.2 m ×1.5 m) in an environmentally controlled room. Pens had smooth, plastic-coated sides, and a fully slatted tribar metal floor; a feeder and a nipple drinker were installed in each pen. Pig weights were recorded at the beginning of each period.

***Diets and Feeding***

Seven diets were prepared (Table 4.2), but 1 diet was unrelated to this experiment; therefore, only 6 diets were used in this experiment. One diet was based on bakery meal and 1 diet was based on broken rice. Three additional diets were formulated by mixing bakery meal and each of the 2 sources of FFRB (**FFRB-1** and **FFRB-2**) or DFRB. The last diet was an N-free that was used to estimate the basal ileal endogenous losses of CP and AA. All diets contained vitamins and minerals in concentrations that exceeded the requirements for growing pigs (NRC, 2012). Chromic oxide (0.4%) was added to all diets as an indigestible marker.

Because all diets contained AA in quantities below the requirements for growing pigs (NRC, 2012), an AA mixture was prepared (Table 4.3). During the initial 5 d of each period, 150g of this mixture was added to the daily fed to each pig.

Pigs were fed twice daily at a level of 3 times the maintenance energy requirement (197 kcal/kg $BW^{0.60}$; NRC, 2012); the feed allowance for each pig was adjusted at the start of each period. Water was available at all times throughout the experiment.

***Sample Collection***

Each period consisted of 5 d of adaptation to the diets followed by 2 d of ileal digesta collection. Ileal digesta collection was initiated at 0800 and ceased at 1600 h. For collection of samples, a plastic bag of 232 mL was attached to the cannula barrel using a cable tie. Bags were

removed when they were filled or every 30 min and stored at -20°C to prevent bacterial degradation of AA. At the conclusion of each period, ileal samples were thawed at room temperature and mixed within animal and a sub-sample was collected. Digesta samples were lyophilized and finely ground prior to chemical analysis.

***Chemical Analyses***

Ingredients were analyzed in duplicate for DM (Method 930.05; AOAC Int., 2007), ash (Method 942.05, AOAC Int., 2007), CP (Method 990.03; AOAC Int., 2007), acid hydrolyzed ether extract (**AEE**) determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN; Table 4.1). Ingredients also were analyzed in duplicate for GE using an adiabatic bomb calorimeter (Model 6300; Parr Instruments, Moline, IL), ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), ADL [Method 973.18 (A-D); AOAC Int., 2007], starch (Method 979.10; AOAC Int., 2007) Ca, P, Mn, Se, Zn, Cu, and Fe (Method 985.01; AOAC Int., 2007)], and AA [Method 982.30 E (a, b, c); AOAC Int., 2007], respectively. All diet and digesta samples were analyzed in duplicate for DM, CP, and AA as explained for the ingredients. All diet and digesta samples were also analyzed in duplicate for chromium (Method 990.08; AOAC Int., 2007).

***Calculations and Statistical Analysis***

Values for AID, basal ileal, endogenous losses, and SID of CP and AA were calculated for all diets except the N-free diet (Stein et al., 2007). The AID of CP and AA in both sources of FFRB, and DFRB, was calculated using the difference procedure (Mosenthin et al., 2007), whereas the AID of CP and AA in bakery meal and broken rice were calculated using the

direct procedure. Data from the bakery meal diet were used to calculate the contribution of AA from bakery meal to the diets containing FFRB or DFRB.

Outliers and homogeneity of the variances among treatments were tested using the UNIVARIATE procedure (Version 9.4: SAS Institute, Inc. Cary, NC). The Mixed procedure of SAS was used to analyze all data. Diet was included in the model as a fixed effect and pig and period were included as random effects. The LSMeans option was used to calculate mean values for each diet and the PDIFF option was used to separate means if they were different. The pig was the experimental unit for all analyses. An alpha level of 0.05 was used to consider significance among dietary treatments.

## RESULTS

### *AID and SID of CP and AA in Diets*

The AID and SID of CP and AA in the broken rice diet were greater ($P < 0.05$) than in the other diets, whereas values for AID and SID of CP and most AA in the DFRB diet were less ($P < 0.05$; Tables 4.4 and 4.5). There were no differences in SID of CP and AA between the 2 diets containing FFRB except for Lys, Trp, Asp, and Cys. Values for AID and SID of CP and AA in the bakery meal diet were less ($P < 0.05$) than the broken rice diet, but greater ($P < 0.05$) for most AA than for the diets containing FFRB or DFRB.

### *AID and SID of CP and AA in Ingredients*

The AID and SID of CP and AA in broken rice were greater ($P < 0.05$) than the AID and SID of CP and AA in all other ingredients (Tables 4.6 and 4.7). The AID of Leu, Lys, Cys, and Ser in FFRB-1was greater ($P < 0.05$) than in FFRB-2, but no differences were observed for CP or other AA between these 2 ingredients. The AID of CP and AA was greater ($P < 0.05$) in both

sources of FFRB than in DFRB except for Arg, Lys, Phe, Thr, Trp, Asp, Glu, and Cys. The AID of the average of indispensable AA was greater ($P < 0.05$) for broken rice and less ($P < 0.05$) for DFRB, than for FFRB.

The SID of CP, His, Lys, Met, Asp, and Gly was greater ($P < 0.05$) in FFRB-1 than in FFRB-2, but the SID of the other AA was not different. The SID of AA was greater ($P < 0.05$) in both sources of FFRB than in DFRB, except for Lys, Thr, Trp, Val, and Gly. The SID for the average of indispensable, dispensable, and total AA in broken rice was greater ($P < 0.05$) than in the other ingredients but there were no differences between the 2 sources of FFRB. The average of SID of AA in DFRB was less ($P < 0.05$) than in all other ingredients.

The concentrations of SID CP and AA in DFRB were greater ($P < 0.05$) than in all other ingredients and less ($P < 0.05$) in broken rice than in other ingredients (Table 4.8). The concentrations of SID CP and AA in the 2 sources of FFRB were not different except for His, Lys, Trp, and Ala, for which the concentration was greater ($P < 0.05$) in FFRB-1, and Ile and Leu and valine, for which values were greater ($P < 0.05$) in FFRB-2.

## DISCUSSION

In this experiment, bakery meal was used in diets with FFRB and DFRB to stimulate intake of the diets. The concentrations of GE, AEE, ADF, starch, CP, Ca, and P in bakery meal were within the range of values previously reported (Slominski et al., 2004; Almeida et al., 2011; NRC, 2012; Rojas et al., 2013). In contrast, the concentration of AA in bakery meal was greater and the concentration of NDF was less than reported by Almeida et al. (2011). Bakery meal is a mixture of inedible products from the bakery and confectionary industries, and its composition may be variable and reflects the source of by-products that were used and the manufacturing

process. Bakery meal is an ingredient that is known for its good palatability in pigs diets (Slominski et al., 2004), which is the reason it was used in this experiment. The AID and SID values for AA observed for bakery meal in this experiment were greater than reported by Almeida et al. (2011), which likely is a result of the reduced values for NDF in the bakery meal used in the current experiment.

The composition of the broken rice used in this experiment was in agreement with previous values for polished white rice and broken (NRC, 2012; Brestenský et al., 2013; Cervantes-Pahm et al., 2014). The AID and SID of CP and AA in the broken rice used in this experiment are greater than values reported by Yin et al. (2008) and Cervantes-Pahm et al. (2014), but less than values reported by Brestenský et al. (2013). Compared with other cereals grains used commonly in diets for pigs, such as yellow dent maize, sorghum, or wheat, polished rice has the greatest AID and SID of AA and CP (Cervantes-Pahm et al., 2014), which is likely due to the low concentration of fiber and anti-nutritional factors (Brestenský et al., 2013). The reduced concentration of fiber in broken rice compared with FFRB and DFRB, likely reduce the specific endogenous losses of CP and AA (Souffrant, 2001). Likewise, the nutritional quality of rice protein is positively influenced by the high concentration of glutein, which has a greater biological value than that of prolamins fraction, which are present in other cereals (Shewry, 2007).

The nutrient composition of the 2 sources of FFRB used in this experiment was similar, except for the concentration of AEE and starch, which were greater in FFRB-2 than in FFRB-1. This is likely the reason for the increased GE in FFRB-2 compared with FFRB-1. The concentration of AEE, CP, and AA in the FFRB used in this experiment were in agreement with values reported by NRC (2012), but less than observed by Kaufmann et al. (2005). However, the

concentrations of NDF and ADF in both sources were less than reported in the literature (Sauvant et al., 2004; NRC, 2012), which indicates that less of the pericarp or more endosperm may have been included in the 2 sources of FFRB used in this experiment compared with the sources used previously.

The reduced concentration of fiber is likely the reason for the greater values AID of CP and AA for both sources of FFRB observed in this experiment compared with values reported by Sauvant et al. (2004) and NRC (2012). The concentration of acid hydrolyzed ether extract and NDF in DFRB used in this experiment were also less than previous values whereas the concentration of CP and AA were within the range of reported values (Sauvant et al., 2004; NRC, 2012). However, the values for AID of CP and AA in DFRB were greater than previously reported (Kaufmann et al., 2005; NRC, 2012), which likely is a consequence of the reduced concentration of NDF in the source of DFRB used in this experiment, because increased concentration of NDF reduces the digestibility of AA (Mosenthin et al., 1994).

The observation that the values for the AID and SID of most AA in both sources of FFRB were greater than in DFRB is in agreement with by Kaufmann et al. (2005), and may be a result of the greater concentration of fat in FFRB compared with DFRB, because there is a positive relationship between the concentration of fat in rice bran and the AID of AA (Kaufmann et al., 2005). Addition of oil to diets fed to pigs also increases the digestibility of AA in other sources of protein (Cervantes-Pahm and Stein, 2008). In addition, the increased concentration of NDF in DFRB used in this experiment likely also contributed to a reduce AID and SID of AA,

The concentration of SID CP and most AA in the broken rice evaluated in this experiment were less than reported for polished white rice (Cervantes-Pahm et al., 2014). However, the concentration of SID CP and AA calculated for the 2 sources of FFRB and DFRB

were greater than the values reported for dehulled barley and similar to values reported for dehulled oats (Cervantes-Pahm et al., 2014). As a consequence, FFRB and DFRB will provide more CP and AA for protein synthesis, compared with other cereal grains commonly fed to pigs.

***Conclusions***

The AID and SID of CP and AA in broken rice was greater than in FFRB and DFRB, but because of the its lower concentration of CP and AA, the concentration of SID CP and AA is less in broken rice than in the other ingredients evaluated in this experiment. The greater concentration of AEE in sources of FFRB improved the AID and SID of CP and AA compared with DFRB. The reduced concentration of NDF in FFRB and DFRB used in this experiment compared with qualities used in previous experiments likely contributed to greater AID and SID of CP and AA. However, experiments to determine the quality and type of fiber in FFRB and DFRB need be conducted to confirm the effects of fiber on AID and SID of CP and AA in growing pigs. The greater concentration of CP and AA and the greater SID of CP and AA in FFRB and DFRB result in greater concentration of SID CP and AA, than the concentration of SID CP and AA reported previously for other cereal grains.

## TABLES

**Table 4.1**. Analyzed nutrient composition (as-fed basis) of bakery meal, broken rice, full fat rice bran (FFRB-1 and FFRB-2), and defatted rice bran (DFRB)

| Item, % | Bakery meal | Broken rice | FFRB-1 | FFRB-2 | DFRB |
|---|---|---|---|---|---|
| GE, kcal/kg | 4,251 | 4,399 | 4,554 | 5,044 | 4,348 |
| DM, % | 89.29 | 88.13 | 95.11 | 96.20 | 90.96 |
| CP, % | 14.03 | 7.67 | 14.30 | 15.31 | 17.08 |
| AEE[1], % | 7.60 | 0.85 | 17.06 | 19.28 | 1.09 |
| Ash, % | 3.55 | 1.25 | 8.69 | 8.04 | 11.97 |
| Starch, % | 43.53 | 76.83 | 25.58 | 29.58 | 28.30 |
| ADF, % | 4.40 | 0.46 | 9.42 | 9.09 | 11.98 |
| NDF, % | 10.72 | 0.61 | 14.76 | 14.13 | 19.27 |
| Lignin, % | 1.20 | 0.35 | 3.01 | 3.51 | 4.32 |
| Minerals | | | | | |
| Ca, % | 0.14 | 0.01 | 0.04 | 0.04 | 0.11 |
| P, % | 0.32 | 0.11 | 1.76 | 1.79 | 2.58 |
| Mn, mg/kg | 20.00 | 11.00 | 195.00 | 165.00 | 2.95 |
| Zn, mg/kg | 28.00 | 17.00 | 63.00 | 60.00 | 92.00 |
| Cu, mg/kg | 7.00 | 3.00 | 7.00 | 8.00 | 13.00 |
| Fe, mg/kg | 78.00 | 30.00 | 81.00 | 92.00 | 173.00 |
| Indispensable AA, % | | | | | |
| Arg | 0.60 | 0.52 | 1.11 | 1.18 | 1.21 |
| His | 0.31 | 0.16 | 0.38 | 0.40 | 0.42 |
| Ile | 0.50 | 0.29 | 0.47 | 0.51 | 0.59 |
| Leu | 1.05 | 0.59 | 0.94 | 1.03 | 1.18 |
| Lys | 0.41 | 0.28 | 0.65 | 0.65 | 0.79 |
| Met | 0.20 | 0.20 | 0.27 | 0.29 | 0.33 |
| Phe | 0.61 | 0.36 | 0.57 | 0.62 | 0.71 |
| Thr | 0.44 | 0.25 | 0.49 | 0.54 | 0.63 |

**Table 4.1**. Cont.

| Item, % | Bakery meal | Broken rice | FFRB-1 | FFRB-2 | DFRB |
|---|---|---|---|---|---|
| Trp | 0.16 | 0.07 | 0.16 | 0.15 | 0.18 |
| Val | 0.62 | 0.40 | 0.72 | 0.79 | 0.91 |
| Total | 4.90 | 3.12 | 5.76 | 6.16 | 6.95 |
| Dispensable AA, % | | | | | |
| Ala | 0.61 | 0.40 | 0.82 | 0.87 | 1.03 |
| Asp | 0.76 | 0.63 | 1.15 | 1.26 | 1.49 |
| Cys | 0.27 | 0.15 | 0.28 | 0.30 | 0.32 |
| Glu | 3.22 | 1.23 | 1.76 | 1.86 | 2.09 |
| Gly | 0.55 | 0.32 | 0.73 | 0.78 | 0.89 |
| Pro | 1.18 | 0.35 | 0.58 | 0.62 | 0.78 |
| Ser | 0.56 | 0.35 | 0.53 | 0.57 | 0.63 |
| Tyr | 0.35 | 0.16 | 0.35 | 0.40 | 0.47 |
| Total | 7.50 | 3.59 | 6.20 | 6.66 | 7.70 |
| Lys:CP ratio[2] (%) | 2.92 | 3.65 | 4.54 | 4.24 | 4.62 |

[1]AEE = acid hydrolyzed ether extract.

[2] Lys:CP = ratio: Calculated by expressing the concentration of Lys in each ingredient as a percentage of the concentration of CP (Stein et al., 2009).

**Table 4.2**. Ingredient and analyzed composition of experimental diets containing bakery meal, broken rice, full fat rice bran (FFRB-1and FFRB-2), defatted rice bran (DFRB), and the N-free diet

| Item | Bakery meal | Broken rice | FFRB-1 | FFRB-2 | DFRB | N-Free |
|---|---|---|---|---|---|---|
| Ingredient, % | | | | | | |
| Bakery meal | 93.06 | - | 37.65 | 37.65 | 33.52 | - |
| Rice coproducts | - | 92.98 | 50.00 | 50.00 | 50.00 | - |
| Cornstarch | - | - | - | - | - | 67.24 |
| Sucrose | - | - | 10.00 | 10.00 | 10.00 | 20.00 |
| Soybean oil | 4.00 | 4.00 | - | - | 4.00 | 4.00 |
| Solka floc[1] | - | - | - | - | - | 5.00 |
| Dicalcium phosphate | 1.75 | 1.25 | 0.15 | 0.15 | 0.06 | 1.72 |
| Limestone | 0.09 | 0.67 | 1.10 | 1.10 | 1.32 | 0.44 |
| Chromic oxide | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Magnesium oxide | - | - | - | - | - | 0.10 |
| Potassium carbonate | - | - | - | - | - | 0.40 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | | | | |
| GE, kcal/kg | 4,210 | 4,180 | 4,199 | 4,227 | 4,172 | 4,191 |
| DM, % | 92.12 | 89.32 | 94.42 | 94.43 | 92.17 | 91.79 |
| CP, % | 14.03 | 6.98 | 12.24 | 13.08 | 13.04 | 0.26 |
| Ash, % | 5.7 | 2.85 | 7.79 | 6.99 | 8.98 | 2.55 |
| AEE[3], % | 11.53 | 5.29 | 12.14 | 12.00 | 6.26 | 4.62 |
| Indispensable AA, % | | | | | | |
| Arg | 0.59 | 0.56 | 0.86 | 0.86 | 0.86 | <0.01 |
| His | 0.31 | 0.16 | 0.33 | 0.33 | 0.33 | <0.01 |
| Ile | 0.47 | 0.28 | 0.42 | 0.44 | 0.46 | <0.01 |

**Table 4.2** Cont.

| Item | Bakery meal | Broken rice | FFRB-1 | FFRB-2 | DDRB | N-Free |
|---|---|---|---|---|---|---|
| Leu | 1.00 | 0.56 | 0.86 | 0.90 | 0.94 | 0.03 |
| Lys | 0.38 | 0.25 | 0.50 | 0.48 | 0.53 | <0.02 |
| Met | 0.20 | 0.19 | 0.22 | 0.22 | 0.23 | <0.01 |
| Phe | 0.60 | 0.36 | 0.53 | 0.56 | 0.58 | 0.01 |
| Thr | 0.43 | 0.24 | 0.43 | 0.44 | 0.47 | <0.01 |
| Trp | 0.14 | 0.19 | 0.15 | 0.15 | 0.15 | <0.14 |
| Val | 0.58 | 0.40 | 0.60 | 0.63 | 0.66 | 0.01 |
| Total indispensable AA | 4.54 | 3.00 | 4.74 | 4.85 | 5.06 | 0.05 |
| Dispensable AA, % | | | | | | |
| Ala | 0.57 | 0.38 | 0.65 | 0.67 | 0.73 | 0.02 |
| Asp | 0.73 | 0.62 | 0.92 | 0.95 | 1.05 | 0.01 |
| Cys | 0.27 | 0.16 | 0.26 | 0.26 | 0.27 | 0.01 |
| Glu | 3.31 | 1.18 | 2.18 | 2.25 | 2.17 | 0.03 |
| Gly | 0.51 | 0.31 | 0.58 | 0.61 | 0.63 | <0.01 |
| Pro | 1.17 | 0.31 | 0.73 | 0.76 | 0.75 | 0.01 |
| Ser | 0.59 | 0.33 | 0.54 | 0.56 | 0.58 | <0.01 |
| Total dispensable AA | 7.15 | 3.29 | 5.86 | 6.05 | 6.18 | 0.09 |

[1]Fiber Sales and Development Corp., Urbana, OH.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin $D_3$ as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrocloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron

**Table 4.2.** Cont.

sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]AEE = acid hydrolyzed ether extract.

**Table 4.3.** Amino acid mixture[1]

| Amino acid | Inclusion, %, as fed |
|---|---|
| Gly | 58.0 |
| L-Lys HCl | 16.3 |
| DL-Met | 3.8 |
| L-Thr | 6.2 |
| L-Trp | 2.2 |
| L-Ile | 4.7 |
| L-Val | 4.8 |
| L-His | 1.1 |
| L-Phe | 2.9 |
| Total | 100 |

[1]One hundred fifty grams of this mixture was fed daily to each pig during the adaptation period.

**Table 4.4**. Apparent ileal digestibility (%) of CP and AA in diets containing bakery meal, broken rice, full fat rice bran (FFRB-1and FFRB-2), or defatted rice bran (DFRB)[1]

| Item | Bakery meal | Broken rice | FFRB-1 | FFRB-2 | DFFB | SEM | *P*-value |
|---|---|---|---|---|---|---|---|
| CP, % | 78.2[b] | 82.0[a] | 75.7[c] | 73.7[cd] | 73.0[d] | 0.90 | < 0.001 |
| Indispensable AA, % | | | | | | | |
| Arg | 83.1[d] | 90.6[a] | 87.5[b] | 86.3b[c] | 85.2[c] | 0.72 | < 0.001 |
| His | 82.5b[c] | 87.8[a] | 84.0[b] | 82.3[c] | 80.2[d] | 0.66 | < 0.001 |
| Ile | 83.2[b] | 86.4[a] | 80.4[c] | 80.2[c] | 77.3[d] | 0.68 | < 0.001 |
| Leu | 87.0[b] | 88.6[a] | 82.5[c] | 82.4[c] | 79.0[d] | 0.63 | < 0.001 |
| Lys | 67.7[d] | 85.2[a] | 79.0[b] | 75.0[c] | 75.5[c] | 0.91 | < 0.001 |
| Met | 84.5[b] | 89.7[a] | 84.4[b] | 83.1[b] | 78.6[c] | 0.63 | < 0.001 |
| Phe | 84.8[a] | 85.4[a] | 78.8[b] | 77.5[b] | 76.8[b] | 1.30 | < 0.001 |
| Thr | 72.2[b] | 79.2[a] | 71.1[b] | 71.3[b] | 70.1[b] | 1.00 | < 0.001 |
| Trp | 75.8[bc] | 83.7[a] | 77.1[b] | 74.7[c] | 74.3[c] | 0.95 | < 0.001 |
| Val | 80.8[b] | 87.6[a] | 80.0[b] | 79.9[b] | 76.9[c] | 0.75 | < 0.001 |
| Mean | 81.4[b] | 87.1[a] | 81.2[b] | 80.5[b] | 78.1[c] | 0.69 | < 0.001 |
| Dispensable AA, % | | | | | | | |
| Ala | 77.1[c] | 84.6[a] | 78.9[b] | 78.1b[c] | 76.5[c] | 0.75 | < 0.001 |
| Asp | 71.2[d] | 86.1[a] | 76[b] | 73.7[c] | 72.6[cd] | 0.79 | < 0.001 |
| Cys | 79.4[b] | 86.1[a] | 77.3[b] | 74.2[c] | 73.2[c] | 1.00 | < 0.001 |
| Glu | 91.1[a] | 89.0[b] | 87.9[c] | 87.3[c] | 84.1[d] | 0.50 | < 0.001 |
| Gly | 65.1[ab] | 69.3[a] | 63.7[ab] | 59.92[b] | 63.2[b] | 2.54 | < 0.001 |
| Pro | 80.9[a] | 54.8[c] | 58.2[bc] | 52.8[bc] | 70.2[ab] | 7.84 | < 0.001 |
| Ser | 79.6[b] | 84.6[a] | 76.9[c] | 76.2[c] | 74.2[d] | 0.72 | < 0.001 |
| Mean[2] | 83.5[b] | 85.2[a] | 80.2[c] | 79.2[c] | 77.3[d] | 0.79 | < 0.001 |
| All AA | 82.6[b] | 86.1[a] | 80.7[c] | 79.9[c] | 77.9[d] | 0.76 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Least square means; n = 7/treatment.

[2]Values for Pro were not included in the calculated mean for dispensable AA.

**Table 4.5**. Standardized ileal digestibility (%) of CP and AA in diets containing bakery meal, broken rice, full fat rice bran (FFRB-1and FFRB-2), or defatted rice bran (DFRB)[1,2]

| Item | Bakery meal | Broken rice | FFRB-1 | FFRB-2 | DFRB | SEM | *P*-value |
|---|---|---|---|---|---|---|---|
| CP, % | 86.6[b] | 97.3[a] | 85.1b[c] | 84.1c | 81.5[d] | 0.88 | < 0.001 |
| Indispensable AA, % | | | | | | | |
| Arg | 91.1[c] | 98.9[a] | 93.1b | 91.9[bc] | 90.7[c] | 0.72 | < 0.001 |
| His | 86.5[bc] | 95.1[a] | 87.8[b] | 86.8[bc] | 83.7[d] | 0.57 | < 0.001 |
| Ile | 87.4[b] | 93.4[a] | 85.2[c] | 84.8[c] | 81.6[d] | 0.68 | < 0.001 |
| Leu | 90.2[b] | 94.2[a] | 86.3c | 86.0c | 82.5[d] | 0.68 | < 0.001 |
| Lys | 74.1[d] | 94.7[a] | 83.9[b] | 80.2[c] | 80.0[c] | 0.91 | < 0.001 |
| Met | 87.7[b] | 93.0[a] | 87.5[bc] | 86.1[c] | 81.8[d] | 0.58 | < 0.001 |
| Phe | 90.4[b] | 94.5[a] | 85.2[c] | 83.6[cd] | 81.7[d] | 1.38 | < 0.001 |
| Thr | 81.5[b] | 95.2[a] | 81.5[b] | 80.5[bc] | 78.5[c] | 0.99 | < 0.001 |
| Trp | 83.0[bc] | 94.5[a] | 83.9[b] | 81.5[c] | 80.9[c] | 0.95 | < 0.001 |
| Val | 85.6[b] | 94.3[a] | 84.7[b] | 84.4[b] | 81.0[c] | 0.71 | < 0.001 |
| Mean | 86.8[b] | 95.1[a] | 86.4[b] | 85.6[b] | 82.9[c] | 0.70 | < 0.001 |
| Dispensable AA, % | | | | | | | |
| Ala | 84.2[bc] | 94.9[a] | 85.2[b] | 84.2[b] | 82.0[c] | 0.752 | < 0.001 |
| Asp | 78.6[c] | 94.5[a] | 81.9[b] | 79.4[c] | 77.7[c] | 0.79 | < 0.001 |
| Cys | 84.4[b] | 94.2[a] | 82.6[b] | 79.4[c] | 78.1[c] | 1.00 | < 0.001 |
| Glu | 93.1[a] | 94.2[a] | 90.8[b] | 90.1[b] | 87.0[c] | 0.55 | < 0.001 |
| Gly | 87.0[b] | 103.9[a] | 83.2[bc] | 78.4[c] | 80.7[c] | 2.54 | < 0.001 |
| Pro | 118.5[b] | 184.4[a] | 122.6[b] | 114.9[b] | 126.7[b] | 10.9 | < 0.001 |
| Ser | 86.4[b] | 96.5[a] | 84.5[c] | 83.5[c] | 81.1[d] | 0.72 | < 0.001 |
| Mean[3] | 88.9[b] | 95.6[a] | 86.5[c] | 85.3[c] | 83.1[d] | 0.797 | < 0.001 |
| All AA | 88.0[b] | 95.3[a] | 86.5[bc] | 85.5[c] | 83.2[d] | 0.768 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Least square means; n = 7/treatment.

[2]Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses. Basal endogenous losses were determined, using pigs fed the N-free diets as (g/kg DMI) CP, 12.26; Arg, 0.51; His, 0.13; Ile, 0.22; Leu, 0.35; Lys,

**Table 4.5.** Cont.

0.26; Met, 0.12; Phe, 0.36; Thr, 0.43; Trp, 0.11; Val 0.30; Ala, 0.43; Asp, 0.58; Cys, 0.14; Glu, 1.27; Gly, 1.19; Pro, 4.99; Ser, 0.43.

[3]Values for Pro were not included in the calculated mean for dispensable AA.

**Table 4.6**. Apparent ileal digestibility (%) of CP and AA in broken rice, 2 sources of full fat (FFRB-1 and FFRB-2), and in defatted rice bran (DFRB)[1]

| Item | Broken rice | FFRB-1 | FFRB-2 | DFRB | SEM | *P*-value |
|---|---|---|---|---|---|---|
| CP, % | 82.0[a] | 73.8[b] | 70.6[b] | 70.0[b] | 1.11 | < 0.001 |
| Indispensable AA, % | | | | | | |
| Arg | 90.6[a] | 88.3[b] | 87.5[bc] | 85.9[c] | 0.80 | < 0.001 |
| His | 87.8[a] | 84.5[b] | 83.3[b] | 79.2[c] | 0.62 | < 0.001 |
| Ile | 86.4[a] | 79.3[b] | 78.0[b] | 74.0[c] | 0.91 | < 0.001 |
| Leu | 88.6[a] | 80.7[b] | 78.7[c] | 74.2[d] | 0.82 | < 0.001 |
| Lys | 85.2[a] | 81.5[b] | 78.6[c] | 78.3[c] | 0.97 | < 0.001 |
| Met | 89.7[a] | 84.6[b] | 82.4[c] | 76.1[d] | 0.65 | < 0.001 |
| Phe | 85.4[a] | 76.5[b] | 74.5[bc] | 72.3[c] | 1.96 | < 0.001 |
| Thr | 79.2[a] | 72.1[b] | 70.7[bc] | 69.0[c] | 1.22 | < 0.001 |
| Trp | 83.7[a] | 77.6[b] | 74.9[bc] | 73.5[c] | 1.19 | < 0.001 |
| Val | 87.6[a] | 79.8[b] | 79.3[b] | 75.1[c] | 0.84 | < 0.001 |
| Mean | 87.1[a] | 81.1[b] | 79.8[b] | 76.5[c] | 0.77 | < 0.001 |
| Dispensable AA, % | | | | | | |
| Ala | 84.6[a] | 79.4[b] | 78.8[b] | 76.3[c] | 0.87 | < 0.001 |
| Asp | 86.1[a] | 77.1[b] | 74.7[c] | 73.1[c] | 0.82 | < 0.001 |
| Cys | 86.1[a] | 76.6[b] | 72.8[c] | 69.6[d] | 1.26 | < 0.001 |
| Glu | 89.0[a] | 85.7[b] | 82.1[c] | 76.7[c] | 0.72 | < 0.001 |
| Gly | 69.3[a] | 63.3[ab] | 61.2[b] | 62.3[a] | 3.24 | < 0.001 |
| Pro | 54.8[a] | 51.6[a] | 46.3[a] | 64.7[a] | 11.02 | 0.305 |
| Ser | 84.6[a] | 75.9[b] | 73.6[c] | 71.0[d] | 0.92 | < 0.001 |
| Mean[2] | 85.2[a] | 78.1[b] | 75.9[c] | 73.4[d] | 1.18 | < 0.001 |
| All AA | 86.1[a] | 80.0[b] | 78.3[b] | 75.3[c] | 1.04 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Least square means; n = 7/treatment.

[2]Values for Pro were not included in the calculated mean for dispensable AA.

**Table 4.7**. Standardized ileal digestibility (%) of CP and AA in broken rice, 2 sources of full fat (FFRB-1 and FFRB-2), and in defatted rice bran (DFRB)[1,2]

| Item | Broken rice | FFRB-1 | FFRB-2 | DFRB | SEM | *P*-value |
|---|---|---|---|---|---|---|
| CP, % | 97.2[a] | 83.9[b] | 79.8[c] | 78.7[c] | 1.25 | < 0.001 |
| Indispensable AA, % | | | | | | |
| Arg | 98.7[a] | 93.8[b] | 92.2[bc] | 90.5[c] | 0.81 | < 0.001 |
| His | 95.1[a] | 88.6[b] | 87.0[c] | 82.7[d] | 0.67 | < 0.001 |
| Ile | 93.2[a] | 83.5[b] | 82.9[b] | 78.4[c] | 1.01 | < 0.001 |
| Leu | 94.1[a] | 83.0[b] | 82.8[b] | 77.7[c] | 0.95 | < 0.001 |
| Lys | 94.5[a] | 88.5[b] | 83.1[c] | 82.3[c] | 1.02 | < 0.001 |
| Met | 92.9[a] | 87.4[b] | 87.2[c] | 78.7[d] | 0.60 | < 0.001 |
| Phe | 94.0[a] | 81.0[b] | 81.1[b] | 78.0[b] | 2.22 | < 0.001 |
| Thr | 95.0[a] | 81.4[b] | 79.8[bc] | 77.0[c] | 1.41 | < 0.001 |
| Trp | 94.3[a] | 84.6[b] | 81.4[bc] | 79.7[c] | 1.35 | < 0.001 |
| Val | 94.2[a] | 84.2[b] | 83.6[b] | 79.0[c] | 0.97 | < 0.001 |
| Mean | 94.9[a] | 86.2[b] | 85.0[b] | 81.7[c] | 1.01 | < 0.001 |
| Dispensable AA, % | | | | | | |
| Ala | 94.7[a] | 85.8[b] | 84.4[b] | 82.3[c] | 1.09 | < 0.001 |
| Asp | 94.4[a] | 83.6[b] | 79.8[c] | 77.4[d] | 0.90 | < 0.001 |
| Cys | 94.2[a] | 81.2[b] | 78.3[b] | 74.5[c] | 1.33 | < 0.001 |
| Glu | 94.1[a] | 87.5[b] | 86.4[b] | 81.8[c] | 1.03 | < 0.001 |
| Gly | 103.6[a] | 81.0[b] | 78.1[bc] | 78.0[b] | 3.40 | < 0.001 |
| Pro | 185.5[a] | 127.0[b] | 126.1[b] | 134.7[b] | 19.01 | < 0.001 |
| Ser | 96.3[a] | 83.0[b] | 81.3[b] | 77.9[c] | 1.06 | < 0.001 |
| Mean[3] | 95.0[a] | 86.2[b] | 85.1[b] | 81.7[c] | 1.30 | < 0.001 |
| All AA | 95.2[a] | 85.3[b] | 84.2[b] | 80.5[c] | 1.14 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Least square means; n = 7/treatment.

**Table 4.7.** Cont.

Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses. Basal endogenous losses were determine using pigs fed the N-free diets as (g/kg DMI) CP, 12.26; Arg, 0.51; His, 0.13; Ile, 0.22; Leu, 0.35; Lys, 0.26; Met, 0.12; Phe, 0.36; Thr, 0.43; Trp, 0.11; Val 0.30; Ala, 0.43; Asp, 0.58; Cys, 0.14; Glu, 1.27; Gly, 1.19; Pro, 4.99; Ser, 0.43.

[3]Values for Pro were not included in the calculated mean for dispensable AA.

**Table 4.8.** Concentrations (g/kg DM) of standardized ileal digestible CP and AA in broken rice, 2 sources of full fat (FFRB-1 and FFRB-2) and in defatted rice bran (DFRB)[1,2]

| Item | Broken rice | FFRB-1 | FFRB-2 | DFRB | SEM | *P*-value |
|---|---|---|---|---|---|---|
| CP, % | 84.6[a] | 126.1[b] | 127.16[b] | 148.3[c] | 2.22 | < 0.001 |
| Indispensable AA | | | | | | |
| Arg | 5.8[d] | 10.0[b] | 11.3[b] | 12.1[a] | 0.97 | < 0.001 |
| His | 1.7[d] | 3.5[c] | 3.6[b] | 3.9[a] | 0.04 | < 0.001 |
| Ile | 3.1[d] | 4.1[c] | 4.4[b] | 5.2[a] | 0.64 | < 0.001 |
| Leu | 6.3[d] | 8.2[c] | 8.7[b] | 10.1[a] | 0.11 | < 0.001 |
| Lys | 3.0[d] | 6.0[b] | 5.5[c] | 7.2[a] | 0.83 | < 0.001 |
| Met | 2.1[c] | 2.5[b] | 2.5[b] | 2.9[a] | 0.04 | < 0.001 |
| Phe | 3.9[c] | 4.9[b] | 5.0[b] | 6.1[a] | 0.13 | < 0.001 |
| Thr | 2.7[c] | [b] | 4.4[b] | 5.4[a] | 0.09 | < 0.001 |
| Trp | 0.7[d] | 1.4[b] | 1.2[c] | 1.6[a] | 0.21 | < 0.001 |
| Val | 4.3[d] | 6.4[c] | 6.8[b] | 8.0[a] | 0.95 | < 0.001 |
| Total indispensable AA | 33.6[c] | 52.2[b] | 53.3[b] | 62.7[a] | 0.70 | <0.002 |
| Dispensable AA | | | | | | |
| Ala | 4.3[d] | 7.4[b] | 5.2[c] | 9.3[a] | 0.11 | < 0.001 |
| Asp | 6.7[c] | 10.1[b] | 10.3[b] | 12.8[a] | 0.14 | < 0.001 |
| Cys | 1.6[c] | 2.4[b] | 2.4[b] | 2.6[a] | 0.05 | < 0.001 |
| Glu | 13.1[c] | 16.2[b] | 16.3[b] | 13.1[a] | 0.25 | < 0.001 |
| Gly | 3.8[c] | 6.2[b] | 6.0[b] | 7.7[a] | 0.28 | < 0.001 |
| Pro | 7.4[b] | 7.7[b] | 7.6[b] | 12.1[a] | 1.07 | < 0.001 |
| Ser | 3.8[c] | 4.6[b] | 4.7[b] | 5.5[a] | 0.07 | < 0.001 |
| Total dispensable AA | 37.2[c] | 51.9[b] | 49.7[b] | 51.9[b] | 0.97 | < 0.001 |
| All AA | 70.8[c] | 104.2[b] | 103.2[b] | 126.1[a] | 1.65 | < 0.001 |

[a-d]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Least square means; n = 7/treatment.

[2]The concentration of SID AA for each ingredient was calculated by multiplying the SID of each AA by the concentration of AA (DM basis) in each rice coproduct.

## LITERATURE CITED


Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 89:4109-4115. doi:10.2527/jas.2011-4143

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

Brestenský, M., S. Nitrayová, P. Patráš, and J. Heger. 2013. Standardized ileal digestibilities of amino acids and nitrogen in rye, barley, soybean meal, malt sprouts, sorghum, wheat germ and broken rice fed to growing pigs. Anim. Feed Sci. Technol. 186:120-124. doi:10.1016/j.anifeedsci.2013.09.006

Cervantes-Pahm, S. K., Y. Liu, and H. H. Stein. 2014. Digestible indispensable amino acid score and digestible amino acids in eight cereal grains. Br. J. Nutr. 111:1663-1672. doi:10.1017/S0007114513004273

Cervantes-Pahm, S. K., and H. H. Stein. 2008. Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs. J. Anim. Sci. 86:1841-1849. doi:10.2527/jas.2007-0721

FAO. 2017. Rice market monitor. 'In, Food and Agriculture Orgranization of the United Nations. Accessed 12 January 2018, http://www.fao.org/3/I8317EN/I8317EN.pdf.

Holst, D. O. 1973. Holst fitration apparatus for Van Soest detergent fiber analysis. J. AOAC. 56:1532-1536.

Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. He, M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. Can. J. Anim. Sci. 85:355-363. doi:10.4141/A04-084

Mosenthin, R., A. J. M. Jansman, and M. Eklund. 2007. Standardization of methods for the determination of ileal amino acid digestibilities in growing pigs. Livest. Sci. 109:276-281. doi:10.1016/j.livsci.2007.01.020

Mosenthin, R., W. C. Sauer, and F. Ahrens. 1994. Dietary pectin's effect on ileal and fecal amino acid digestibility and exocrine pancreatic secretions in growing pigs. J. Nutr. 124:1222-1229.

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Rojas, O. J., Y. Liu, and H. H. Stein. 2013. Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 91:5326-5335. doi:10.2527/jas.2013-6324

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats, Recent advances in animal nutrition. Butterworths, London, UK. p. 77-81.

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Shewry, P. R. 2007. Improving the protein content and composition of cereal grain. J. Cereal Sci. 46:239-250. doi:doi.org/10.1016/j.jcs.2007.06.006

Singh, A., M. Das, S. Bal, and R. Banerjee. 2014. Rice processing. In: R. P. Ferrerira-Guiné and P. M. dois-Reis-Correia, editors, Engineering aspects of cereal and cereal-based proudcts. CRC Press, Boca Raton, FL. p. 71-96.

Slominski, B. A., D. Boros, L. D. Campbell, W. Guenter, and O. Jones. 2004. Wheat by-products in poultry nutrition. Part I. Chemical and nutritive composition of wheat screenings, bakery by-products and wheat mill run. Can. J. Anim. Sci. 84:421-428. doi:10.4141/A03-112

Souffrant, W. B. 2001. Effect of dietary fibre on ileal digestibility and endogenous nitrogen losses in the pig. Anim. Feed Sci. Technol. 90:93-102. doi:10.1016/S0377-8401(01)00199-7

Stein, H. H., S. P. Connot, and C. Pedersen. 2009. energy and nutrient digestibility in four sources of distillers dried grains with solubles produced from corn grown within a narrow geographical area and fed to growing pigs. Asian-Australas. J. Anim. Sci. 22:1016-1025. doi:10.5713/ajas.2009.80484

Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172-180. doi:10.2527/jas.2005-742

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: a technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433-1436. doi:10.2527/1998.7651433x

USA-Rice-Federation. 2011. Rice technical information kit. The complete guide for using U. S. rice as an ingredient. https://www.usarice.com (Acceseed 21 January 2013).

Vicente, B., D. G. Valencia, M. P. Serrano, R. Lázaro, and G. G. Mateos. 2008. Effects of feeding rice and the degree of starch gelatinisation of rice on nutrient digestibility and ileal morphology of young pigs. Br. J. Nutr. 101:1278-1281. doi:10.1017/S0007114508060789

Yin, Y. L., T. J. Li, R. L. Huang, Z. Q. Liu, X. F. Kong, W. Y. Chu, B. E. Tan, D. Deng, P. Kang, and F. G. Yin. 2008. Evaluating standardized ileal digestibility of amino acids in growing pigs. Anim. Feed Sci. Technol. 140:385-401. doi:10.1016/j.anifeedsci.2007.04.005

# CHAPTER 5: EFFECTS OF MICROBIAL XYLANASE ON DIGESTIBILITY OF DRY MATTER, ORGANIC MATTER, NEUTRAL DETERGENT FIBER, AND ENERGY AND THE CONCENTRATIONS OF DIGESTIBLE AND METABOLIZABLE ENERGY IN RICE COPRODUCTS FED TO WEANLING PIGS

**ABSTRACT:** The objective of this experiment was to test the hypothesis that the apparent total tract digestibility (ATTD) of DM, OM, fiber, and GE by weanling pigs and the concentration of DE and ME in full-fat rice bran (FFRB), defatted rice bran (DFRB), brown rice, and broken rice is improved if microbial xylanase is added to the diet. Eighty pigs (initial BW: 13.6 ± 0.8 kg) were allotted to 10 diets with 8 replicate pigs per diet in a randomized complete block design with 2 blocks of 40 pigs. A basal diet based on corn and soybean meal and 4 diets containing corn, soybean meal, and each of the 4 rice coproducts were formulated. The rice coproducts and corn and soybean meal were the only sources of energy in the diets. Five additional diets that were similar to the initial 5 diets with the exception that they also contained 16,000 units of xylanase (Econase XT-25, AB Vista, Marlborough, UK) were also formulated. All diets also contained 1,500 units of microbial phytase (Quantum Blue 5G, AB Vista, Marlborough, UK). The DE and ME and the ATTD of DM, OM, fiber, and GE in diets and ingredients were calculated using the direct method and the difference method, respectively. Results indicated that the concentrations of DE and ME (DM basis) in FFRB and DFRB increased ($P < 0.05$) if xylanase was used. Broken rice had a greater ($P < 0.05$) concentration of DE and ME than FFRB and DFRB if no xylanase was added to the diets, but if xylanase was used, no differences in ME among FFRB, brown rice, and broken rice were observed. The ATTD of DM was greater ($P < 0.05$) in ingredients with xylanase than in ingredients without xylanase and there was a tendency

($P = 0.067$) for the ATTD of OM to be greater if xylanase was used. The ATTD of NDF in FFRB was greater ($P < 0.05$) when xylanase was added than if no xylanase was used, whereas the ATTD of NDF in DFRB was not affected by the addition of xylanase. In conclusion, if no xylanase was used broken rice and brown rice have greater concentrations of DE and ME than FFRB and DFRB, and these values were not increased by microbial xylanase. However, xylanase increased the concentration of DE and ME (DM basis) in FFRB and DFRB.

## INTRODUCTION

Coproducts from the rice milling industry include rice hulls, rice bran, rice mill feed, brown rice, and broken rice (Singh et al., 2014). Rice hulls constitute about 20% of the weight of the paddy rice, but contain large quantities of lignin and silica, and therefore, is not used as a food or feed ingredient (Serna-Saldivar, 2010). Brown rice is the whole rice grain that is left after the hull layer has been removed, leaving the germ and bran layers. Rice bran is the outer brown layer of brown rice and includes several sub layers within the pericarp and aleurone layers. Those layers are removed to produce polished white rice for human consumption and results in production of rice bran, which contains 14 to 25% ether extract. Rice bran may be defatted, which reduces the concentration of ether extract to less than 5%. Broken rice is made up of fragments of grain that are generated during milling of rice, and is used for brewing or other fermented products, for production of rice meal, or for animal feeding (USA-Rice-Federation, 2011).

The concentration of non–starch polysaccharides (**NSP**) in defatted rice bran is 20 to 25% and mainly consists of arabinoxylan and cellulose (Choct, 1997). The high concentration of NSP in rice bran has negative effects on the utilization of nutrients by pigs and may restrict the

inclusion rate in diets for pigs (Noblet and Le Goff, 2001). Addition of microbial xylanase to wheat coproducts, which also have high concentrations of NSP, may improve the digestibility of energy (Nortey et al., 2007; Zijlstra et al., 2010 ), but there is limited information about the effects of adding microbial xylanases to rice coproducts. Therefore, the objective of this experiment was to test the hypothesis that the apparent total tract digestibility (**ATTD**) of DM, OM, fiber, and GE by weanling pigs and the concentration of DE and ME in full fat rice bran (**FFRB**), defatted rice bran (**DFRB**), brown rice, and broken rice is improved if microbial xylanase is added to the diet.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Four rice coproducts were evaluated: FFRB, DFRB, brown rice, and broken rice (Table 5.1). Brown rice and broken rice were sourced from Augason Farms, Salt Lake City, UT, and Consumers Supply Distributing, North Sioux City, SD, respectively. Defatted rice bran and FFRB were sourced from RiceBran Technologies, Scottsdale, AR, and Triple Crown Nutrition Inc., Waynata, MN, respectively.

### *Animals and Housing*

Eighty castrated male pigs that were the offspring of F-25 females mated to G – Performer males (Genetiporc, Alexandria, MN) with an average initial BW of 13.6 ± 0.8 kg were randomly allotted to 10 diets with 8 replicate pigs per diet in a randomized complete block design with 2 blocks of 40 pigs. Pigs were housed individually in metabolism crates that were equipped with a feeder and a nipple drinker, a fully slatted floor, a screen floor, and a urine tray, which allowed for the total collection of feces and urine.

### *Diets and Feeding*

A basal diet based on corn and soybean meal and 4 diets containing corn, soybean meal, and one of the 4 rice coproducts were formulated (Table 5.2). Each rice coproduct was included at 50% in the diets and the ratio between corn and soybean meal remained constant in all diets. The rice coproducts and corn and soybean meal were the only sources of energy in the diets. Five additional diets that were similar to the initial 5 diets with the exception that they also contained 16,000 units of microbial xylanase (Econase XT-25, AB Vista, Marlborough, UK) were also formulated. All diets also contained 1,500 units of microbial phytase (Quantum Blue 5G, AB Vista, Marlborough, UK), and vitamins and minerals were included in concentrations that exceeded the requirements for 11 to 25 kg pigs (NRC, 2012). Feed was provided at a daily level of 3 times the maintenance energy requirement (197 kcal/kg $BW^{0.60}$; NRC, 2012), and pigs were fed equal amounts of feed twice daily at 0800 and 1700 h. Water was available at all times throughout the experiment.

### *Sample Collection*

Pigs were fed experimental diets for 14 d. The initial 7 d were considered an adaptation period to the diet. Fecal markers were fed in the morning meals on d 8 (chromic oxide) and d 13 (ferric oxide) and fecal collection was initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Kong and Adeola, 2014). Feces were collected twice daily and stored at -20ºC as soon as collected. Urine collection started on d 8 at 1700 h and ceased on d 13 at 1700 h. Urine was collected in buckets placed under the metabolism crates that contained a preservative of 50 mL of 6*N* HCL. Buckets were emptied daily, weights of the collected urine were recorded, and 20% of the collected urine was stored a -20º C. At the conclusion of the

experiment, urines samples were thawed and mixed within animal and diet and subsamples were collected for energy analysis.

***Chemical Analyses***

Fecal samples were dried at 65ºC in a forced air oven, ground through a 1 mm screen and urine samples were lyophilized before energy analysis as described by Kim et al. (2009). Samples of ingredients, diets, feces, and urine were analyzed for GE using an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. Samples of ingredients, diets, and feces were analyzed for DM (Method 930.15; AOAC Int., 2007), and ash (Method 942.05; AOAC Int., 2007) and ingredients and diets were analyzed for CP by combustion (Method 990.03; AOAC Int., 2007) using an Elementar Rapid N-cube Protein/Nitrogen Apparatus (Elementar Americas Inc., Mt Laurel, NJ). Ingredients were also analyzed for acid hydrolyzed ether extract (**AEE**) by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.6; AOAC Int., 2007) on an automated analyzer (Soxtec 2050; FOSS North America, Eden Prairie, MN). Concentrations of ADF and NDF were determined in ingredients, diets, and feces using Ankom Technology Method 12 and 13 respectively (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY). Starch was analyzed in corn and all rice coproducts (Method 979.10; AOAC Int., 2007) and all ingredients were analyzed for phytate (Ellis and Morris, 1977) and lignin (Ankom Technology Method 9). Calcium and P were analyzed in all ingredients and diets (Method 985.01; AOAC Int., 2007). Xylanase activity (ELISA Method, AB Vista, Marlborough, UK) and phytase activity (AB Vista Quantum Method) were also analyzed in all diets.

***Calculations and Statistical Analysis***

Organic matter was calculated as the difference between dry matter and ash. Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004). Nonphytate P was calculated as the difference between total P and phytate-bound P. The DE and ME and ATTD of GE, DM, OM, ADF, and NDF in all diets were calculated using the direct procedure (Kong and Adeola, 2014). The contribution of DE and ME from the basal diet to the diets containing rice coproducts was subtracted from the DE and ME that were calculated for these diets and the DE and ME in each rice-coproduct was then calculated by difference (Adeola, 2001). A similar approach was used to calculate the ATTD of GE, DM, OM, ADF, and NDF. Outliers and homogeneity of the variances among treatments was tested using the UNIVARIATE procedure. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a 5 × 2 factorial for diets and a 4 × 2 factorial for ingredients. The fixed effects were the diet or ingredient, xylanase, and the interaction between diet or ingredient and xylanase. Block and replicate were considered random effects. Diet or ingredient and xylanase were the main effects. The least squares mean statement was used to calculate treatment means, and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses. An alpha level of 0.05 was used to assess significance among dietary treatments, and if the *P*-value was > 0.05, but < 0.10, the difference was considered a trend.

## RESULTS

The concentration of CP, Ca, P, NDF, and ADF in all diets was in agreement with expected values. The concentration of xylanase in all diets without added xylanase was not detectable, and in diets with added xylanase, the analyzed concentration ranged between 18,700 and 23,400 units/kg (Table 5.2). All diets contained more than 1,480 units/kg of phytase.

Fecal excretion of GE was reduced ($P < 0.05$) in pigs fed diets containing DFRB with xylanase compared with pigs fed DFRB without xylanase (Table 5.3), but for all other diets, no effect of xylanase on GE excretion was observed (interaction, $P < 0.05$). The DE of diets containing FFRB and DFRB increased ($P < 0.05$) if xylanase was added, but that was not the case for the basal diet and the diets containing brown rice or broken rice (interaction, $P < 0.05$). The ATTD of GE, DM, OM, and ADF, and the ME of diets containing rice coproducts were not affected by addition of xylanase. However, the ATTD of NDF in pigs fed diets containing FFRB was greater ($P < 0.05$) when xylanase was added than if no xylanase was included in the diets, but that was not the case for the other diets (interaction, $P < 0.05$).

The ATTD of DM, was greater ($P < 0.05$) in ingredients with xylanase than in ingredients without xylanase and there was a tendency ($P = 0.067$) for the ATTD of OM to be greater if xylanase was used (Table 5.4). If xylanase was added, the ATTD of NDF in FFRB was greater ($P < 0.05$) than if no xylanase was used, whereas the ATTD of NDF in DFRB was not affected by the addition of xylanase. The ATTD of ADF was not affected by addition of xylanase. The concentration of DE (as-is basis) and the concentration of ME (DM basis) in DFRB were greater ($P < 0.05$) if xylanase was used than if no xylanase was added, and DE and ME were greater in FFRB with xylanase (as-is and DM basis) than in FFRB without xylanase, but xylanase did not affect the concentration of DE or ME in brown rice or broken rice (interaction, $P < 0.05$). The DE and ME of FFRB, brown rice, and broken rice were greater ($P < 0.05$) than the ME of DFRB regardless of the level of xylanase in the diet and DE and ME in broken rice without xylanase were greater ($P < 0.05$) than in FFRB. However, if xylanase was used, no differences in ME among FFRB, brown rice, and broken rice were observed, but the DE was greater ($P < 0.05$) in FFRB than in broken rice.

## DISCUSSION

Rice is primarily used for human consumption, but several coproducts are generated during the milling process and these coproducts may be used for animal feeding. The physical and chemical composition of rice coproducts depends on rice variety, treatment of the grain prior to milling, type of milling system, degree of milling, and the fractionation processes used during milling (Saunders, 1985).

The concentrations of GE, AEE, ADF, starch, CP, Ca, and P in corn and soybean meal were within the range of values previously reported (NRC, 2012). The nutrient composition of the broken rice and brown rice used in this experiment was also in agreement with previous values, except for the concentration of ADF and NDF, which were less than reported values (Robles and Ewan, 1982; Warren and Farrell, 1990; Li et al., 2002; Sauvant et al., 2004; NRC, 2012; Cervantes-Pahm et al., 2014). The content of GE, CP, ash, starch, ADF, Ca, and P in FFRB and DFRB concurs with values reported in the literature (Robles and Ewan, 1982; Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012). However, values for NDF in FFRB and DFRB and the concentration of AEE in DFRB were less than previous values (Maniñgat and Juliano, 1982; Robles and Ewan, 1982; Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012), and the concentration of AEE in FFRB was greater than the values previously reported (Robles and Ewan, 1982; Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012).

The DE and ME that were determined for the basal diet were close to values that can be calculated from the DE and ME in corn and soybean meal (NRC, 2012). In contrast, values for DE and ME in diets containing broken rice without and with xylanase were less than values reported previously (Robles and Ewan, 1982; Sauvant et al., 2004), but the DE and ME in diets containing FFRB without xylanase were in agreement with values reported by Robles and Ewan

(1982). The observation that DE and ME in diets containing broken rice and brown rice were not affected by microbial xylanase, whereas DE and ME of diets containing FFRB and DFRB increased when xylanase was added, likely is a result of the high concentration of starch and low concentration of NSP in diets containing broken rice and brown rice compared with diets containing FFRB and DFRB. Microbial xylanase mainly has activity on the xylan chain in arabinoxylan, which represents 29 to 46% of hemicellulose in FFRB and DFRB (Maniñgat and Juliano, 1982; Shibuya and Iwasaki, 1985; Annison et al., 1995; Paloheimo et al., 2010), whereas broken rice and brown rice contain less than 2% arabinoxylan (Choct, 1997).

The non-starch polysaccharides in corn consist of almost 50% arabinoxylan (Jaworski et al., 2015), but because non-starch polysaccharides contribute only around 8% of the DM in corn, the concentration of arabinoxylan in corn DM is only around 4%. Therefore, with 57.5% corn in the basal diet, the calculated concentration of arabinoxylan in the basal diet was less than 2.5%, which is likely the reason for the lack of a measurable effect of xylanase in the basal diet.

Values for DE and ME in broken rice and brown rice without xylanase concur with reported values (Li et al., 2002; Cervantes-Pahm et al., 2014), but DE and ME of FFRB and DFRB without xylanase were greater than previous values (Sauvant et al., 2004; NRC, 2012), which may be a result of differences in nutrient composition that are observed among sources of FFRB and DFRB.

The increase in DE and ME of FFRB and DFRB that was a result of xylanase addition is likely a result of hydrolysis of the xylan backbone in the arabinoxylan in FFRB and DFRB, which may reduce the viscosity of digesta and increase release of the starch attached to the NSP and increase the digestibility of energy (Kim et al., 2005; Paloheimo et al., 2010). The increase in DE and ME of FFRB concurs with the increase in the ATTD of NDF that was observed if

xylanase was added. However, the increased DE in FFRB that was a result of xylanase addition may also be a result of greater digestibility of fat in diets supplemented with xylanase as a result of increased absorptive capacity in the small intestine and a reduction in the population of bacteria that are able to hydrolyze bile salts (Mathlouthi et al., 2002; Adeola and Cowieson, 2011). Although effects of xylanase were not evident in previous studies, nutrient digestibility depends on the composition of carbohydrates in the diet (Kim et al., 2008). The low arabinose to xylose ratio reported in DFRB and FFRB indicates that the arabinose substitution of the xylose backbone in rice bran arabinoxylan may have been less than in other cereal coproducts (Shibuya and Iwasaki, 1985). This may have increased the effects of the microbial xylanase because the oligosaccharides that are released after action of xylanase are more fermentable if the arabinose substitution is reduced (Bach Knudsen, 2014).

The observation that diets containing broken rice, brown rice, or FFRB contained more DE than the basal diet demonstrates that any of these coproducts may be added to diets fed to pigs without compromising the energy concentration in the diet. Specifically, the high DE and ME in the diet containing FFRB indicates that FFRB is a very good source of energy when fed to weanling pigs. In contrast, the DE in diets containing DFRB is less than in a corn-soybean meal diet even if xylanase is added to the diet, which indicates, that DFRB may not be an ideal feed ingredient in diets fed to weanling pigs.

***Conclusions***

Broken rice and brown rice have greater concentration of DE and ME than FFRB and DFRB, but these values were not affected by microbial xylanase. In contrast, microbial xylanase may increase the concentration of DE and ME in FFRB and DFRB, because of greater concentration of arabinoxylan in those ingredients. There are no difference in ME among FFRB,

broken rice, and brown rice if microbial xylanase is used, but DFRB contains less DE and ME than the other rice coproducts.

## TABLES

**Table 5.1**. Analyzed nutrient composition of soybean meal, corn, brown rice, broken rice, full fat rice bran (FFRB) and defatted rice bran (DFRB)

| Item | Corn | Soybean meal | Brown rice | Broken rice | FFRB | DFRB |
|---|---|---|---|---|---|---|
| GE, kcal/kg | 3,848 | 4,071 | 3,841 | 4,399 | 5,044 | 4,348 |
| DM, % | 83.3 | 88.5 | 88.1 | 88.1 | 96.2 | 91.0 |
| CP, % | 6.64 | 50.3 | 9.51 | 7.67 | 15.3 | 17.1 |
| AEE[1], % | 2.02 | 1.09 | 3.15 | 1.42 | 19.28 | 1.11 |
| Ash, % | 0.83 | 5.56 | 1.22 | 1.25 | 8.04 | 11.97 |
| Starch, % | 69.10 | - | 66.80 | 76.80 | 29.60 | 28.30 |
| ADF, % | 3.11 | 4.99 | 1.37 | 0.46 | 9.09 | 12.0 |
| NDF, % | 8.56 | 6.80 | 2.66 | 0.61 | 14.13 | 19.27 |
| Lignin, % | 0.69 | 0.39 | 0.65 | 0.38 | 3.01 | 4.34 |
| Ca, % | 0.01 | 0.30 | 0.01 | 0.01 | 0.04 | 0.11 |
| P, % | 0.20 | 0.57 | 0.27 | 0.11 | 1.79 | 2.58 |
| Phytate, % | 0.49 | 1.31 | 0.79 | 0.22 | 5.82 | 8.43 |
| Phytate-bound P,[2] % | 0.13 | 0.37 | 0.22 | 0.06 | 1.62 | 2.36 |
| Phytate-bound P, % of total P, | 65.0 | 64.9 | 81.5 | 54.5 | 90.5 | 91.5 |
| Nonphytate P,[3] % | 0.07 | 0.20 | 0.05 | 0.05 | 0.17 | 0.22 |
| Nonphytate-bound P, % of total P | 35.0 | 35.1 | 18.5 | 45.4 | 9.5 | 8.5 |

[1]AEE = acid hydrolyzed ether extract.

[2]Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[3]Nonphytate P was calculated as the difference between total P and phytate-bound P.

**Table 5.2.** Composition of experimental diets containing brown rice, broken rice, full fat rice bran (FFRB), and defatted rice bran (DFRB) without or with microbial xylanase[1]

| Ingredient, % | Basal | Brown rice | Broken rice | FFRB | DFRB |
|---|---|---|---|---|---|
| Corn | 57.50 | 27.35 | 27.35 | 27.50 | 27.50 |
| Soybean meal | 39.00 | 18.9 | 18.90 | 19.00 | 19.00 |
| Rice coproducts | - | 50.00 | 50.00 | 50.00 | 50.00 |
| Limestone | 1.30 | 1.05 | 0.90 | 1.80 | 1.80 |
| Dicalcium phosphate | 0.50 | 1.00 | 1.15 | - | - |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Phytase-xylanase premix[3] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Analyzed composition | | | | | |
| Diets without xylanase | | | | | |
| GE, kcal/kg | 3,797 | 3,755 | 3,746 | 4,355 | 3,724 |
| DM, % | 86.93 | 87.90 | 87.92 | 91.78 | 88.99 |
| CP, % | 21.70 | 15.50 | 15.15 | 18.80 | 19.70 |
| Ash, % | 5.29 | 4.74 | 3.96 | 7.48 | 9.15 |
| NDF, % | 6.91 | 5.45 | 5.13 | 9.16 | 14.25 |
| ADF, % | 3.47 | 2.73 | 2.35 | 5.14 | 6.67 |
| Ca, % | 0.92 | 0.56 | 0.69 | 0.89 | 0.88 |
| P, % | 0.46 | 0.51 | 0.43 | 1.04 | 1.42 |
| Xylanase, units / kg | N.D.[4] | N.D. | N.D. | N.D. | N.D. |
| Phytase, units/kg | 1,660 | 1,800 | 1,870 | 1,920 | 2,020 |
| Diets with xylanase | | | | | |
| GE, kcal/kg | 3,820 | 3,777 | 3,717 | 4,412 | 3,716 |
| DM, % | 87.09 | 87.35 | 88.26 | 91.82 | 89.10 |
| CP, % | 23.4 | 15.0 | 14.0 | 18.4 | 19.7 |

**Table 5.2** Cont.

| Ingredient, % | Basal | Brown rice | Broken rice | FFRB | DFRB |
|---|---|---|---|---|---|
| Ash, % | 5.15 | 4.31 | 4.08 | 7.19 | 9.38 |
| NDF, % | 7.20 | 5.67 | 4.45 | 10.36 | 13.29 |
| ADF, % | 3.47 | 2.53 | 2.79 | 5.65 | 6.61 |
| Ca, % | 0.64 | 0.57 | 0.72 | 0.79 | 0.86 |
| P, % | 0.44 | 0.50 | 0.44 | 1.11 | 1.41 |
| Xylanase, units/kg | 18,700 | 21,100 | 20,900 | 21,900 | 23,400 |
| Phytase, units/kg | 1,520 | 1,480 | 1,620 | 1,880 | 1,650 |

[1]Five diets were formulated without xylanase and 5 diets were formulated with xylanase.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

[3]The phytase-xylanase premix contained either phytase [Quantum Blue (5,000 units per gram) AB Vista, Marlborough, UK] or phytase and xylanase [Econase XT-25 (160,000 units per gram) AB Vista, Marlborough, UK]] mixed with corn.The mixture was formulated to provide 1,500 units of phytase per kilogram of complete feed in all diets and 16,000 units of xylanase per kg of complete feed in all xylanase containing diets.

[4]N.D. = Not detected.

**Table 5.3.** Intake and output of energy, apparent total tract digestibility (ATTD) of energy, and concentrations of DE and ME by weanling pigs fed a basal corn-soybean meal based diet or diets containing brown rice, broken rice, full fat rice bran (FFRB), or defatted rice bran (DFRB) without or with microbial xylanase[1,2,3]

| Item | GE intake, kcal/d | GE in feces, kcal/d | GE in urine, kcal/d | ATTD of GE, % | DE, kcal/kg | ME, kcal/kg | ATTD of DM, % | ATTD of OM, % | ATTD of NDF, % | ATTD of ADF, % |
|---|---|---|---|---|---|---|---|---|---|---|
| Without xylanase | | | | | | | | | | |
| Basal diet | 3,485 | 413[c] | 139 | 86.9 | 3,301[d] | 3,144 | 88.9 | 89.6 | 62.8[b] | 66.7 |
| Brown rice | 3,343 | 288[d] | 92 | 90.9 | 3,413[c] | 3,308 | 92.3 | 93.0 | 69.2[a] | 68.0 |
| Broken rice | 3,774 | 277[d] | 97 | 91.9 | 3,439[bc] | 3,337 | 92.6 | 93.3 | 73.2[a] | 71.8 |
| FFRB | 3,668 | 700[b] | 114 | 80.8 | 3,520[b] | 3,383 | 81.9 | 82.9 | 44.5[d] | 42.7 |
| DFRB | 4,157 | 874[a] | 109 | 79.5 | 2,960[f] | 2,914 | 79.5 | 82.4 | 59.0b[c] | 50.4 |
| With xylanase | | | | | | | | | | |
| Basal diet | 4,504 | 456[c] | 122 | 86.6 | 3,308[d] | 3,175 | 88.9 | 89.1 | 59.6[bc] | 63.3 |
| Brown rice | 3,431 | 323[d] | 90 | 90.5 | 3,419[c] | 3,320 | 91.8 | 92.7 | 70.5[a] | 65.9 |
| Broken rice | 3,480 | 286[d] | 96 | 91.5 | 3,401[c] | 3,297 | 91.8 | 93.4 | 70.7[a] | 75.8 |
| FFRB | 4,053 | 721[b] | 108 | 82.4 | 3,637[a] | 3,509 | 82.4 | 83.6 | 56.7[c] | 46.1 |
| DFRB | 4,276 | 726[b] | 107 | 82.5 | 3,103[e] | 3,011 | 80.8 | 84.3 | 60.3[bc] | 49.8 |
| SEM | 142.13 | 33.91 | 9.79 | 1.03 | 36.48 | 43.38 | 0.56 | 0.617 | 2.08 | 2.36 |

**Table 5.3.** Cont.

| Item | GE intake, kcal/d | GE in feces, kcal/d | GE in urine, kcal/d | ATTD of GE, % | DE, kcal/kg | ME, kcal/kg | ATTD of DM, % | ATTD of OM, % | ATTD of NDF, % | ATTD of ADF, % |
|---|---|---|---|---|---|---|---|---|---|---|
| *P*-value | | | | | | | | | | |
| Diet | < 0.001 | < 0.001 | 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Xylanase | 0.121 | 0.644 | 0.352 | 0.224 | 0.029 | 0.074 | 0.228 | 0.294 | 0.152 | 0.847 |
| Diet × xylanase | 0.484 | 0.011 | 0.923 | 0.227 | 0.038 | 0.243 | 0.284 | 0.245 | 0.001 | 0.272 |

[a-e]Means within a column lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 8 observations per treatment.

[2]Microbial phytase [Quantum blue 5G, AB Vista, Marlborough, UK, (5,000 units per gram)] was included in all diets to provide 1,500 units of phytase per kilogram of complete feed.

[3]Xylanase [Econase XT-25, AB Vista, Marlborough, UK, (160,000 units per gram)] was include in the xylanase containing diets to provide 16,000 units of xylanase per kilogram of complete feed.

**Table 5.4.** Concentration of DE and ME, and apparent total tract digestibility (ATTD) of energy by weanling pigs in brown rice, broken rice, full fat rice bran (FFRB), and defatted rice bran (DFRB) without or with xylanase[1,2,3]

| Item | ATTD of GE, % | DE, kcal/kg of DM | ME, kcal/kg of DM | ATTD of DM, % | ATTD of OM, % | ATTD of NDF, % | ATTD of ADF, % |
|---|---|---|---|---|---|---|---|
| Without xylanase | | | | | | | |
| Brown rice | 94.8 | 4,120$^{bc}$ | 4.055$^{ab}$ | 94.6 | 96.2 | 75.4$^{b}$ | 68.8 |
| Broken rice | 96.4 | 4,183$^{ab}$ | 4,124$^{a}$ | 95.3 | 96.0 | 86.4$^{a}$ | 74.4 |
| FFRB | 75.6 | 3,984$^{c}$ | 3,856$^{b}$ | 72.8 | 73.7 | 30.8$^{d}$ | 27.3 |
| DFRB | 76.7 | 3,054$^{d}$ | 2,936$^{d}$ | 72.9 | 77.0 | 54.9$^{c}$ | 47.2 |
| With xylanase | | | | | | | |
| Brown rice | 94.4 | 4,127$^{ab}$ | 4,047$^{ab}$ | 94.9 | 96.5 | 77.6$^{b}$ | 62.2 |
| Broken rice | 96.0 | 4,087$^{bc}$ | 3,995$^{ab}$ | 96.7 | 97.3 | 86.4$^{a}$ | 89.5 |
| FFRB | 80.8 | 4,311$^{a}$ | 4,198$^{a}$ | 75.8 | 77.2 | 55.3$^{c}$ | 39.9 |
| DFRB | 79.0 | 3,192$^{d}$ | 3,225$^{c}$ | 74.3 | 77.2 | 56.8$^{c}$ | 48.8 |
| SEM | 2.21 | 70.84 | 81.87 | 1.32 | 1.44 | 3.09 | 5.37 |
| *P*-value | | | | | | | |
| Ingredient | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Xylanase | 0.176 | 0.038 | 0.0321 | 0.043 | 0.067 | 0.001 | 0.109 |
| Ingredient × xylanase | 0.304 | 0.007 | 0.010 | 0.628 | 0.303 | < 0.001 | 0.125 |

[a-d]Means within a column lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 8 observations per treatment.

[2]Microbial phytase [Quantum blue 5G, AB Vista, Marlborough, UK, (5,000 units per gram)] was included in all diets to provide 1,500 units of phytase per kilogram of complete feed.

[3]Xylanase [Econase XT-25, AB Vista, Marlborough,UK, (160,000 units per gram)] was include in the xylanase containing diets to provide 16,000 units of xylanase per kilogram of complete feed.

## LITERATURE CITED


Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine Nutrition. CRC Press, Washington, DC. p. 903-916.

Adeola, O., and A. J. Cowieson. 2011. Board-invited review: Opportunities and challenges in using exogenous enzymes to improve nonruminant animal production. J. Anim. Sci. 89:3189-3218. doi:10.2527/jas.2010-3715

Annison, G., P. J. Moughan, and D. V. Thomas. 1995. Nutritive activity of soluble rice bran arabinoxylans in broiler diets. Br. Poult. Sci. 36:479-488. doi:10.1080/00071669508417793

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

Bach Knudsen, K. E. 2014. Fiber and nonstarch polysaccharide content and variation in common crops used in broiler diets. Poult. Sci. 93:2380-2393. doi:10.3382/ps.2014-03902

Cervantes-Pahm, S. K., Y. Liu, and H. H. Stein. 2014. Comparative digestibility of energy and nutrients and fermentability of dietary fiber in eight cereal grains fed to pigs. J. Sci. Food Agric. 94:841-849. doi:10.1002/jsfa.6405

Choct, M. 1997. Feed Non-Starch Polysaccharides: Chemical Structures and Nutritional Significance. Feed Mill. Int.:13-26.

Ellis, R., and E. R. Morris. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem. 77:536-539.

Jaworski, N. W., H. N. Lærke, K. E. Bach Knudsen, and H. H. Stein. 2015. Carbohydrate composition and *in vitro* digestibility of dry matter and nonstarch polysaccharides in

corn, sorghum, and wheat and coproducts from these grains. J. Anim. Sci. 93:1103-1113. doi:10.2527/jas.2014-8147

Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. He, M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. Can. J. Anim. Sci. 85:355-363. doi:10.4141/A04-084

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J. Anim. Sci. 87:4013-4021. doi:10.2527/jas.2009-2060

Kim, J. C., J. S. Sands, B. P. Mullan, and J. R. Pluske. 2008. Performance and total-tract digestibility responses to exogenous xylanase and phytase in diets for growing pigs. Anim. Feed Sci. Technol. 142:163-172. doi:10.1016/j.anifeedsci.2007.07.004

Kim, J. C., P. H. Simmins, B. P. Mullan, and J. R. Pluske. 2005. The digestible energy value of wheat for pigs, with special reference to the post-weaned animal [Review]. Anim. Feed Sci. Technol. 122:257-287. doi:10.1016/j.anifeedsci.2005.02.022

Kong, C., and O. Adeola. 2014. Evaluation of amino acid and energy utilization in feedstuff for swine and poultry diets. Asian-Australas. J. Anim. Sci. 27:917-925. doi:10.5713/ajas.2014.r.02

Li, D., D. F. Zhang, X. S. Piao, I. K. Han, C. J. Yang, J. B. Li, and J. H. Lee. 2002. Effects of replacing corn with chinese brown rice on growth performance and apparent fecal digestibility of nutrients in weanling pigs. Asian-Australas. J. Anim. Sci. 15:1191-1197. doi:10.5713/ajas.2002.1191

Maniñgat, C. C., and B. O. Juliano. 1982. Composition of cell wall preparations of rice bran and germ. Phytochemistry. 21:2509-2516. doi:10.1016/0031-9422(82)85247-3

Mathlouthi, N., J. P. Lallès, P. Lepercq, C. Juste, and M. Larbier. 2002. Xylanase and β-glucanase supplementation improve conjugated bile acid fraction in intestinal contents and increase villus size of small intestine wall in broiler chickens fed a rye-based diet1. J. Anim. Sci. 80:2773-2779. doi:10.2527/2002.80112773x

Noblet, J., and G. Le Goff. 2001. Effect of dietary fibre on the energy value of feeds for pigs. Anim. Feed Sci. Technol. 90:35-52. doi:10.1016/S0377-8401(01)00195-X

Nortey, T. N., J. F. Patience, P. H. Simmins, N. L. Trottier, and R. T. Zijlstra. 2007. Effects of individual or combined xylanase and phytase supplementation on energy, amino acid, and phosphorus digestibility and growth performance of grower pigs fed wheat-based diets containing wheat millrun. J. Anim. Sci. 85:1432-1443. doi:10.2527/jas.2006-613

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Paloheimo, M., J. Piironen, and J. Vehmaanperä. 2010. Xylanases and cellulases as feed additives. In: M. Bedford and G. Partridge, editors, Enzymes in farm animal nutrition. CAB International, Boston, MA. p. 12-53.

Robles, A., and R. C. Ewan. 1982. Utilization of energy of rice and rice bran by young pigs. J. Anim. Sci. 55:572-577. doi:10.2527/jas1982.553572x

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats. Recent advances in animal nutrition. Butterworths, London, UK. p. 77-81.

Saunders, R. M. 1985. Rice bran: Composition and potential food uses. Food Rev. Intl. 1:465-495. doi:10.1080/87559128509540780

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Shibuya, N., and T. Iwasaki. 1985. Structural features of rice bran hemicellulose. Phytochemistry. 24:285-289. doi:10.1016/S0031-9422(00)83538-4

Singh, A., M. Das, S. Bal, and R. Banerjee. 2014. Rice processing. In: R. P. Ferrerira-Guiné and P. M. dois-Reis-Correia, editors, Engineering aspects of cereal and cereal-based proudcts. CRC Press, Boca Raton, FL. p. 71-96.

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value. In: A. Ponter, D. Sauvant, J.-M. Perez and G. Tran, editors, Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses and fish. Wageningen Academic Publishers, Wageningen, the Netherlands. p. 17-24.

USA-Rice-Federation. 2011. Rice technical information kit. The complete guide for using U. S. rice as an ingredient. https://www.usarice.com (Acceseed 21 January 2013).

Warren, B. E., and D. J. Farrell. 1990. The nutritive value of full-fat and defatted Australian rice bran. I. Chemical composition. Anim. Feed Sci. Technol. 27:219-228. doi:10.1016/0377-8401(90)90084-L

Zijlstra, R. T., A. Owusu-Asiedu, and P. H. Simmins. 2010. Future of NSP-degrading enzymes to improve nutrient utilization of co-products and gut health in pigs. Livest. Sci. 134:255-257. doi:10.1016/j.livsci.2010.07.017

# CHAPTER 6: GESTATING SOWS HAVE GREATER DIGESTIBILITY OF ENERGY IN FULL FAT RICE BRAN AND DEFATTED RICE BRAN THAN GROWING GILTS REGARDLESS OF LEVEL OF FEED INTAKE

**ABSTRACT:** The first objective of this experiment was to test the hypothesis that apparent total tract digestibility (ATTD) of GE and nutrients in full fat rice bran (FFRB) and defatted rice bran (DFRB) determined in gestating sows is greater if feed is provided at 1.5 × the ME required for maintenance than at 3.5 × the ME requirement. The second objective was to test the hypothesis that the ATTD of GE and nutrients and the concentrations of DE and ME in FFRB and DFRB is not different between growing gilts and gestating sows if both groups of animals are fed 3.5 × the maintenance requirement for ME. Forty eight gestating sows (parity 2 to 6) were allotted to 3 diets and 2 levels of feed intake (i.e., 1.5 or 3.5 × the maintenance requirement for ME) in a randomized complete block design, with 4 blocks of 12 sows and 2 replicate sows per block for a total of 8 replicate sows per diet. Twenty four growing gilts (51.53 ± 3.1 kg BW) were randomly allotted to the same 3 diets, but all gilts were fed at 3.5 × the maintenance requirement for ME. A basal diet containing corn and soybean meal and 2 diets that consisted of 60% basal diet and 40% FFRB or DFRB were used. Results of the experiment indicated that there were no effects of level of feed intake of sows on ATTD of GE, DM, OM, or NDF, or on concentrations of DE and ME. However, concentrations of DE and ME were greater ($P < 0.05$) in FFRB than in DFRB regardless of feed intake level. The ATTD of GE, OM, DM, and NDF of diets containing FFRB or DFRB was less ($P < 0.05$) than in the basal diet, regardless of the physiological stage of the animals. However, the ATTD of GE, OM, and NDF of the basal diet and diets containing FFRB or DRFB was greater ($P < 0.05$) in gestating sows than in growing gilts. Concentrations of DE

and ME in the diets were also greater ($P < 0.05$) if determined in gestating sows than in growing gilts. The ATTD of GE and the concentrations of DE and ME of FFRB were greater ($P < 0.05$) than in DFRB and these values were also greater ($P < 0.05$) in gestating sows than in growing gilts. In conclusion, the level of feed intake by gestating sows did not affect the digestibility of GE and nutrients or the concentrations of DE and ME in diets or in FFRB or DFRB, but the ATTD of GE and the concentration of DE and ME in diets and in FFRB and DFRB were greater in gestating sows than in growing gilts.

## INTRODUCTION

The apparent total tract digestibility (**ATTD**) of energy by pigs may be affected by the physiological stage of the animals and the feeding level (Noblet and Shi, 1993; Chastanet et al., 2007). Differences in digestibility of energy between growing pigs and sows have been demonstrated and explained by the greater capacity for degradation of fiber in sows compared with growing pigs (Shi and Noblet, 1993; Le Goff and Noblet, 2001). However, gestating sows are usually restricted in their feed allowance, which may affect rate of passage through the intestinal tract and the efficiency of digestion. It is, therefore, not known if the greater digestibility of energy by gestating sows is due to only physiological differences between sows and growing pigs or if the fact that gestating sows are fed less than growing pigs contributes to the differences that have been reported (Shi and Noblet, 1993; Le Goff and Noblet, 2001; Fernández et al., 2010). There is, therefore, a need to separate the effect of physiological stage and the effect of the level of feed intake on ATTD of energy and nutrients by gestating sows and growing pigs.

The ATTD of GE is between 72.8 and 80.0% in full fat rice bran (**FFRB**) and defatted rice bran (**DFRB**) fed to growing pigs (Robles and Ewan, 1982; Kaufmann et al., 2005; Casas and Stein, 2016). However, no values for the ATTD of GE or for DE and ME of FFRB and DFRB fed to gestating sows have been reported. Therefore, the first objective of this experiment was to test the hypothesis that the ATTD of GE, DM, OM, and NDF in FFRB and DFRB determined in gestating sows is greater at a feed intake level of 1.5 × ME required for maintenance than at 3.5 × the ME requirement. The second objective was test the hypothesis that the ATTD of GE and nutrients and the concentrations of DE and ME in FFRB and DFRB is not different between growing gilts or gestating sows if both groups of animals are allowed to consume feed at a level that is close to ad libitum intake.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

### *Animals, Housing, Diets and Sample Collection*

Forty eight gestating sows (35 ± 0.8 d of pregnancy; parity 2 to 6), were allotted to a randomized complete block design with 3 diets and 2 levels of feed intake (1.5 or 3.5 × the maintenance ME requirement) for a total of 6 dietary treatments. There were 4 blocks of 12 sows, 2 replicate sows per block, and 8 replicate sows per treatment. Twenty-four growing gilts (51.53 ± 3.1 kg BW) were randomly allotted to the same 3 diets, and they were provided feed at 3.5 × the maintenance ME requirement. Sows were Fertilis 25 (Genetiporc, Alexandria, MN) and gilts were the offspring of F-25 females mated to G-Performer males (Genetiporc Inc., Alexandria, MN). The ME requirement for sows was estimated at 100 kcal ME per kg $BW^{0.75}$

(NRC, 2012), and the ME requirement for growing gilts was estimated at 197 kcal ME per kg $BW^{0.60}$ (NRC, 2012).

A basal diet containing corn and soybean meal and 2 diets based on corn, soybean meal, and FFRB or DFRB were used (Table 6.1). Full fat rice bran and DFRB were included at 40% of the diets (Table 6.2). All diets were formulated to contained 500 units per kg of microbial phytase [Quantum Blue, (5,000 phytase units per gram) AB Vista, Marlborough, UK], and vitamins and minerals in concentrations that exceeded the requirement for growing pigs and gestating sows (NRC, 2012). The same batch of the 3 diets was fed to all animals throughout the experiment. Gilts and sows were fed equal amounts of feed daily at 0700 and 1600 h and all animals had free access to water throughout the experiment.

Growing gilts and gestating sows were fed experimental diets for 24 d. For the initial 12 d, sows and gilts were housed in individual pens, but on d 13, they were moved to metabolism crates. Metabolism crates were equipped with a feeder and a nipple drinker, a fully slatted floor, a screen floor, and a urine pan.

Five d after gilts and sows were moved to the metabolism crates (d 18 of the experiment), a color marker was included in the morning meal (chromic oxide) and a second marker (ferric oxide) was included in the morning meal on d 23. Fecal collection was initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at -20ºC as soon as collected. Urine collections started on d 18 at 1700 h and ceased on d 23 at 1700 h. Urine was collected in buckets placed under the metabolism crates over a preservative of 50 mL of 6*N* HCl. Buckets were emptied daily, the weight of the collected urine was recorded, and 10% of the collected urine was stored a -20ºC. At

the conclusion of the experiment, urine samples were thawed and mixed within animal and subsamples were collected for analysis.

***Chemical Analyses***

Fecal samples were dried at 65ºC in a forced air oven and ground through a 1 mm screen before analysis. Urine samples were lyophilized before analysis (Kim et al., 2009). Samples of energy-containing ingredients, diets, feces, and urine were analyzed for GE using an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. Samples of ingredients, diets, and feces were analyzed for DM (Method 930.15; AOAC Int., 2007) and ash (Method 942.05; AOAC Int., 2007). These samples were also analyzed for NDF using Ankom Technology method 13 (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY). Ingredients and diets were also analyzed for ADF and lignin using Ankom Technology methods 12 and 9, respectively (Ankom 2000 Fiber Analyzer, Ankom Technology, and the Daisy$^{II}$ Incubator, Ankom Technology, Macedon, NY). Crude protein was analyzed in ingredients and diets by combustion (Method 990.03; AOAC Int., 2007) using an Elementar Rapid N-cube Protein/Nitrogen Apparatus (Elementar Americas Inc., Mt Laurel, NJ), and acid hydrolyzed ether extract (**AEE**) was analyzed by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.6; AOAC Int., 2007) on an automated analyzer (Soxtec 2050; FOSS North America, Eden Praire, MN). Ingredients and diets were also analyzed for Ca and P (Method 975.03; AOAC Int., 2007) and all ingredients were analyzed for starch (Method 979.10; AOAC Int., 2007). Phytase activity (method 2000.012; AOAC Int., 2007) was also analyzed in all diets.

***Calculations and Statistical Analysis***

Organic matter was calculated as the difference between DM and ash. The DE and ME and the ATTD of GE, DM, and NDF in diets were calculated using the direct method (Adeola, 2001). The contribution of the basal diet to the diets containing rice coproducts was subtracted from the values for these diets and the DE and ME and ATTD of GE, DM, OM, and NDF in FFRB and DFRB were calculated by difference (Adeola, 2001). Outliers and homogeneity of the variances among treatments were tested using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Data were analyzed using the MIXED procedure of SAS. To test the effect of feeding level in gestating sows or the effects of the physiological stage, data were analyzed as a randomized complete block design in a 2 × 3 factorial arrangement for diets and 2 × 2 factorial arrangement for ingredients. The fixed effects were the diet or ingredient and the feeding level or physiological stage, and the interaction between diet or ingredient and feeding levels or physiological stage. Block and replicate were considered random effects. The LSMeans statement was used to calculate treatment means and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and statistical significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

## RESULTS

The basal diet and diets containing FFRB or DFRB contained 3,819, 4,260, and 3,809 kcal/kg of GE, respectively and concentrations of CP were 20.6, 17.5, and 18.9%, respectively (Table 6.2). Values for ADF and NDF were 4.78 and 9.07% for the basal diet, 5.74 and 11.48 for the FFRB diet, and 6.75 and 12.17% for the DFRB diet. All analyzed values were close to formulated values.

### *Effects of Level of Feed Intake on DE and ME in Gestating Sows*

Intake of GE was greater ($P < 0.05$) if sows were fed 3.5 × the maintenance ME requirement than if they were fed 1.5 × the maintenance requirement ME and sows fed diets containing FFRB or DFRB consumed more ($P < 0.05$) GE than sows fed the basal diet (Table 6.3).

An interaction ($P < 0.05$) between diet and feeding level was observed for GE excreted in feces. If sows were fed 3.5 × the maintenance ME requirement, GE in feces was greater ($P < 0.05$) for sows fed diets containing FFRB or DFRB compared with sows fed the basal diet, but if sows were fed 1.5 × the maintenance ME requirement, only sows fed the DFRB diet had a greater ($P < 0.05$) fecal excretion of GE than sows fed the basal diet. A tendency for an interaction ($P = 0.08$) was observed for GE in urine, with greater urine output from sows fed the basal diet at 3.5 × the maintenance ME requirement than in sows fed the FFRB or DFRB diets at 3.5 × the ME requirement for maintenance, but there was no difference among diets if feed intake was 1.5 × the maintenance ME requirement. There were no effects of level of feed intake on ATTD of GE, DM, OM, or NDF or on concentrations of DE and ME in the diets, but the ATTD of GE, DM, OM, and NDF was greater ($P < 0.05$) in the basal diet than in diets containing FFRB or DFRB. However, the DE and ME were greater ($P < 0.05$) in the diet containing FFRB than in the basal diet or the diet containing DFRB regardless of intake level.

There were no effects of level of feed intake on ATTD of GE or NDF in FFRB and DFRB or on DE and ME of ingredients (Table 6.4). However, DE and ME and ATTD of GE were greater ($P < 0.05$) in FFRB than in DFRB, but that was not the case for ATTD of NDF.

### *Effects of Physiological Stage*

The daily intake of GE was greater ($P < 0.05$) in gestating sows than in growing gilts and sows and gilts fed diets containing FFRB or DFRB had greater ($P < 0.05$) daily intake of GE than those fed the basal diet (Table 6.5). The daily excretion of GE in feces was greater ($P < 0.05$) from sows fed diets containing FFRB or DFRB than in growing gilts fed these diets, but fecal GE excretion from both sows and gilts was greater ($P < 0.05$) if FFRB or DFRB diets were fed rather than the basal diet. Excretion of GE in urine was also greater ($P < 0.05$) in sows than in gilts and tended ($P = 0.055$) to be greater if the basal diet was fed instead of the FFRB or DFRB diets. The ATTD of GE, DM, and NDF of diets containing FFRB or DFRB was less ($P < 0.05$) than of the basal diet, regardless of the physiological stage of the animals. The ATTD of GE of diets was greater ($P < 0.05$) in gestating sows than in growing gilts, but the ATTD of DM and NDF was not influenced by the physiological stage of the animals. The ATTD of OM was also greater ($P < 0.05$) for the basal diet than for the other diets for both gilts and sows, but for sows, no differences between FFRB and DFRB diets were observed, whereas the ATTD of OM was greater for FFRB than for DFRB if diets were fed to gilts (interaction, $P < 0.05$). The concentrations of DE and ME in diets were greater ($P < 0.05$) for gestating sows than for gilts, but for both groups of animals, the DE and ME were greater for the FFRB diet than for the other diets.

The ATTD of GE and the concentrations of DE and ME in FFRB and DFRB were greater ($P < 0.05$) in gestating sows than in gilts and also greater ($P < 0.05$) in FFRB than in DFRB (Table 6.6). However, the ATTD of NDF for FFRB and DFRB was not affected by the physiological stage of the animals.

## DISCUSSION

The analyzed composition of corn and soybean meal used in this experiment are in agreement with reported values (Sauvant et al., 2004; NRC, 2012; Casas and Stein, 2016). However, the concentration of AEE in FRRB was greater than previous values, whereas the concentration of starch in FFRB and DFRB was slightly less than reported (Sauvant et al., 2004; NRC, 2012; Casas and Stein, 2016). Variation in the milling of rice or extraction of oil from the bran may be the reason for the variation in composition among sources of rice bran because different amounts of endosperm or oil may remain in the final product (Saunders, 1985).

Values for ATTD of GE and nutrients and values for DE and ME in most feed ingredients have been obtained in growing pigs that were provided feed at a level that was close to the voluntary feed intake of the animals (Le Goff and Noblet, 2001). However, results of experiments conducted to evaluate effects of level of feed intake on digestibility of energy and nutrients in growing pigs are contradictory and may not always be applicable if gestating sows are provided a limited amount of feed (Le Goff and Noblet, 2001). The observation in this experiment that values for digestibility of GE and nutrients in gestating sows were not influenced by feeding level concurs with previous reports that concluded that ATTD of GE is not different if growing pigs are fed at 1, 2, or 3 times the ME requirement for maintenance (Haydon et al., 19844; Moter and Stein, 2004). However, results of this experiment contrast data reported by Chastanet et al. (2007) and Oresanya et al. (2008) who observed a decline in digestibility if pigs were allowed ad libitum intake of feed compared with pigs that were restricted in their intake. Feeding gestating sows approximately 1.5 times the maintenance requirement is a common practice under commercial conditions, but results of this experiment indicate that this does not change DE and ME values of diets compared with animals allowed greater levels of feed intake.

Thus, it appears that the retention time of digesta in sows is sufficient to maximize digestion and fermentation regardless of the level of feed intake.

Greater digestibility of nutrients by sows compared with growing pigs has been reported (Le Goff and Noblet, 2001; Fernández et al., 2010; Lowell et al., 2015), but previous data were obtained using sows restricted in their feed intake and growing pigs allowed to consume feed in greater quantities. As a consequence, we hypothesized that effects of intake level and the physiological stage may have been confounded. However, the observation that level of feed intake does not influence DE and ME in sows demonstrates that there is a physiological difference between sows and growing pigs that allow sows to obtain more energy from feed regardless of the level of feed intake. The increased ATTD of GE and the increased DE and ME in diets fed to sows have been explained by greater digestive capacity, slower rate of passage, and more efficient fermentation of fiber in the large intestine (Noblet and van Milgen, 2004). However, the observation that the ATTD of NDF was not greater in sows than in growing pigs indicates that it may not be the fiber fraction that resulted in improved ATTD of GE in sows. This conclusion is in agreement with data by Lowell et al. (2015) and the exact reason for the greater ATTD of GE and DM that is observed in sows compared with growing gilts remains to be elucidated. However, it is possible that starch or lipids are more efficiently digested in sows than in growing pigs, but use of ileal cannulated animals is required to test this hypothesis.

Values for ATTD of GE and the concentration of DE and ME in FFRB and DFRB that were obtained in this experiment for growing pigs concur with previous values for growing pigs (Warren and Farrell, 1990; Casas and Stein, 2016). Likewise, the greater concentration of ME in FFRB than in DFRB agrees with previous data (Warren and Farrell, 1990; Casas and Stein, 2016) and likely is explained by the greater concentrations of AEE in FFRB compared with

DFRB. However, to our knowledge, there are no previous values for ATTD of GE or concentrations of DE and ME in FFRB and DFRB fed to gestating sows, but the present data indicate that both ingredients are well utilized by sows.

***Conclusions***

The first hypothesis for this work was that sows fed 3.5 × the maintenance requirement for ME will have reduced DE and ME compared with sows fed 1.5 × the maintenance requirement for ME. However, we had to reject this hypothesis because results indicated that the level of intake of feed does not affect the ATTD of GE, DM, OM, or NDF or the concentration of DE and ME of a corn-soybean meal diet or diets containing FFRB or DFRB. The second hypothesis was that if both sows and growing gilts are fed at 3.5 × the maintenance requirement for ME, no differences in DE and ME between sows and gilts will be observed. We also rejected this hypothesis because results demonstrated that concentrations of DE and ME in a corn-soybean meal diet and in diets containing FFRB or DFRB and in FFRB and DFRB are greater if fed to gestating sows than to growing gilts even if the level of feed intake is the same. Therefore, it is concluded that there are physiological differences between gestating sows and growing gilts that result in sows having greater DE and ME of diets than growing gilts. However, it does not appear that the greater digestibility of energy in sows than in gilts is a result of increased fermentation of fiber.

## TABLES

**Table 6.1**. Analyzed nutrient composition of corn, soybean meal, full fat rice bran (FFRB), and defatted rice bran (DFRB)

| Item | Corn | Soybean meal | FFRB | DFRB |
|---|---|---|---|---|
| GE, kcal/kg | 3,835 | 4,183 | 5,116 | 3,874 |
| DM, % | 87.20 | 90.25 | 97.90 | 90.60 |
| CP,% | 7.16 | 47.11 | 16.25 | 16.34 |
| AEE[1], % | 3.42 | 0.28 | 16.70 | 3.97 |
| Ash, % | 1.56 | 5.89 | 9.20 | 12.10 |
| Starch,% | 62.42 | 0.15 | 12.90 | 19.8 |
| ADF, % | 2.37 | 3.96 | 9.73 | 8.81 |
| NDF, % | 8.00 | 8.47 | 18.28 | 17.78 |
| Lignin, % | 1.39 | 1.03 | 9.35 | 5.03 |
| Ca, % | 0.01 | 0.30 | 0.05 | 1.07 |
| P, % | 0.26 | 0.64 | 2.00 | 2.24 |

[1]AEE = acid hydrolyzed ether extract.

**Table 6.2.** Composition of basal diet and diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)

| Item, | Basal | FFRB | DFRB |
|---|---|---|---|
| Ingredient, % | | | |
| Corn | 63.60 | 37.11 | 37.11 |
| Soybean meal | 32.27 | 19.05 | 19.05 |
| Rice coproducts | - | 40.00 | 40.00 |
| Limestone | 0.78 | 1.64 | 1.64 |
| Dicalcium phosphate | 1.15 | - | - |
| Sodium chloride | 0.40 | 0.40 | 0.40 |
| Vitamin mineral premix[1] | 0.30 | 0.30 | 0.30 |
| Phytase premix[2] | 1.00 | 1.00 | 1.00 |
| Titanium dioxide | 0.50 | 0.50 | 0.50 |
| Total | 100.00 | 100.00 | 100.00 |
| Analyzed composition | | | |
| GE, kcal/kg | 3,819 | 4,260 | 3,809 |
| DM, % | 88.03 | 92.63 | 88.95 |
| CP, % | 20.26 | 17.58 | 18.96 |
| AEE[3], % | 2.15 | 8.32 | 3.50 |
| Ash, % | 5.30 | 6.90 | 8.80 |
| ADF, % | 4.78 | 5.74 | 6.75 |
| NDF, % | 9.07 | 11.48 | 12.17 |
| Lignin, % | 0.73 | 1.42 | 2.63 |
| Ca, % | 0.65 | 0.66 | 1.16 |
| P, % | 0.6 | 0.98 | 1.09 |
| Phytase, phytase units/kg | 690 | 690 | 430 |

[1]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as

**Table 6.2**. Cont.

menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

[2]The phytase premix was formulated to provide 500 units of phytase per kilogram of complete feed in all diets. The premix was prepared by mixing 10 g of phytase [Quantum Blue (5,000 units per gram) AB Vista, Marlborough, UK] with 990 g of ground corn. The premix thus contained 50,000 units of phytase per kilogram, and at 1% inclusion provided 500 units of phytase per kilogram of complete diet.

[3]AEE = acid hydrolyzed ether extract.

**Table 6.3.** Effect of feed intake level on apparent total tract digestibility (ATTD) of GE, DM, OM, and NDF and concentration of DE and ME of the basal diet and diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB) fed to gestating sows[1]

| Item | 3.5 × maintenance ME | | | 1.5 × maintenance ME | | | SEM | *P*- value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | DFRB | Basal | FFRB | DFRB | | Diet | Intake level | Diet × intake level |
| Feed intake, kg/d | 6.11 | 6.29 | 6.83 | 2.75 | 2.75 | 3.32 | 0.25 | 0.034 | < 0.001 | 0.935 |
| Intake of GE, kcal/d | 23,368 | 26,795 | 26,017 | 10,530 | 11,755 | 12,659 | 1,088 | 0.036 | < 0.001 | 0.525 |
| GE in feces, kcal/d | 2,632[b] | 4,015[a] | 4,371[a] | 1,223[d] | 1,756[cd] | 2,083[bc] | 194 | < 0.001 | < 0.001 | 0.048 |
| GE in urine, kcal/d | 987 | 610 | 676 | 467 | 410 | 524 | 112 | 0.049 | < 0.001 | 0.080 |
| ATTD of GE, % | 88.65 | 84.87 | 83.26 | 88.49 | 85.07 | 83.54 | 0.70 | < 0.001 | 0.855 | 0.947 |
| ATTD of DM, % | 88.52 | 82.52 | 80.88 | 87.99 | 82.62 | 80.51 | 0.81 | < 0.001 | 0.657 | 0.901 |
| ATTD of OM, % | 91.02 | 87.01 | 87.38 | 90.90 | 87.09 | 87.43 | 0.52 | < 0.001 | 0.995 | 0.980 |
| ATTD of NDF, % | 70.55 | 48.80 | 51.38 | 70.41 | 49.22 | 52.27 | 2.41 | < 0.001 | 0.910 | 0.550 |
| DE, kcal/kg | 3,385 | 3,615 | 3,171 | 3,379 | 3,624 | 3,182 | 27 | < 0.001 | 0.847 | 0.946 |
| ME, kcal/kg | 3,226 | 3,516 | 3,072 | 3,206 | 3,474 | 3,029 | 35 | < 0.001 | 0.181 | 0.910 |

[a-c]Means within a column lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 8 observations per treatment.

**Table 6.4**. Effect of feed intake level on apparent total tract digestibility (ATTD) of GE, and NDF and concentration of DE and ME in full fat rice bran (FFRB) or defatted rice bran (DFRB) fed to gestating sows[1]

| Item | 3.5 × maintenance ME | | 1.5 × maintenance ME | | SEM | *P*-value | | |
|---|---|---|---|---|---|---|---|---|
| | FFRB | DFRB | FFRB | DFRB | | Ingredient | Intake level | Ingredient × intake level |
| ATTD of GE, % | 81.49 | 77.03 | 81.34 | 78.48 | 1.46 | 0.006 | 0.955 | 0.960 |
| ATTD of NDF, % | 36.68 | 37.96 | 30.49 | 42.36 | 4.02 | 0.108 | 0.821 | 0.188 |
| DE, kcal/kg DM | 4,168 | 3,241 | 4,185 | 3,224 | 82 | < 0.001 | 0.999 | 0.824 |
| ME, kcal/kg DM | 4,119 | 3,228 | 4,062 | 3,158 | 85 | < 0.001 | 0.469 | 0.940 |

[1]Data are means of 8 observations per treatment.

**Table 6.5**. Effects of the physiological stage on the apparent total tract digestibility (ATTD) of GE, DM, OM, and NDF and concentrations of DE and ME of the basal diet and diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB) and fed to gestating sows or growing gilts at 3.5 × the estimated ME requirement for maintenance[1]

| Item | Gestating sows | | | Growing gilts | | | SEM | *P*-value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | DFRB | Basal | FFRB | DFRB | | Diet | Stage | Diet × stage |
| Feed intake, kg/d | 6.11 | 6.29 | 6.83 | 2.11 | 2.23 | 2.57 | 0.26 | 0.066 | < 0.001 | 0.873 |
| Intake of GE, kcal/d | 23,368 | 26,795 | 26,017 | 8,092 | 9,511 | 9,846 | 1016 | 0.036 | < 0.001 | 0.600 |
| GE in feces, kcal/d | 2,632$^{b}$ | 4,015$^{a}$ | 4,371$^{a}$ | 1,006$^{d}$ | 1,625$^{c}$ | 1,815$^{c}$ | 192 | < 0.001 | < 0.001 | 0.027 |
| GE in urine, kcal/d | 987 | 610 | 676 | 298 | 278 | 267 | 92 | 0.055 | < 0.001 | 0.106 |
| ATTD of GE, % | 88.65 | 84.87 | 83.26 | 87.62 | 82.89 | 80.92 | 0.58 | < 0.001 | < 0.001 | 0.514 |
| ATTD of DM, % | 88.52 | 82.52 | 80.88 | 88.89 | 82.54 | 80.5 | 0.50 | < 0.001 | 0.892 | 0.887 |
| ATTD of OM, % | 91.02$^{a}$ | 87.01$^{bc}$ | 87.38$^{c}$ | 90.40$^{a}$ | 85.60$^{b}$ | 84.00$^{d}$ | 0.49 | < 0.001 | 0.005 | 0.004 |
| ATTD of NDF, % | 70.55 | 48.80 | 51.38 | 65.81 | 46.34 | 48.96 | 2.67 | < 0.001 | 0.149 | 0.884 |
| DE, kcal/kg | 3,385 | 3,615 | 3,171 | 3,346 | 3,531 | 3,082 | 22.62 | < 0.001 | < 0.001 | 0.483 |
| ME, kcal/kg | 3,226 | 3,516 | 3,072 | 3,203 | 3,406 | 2,932 | 31.20 | < 0.001 | < 0.001 | 0.168 |

[a-c]Means within a column lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 8 observations per treatment.

**Table 6.6**. Effects of the physiological stage on the apparent total tract digestibility (ATTD) of GE and NDF and concentrations of DE and ME in full fat rice bran (FFRB) and defatted rice bran (DFRB) fed to gestating sows or growing gilts at 3.5 × the estimated ME requirement for maintenance[1]

| Item | Gestating sows | | Growing gilts | | SEM | *P*-value | | |
|---|---|---|---|---|---|---|---|---|
| | FFRB | DFRB | FFRB | DFRB | | Ingredient | Stage | Ingredient × stage |
| ATTD of GE, % | 81.49 | 77.03 | 78.06 | 73.45 | 1.40 | 0.003 | 0.019 | 0.957 |
| ATTD of NDF, % | 36.68 | 37.96 | 30.49 | 38.68 | 4.32 | 0.280 | 0.539 | 0.438 |
| DE, kcal/kg DM | 4,168 | 3,241 | 3,975 | 3,058 | 67 | < 0.001 | 0.009 | 0.940 |
| ME, kcal/kg DM | 4,119 | 3,228 | 3,871 | 2,933 | 81 | < 0.001 | 0.002 | 0.773 |

[1]Data are means of 8 observations per treatment.

## LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine Nutrition. CRC Press, Washington, DC. p. 903-916.

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

Casas, G. A., and H. H. Stein. 2016. Effects of microbial xylanase on digestibility of dry matter, organic matter, neutral detergent fiber, and energy and the concentrations of digestible and metabolizable energy in rice coproducts fed to weanling pigs. J. Anim. Sci. 94:1933-1939. doi:10.2527/jas2015-0064

Chastanet, F., A. A. Pahm, C. Pedersen, and H. H. Stein. 2007. Effect of feeding schedule on apparent energy and amino acid digestibility by growing pigs. Anim. Feed Sci. Technol. 132:94-102. doi:10.1016/j.anifeedsci.2006.03.012

Fernández, J. A., H. Jørgensen, and A. Just. 2010. Comparative digestibility experiments with growing pigs and adult sows. Anim. Sci. 43:127-132. doi:10.1017/S0003356100018419

Haydon, K. D., D. A. Knabe, and T. D. Tanksley. 1984. Effects of level of leed intake on nitrogen, amino acid and energy digestibilities measured at the end of the small intestine and over the total digestive tract of growing pigs. J. Anim. Sci. 59:717-724. doi:10.2527/jas1984.593717x

Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. He, M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. Can. J. Anim. Sci. 85:355-363. doi:10.4141/A04-084

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried

grains and their effects on growth performance of pigs. J. Anim. Sci. 87:4013-4021. doi:10.2527/jas.2009-2060

Le Goff, G., and J. Noblet. 2001. Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. J. Anim. Sci. 79:2418-2427. doi:10.2527/2001.7992418x

Lowell, J. E., Y. Liu, and H. H. Stein. 2015. Comparative digestibility of energy and nutrients in diets fed to sows and growing pigs. Arch. Anim. Nutr. 69:79-97. doi:10.1080/1745039X.2015.1013664

Moter, V., and H. H. Stein. 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs12. J. Anim. Sci. 82:3518-3525. doi:10.2527/2004.82123518x

Noblet, J., and X. S. Shi. 1993. Comparative digestibility of energy and nutrients in growing pigs fed ad libitum and adults sows fed at maintenance. Livest. Prod. Sci. 34:137-152. doi:10.1016/0301-6226(93)90042-G

Noblet, J., and J. van Milgen. 2004. Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J. Anim. Sci. 82:E229-E238. doi:10.2527/2004.8213_supplE229x

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Oresanya, T. F., A. D. Beaulieu, and J. F. Patience. 2008. Investigations of energy metabolism in weanling barrows: The interaction of dietary energy concentration and daily feed (energy) intake. J. Anim. Sci. 86:348-363. doi:10.2527/jas.2007-0009

Robles, A., and R. C. Ewan. 1982. Utilization of energy of rice and rice bran by young pigs. J. Anim. Sci. 55:572-577. doi:10.2527/jas1982.553572x

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats. Recent advances in animal nutrition. Butterworths, London, UK. p. 77-81.

Saunders, R. M. 1985. Rice bran: Composition and potential food uses. Food Rev. Int. 1:465-495. doi:10.1080/87559128509540780

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Shi, X. S., and J. Noblet. 1993. Digestible and metabolizable energy values of ten feed ingredients in growing pigs fed ad libitum and sows fed at maintenance level; comparative contribution of the hindgut. Anim. Feed Sci. Technol. 42:223-236. doi:10.1016/0377-8401(93)90100-X

Warren, B. E., and D. J. Farrell. 1990. The nutritive value of full-fat and defatted Australian rice bran. III. The apparent digestible energy content of defatted rice bran in rats and pigs and the metabolisability of energy and nutrients in defatted and full-fat bran in chickens and adult cockerels. Anim. Feed Sci. Technol. 27:247-257. doi:10.1016/0377-8401(90)90086-N

# CHAPTER 7: EFFECTS OF MICROBIAL PHYTASE ON THE APPARENT AND STANDARDIZED TOTAL TRACT DIGESTIBILITY OF PHOSPHORUS IN RICE COPRODUCTS FED TO GROWING PIGS

**ABSTRACT:** The objectives of this experiment were to determine the apparent total tract digestibility (ATTD) and the standardized total tract digestibility (STTD) of P, and the effect of microbial phytase on ATTD and STTD of P in full-fat rice bran (FFRB), defatted rice bran (DFRB), brown rice, broken rice, and rice mill feed when fed to pigs. Ninety six barrows (initial BW of 19.4 ± 1.4 kg) were allotted to 12 diets with 8 replicate pigs per diet in a randomized complete block design. A basal diet based on corn and soybean meal was formulated. Five additional containing corn, soybean meal, and each rice coproduct were formulated, and the ratio between corn and soybean meal in these diets was similar to that in the basal diet. Six additional diets that were similar to the initial 6 diets with the exception that 1,000 units of microbial phytase were added to the diets were also formulated. The ATTD and STTD of P were calculated for each diet using the direct procedure and the ATTD and STTD of P in each rice coproduct were calculated using the difference procedure. Results of the experiment indicated that the concentration of P in feces was reduced ($P < 0.05$) from pigs fed diets with microbial phytase compared with pigs fed diets without phytase. No differences were observed between the basal diet and the broken rice diet, but the ATTD and the STTD of P in those diets was greater ($P < 0.05$) than in all other diets both without and with phytase. Among the rice coproducts, the greatest ($P < 0.05$) ATTD and STTD of P were observed for broken rice regardless of inclusion of phytase. If no microbial phytase was used, values for STTD of P in brown rice, FFRB, DFRB, and rice mill feed were not different, but if microbial phytase was included in the diet, ATTD

and STTD of P in brown rice was greater ($P < 0.05$) than in FFRB, DFRB, and rice mill feed. The STTD of P in brown rice, FFRB, and rice mill feed was greater ($P < 0.05$) if microbial phytase was used than if no microbial phytase was used. Addition of microbial phytase to the diets also increased ($P < 0.05$) the ATTD of Ca regardless of the rice coproducts used. In conclusion, the STTD of P is greater in broken rice than in all other rice coproducts. The STTD of P in brown rice, FFRB, DFRB, and rice mill feed is relatively low due to the high concentration of phytate in these ingredients, but addition of microbial phytase will increase the STTD of P in most rice coproducts.

## INTRODUCTION

Coproducts from the rice milling industry include rice hulls, rice bran, broken rice, and rice mill feed (Singh et al., 2014). Approximately 20% of the weight of paddy rice is rice hulls, which contains large quantities of lignin and silica, and therefore, is not used as a food or feed ingredient (Serna-Saldivar, 2010). Brown rice is the whole rice grain that is left after the hull layer has been removed. When white polished rice is produced for human consumption the brown layer is also removed and is called rice bran. Rice bran includes several sub layers within the pericarp and aleurone layers and makes up 8 to 10% of the weight of the paddy rice. Rice bran may be sold as full-fat rice bran (**FFRB**) with a concentration of ether extract of 14 to 24%, or it may be defatted and marketed as defatted rice bran (**DFRB**) with a concentration of ether extract of less than 5% (Sauvant et al., 2004).

Broken rice is made up of fragments and broken kernels of white rice grain that are generated during milling, and is used for brewing, rice flour production, or for animal feeding (USA-Rice-Federation, 2011). Rice mill feed is a combination of rice hulls, rice bran, and rice

polishings, but limited information is available about the nutritional value of rice mill feed fed to pigs (Stacey and Rankins, 2004).

Most P in rice coproducts is bound to phytate (Sauvant et al., 2004), which results in low digestibility of P by pigs, and the majority of phytate is located in the bran layers. As a consequence, rice bran has a greater concentration of phytate than other ingredients commonly used in diets for pigs (NRC, 2012). It is, therefore, likely that the digestibility of P in rice coproducts may be improved if microbial phytase is included in the diets. Therefore, the objective of this experiment was to test the hypothesis that the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P in rice coproducts fed to pigs is improved if microbial phytase is included in the diet.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Five rice coproducts were evaluated: broken rice, brown rice, FFRB, DFRB, and rice mill feed (Table 7.1). Brown rice was sourced from Augason Farms, Salt Lake City, UT, and broken rice was procured from Consumers Supply Distributing, North Sioux City, SD; DFRB and FFRB were purchased from NutraCea, Scotsdale, AR, and Triple Crown Nutrition, Inc., Wayzata, MN, respectively, and rice mill feed was obtained from Crescent Feed Co., Springfield, MO.

### *Animals and Housing*

Ninety six barrows that were the offspring of F-25 females that were mated to G-Performer males (Genetiporc, Alexandria, MN) with an average initial BW of 19.4 ± 1.4 kg were allotted to 12 diets in a randomized complete block design. The experiment was conducted in 3

blocks with 2 blocks each containing 36 pigs (3 replicates) and 1 block containing 24 pigs (2 replicates). Therefore, there were 8 replicate pigs per diet. Pigs were placed in metabolism cages that were equipped with a feeder and a nipple drinker, fully slatted floors, and a screen floor, which allowed for the total collection of feces.

***Diets and Feeding***

A basal diet based on corn and soybean meal was formulated (Table 7.2). Five additional diets were formulated by adding each of the 5 rice coproducts to the basal diet in such a way that the ratio between corn and soybean meal remained constant at 1.5:1. The rice coproducts and corn and soybean meal were the only sources of P in the diets. Six additional diets that were identical to the initial 6 diets with the exception that 1,000 units of microbial phytase (Optiphos; Enzyvia, Sheridan, IN) were included in each diet were also formulated.

Diets containing FFRB and DFRB were formulated to contain approximately 0.33% STTD of P, but because of the low P concentration in the other coproducts, diets containing brown rice, broken rice, or rice mill feed contained less STTD P. Vitamins and all minerals except P were included in the diets according to requirements (NRC, 2012). Feed was provided daily in an amount of 3 times the maintenance energy requirement (i.e., 197 kcal ME per $kg^{0.60}$; NRC, 2012). Pigs were fed twice daily at 0800 and 1700 h and water was provided on ad libitum basis.

***Sample Collection***

Pigs were fed experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed in the morning meals on d 6 (carmine blue) and d 11 (ferric oxide) and fecal collections were initiated when carmine blue appeared in the feces and

ceased when ferric oxide appeared (Kong and Adeola, 2014). Feces were collected twice daily and stored at -20ºC as soon as collected.

***Chemical Analyses***

Samples of ingredients, diets, and feces were analyzed for DM (Method 930.15; AOAC Int., 2007) and Ca and P (Method 985.01 A, B and C; AOAC Int., 2007). Diets and ingredients were also analyzed for ash (Method 942.05; AOAC Int., 2007). All ingredients were analyzed for GE by adiabatic bomb calorimetry, CP by combustion (Method 990.03; AOAC Int., 2007), acid hydrolyzed ether extract by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.06; AOAC Int., 2007), ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), and phytate concentration (Ellis and Morris, 1977). Phytase activity (Method 200.12; AOAC Int., 2007) was also analyzed in all diets.

***Calculation and Statistical Analysis***

The concentration of non-phytate-P and phytate-bound P in corn, soybean meal, and rice coproducts were calculated as previously described (Tran and Sauvant, 2004). The ATTD of P was calculated for each diet using the direct procedure using the following equation (Almeida and Stein, 2010).

ATTD (%) = [(Pi – Pf)/Pi] × 100,

where Pi is the total P intake (g) from d 6 to 11 and Pf is the total P output in the same period . The STTD of P was calculated for each diet by correcting the ATTD of P for the basal endogenous P loss, which was assumed to be 200 mg/kg DMI (Stein, 2011). Data from the corn-soybean meal diet were used to calculate the contribution of P from the basal diet to the diets that contained rice coproducts and the ATTD and STTD of P in each rice coproduct were calculated using the difference procedure, which assumes that there are not interactions between the test

ingredients and the ingredients in basal diets that alter the digestibility of the nutrient of interest (Kong and Adeola, 2014). The ATTD and STTD in rice coproducts were calculated according with the following equation (Mosenthin et al., 2007):

$$DA = (DD - DB \times SB)/SA,$$

where $D_A$ is the ATTD or STTD of P in test ingredient, DD is the ATTD or STTD of P in the diet with test ingredient, DB is the ATTD or STTD of P in basal diet, $S_B$ is the contribution level of basal diet, and SA is the contribution level of the P from test feed ingredient to the assay diet (%). The ATTD and STTD of ingredients without phytase were calculated using data from basal diet without phytase, and the ATTD and STTD of P in the ingredients with phytase were calculated using data from basal diet with phytase.

Outliers and homogeneity of the variances among treatments were tested using the UNIVARIATE procedure. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a 5 × 2 factorial. The fixed effects were the diet, phytase, and the interaction between diets and phytase. Block was considered a random effect. The LSMeans statement was used to calculate treatment means, and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and an alpha level of 0.05 was used to consider significance among dietary treatments.

## RESULTS

The concentrations of P were 2.58% in DFRB, 1.79% in FFRB, 0.63% in rice mill feed, 0.27% in brown rice, and 0.11% in broken rice (Table 7.1). Corn and soybean meal contained 0.20 and 0.57% P, respectively. The concentration of phytate-bound P in rice coproducts was 2.36% in DFRB, 1.36% in FFRB, 0.56% in rice mill feed, 0.22% in brown rice, and 0.06% in

broken rice. As a consequence 91.5, 90.5, 88.9, 81.5, and 54.0% of total P in FFRB, DFRB, rice mill feed, brown rice, and broken rice, respectively, was bound to phytate. Corn and soybean meal contained 0.37 and 0.13% phytate-bound P, respectively, which amounted to approximately 65% of total P. Calcium concentration was 0.01% in broken rice and brown rice, 0.11% in DFRB and rice mill feed, and 0.04% in FFRB. Corn and soybean meal contained 0.01 and 0.30% Ca, respectively.

All diets had concentrations of P and Ca that were in good agreement with the formulated values (Table 7.2). All diets without microbial phytase did not contain detectable levels of phytase, whereas diets with phytase analyzed between 840 and 1,700 units of phytase.

Daily intake of P was greater ($P < 0.05$) for pigs fed diets with FFRB or DFRB than for pigs fed diets containing broken rice, brown rice, rice mill feed, or the basal diet (Table 7.3). However, microbial phytase did not influence daily P intake. The concentration of P in feces was reduced ($P < 0.05$) from pig fed diets with microbial phytase compared with pig fed diets without phytase. The daily P output in feces from pigs fed diets with phytase was also less ($P < 0.05$) than in feces from pigs fed diets without microbial phytase, except for diets containing broken rice and rice mill feed (interaction $P < 0.05$).

The amount of P absorbed daily was greater ($P < 0.05$) for all diets with phytase than for diets without phytase. The greatest ($P < 0.05$) amount of P absorbed was from diets containing FFRB or DFRB. There were no differences in P absorbed between pigs fed diets containing broken rice and brown rice.

The ATTD of P was greater ($P < 0.05$) in diets with phytase compared with diets without phytase. No differences were observed between the basal diet and the broken rice diet, but the ATTD of P in those diets was greater ($P < 0.05$) than in all other diets. The least ($P < 0.05$)

ATTD of P was observed for diets containing FFRB, DFRB, or rice mill feed. Addition of microbial phytase to the diets did not influence the basal endogenous loss of P, but the STTD of P in diets with phytase was greater ($P < 0.05$) than in diets without phytase. If no phytase was used, pigs fed the basal diet or the diet containing broken rice had greater ($P < 0.05$) STTD of P than pigs fed all other diets, whereas pigs fed the FFRB diet had the least ($P < 0.05$) STTD of P. If microbial phytase was used, pigs fed the basal diet or the broken rice diet also had the greatest ($P < 0.05$) STTD of P, and pigs fed the FFRB or the DFRB diet had the least ($P < 0.05$) STTD of P. Values for the brown rice diet and the diet containing rice mill feed were intermediate between the broken rice diet and the FFRB and DFRB diets.

The ATTD and STTD of P in rice coproducts increased ($P < 0.05$) if microbial phytase was added to the diets (Table 7.4). Among the rice coproducts, the greatest ($P < 0.05$) ATTD and STTD of P were observed for broken rice, and if microbial phytase was used, FFRB, DFRB, and rice feed had less ($P < 0.05$) ATTD and STTD than brown rice.

Daily intake of Ca was greater ($P < 0.05$) for pigs fed with diets containing brown rice and rice mill feed diet with microbial phytase than for pigs fed other diets except the brown rice diet with phytase and the FFRB diet without phytase (Table 7.5). The concentration of Ca in feces and total daily Ca output from pigs fed diets with microbial phytase was less ($P < 0.05$) than from pigs fed diets without microbial phytase. Addition of microbial phytase increased ($P < 0.05$) the ATTD of Ca regardless of which diet was fed, and the ATTD of Ca was greater ($P < 0.05$) in diets with brown rice or broken rice than in all other diets, whereas the diets with FFRB and DFRB had the least ($P < 0.05$) ATTD of Ca.

# DISCUSSION

## *Composition of Ingredients*

The chemical composition of corn and soybean meal used in this experiment was in agreement with values reported by Almeida and Stein (2010), Rodríguez et al. (2013), and Rojas et al. (2013), but the concentration of phytate was greater in corn and less in soybean meal compared with data reported by NRC (2012). Most of the total P in cereals is bound to phytate, which results in low digestibility for pigs because they lack endogenous phytase to release the P from the phytate molecule. This results in relatively large output of P in the manure and reduces the availability of other minerals such as Ca, Mn, Zn, and Fe (Steiner et al., 2007).

In rice, 84 to 88% of phytate is stored in the aleurone layer, which is included in the rice bran fraction after processing of the rice (Reddy et al., 1982). As a consequence, the concentration of phytate and P in rice bran is very high compared with other plant ingredients, whereas the concentration of phytate and P in polished rice and broken rice is low. However, concentrations of P and phytate in all rice coproducts may vary depending on variety, climatic conditions, growing locations, soil type, and the quality of the milling process (Steiner et al., 2007).

The concentration of P, Ca, and phytate in brown rice used in this experiment concur with values reported by Reddy et al. (1982), Sauvant et al., 2004, and Li et al. (2006), although a greater concentration of P has also been reported (Yang et al., 2007). Broken rice in this experiment contained less P and Ca than reported previously, but the phytate-bound P was close to values in the literature (Sauvant et al., 2004; NRC, 2012).

The P concentration and phytate-bound P in FFRB were within the range reported previously, but the concentration of Ca was less than previously reported (Sauvant et al., 2004;

NRC, 2012; Abelilla, 2014). The concentration of P and phytate-bound P in DFRB were greater than reported by Sauvant et al. (2004)) and NRC (2012), whereas the concentration of Ca was in agreement with values reported previously. The concentrations of P and Ca in rice mill feed were less compared with values reported by Ofogo et al. (2008), but these values were greater than those observed in brown rice and broken rice and less than in FFRB or DFRB. To our knowledge, no values for the concentration of phytate in rice mill feed have been reported before.

***Digestibility of Phosphorus and Calcium***

The difference procedure was used to calculate the digestibility of P in rice coproducts. This procedure has the advantage that diets that are palatable to the pigs can be formulated, which may not always be the case if the direct procedure is used. In addition, the digestibility of P in ingredients with low concentration of P can be determined. However, accurate results for individual ingredients are obtained using the difference procedure only if the calculated digestibility of P in the basal diets is accurate and if there are no interactions between the basal and the ingredients used (Kong and Adeola, 2014). In the present experiment, the STTD of P in the basal diet without microbial phytase was slightly greater (50.0 vs. 43.4%) than the STTD of P that can be calculated for this diet from NRC (2012), but this is likely a result of the reduced concentration of phytate in the soybean meal used in this experiment compared with the soybean meal used by NRC (2012). This hypothesis is supported by the fact that the STTD of P for basal diet with microbial phytase is in agreement with STTD of P that can be calculated from Almeida and Stein (2010). It is, therefore, likely that results obtained in this experiment for basal diet are accurate, which indicates that results obtained for the rice coproducts are also accurate.

Values for STTD of P were calculated by correcting values for the ATTD of P for the basal endogenous loss of P, which was assumed to be 200 mg/kg DMI (Stein, 2011). This value is very good agreement with the basal endogenous loss of P (199 mg/kg DMI) that can be calculated from recently published equation (basal endogenous loss [g/kg DMI] = 2.23 × initial BW + 156.4; Son et al., 2013).

The ATTD of P in brown rice obtained in this experiment concurs with the value reported by Yang et al. (2007), whereas the values for ATTD and STTD of P in broken rice were greater than reported by Wu et al. (2008). The ATTD of P in diets containing FFRB without phytase is in agreement with the value reported by Agudelo et al. (2010), when 7.5% of FFRB was added to the basal diet, however, when the inclusion of FFRB was increased to 30%, the ATTD was less than observed in this experiment in which the inclusion of FFRB was 50%. The ATTD of P in diets containing FFRB with phytase was also greater in this experiment compared with Agudelo et al. (2010). In contrast, the ATTD and STTD of P for FFRB in this experiment were less than reported by Abelilla (2014). These differences may be a result of variation in the concentration of phytate in FFRB used in each experiment, but the concentration of phytate in the diets used by Agudelo et al. (2010) and Abelilla (2014) was not reported. It is also possible that the coproducts designated as FFRB may sometimes include other fractions of rice than only the bran depending on the quality of the milling process, and because of the large variation in the phytate concentration among different fractions of rice this may influence the ATTD and STTD of P in the rice bran. The ATTD and STTD of P in DFRB obtained in this experiment are in agreement with values reported by NRC (2012), but are greater than reported by Wu et al. (2008). To our knowledge, no values for ATTD and STTD of P in rice mill feed have been reported before.

The reason broken rice had the greatest ATTD and STTD of P is that the concentration of phytate in broken rice is less than in the other coproducts because of the removal of the aleurone layers during the milling process. In contrast, brown rice, FFRB, DFRB, and rice mill feed contain different proportions of the aleurone layer where phytate is stored, which is the reason the ATTD and STTD of P in these coproducts are less than in broken rice.

Positive effects of addition of microbial phytase to pig diets and ingredients to improve the P digestibility and reduce P output has been reported (Selle and Ravindran, 2008; Almeida and Stein, 2010; Goebel and Stein, 2011; Rojas and Stein, 2012; Rojas et al., 2013). However, there are limited data on the effects of phytase on ATTD or STTD of P in rice coproducts. In this experiment, addition of microbial phytase increased the ATTD and STTD of P in all rice coproducts, but the effect was relatively less in FFRB, DFRB, and rice mill feed than in broken rice and brown rice. This may be a result of differences in the chemical composition as a result of the milling process or interactions between intrinsic phytase in these rice coproducts and exogenous phytase (Selle and Ravindran, 2008). In previous experiments with FFRB, addition of phytase also increased the digestibility of P (Agudelo et al., 2010; Abelilla, 2014), which is most likely due to release of some of the phytate bound P (Selle and Ravindran, 2008).

The reduced daily output of Ca and increased ATTD of Ca that was observed as phytase was added to the diets, agree with previous reports (Goebel and Stein, 2011; González-Vega et al., 2013; Rodríguez et al., 2013), however, the effect was less in diets with broken rice that had less concentration of phytate compared with diets containing brown rice, DFRB, or FFRB. This observation is most likely due to greater availability of Ca in broken rice as a result of the reduced concentration of phytate and thus reduced formation of insoluble Ca-phytate complexes (Selle et al., 2009).

### *Conclusions*

The ATTD and STTD of P in broken rice were greater than in brown rice, FFRB, DFRB, and rice mill feed. The addition of microbial phytase to rice coproducts increased the ATTD and STTD of P and decreased the excretion of P from pigs fed diets containing all rice coproducts. Thus, the relatively low digestibility of P in rice coproducts can be increased by use of microbial phytase. The high concentration of P in several of the rice coproducts make these ingredients valuable sources of digestible P in diets for growing pigs if used in combination with microbial phytase. Addition of microbial phytase to rice coproducts also reduces the excretion of Ca and increases the ATTD of Ca in diets containing rice coproducts.

## TABLES

**Table 7.1**. Analyzed nutrient composition of soybean meal, corn, brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed, as-fed basis

| Item | Soybean meal | Corn | Brown rice | Broken rice | FFRB | DFRB | Rice mill feed |
|---|---|---|---|---|---|---|---|
| GE, kcal/kg | 4,071 | 3,848 | 3,841 | 4,399 | 5,044 | 4,348 | 4,251 |
| DM, % | 88.5 | 83.3 | 88.1 | 88.1 | 96.2 | 91.0 | 91.0 |
| CP, % | 50.3 | 6.6 | 9.5 | 7.7 | 15.3 | 17.1 | 7.2 |
| AEE[1], % | 1.1 | 2.0 | 3.1 | 1.4 | 19.3 | 1.1 | 5.0 |
| Ash, % | 5.6 | 0.8 | 1.2 | 1.2 | 8.0 | 12.0 | 14.2 |
| ADF, % | 5.0 | 3.1 | 1.4 | 0.5 | 9.1 | 12.0 | 44..0 |
| NDF, % | 6.8 | 8.6 | 2.7 | 0.6 | 14.1 | 19.3 | 45.7 |
| Ca, % | 0.3 | 0.01 | 0.01 | 0.01 | 0.04 | 0.1 | 0.1 |
| P, % | 0.6 | 0.2 | 0.3 | 0.1 | 1.8 | 2.6 | 0.6 |
| Phytate, % | 1.3 | 0.5 | 0.8 | 0.2 | 5.8 | 8.4 | 2.0 |
| Phytate-bound P,[2] % | 0.4 | 0.1 | 0.2 | 0.06 | 1.6 | 2.4 | 0.6 |
| Phytate-bound P, % of total P | 64.9 | 65.0 | 81.5 | 54.5 | 90.5 | 91.5 | 88.9 |
| Nonphytate P,[3] % | 0.2 | 0.07 | 0.05 | 0.05 | 0.2 | 0.2 | 0.07 |
| Nonphytate-bound P, % of total P | 35.1 | 35.0 | 18.5 | 45.4 | 9.5 | 8.5 | 11.1 |

[1]AEE = acid hydrolyzed ether extract.

[2]Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[3]Nonphytate P was calculated as the difference between total P and phytate-bound P.

**Table 7.2**. Composition of basal diet and diets containing brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), or rice mill feed without or with microbial phytase, as-fed basis

| Ingredient, % | Basal | Brown rice | Broken rice | FFRB | DFRB | Rice mill feed |
|---|---|---|---|---|---|---|
| Corn | 52.2 | 25.5 | 25.5 | 28.5 | 37.4 | 26.9 |
| Soybean meal | 35.0 | 17.0 | 17.0 | 19.0 | 25.0 | 18.0 |
| Rice co products | - | 50.0 | 50.0 | 50.0 | 30.0 | 40.0 |
| Sucrose | 6.4 | 1.05 | 1.05 | 0.1 | 1.2 | 8.65 |
| Soybean oil | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Limestone | 1.6 | 1.75 | 1.75 | 1.7 | 1.6 | 1.75 |
| Sodium chloride | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Vitamin mineral premix[2] | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Analyzed composition | | | | | | |
| Diets without microbial phytase | | | | | | |
| DM, % | 86.9 | 88.5 | 85.6 | 90.7 | 88.2 | 89.6 |
| Ca, % | 0.62 | 0.75 | 0.76 | 0.70 | 0.68 | 0.68 |
| P, % | 0.31 | 0.28 | 0.23 | 0.97 | 0.95 | 0.37 |
| Ash, % | 4.77 | 3.52 | 2.93 | 7.73 | 7.09 | 9.28 |
| Phytase, phytase units/kg | < 70 | < 70 | < 70 | < 70 | < 70 | < 70 |
| Diets with microbial phytase | | | | | | |
| DM, % | 87.5 | 87.9 | 88.0 | 90.5 | 87.8 | 90.2 |
| Ca, % | 0.68 | 0.82 | 0.66 | 0.70 | 0.67 | 0.72 |
| P, % | 0.31 | 0.29 | 0.22 | 1.03 | 0.91 | 0.39 |
| Ash, % | 4.59 | 3.69 | 3.49 | 7.26 | 7.52 | 8.95 |
| Phytase, phytase units/kg | 840 | 1,500 | 1,300 | 1,700 | 1,000 | 1,400 |

**Table 7.2**. Cont.

[1]All diets were produced without microbial phytase and with inclusion of 1,000 units per kilogram complete feed of microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN).

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

**Table 7.3**. Apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P (%) by pigs fed a basal corn-soybean meal based diet or diets containing brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), or rice mill feed without or with microbial phytase[1,2]

| Item | Feed intake, g DM/d | P intake, g/d | P in feces, % | P output, g/d | P absorbed, g/d | ATTD of P, % | Basal EPL,[3] mg/d | STTD of P[4], % |
|---|---|---|---|---|---|---|---|---|
| Without phytase | | | | | | | | |
| Basal diet | 837 | 3.09$^{d}$ | 1.83$^{e}$ | 1.70$^{e}$ | 1.36$^{f}$ | 44.4$^{cde}$ | 171.7 | 50.0$^{c}$ |
| Brown rice | 768 | 2.46$^{e}$ | 2.55$^{c}$ | 1.66$^{e}$ | 0.77$^{h}$ | 31.6$^{fg}$ | 153.9 | 38.0$^{e}$ |
| Broken rice | 733 | 2.05$^{e}$ | 2.03$^{d}$ | 1.10$^{f}$ | 0.93$^{gh}$ | 46.1$^{cd}$ | 147.3 | 53.5$^{c}$ |
| FFRB | 885 | 9.43$^{a}$ | 3.73$^{a}$ | 6.85$^{a}$ | 2.54$^{d}$ | 27.1$^{g}$ | 177.3 | 28.9$^{f}$ |
| DFRB | 890 | 9.55$^{a}$ | 3.81$^{a}$ | 6.47$^{a}$ | 3.04$^{c}$ | 32.0$^{f}$ | 178.3 | 35.4$^{e}$ |
| Rice mill feed | 843 | 3.6$^{cd}$ | 0.90$^{g}$ | 2.44$^{d}$ | 1.12$^{fg}$ | 31.7$^{fg}$ | 169.1 | 36.6$^{e}$ |
| With phytase | | | | | | | | |
| Basal diet | 862 | 3.15$^{d}$ | 1.20$^{f}$ | 1.10$^{f}$ | 1.96$^{e}$ | 65.1$^{a}$ | 173.2 | 70.8$^{a}$ |
| Brown rice | 740 | 2.42$^{e}$ | 1.69$^{e}$ | 0.99$^{f}$ | 1.35$^{f}$ | 58.5$^{b}$ | 148.3 | 63.7$^{b}$ |
| Broken rice | 777 | 2.21$^{e}$ | 1.37$^{f}$ | 0.78$^{f}$ | 1.24$^{f}$ | 63.7$^{a}$ | 158.5 | 71.3$^{a}$ |
| FFRB | 860 | 9.75$^{a}$ | 3.18$^{b}$ | 5.72$^{b}$ | 3.99$^{a}$ | 42.9$^{de}$ | 172.4 | 44.6$^{d}$ |
| DFRB | 856 | 8.84$^{b}$ | 3.13$^{b}$ | 5.19$^{c}$ | 3.47$^{b}$ | 41.2$^{e}$ | 171.5 | 43.1$^{d}$ |
| Rice mill feed | 923 | 4.04$^{c}$ | 0.70$^{h}$ | 2.08$^{de}$ | 1.98$^{e}$ | 48.6$^{c}$ | 185.6 | 53.2$^{c}$ |
| SEM | 42.6 | 0.32 | 0.06 | 0.18 | 0.11 | 1.7 | 9.3 | 1.61 |
| *P*-values | | | | | | | | |
| Diets | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Phytase | 0.41 | 0.68 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | 0.48 | < 0.001 |
| Diets × phytase | 0.10 | 0.04 | 0.002 | 0.007 | < 0.001 | < 0.001 | 0.09 | < 0.001 |
| *P*-values | | | | | | | | |

**Table 7.3**. Cont.

[a-h]Means within a column lacking a common superscript letter are different ($P < 0.05$).

[1]Microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN) was included at 1,000 units per kilogram complete feed.

[2]Data are means of 8 observations per treatment.

[3]EPL = basal endogenous P loss. The daily basal EPL was calculated by multiplying DMI by 200 mg/kg DMI (Stein, 2011).

[4]Values for STTD were calculated by correcting values for ATTD for basal EPL.

**Table 7.4.** Apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P (%) by pigs in brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed without or with microbial phytase[1,2]

| Item | ATTD | STTD |
|---|---|---|
| Without phytase | | |
| Brown rice | 19.2$^{f}$ | 31.7$^{ef}$ |
| Broken rice | 50.1$^{b}$ | 75.6$^{a}$ |
| FFRB | 24.3$^{ef}$ | 26.4$^{f}$ |
| DFRB | 30.8$^{de}$ | 33.1$^{def}$ |
| Rice mill feed | 24.4$^{ef}$ | 32.3$^{def}$ |
| With phytase | | |
| Brown rice | 49.8$^{b}$ | 64.5$^{b}$ |
| Broken rice | 60.8$^{a}$ | 79.8$^{a}$ |
| FFRB | 39.2$^{cd}$ | 41.3$^{cd}$ |
| DFRB | 35.2$^{cd}$ | 37.6$^{cde}$ |
| Rice mill feed | 39.5$^{c}$ | 46.7$^{c}$ |
| SEM | 3.05 | 3.29 |
| *P*-value | | |
| Ingredients | < 0.001 | < 0.001 |
| Phytase | < 0.001 | < 0.001 |
| Ingredient × phytase | 0.001 | 0.002 |

[a-f]Means within a column lacking a common superscript letter are different ($P < 0.05$).

[1]Microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN) was included at 1,000 units per kilogram of complete diet.

[2]Data are means of 8 observations per treatment.

**Table 7.5.** Apparent total tract digestibility (ATTD ) of Ca (%) by pigs in a basal corn-soybean meal based diet or diets containing brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), or rice mill feed without or with microbial phytase[1,2]

| Item | Ca intake, g/d | Ca in feces, % | Ca output, g/d | Ca absorbed, g/d | ATTD of Ca, % |
|---|---|---|---|---|---|
| Without phytase | | | | | |
| Basal diet | 6.13$^{de}$ | 3.59 | 3.28 | 2.95$^{d}$ | 46.8 |
| Brown rice | 6.42$^{cde}$ | 4.06 | 2.67 | 3.82$^{bc}$ | 59.2 |
| Broken rice | 6.51$^{cd}$ | 4.25 | 2.46 | 4.19$^{b}$ | 63.4 |
| FFRB | 6.83$^{abc}$ | 2.26 | 4.59 | 2.73$^{d}$ | 39.7 |
| DFRB | 6.78$^{bc}$ | 2.47 | 3.95 | 2.87$^{d}$ | 38.3 |
| Rice mill feed | 6.56$^{bcd}$ | 1.45 | 3.68 | 2.66$^{d}$ | 41.0 |
| With phytase | | | | | |
| Basal diet | 6.72$^{bc}$ | 2.90 | 2.65 | 4.20$^{b}$ | 61.4 |
| Brown rice | 7.06$^{ab}$ | 3.44 | 2.04 | 5.02$^{a}$ | 71.0 |
| Broken rice | 5.85$^{e}$ | 3.83 | 2.12 | 3.81$^{bc}$ | 64.5 |
| FFRB | 6.66$^{bcd}$ | 2.05 | 3.56 | 3.08$^{d}$ | 46.1 |
| DFRB | 6.54$^{bcd}$ | 2.00 | 3.31 | 3.22$^{cd}$ | 49.2 |
| Rice mill feed | 7.37$^{a}$ | 1.24 | 3.41 | 3.77$^{bc}$ | 50.7 |
| SEM | 0.37 | 0.19 | 0.26 | 0.28 | 3.35 |
| *P*-value | | | | | |
| Diets | 0.005 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Phytase | 0.159 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Diets × phytase | 0.001 | 0.687 | 0.571 | 0.002 | 0.353 |

[a-e]Means within column lacking a common superscript letter are different ($P < 0.05$).

[1]Microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN) was included at 1,000 units per kilogram complete diet.

[2]Data are means of 8 observations per treatment.

## LITERATURE CITED

Abelilla, J. J. 2014. Standardized total tract digestibility of phosphorus in rice bran with and without phytase supplementation in swine diets. MS Thesis, Univ. of the Philippines Los Baños, the Philippines.

Agudelo, J. H., M. D. Lindemann, and G. L. Cromwell. 2010. Phosphorus utilization in growing pigs fed a phosphorus deficient diet supplemented with a rice bran product and amended with phytase. Rev. Colomb. Cienc. Pecu. 23:429-443.

Almeida, F. N., and H. H. Stein. 2010. Performance and phosphorus balance of pigs fed diets formulated on the basis of values for standardized total tract digestibility of phosphorus. J. Anim. Sci. 88:2968-2977. doi:10.2527/jas.2009-2285

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

Ellis, R., and E. R. Morris. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem. 77:536-539.

Goebel, K. P., and H. H. Stein. 2011. Phosphorus digestibility and energy concentration of enzyme-treated and conventional soybean meal fed to weanling pigs. J. Anim. Sci. 89:764-772. doi:10.2527/jas.2010-3253

González-Vega, J. C., C. L. Walk, Y. Liu, and H. H. Stein. 2013. Determination of endogenous intestinal losses of calcium and true total tract digestibility of calcium in canola meal fed to growing pigs. J. Anim. Sci. 91:4807-4816. doi:10.2527/jas.2013-6410

Kong, C., and O. Adeola. 2014. Evaluation of amino acid and energy utilization in feedstuff for swine and poultry diets. Asian-Australas. J. Anim. Sci. 27:917-925. doi:10.5713/ajas.2014.r.02

Li, X. L., S. L. Yuan, X. S. Piao, C. H. Lai, J. J. Zang, Y. H. Ding, L. J. Han, and I. K. Han. 2006. The nutritional value of brown rice and maize for growing pigs. Asian-Australas. J. Anim. Sci. 19:892-897. doi:10.5713/ajas.2006.892

Mosenthin, R., A. J. M. Jansman, and M. Eklund. 2007. Standardization of methods for the determination of ileal amino acid digestibilities in growing pigs. Livest. Sci. 109:276-281. doi:10.1016/j.livsci.2007.01.020

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Ofogo, S. T., S. Kehraus, E. A. Iyayi, and K. H. Sudekem. 2008. Rice mill feed: an agro-industrial by product wih potential for rural development. In: Conference on International Research of Food Security, Rural Resoruce Management and Rural Development, University of Hohenheim, Germany http://www.researchgate.net/publication (Accessed 15 July 2014).

Reddy, N. R., S. K. Sathe, and D. K. Salunkhe. 1982. Phytates in Legumes and Cereals. In: E. M. M. C.O. Chichester and G. F. Stewart, editors, Adv. Food Res. 28. Academic Press. p. 1-92. doi:10.1016/S0065-2628(08)60110-X

Rodríguez, D. A., R. C. Sulabo, J. C. González-Vega, and H. H. Stein. 2013. Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs. Can. J. Anim. Sci. 93:493-503. doi:10.4141/cjas2013-020

Rojas, O. J., Y. Liu, and H. H. Stein. 2013. Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 91:5326-5335. doi:10.2527/jas.2013-6324

Rojas, O. J., and H. H. Stein. 2012. Digestibility of phosphorus by growing pigs of fermented and conventional soybean meal without and with microbial phytase. J. Anim. Sci. 90:1506-1512. doi:10.2527/jas.2011-4103

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats, Recent advances in animal nutrition. Butterworths, London, UK. p. 77-81.

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Selle, P. H., A. J. Cowieson, and V. Ravindran. 2009. Consequences of calcium interactions with phytate and phytase for poultry and pigs. Livest. Sci. 124:126-141. doi:10.1016/j.livsci.2009.01.006

Selle, P. H., and V. Ravindran. 2008. Phytate-degrading enzymes in pig nutrition. Livest. Sci. 113:99-122. doi:10.1016/j.livsci.2007.05.014

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Singh, A., M. Das, S. Bal, and R. Banerjee. 2014. Rice processing. In: R. P. Ferrerira-Guiné and P. M. dois-Reis-Correia, editors, Engineering aspects of cereal and cereal-based proudcts. CRC Press, Boca Raton, FL. p. 71-96.

Son, A. R., S. Y. Shin, and B. G. Kim. 2013. Standardized total tract digestibility of phosphorus in copra expellers, palm kernel expellers, and cassava root fed to growing pigs. Asian-Australas. J. Anim. Sci. 26:1609-1613. doi:10.5713/ajas.2013.13517

Stacey, W. N., and D. L. Rankins. 2004. Rice mill feed as a replacement for broiler litter in diets for growing beef cattle. J. Anim. Sci. 82:2193-2199. doi:10.2527/2004.8272193x

Stein, H. H. 2011. Standardized total tract digestibility (STTD) of phosphorus. In: Proc. Midwest Swine Nutr. Conf., Indianapolis, IN. p. 47-52.

Steiner, T., R. Mosenthin, B. Zimmermann, R. Greiner, and S. Roth. 2007. Distribution of phytase activity, total phosphorus and phytate phosphorus in legume seeds, cereals and cereal by-products as influenced by harvest year and cultivar. Anim. Feed Sci. Technol. 133:320-334. doi:10.1016/j.anifeedsci.2006.04.007

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value. In: A. Ponter, D. Sauvant, J.-M. Perez and G. Tran, editors, Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses and fish. Wageningen Academic Publishers, Wageningen, the Netherlands. p. 17-24.

USA-Rice-Federation. 2011. Rice technical information kit. The complete guide for using U. S. rice as an ingredient. https://www.usarice.com (Acceseed 21 January 2013).

Wu, X., Z. Ruan, Y. G. Zhang, Y. Q. Hou, Y. L. Yin, T. J. Li, R. L. Huang, W. Y. Chu, X. F. Kong, B. Gao, and L. X. Chen. 2008. True digestibility of phosphorus in different resources of feed ingredients in growing pigs. Asian-Australas. J. Anim. Sci. 21:107-119. doi:10.5713/ajas.2008.70143

Yang, H., A. K. Li, Y. L. Yin, T. J. Li, Z. R. Wang, G. Wu, R. L. Huang, X. F. Kong, C. B. Yang, P. Kang, J. Deng, S. X. Wang, B. E. Tan, Q. Hu, F. F. Xing, X. Wu, Q. H. He, K. Yao, Z. J. Liu, Z. R. Tang, F. G. Yin, Z. Y. Deng, M. Y. Xie, and M. Z. Fan. 2007. True phosphorus digestibility and the endogenous phosphorus outputs associated with brown rice for weanling pigs measured by the simple linear regression analysis technique. Animal. 1:213-220. doi:10.1017/S1751731107257945

# CHAPTER 8: EFFECTS OF FULL FAT OR DEFATTED RICE BRAN ON GROWTH PERFORMANCE AND BLOOD CHARACTERISTICS OF WEANLING PIGS

**ABSTRACT:** The objective of this experiment was to determine the effect of increased levels of full fat rice bran (FFRB) or defatted rice bran (DFRB) in diets without or with supplementation of an exogenous xylanase on growth performance and blood characteristics in weanling pigs. A total of 532 pigs (initial BW: 9.3 ± 0.5kg) were allotted to 14 diets in 4 blocks and 8 replicate pens per diet, in a randomized complete block design in a 2 × 2 × 3 factorial arrangement. There were 4 or 5 pigs per pen. A basal diet containing corn, soybean meal, and whey powder and 6 diets containing corn, soybean meal, whey powder, and 10, 20, or 30% FFRB or 10, 20, or 30% DFRB were used. Seven additional diets that were similar to the initial 7 diets with the exception that they also contained 16,000 units/kg of microbial xylanase (Econase XT-25, AB Vista, Marlborough, UK) were also formulated. On the last day of the 23 d experiment, 2 blood samples were collected from one pig in each pen. Tumor necrosis factor- α (TNF- α), IgA, and peptide YY (PYY) were measured in plasma samples and blood urea nitrogen (BUN), total protein, and albumin were measured in serum samples. Initial and final BWs were not affected by the inclusion level of FFRB or DFRB, or by the addition of xylanase. The ADFI linearly decreased ($P < 0.05$) as inclusion of FFRB increased in diets and there was a tendency ($P = 0.08$) for reduced ADFI as DFRB was increased in the diets. Pigs fed diets containing DFRB had greater ADFI ($P < 0.05$) than pigs fed diets containing FFRB. The ADG increased and then decreased (quadratic, $P < 0.05$) with increasing level of FFRB or DFRB, in the diets. The G:F ratio increased linearly and quadratically ($P < 0.05$) as the inclusion of FFRB increased, and G:F was greater ($P < 0.05$) in pigs fed diets containing FFRB than in pigs fed diets containing DFRB. The concentration of BUN linearly decreased ($P < 0.05$) when pigs were fed diets containing

increasing levels of FFRB or DFRB. There was a tendency for the concentrations of TNF-α and PYY to decrease linearly ($P = 0.09$ and $P = 0.075$, respectively) as the inclusion of FFRB increased in the diet. In conclusion, ADG of weanling pigs was not affected by at least 20% FFRB or DFRB, and inclusion of 30% of DFRB has no effect on G:F whereas 30% FFRB will increase G:F. However, microbial xylanase did not influence growth performance under the conditions of this experiment and there was minimal influence of rice coproducts of xylanase on blood characteristics.

## INTRODUCTION

Rice bran is a coproduct of rice milling and represents approximately 12.4% of paddy rice (Serna-Saldivar, 2010). Concentrations of total dietary fiber and soluble dietary fiber in full fat rice bran (**FFRB)** and defatted rice bran (**DFRB**) range between 20 and 50% and 2 and 3%, respectively (Hargrove, 1994). Soluble dietary fiber may be fermented by intestinal microbes and may promote the colonization of a healthy intestinal microbiota (Herfel et al., 2013). Inclusion of 10% FFRB in diets fed to mice increased serum concentrations of IgA indicating an improved immune response and also increased colonization of *Lactobacillus*, which indicates that consumption of rice bran may induce a prebiotic effect in mice (Henderson et al., 2012). Ingredients with prebiotic effects usually reduce infection by pathogens, resulting in a reduced inflammatory response (Henderson et al., 2012). Likewise, inclusion of 10% stabilized FFRB improved feed efficiency and increased the concentration of colonic bifidobacteria in weanling pigs (21 to 49 d) indicating that stabilized FFRB also may have prebiotic properties in weanling pigs (Herfel et al., 2013).

However, the high concentration of non-starch polysaccharides (**NSP**) in rice coproducts may have negative effects on the utilization of nutrients by pigs and may restrict the inclusion in diets. Addition of exogenous xylanase to wheat coproducts, which also have high concentrations of NSP, may improve digestibility of energy (Nortey et al., 2007; Zijlstra et al., 2010), and recent data from our laboratory indicate that the DE and ME in both FFRB and DFRB are increased if exogenous xylanase is added to the diet (Casas and Stein, 2016). Therefore, the objectives of this experiment were to determine the effects of increased inclusion levels of FFRB or DFRB to diets without or with exogenous xylanase on growth performance, and blood concentrations of indicators for protein utilization, inflammatory responses, and prebiotic effects.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

### *Animals and Housing*

A total 532 pigs (initial BW: 9.3 ± 0.5 kg) were weaned at 3 weeks of age, fed a common diet for 2 weeks post-weaning, and then allotted to treatments using a completely randomized block design. Pigs were blocked by farrowing group with 2 replicates selected from each of 4 farrowing groups, with group farrowing every other week. Pigs were the offspring of Line 359 boars mated to C-46 sows (Pig Improvement Company, Hendersonville, TN). Pigs were allotted to 14 dietary treatments, with 28 pens of 5 pigs (3 gilts and 2 barrows or 2 gilts and 3 barrows) in blocks 1, 2, and 4, and 28 pens of 4 pigs (2 gilts and 2 barrows) in block 3. There were 2 replicate treatments per block for a total of 8 replicates per treatment. Pigs were housed in pens (1.2 × 1.4 m) with fully slatted floors for block 1 and 2 and mesh floors for blocks 3 and 4, each

pen was equipped with a feeder and a nipple drinker and the room temperature was set at 28ºC at the beginning of the experiment and reduced by 1ºC/wk thereafter.

***Diets and Feeding***

Defatted rice bran was purchased from Riceland Foods (Stuttgart, AR), FFRB was sourced from RiceBran Technologies (Scottsdale, AZ), whey powder was purchased from Associate Milk Producers (New Ulm, MN), and corn and soybean meal were sourced from University of Illinois Feed Mill (Champaign, IL;Table 8.1). A basal diet containing corn, soybean meal, and whey powder and 6 diets containing corn, soybean meal, whey powder, and 10, 20, or 30% FFRB, or 10, 20, or 30% DFRB were used (Tables 8.2 and 8.3). Diets were formulated to be equal in concentration of standardized ileal digestible indispensable AA and meet or exceed requirements for vitamins and minerals for 9 to 25 kg weanling pigs (NRC, 2012). All diets also contained 1,500 units per kg of microbial phytase (Quantum Blue, AB Vista, Marlborough, UK). Seven additional diets that were similar to the initial 7 diets with the exception that they also contained 16,000 units per kg of microbial xylanase (Econase XT-25, AB Vista, Marlborough, UK) were also formulated. Therefore, a total of 14 diets were used. Pigs were fed experimental diets for 23 d and feed was provided on an ad libitum basis with water being available at all times. Pig weights were recorded at the start of the experiment and on the last d of the experiment. The amount of feed offered to each pen was recorded daily and the amount of feed left in the feeder was recorded on the last d of the experiment to calculated total feed disappearance for each pen.

***Blood Collection and Analysis***

At the last d of the experiment, the pig in each pen with a BW that was closest to the pen average was identified and 2 blood samples were collected from the jugular vein of this pig. One

sample was collected in a vacutainer without EDTA and the other sample was collected into a vacutainer containing EDTA. All samples were centrifuged at 1,500 × g at 4ºC for 15 min to collect plasma and serum, respectively. All samples were then stored at -20ºC until analyzed.

Tumor necrosis factor-α (**TNF- α**), IgA, and peptide YY (**PYY**) were measured in plasma samples using ELISA kits according to the recommendations from the manufacturer (R&D Systems, Inc., Minneapolis, MN, Bethyl Laboratories, Inc., Montgomery, TX; and MyBioSource, Inc., San Diego, CA, respectively). All samples were analyzed in duplicate. Serum samples were analyzed for blood urea nitrogen (**BUN**), albumin, and total protein using a Beckman Coulter Clinical Chemistry AU analyzer (Beckman Coulter, Inc., Brea, CA).

***Analyses of Ingredients and Diets***

Diets and ingredients were analyzed for DM (Method 930.15; AOAC Int., 2007) and ash (Method 942.05; AOAC Int., 2007), and GE was analyzed on an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) using benzoic acid as the standard for calibration. Crude protein was analyzed by combustion (Method 990.03; AOAC Int., 2007) using an Elementar Rapid N-cube Protein/Nitrogen apparatus (Elementar Americas Inc., Mt Laurel, NJ) and acid hydrolyzed ether extract was analyzed (**AEE**) using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by fat extraction (Ankom XT15 Extractor, Ankom Technology, Macedon, NY). Concentrations of ADF and NDF were analyzed using Ankom Technology method 12 and 13, respectively (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY). Ingredients and diets were also analyzed for Ca and P using inductively coupled plasma spectroscopy (Method 985.01 A, B, and C; AOAC Int., 2007) and for starch (Method 979.10; AOAC Int., 2007) and AA [Method 982.30 E (a, b, c); AOAC Int., 2007]. Phytase activity and xylanase activity in all diets were analyzed by

ELISA methods using Quantiplate kits for Quantum Blue (ESC Standard Analytical Method SAM099, AB Vista, Marlborough, UK) and Quantiplate kits for Econase XT (ESC Standard SAM 115, AB Vista, Marlborough, UK), respectively. Bulk density was determined as was previously described by Cromwell et al. (2000) and water binding capacity was measured as described by Robertson et al. (2000).

***Calculations and Statistical Analysis***

Data were summarized to calculate ADG, ADFI, and G:F. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with a randomized complete block design in a 2 × 2 × 3 factorial arrangement. The main effects in the initial model were xylanase, ingredient, inclusion level and the interactions between ingredient, xylanase, and inclusion levels. However, there were no significant effects of xylanase and no interactions between xylanase and ingredient or inclusion level; therefore, xylanase and the interactions between xylanase and ingredient were removed and the final model included only diet as main effect. Outliers and normality of data among treatments were tested using the UNIVARIATE procedure. Contrast statements were used to determine the effects of FFRB and DFRB; the linear and quadratic effects of inclusion level of FFRB or DFRB on all response variables were also analyzed using contrast statements. The pen was the experimental unit for all analyses and an alpha value of 0.05 was used to assess significance among dietary treatments. Tendencies were considered at $0.05 \leq P < 0.10$.

## RESULTS

### *Diet Composition*

The GE of the diets containing FFRB was between 4,151 kcal/kg and 4,366 kcal/kcal, whereas the GE in diets containing DFRB was between 4,033 and 4,059 kcal/kg. All diets contained approximately 20% CP and 1.38% Lys (Table 8.3). Diets containing FFRB contained between 6.57 and 10.13% AEE, but diets with DFBR contained approximately 6% AEE. The content of ADF increased from approximately 3% in the basal diet to 5 to 6% as FFRB or DFRB increased in the diets. The analyzed concentration of Ca in diets with FFRB was 0.8%, whereas in diets containing DFRB varied between 0.96 to 1.2%, and the analyzed concentration of P increased as the inclusion of FFRB and DFRB increased in the diets. The analyzed phytase activity in experimental diets was between 1,320 and 2,470 phytase units per kg. Xylanase activity was not detected in diets without xylanase, whereas in diets with xylanase, values were between 20,400 and 22,800 xylanase units per kg.

### *Effects of Rice Bran*

Initial and final BW were not affected by the inclusion of FFRB or DFRB in the diets (Table 8.4). However, ADFI decreased linearly ($P < 0.05$) as inclusion of FFRB increased in diets and there was a tendency for reduced ADFI as the concentration of DFRB increased in the diets (linear, $P = 0.08$). Pigs fed diets containing DFRB had greater ADFI ($P < 0.05$) than pigs fed diets containing FFRB. Intake of ME decreased linearly ($P < 0.05$) as the inclusion of FFRB and DFRB increased in the diets. The ADG increased and then decreased as increasing concentrations of FFRB were included in the diets (quadratic, $P < 0.05$), and this was also the case when the concentrations of DFRB increased in the diets (quadratic, $P < 0.05$). The G:F ratio was not affected by the inclusion of DFRB, but increased (quadratic, $P < 0.05$) as the inclusion

of FFRB increased. The G:F ratio was greater ($P < 0.01$) in pigs fed diets containing FFRB than in pigs fed diets containing DFRB.

The concentration of BUN linearly decreased ($P < 0.05$) when pigs were fed diets containing increasing levels of FFRB or DFRB and there was a tendency ($P < 0.06$) for pigs fed FFRB to have less BUN than pigs fed DFRB (Table 8.5). Concentrations of TNF-α were between 105.5 and 163.0 ng/mL and there was a tendency for the concentration of TNF-α to decrease linearly ($P < 0.09$) as the inclusion of FFRB increased in the diet, but that was not the case when DFRB increased in the diets. Concentrations of total protein, albumin and IgA were not affected by FFRB or DFRB. Concentrations of PYY were between 2.29 and 2.84 ng/mL and there was a tendency for a reduced concentration of PYY in plasma (linear, $P = 0.075$) as the inclusion of FFRB increased in the diets, but increasing concentrations of DFRB did not affect the concentration of PYY.

***Effects of Microbial Xylanase***

There was no effect of the addition of xylanase on any of the growth performance data that were calculated in this experiment (Table 8.6). Likewise, addition of microbial xylanase to the diets did no influence BUN or other protein parameters in the blood or concentration of TNF-α, Ig A, or PYY.

## DISCUSSION

The analyzed concentration of CP and AA in FFRB and DFRB agree with previous reports (Sauvant et al., 2004; NRC, 2012; Stein et al., 2016). The concentration of NDF, starch, and AEE in FFRB used in this experiment were 15.2, 21.9, and 19.5%, respectively, whereas the values reported by NRC (2012) are 26.3, 27.0, and 19.5%, respectively. Likewise, the

concentrations of these nutrients in DFRB were 18.1, 18.6, and 7.1% and the values reported by NRC (2012) are 23.56, 26.25, and 3.57%, respectively. The differences in the composition of ingredients were reflected in the nutritional composition of the diets in which analyzed values for NDF were lower than calculated and AEE values were greater than values calculated from NRC (2012). The analyzed concentration of Ca in FFRB was 0.04%, which is less than reported by Sauvant et al., 2004 and NRC, 2012; but agrees with the values reported by Casas and Stein (2015). In contrast, the concentration of Ca in DFRB used in this experiment was greater than previous values. The high concentration of Ca in DFRB also was reflected in the analyzed composition of the diets. The variation on the composition of these coproducts may be a result of differences among rice mills in the milling process in which some fractions of the hulls and varying proportions of starch may be included in the rice bran. The concentration of P in the diets also increased as FFRB or DFRB increased in the diets, which is a consequence of the high concentrations of P in these ingredients and, therefore, something that was expected because FFRB and DFRB have very high concentration of P (NRC, 2012).

The reason pigs fed diets containing DFRB had greater ADFI than pigs fed diets containing FFRB was probably that diets containing DFRB had reduced concentrations of ME compared with diets containing FFRB. Similar results were observed in growing pigs from 19 to 45 kg fed diets containing DFRB (Warren and Farrell, 1990).

The quadratic response to ADG resulting from inclusion of FFRB or DFRB indicates that a least 20% FFRB or DFRB may be included in the diets for weanling pigs without reducing ADG of pigs. This observation is in agreement with results of previous experiments, in which inclusion of 10% FFRB or 20% DFRB did not affect ADG of pigs from 5 to 10 kg or from 19 to 45kg, respectively (Warren and Farrell, 1990; Herfel et al., 2013).

The quadratic increase in G:F that was observed as FFRB increased in diets is a reflection of the greater concentration of ME in FFRB than in the basal diet. The greater G:F observed in pigs fed diets containing FFRB compared with DFRB, is also a consequence of the greater ME in FFRB compared with DFRB (Casas and Stein, 2016). However, the G:F was not affected by inclusion level of DFRB, which concurs with results reported by Warren and Farrell (1990). This observation indicates that the ME in DFRB may have been underestimated because if the ME in diets containing DFRB were reduced compared with the basal diet, G:F should also have been reduced.

The relatively high concentration of NDF in FFRB and DFRB is believed to be one of the main factors that restrict the utilization of these ingredients in diets for weanling pigs. Approximately 42% of NSP in FFRB are insoluble non-cellulosic polysaccharides that mainly consist of arabinoxylans (Ngoc et al., 2012). Xylanases have been used to improve the digestibility of energy and nutrients in coproducts from wheat that also contain arabinoxylans (Nortey et al., 2007; Woyengo et al., 2008), but data for effects of xylanase on growth performance of pigs fed diets containing rice bran have not been reported. The lack of an effect of xylanase on growth performance of the pigs that was observed in this experiment may be a consequence of too low inclusion rates of FFRB and DFRB, and therefore, not enough substrate for the enzyme. Likewise, it is possible that the energy released from diets containing FFRB or DFRB with xylanase, was not used with the same efficiency as other nutrients because xylanase may only hydrolyze the xylose backbone of the arabino-xylan molecule, and energy would then obtained only via microbial fermentation.

The efficiency of utilization of N in pigs may be estimated by measuring BUN (Kohn et al., 2005). The linear reduction in the concentration of BUN that was observed as FFRB and

DFRB increased in the diets may, at least partly, be a result of the decreased ADFI observed for these diets. However, the reduction in BUN also indicates that AA were better utilized in these diets and that less deamination of AA was taking place in pigs fed diets containing FFRB or DFRB compared with pigs fed the control diet. Concentrations of total protein and albumin were within the normal physiological ranges (Tumbleson and Kalish, 1972), and the lack of differences among treatments indicates that FFRB and DFRB did not change serum protein concentration.

Results of previous research have indicated that rice bran may improve the immune response and increase systemic and intestinal concentrations of IgA in mice, and it was hypothesized that rice bran may acts as a substrate for commensal bacteria in the intestine (Henderson et al., 2012). Similar effects were observed in gnotobiotic pigs that were infected with rotavirus (Yang et al., 2014). However, in the present experiment, no differences were observed in the concentrations of IgA in response to inclusion of FFRB or DFRB. The reason for this observation may be that there were not enough immunological stimuli to induce changes in plasma concentration of IgA, because pigs used in this experiment were of high health status.

Concentration of TNF-α usually increases after infections or injuries in different tissues of the animal and high concentrations of TNF-α may induce inflammatory responses that may reduce ADFI (Langhans and Hrupka, 1999). The tendency for decreasing concentrations of TNF-α in plasma observed in pigs fed diets with increasing concentrations of FFRB indicates a potential for reducing inflammatory responses in the intestine by including FFRB in the diets, which concurs with the lack of changes in the concentrations of IgA. However, additional research is needed to determine the response to FFRB in pigs that are kept in environments with

greater immunological challenges. Research is also needed to identify the components in FFRB that may influence immune responses in pigs.

Peptide YY is synthetized in the distal portion of the small intestine in response to neural or nutritional stimuli and functions to regulate feed intake and homeostasis of energy (Ueno et al., 2008). Increasing energy intake may induce greater concentrations of PYY in humans (Ito et al., 2006). Concentrations of PYY in plasma of pigs allowed ad libitum intake of feed were 2.2 ± 0.2 ng/mL and values did not change during the day-night cycle (Ito et al., 2006). Concentrations of PYY in plasma observed in this experiment were in agreement with values previously reported, and the tendency for a linear decrease that was observed as the concentration of FFRB increased in the diets, is likely a result of the reduction in ADFI of pigs fed diets containing FFRB.

The lack of a response to the microbial xylanase in plasma concentrations of IgA, TNF-α, and PYY was expected because of the lack of response in growth performance. However, it is possible that a different response would be observed if pigs of a lower health status were used, but research to confirm this hypothesis has not been reported.

In conclusion, increased inclusion of FFRB and DFRB in diets fed to weanling pigs decreased the ADFI, and improved G:F ratio in pigs fed FFRB. Pigs fed diets containing FFRB also had greater G:F than pigs fed diets containing DFRB, and ADG increased quadratically with the greatest values observed if 10 to 20% FFRB or DFRB was included in the diets. Concentrations of TNF-α in pigs fed diets containing FFRB had a tendency to decrease, which may indicate a potential probiotic effect of FFRB. Concentrations of PYY tended to decrease as the concentration of FFRB increased in the diets, but there was no effect of inclusion of DFRB on concentration of PYY, indicating that the energy status of the pigs was not changed by DFRB

indicating that the energy status of the pigs was not changed by DFRB. Concentrations of BUN decreased if FFRB or DFRB was included in the diets indicating a better balance of AA in these diets compared with the requirements of the pigs. There was no effect of the addition of microbial xylanase to diets containing FFRB or DFRB on variables tested.

## TABLES

**Table 8.1**. Analyzed nutrient composition of corn, soybean meal, whey powder, full fat rice bran (FFRB), and defatted rice bran (DFRB)

| Item | Corn | Soybean meal | Whey powder | FFRB | DFRB |
|---|---|---|---|---|---|
| GE, kcal/kg | 3,929 | 4,170 | 3,720 | 4,856 | 3,952 |
| DM, % | 88.47 | 88.37 | 86.84 | 96.45 | 90.16 |
| CP, % | 6.69 | 47.27 | 13.2 | 13.42 | 16.28 |
| AEE[1], % | 3.35 | 1.63 | 1.95 | 19.51 | 7.11 |
| Ash, % | 8.02 | 8.68 | 7.75 | 9.4 | 13.14 |
| Starch, | 56.97 | 0.92 | 0.35 | 21.89 | 18.58 |
| ADF, % | 2.36 | 5.17 | - | 8.43 | 9.17 |
| NDF, % | 7.15 | 6.82 | - | 15.24 | 18.1 |
| Ca, % | 0.04 | 0.56 | 0.51 | 0.04 | 0.9 |
| P, % | 0.22 | 0.57 | 0.63 | 1.78 | 1.95 |
| Indispensable AA, % | | | | | |
| Arg | 0.29 | 3.42 | 0.38 | 1.05 | 1.28 |
| His | 0.23 | 1.36 | 0.29 | 0.40 | 0.47 |
| Ile | 0.24 | 2.21 | 0.62 | 0.48 | 0.57 |
| Leu | 0.81 | 3.61 | 1.15 | 0.93 | 1.10 |
| Lys | 0.24 | 2.97 | 0.98 | 0.68 | 0.78 |
| Met | 0.15 | 0.65 | 0.19 | 0.27 | 0.33 |
| Phe | 0.32 | 2.35 | 0.41 | 0.57 | 0.67 |
| Thr | 0.23 | 1.78 | 0.73 | 0.50 | 0.59 |
| Trp | 0.06 | 0.67 | 0.22 | 0.14 | 0.21 |
| Val | 0.34 | 2.41 | 0.67 | 0.76 | 0.90 |
| Total | 2.91 | 21.43 | 5.64 | 5.78 | 6.90 |

**Table 8.1.** Cont.

| Item | Corn | Soybean meal | Whey powder | FFRB | DFRB |
|---|---|---|---|---|---|
| Dispensable AA, % | | | | | |
| Ala | 0.50 | 1.97 | 0.55 | 0.81 | 0.97 |
| Asp | 0.44 | 5.28 | 1.17 | 1.19 | 1.41 |
| Cys | 0.15 | 0.64 | 0.24 | 0.28 | 0.32 |
| Glu | 1.22 | 8.13 | 1.88 | 1.67 | 2.12 |
| Gly | 0.28 | 1.95 | 0.29 | 0.73 | 0.87 |
| Pro | 0.57 | 2.19 | 0.63 | 0.54 | 0.66 |
| Ser | 0.31 | 1.99 | 0.57 | 0.51 | 0.61 |
| Tyr | 0.31 | 1.99 | 0.57 | 0.33 | 0.44 |
| Total | 3.78 | 24.14 | 5.90 | 6.06 | 7.40 |
| All AA | 2.91 | 21.43 | 5.64 | 5.78 | 6.90 |

[1]AEE = acid hydrolyzed ether extract.

**Table 8.2.** Ingredient composition of experimental diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1,2]

| Item | Diet1 | | | | | | |
|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | |
| | - | 10% | 20% | 30% | 10% | 20% | 30% |
| Ground corn | 52.55 | 44.25 | 35.75 | 27.25 | 44.30 | 35.85 | 27.35 |
| Soybean meal | 30.50 | 29.00 | 27.5 | 26.00 | 29.00 | 27.50 | 26.00 |
| Whey powder | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| FFRB | - | 10.00 | 20.00 | 30.00 | - | - | - |
| DFRB | - | - | - | - | 10.0 | 20.0 | 30.0 |
| Choice white grease | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Enzyme premix[3] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Limestone | 1.48 | 1.47 | 1.47 | 1.46 | 1.45 | 1.42 | 1.43 |
| Dicalcium phosphate | 0.17 | - | - | - | - | - | - |
| L-Lys-HCl | 0.35 | 0.35 | 0.35 | 0.35 | 0.34 | 0.33 | 0.32 |
| DL-Met | 0.10 | 0.10 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 |
| L-Thr | 0.10 | 0.08 | 0.08 | 0.09 | 0.07 | 0.06 | 0.06 |
| Sodium chloride | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| Vitamin-mineral premix[4] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

[1]Two identical diets with the same ingredient composition were formulated. One of these diets contained no microbial xylanase, but the other diet contained xylanase.

[2]All diets were formulated to contain 1.26% standardized ileal digestible Lys.

[3]The enzyme premix contained either phytase [Quantum Blue (5,000 units per gram), AB Vista, Marlborough, UK] or phytase and xylanase [Econase XT-25 (160,000 units per gram), AB Vista, Marlborough, UK] mixed with corn. The mixture was formulated to provide 1,500 units of phytase per kilogram of complete feed in all diets, and 16,000 units of xylanase per kilogram of complete feed in all xylanase containing diets.

**Table 8.2**. Cont.

[4]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

**Table 8.3**. Analyzed nutrient composition and physical characteristics of experimental diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1]

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | - | 10% | 20% | 30% | 10% | 20% | 30% |
| GE, kcal/kg | 4,026 | 4,151 | 4,239 | 4,366 | 4,053 | 4,059 | 4,033 |
| ME, kcal/kg[2] | 3,407 | 3,376 | 3,338 | 3,299 | 3,286 | 3,158 | 3,028 |
| DM, % | 87.65 | 88.32 | 89.09 | 90.02 | 88.06 | 88.31 | 88.57 |
| CP, % | 19.51 | 19.56 | 20.05 | 20.66 | 20.39 | 21.11 | 20.33 |
| AEE[2], % | 4.54 | 6.57 | 8.59 | 10.13 | 6.23 | 6.18 | 5.86 |
| Ash, % | 5.46 | 5.90 | 6.03 | 6.84 | 6.02 | 7.06 | 8.07 |
| Starch, % | 31.91 | 28.36 | 25.12 | 21.60 | 25.14 | 25.01 | 23.53 |
| ADF, % | 2.64 | 3.60 | 4.21 | 5.48 | 3.55 | 4.73 | 4.98 |
| NDF, % | 6.13 | 6.97 | 8.45 | 9.66 | 7.52 | 8.81 | 10.10 |
| Ca, % | 0.87 | 0.80 | 0.80 | 0.79 | 0.96 | 1.11 | 1.20 |
| P, % | 0.45 | 0.60 | 0.77 | 0.96 | 0.64 | 0.85 | 1.0 |
| STTD P[4] | 0.33 | 0.35 | 0.41 | 0.46 | 0.38 | 0.51 | 0.61 |
| Phytase activity, FTU/kg[5] | 1,700 | 1,640 | 1,650 | 1,705 | 1,800 | 1,965 | 2,095 |
| Xylanase activity, BXU/kg[6] | 22,800 | 21,900 | 21,500 | 21,500 | 22,700 | 22,100 | 20,400 |
| Indispensable AA, % | | | | | | | |
| Arg | 1.26 | 1.28 | 1.35 | 1.35 | 1.31 | 1.37 | 1.41 |
| His | 0.51 | 0.51 | 0.53 | 0.52 | 0.52 | 0.53 | 03.54 |
| Ile | 0.88 | 0.87 | 0.90 | 0.87 | 0.88 | 0.90 | 0.87 |
| Leu | 1.68 | 1.63 | 1.63 | 1.58 | 1.64 | 1.67 | 1.62 |
| Lys | 1.38 | 1.37 | 1.40 | 1.39 | 1.38 | 1.40 | 1.39 |
| Met | 0.37 | 0.37 | 0.40 | 0.38 | 0.37 | 0.38 | 0.38 |
| Phe | 0.95 | 0.94 | 0.97 | 0.93 | 0.95 | 0.98 | 0.97 |
| Thr | 0.83 | 0.82 | 0.82 | 0.82 | 0.79 | 0.81 | 0.83 |
| Trp | 0.24 | 0.25 | 0.26 | 0.24 | 0.25 | 0.25 | 0.26 |
| Val | 0.94 | 0.94 | 1.00 | 0.98 | 0.97 | 1.01 | 1.03 |

**Table 8.3.** Cont.

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | - | 10% | 20% | 30% | 10% | 20% | 30% |
| Total | 9.06 | 8.96 | 9.25 | 9.04 | 9.04 | 8.80 | 9.33 |
| Dispensable AA, % | | | | | | | |
| Ala | 0.94 | 9.94 | 0.98 | 0.96 | 0.96 | 1.00 | 1.01 |
| Asp | 1.99 | 1.97 | 2.05 | 1.99 | 1.99 | 2.05 | 2.04 |
| Cys | 0.30 | 0.31 | 0.32 | 0.32 | 0.31 | 0.32 | 0.32 |
| Glu | 3.42 | 3.33 | 3.39 | 3.22 | 3.35 | 3.41 | 3.32 |
| Gly | 0.78 | 0.80 | 0.85 | 0.85 | 0.81 | 0.86 | 0.88 |
| Pro | 1.05 | 1.03 | 1.04 | 0.99 | 1.03 | 1.02 | 1.02 |
| Ser | 0.82 | 0.83 | 0.82 | 0.80 | 0.80 | 0.85 | 0.88 |
| Tyr | 0.61 | 0.61 | 0.63 | 0.61 | 0.63 | 0.64 | 0.63 |
| Total | 9.62 | 9.51 | 9.74 | 9.43 | 9.55 | 9.82 | 9.77 |
| All AA | 18.68 | 18.47 | 18.99 | 18.46 | 18.59 | 18.62 | 19.09 |
| Physic characteristics | | | | | | | |
| Loose bulk density, g/L | 654 | 628 | 615 | 576 | 642 | 633 | 642 |
| Water binding capacity | 1.28 | 1.31 | 1.34 | 1.20 | 1.36 | 1.35 | 1.52 |

[1]Average of analyzed values of diets without or with xylanase.

[2]Values for ME were calculated rather than analyzed (NRC, 2012).

[3]AEE = acid hydrolyzed ether extract.

[4]STTD P = standardized total tract digestible P. These values were calculated (NRC, 2012; Casas and Stein, 2015) rather than analyzed.

[5]FTU = phytase units.

[6]BXU = xylanase units.

**Table 8.4**. Growth performance of pigs fed diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1]

| Item | Diets | | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFBR | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[2] | Linear | Quad[2] | - |
| Initial BW, kg | 9.90 | 9.93 | 9.82 | 9.92 | 9.97 | 9.95 | 9.84 | 0.330 | 0.950 | 0.887 | 0.856 | 0.727 | 0.879 |
| Final BW, kg | 20.76 | 21.27 | 20.46 | 19.99 | 21.25 | 21.08 | 20.33 | 0.530 | 0.122 | 0.282 | 0.465 | 0.172 | 0.393 |
| ADFI, kg | 0.809 | 0.799 | 0.748 | 0.712 | 0.83 | 0.797 | 0.772 | 0.032 | < 0.001 | 0.472 | 0.082 | 0.206 | 0.002 |
| ME intake, kcal/d | 2,756 | 2,700 | 2,498 | 2,351 | 2,728 | 2,519 | 2,340 | 105 | < 0.001 | 0.440 | < 0.001 | 0.204 | 0.801 |
| ADG, kg | 0.517 | 0.539 | 0.506 | 0.479 | 0.537 | 0.530 | 0.499 | 0.017 | 0.006 | 0.038 | 0.254 | 0.034 | 0.164 |
| G:F | 0.643 | 0.676 | 0.682 | 0.675 | 0.649 | 0.671 | 0.648 | 0.031 | 0.013 | 0.028 | 0.367 | 0.114 | 0.003 |

[1]Data are least squares means of 16 observations for all diets and values are the average for diets without and with microbial xylanase.

[2]Quad = quadratic effect.

**Table 8.5**. Blood urea nitrogen (BUN), total protein and albumin in serum, and tumor necrosis factor-α (TNF- α), IgA, and Peptide YY (PYY) in plasma of weanling pigs fed diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1]

| Item | Diets | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFBR | | DFRB | | FFRB vs. DFRB |
| | | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[2] | Linear | Quad[2] | |
| BUN, mg/dL | 9.20 | 7.37 | 6.50 | 6.25 | 7.25 | 8.37 | 6.93 | 0.520 | < 0.001 | 0.107 | 0.014 | 0.589 | 0.052 |
| Total protein, g/dL | 5.11 | 5.16 | 4.99 | 5.09 | 5.15 | 5.13 | 5.20 | 0.095 | 0.512 | 0.769 | 0.566 | 0.854 | 0.269 |
| Albumin, g/dL | 2.85 | 2.95 | 2.83 | 2.93 | 2.93 | 3.02 | 2.88 | 2.95 | 0.688 | 1.000 | 0.561 | 0.446 | 0.361 |
| TNF-α, pg/mL | 142.0 | 131.8 | 122.6 | 113.5 | 113.8 | 132.8 | 140.9 | 16.50 | 0.088 | 0.962 | 0.777 | 0.144 | 0.516 |
| IgA, mg/mL | 1.28 | 1.29 | 1.21 | 1.27 | 1.54 | 1.06 | 1.23 | 0.156 | 0.840 | 0.849 | 0.201 | 0.651 | 0.838 |
| PYY, ng/mL | 2.84 | 2.85 | 2.65 | 2.29 | 2.50 | 2.36 | 2.41 | 0.463 | 0.075 | 0.422 | 0.172 | 0.398 | 0.365 |

[1]Data are least squares means of 16 observations for all diets and values are the average for diets without and with microbial xylanase.

[2]Quad = quadratic effect.

**Table 8.6.** Effects of microbial xylanase on growth performance and blood characteristics of weanling pigs fed diets containing full fat rice bran or defatted rice bran without or with xylanse[1]

| | Without xylanase | With xylanase | SEM | *P*-value |
|---|---|---|---|---|
| Growth performance | | | | |
| Initial BW, kg | 9.92 | 9.89 | 0.252 | 0.902 |
| Final BW, kg | 20.68 | 20.79 | 0.369 | 0.759 |
| ADFI, kg | 0.777 | 0.785 | 0.028 | 0.587 |
| ME intake, kcal/d | 2,542 | 2,570 | 94.20 | 0.600 |
| ADG, kg | 0.512 | 0.518 | 0.014 | 0.523 |
| G:F | 0.662 | 0.664 | 0.030 | 0.808 |
| Blood characteristics | | | | |
| BUN, mg/dL | 7.48 | 7.33 | 0.305 | 0.739 |
| Total protein, g/dL | 5.15 | 5.09 | 0.062 | 0.342 |
| Albumin, g/dL | 2.91 | 2.93 | 0.058 | 0.710 |
| TNF-α, pg/mL | 132.04 | 124.43 | 12.80 | 0.417 |
| IgA, mg/mL | 1.33 | 1.20 | 0.116 | 0.130 |
| PYY, ng/mL | 2.62 | 2.50 | 0.423 | 0.457 |

[1]Data are least squares means of 56 observations for treatment and values are the average for diets containing full fat rice bran or defatted rice bran.

## LITERATURE CITED

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

Casas, G. A., and H. H. Stein. 2015. Effects of microbial phytase on the apparent and standardized total tract digestibility of phosphorus in rice coproducts fed to growing pigs. J. Anim. Sci. 93:3441-3448. doi:10.2527/jas.2015-8877

Casas, G. A., and H. H. Stein. 2016. Effects of microbial xylanase on digestibility of dry matter, organic matter, neutral detergent fiber, and energy and the concentrations of digestible and metabolizable energy in rice coproducts fed to weanling pigs. J. Anim. Sci. 94:1933-1939. doi:10.2527/jas2015-0064

Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, D. C. Mahan, J. L. Nelssen, J. E. Pettigrew, T. L. Veum, and J. T. Yen. 2000. Variability among sources and laboratories in analyses of wheat middlings. NCR-42 Committee on Swine Nutrition. J. Anim. Sci. 78:2652-2658. doi:10.2527/2000.78102652x

Hargrove, K. L. J. 1994. Processing and utilization of rice bran in the United States. In: W. E. Marshall and J. I. Wadsworth, editors, Rice, science and technology. Marcel Dekker, NY. p. 381-404.

Henderson, A. J., A. Kumar, B. Barnett, S. W. Dow, and E. P. Ryan. 2012. Consumption of rice bran increases mucosal immunoglobulin a concentrations and numbers of intestinal *Lactobacillus spp*. J. Med. Food. 15:469-475. doi:10.1089/jmf.2011.0213

Herfel, T., S. Jacobi, X. Lin, E. Heugten, V. Fellner, and J. Odle. 2013. Stabilized rice bran improves weaning performance via a prebiotic mechanism. J. Anim. Sci. 91:907-913. doi:10.2527/jas.2012-5287

Ito, T., H. ThidarMyint, T. Murata, H. Inoue, R. M. Neyra, and H. Kuwayama. 2006. Effects of peripheral administration of PYY3–36 on feed intake and plasma acyl-ghrelin levels in pigs. J. Endocrinol. 191:113-119. doi:10.1677/joe.1.06855

Kohn, R. A., M. M. Dinneen, and E. Russek-Cohen. 2005. Using blood urea nitrogen to predict nitrogen excretion and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. J. Anim. Sci. 83:879-889. doi:10.2527/2005.834879x

Langhans, W., and B. Hrupka. 1999. Interleukins and tumor necrosis factor as inhibitors of food intake. Neuropeptides. 33:415-424. doi:10.1054/npep.1999.0048

Ngoc, T. T. B., N. T. Len, and J. E. Lindberg. 2012. Chemical characterization and water holding capacity of fibre-rich feedstuffs used for pigs in Vietnam. Asian-Australas. J. Anim. Sci. 25:861-868. doi:10.5713/ajas.2011.11294

Nortey, T. N., J. F. Patience, P. H. Simmins, N. L. Trottier, and R. T. Zijlstra. 2007. Effects of individual or combined xylanase and phytase supplementation on energy, amino acid, and phosphorus digestibility and growth performance of grower pigs fed wheat-based diets containing wheat millrun. J. Anim. Sci. 85:1432-1443. doi:10.2527/jas.2006-613

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Robertson, J. A., F. D. de Monredon, P. Dysseler, F. Guillon, R. Amado, and J.-F. Thibault. 2000. Hydration properties of dietary fibre and resistant starch: A european collaborative study. LWT - Food Sci. Technol. 33:72-79. doi:10.1006/fstl.1999.0595

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands. doi:10.3920/978-90-8686-668-7

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Stein, H. H., L. V. Lagos, and G. A. Casas. 2016. Nutritional value of feed ingredients of plant origin fed to pigs. Anim. Feed Sci. Technol. 218:33-69. doi:10.1016/j.anifeedsci.2016.05.003

Tumbleson, M. E., and P. R. Kalish. 1972. Serum biochemical and hematological parameters in crossbred swine from birth through eight weeks of age. Can. J. Com. Med. 36:202-209.

Ueno, H., H. Yamaguchi, M. Mizuta, and M. Nakazato. 2008. The role of PYY in feeding regulation. Regul. Pept. 145:12-16. doi:10.1016/j.regpep.2007.09.011

Warren, B. E., and D. J. Farrell. 1990. The nutritive value of full-fat and defatted Australian rice bran. II. Growth studies with chickens, rats and pigs. Anim. Feed Sci. Technol. 27:229-246. doi:10.1016/0377-8401(90)90085-m

Woyengo, T. A., J. S. Sands, W. Guenter, and C. M. Nyachoti. 2008. Nutrient digestibility and performance responses of growing pigs fed phytase- and xylanase-supplemented wheat-based diets. J. Anim. Sci. 86:848-857. doi:10.2527/jas.2007-0018

Yang, X., K. Wen, C. Tin, G. Li, H. Wang, and J. Kocher. 2014. Dietary rice bran protects against rotavirus diarrhea and promotes Th1-type immune responses to human rotavirus vaccine in gnotobiotic pigs. Clin. Vaccine Immunol. 21. doi:10.1128/cvi.00210-14

Zijlstra, R. T., A. Owusu-Asiedu, and P. H. Simmins. 2010. Future of NSP-degrading enzymes to improve nutrient utilization of co-products and gut health in pigs. Livest. Sci. 134:255-257. doi:10.1016/j.livsci.2010.07.017

# CHAPTER 9: EFFECTS OF FULL FAT RICE BRAN AND DEFATTED RICE BRAN ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF GROWING-FINISHING PIGS

**ABSTRACT:** The objective was to test the hypothesis that increasing inclusion levels of full fat rice bran (FFRB) or defatted rice bran (DFRB) are not detrimental to growth or carcass characteristics, longissimus muscle (LM) quality, or fat quality when fed to growing-finishing pigs. A total of 224 barrows and gilts were randomly allotted to 7 treatments, with 4 pigs per pen and 8 pen replicates per treatment. Pigs had an average initial BW of 28.2 ± 4.1 kg and a 3-phase feeding program was used. A basal diet containing corn and soybean meal, 3 diets containing corn, soybean meal, and 10, 20, or 30% FFRB, and 3 diets containing corn, soybean meal, and 10, 20, or 30% DFRB were formulated within each phase. Daily feed allotments and pig BW at the start of the experiment and at the conclusion of each phase were recorded. On the last d of the experiment, 1 pig per pen was harvested and carcass characteristics, LM quality, and fat quality were determined. For the overall experimental period, no effects of dietary treatments were observed for average daily gain (ADG). However, average daily feed intake (ADFI) decreased (linear, $P < 0.05$) and gain to feed ratio (G:F) increased (linear, $P < 0.05$) for pigs fed diets with increasing concentrations of FFRB. In contrast, ADFI increased linearly ($P < 0.05$) and G:F decreased (linear, $P < 0.05$) as DFRB was included in the diets. There were no effects of dietary treatments on LM quality. The length of the bellies decreased (linear and quadratic, $P < 0.05$) as the inclusion of FFRB or DFRB increased in the diets. The concentration of crude fat in adipose tissue of pigs increased linearly ($P < 0.05$) as the concentration of FFRB or DFRB increased in the diets. The concentration of saturated fatty acids (SFA) in adipose tissue of pigs fed diets

containing FFRB decreased (linear, $P < 0.05$), whereas the concentration of polyunsaturated fatty acids (PUFA) increased (linear, $P < 0.05$). In contrast, addition of DFRB did not affect the concentration of fatty acids in adipose tissue. In conclusion, 30% FFRB included in diets for growing-finishing pigs may improve G:F without affecting carcass characteristics or LM quality with the exception that PUFA in adipose tissue will increase. However, inclusion of DFRB in diets for growing-finishing pigs will reduce G:F without affecting LM quality or composition of adipose tissue.

## INTRODUCTION

Rice bran is a coproduct of the rice milling process that is needed to produce white polished rice, which is the main food for more than 3 billion people in the world (Serna-Saldivar, 2010). Therefore, large quantities of rice bran are available for animal feeding. The concentration of crude fat ranges from 14.1 to 24.4% in full fat rice bran (**FFRB**) and from 3.1 to 5.4% in defatted rice bran (**DFRB**; Sauvant et al., 2004; Kaufmann et al., 2005; de Blas et al., 2010; NRC, 2012). Oleic acid represents approximately 40% of fatty acids in FFRB and linoleic acid and palmitic acid contribute approximately 35.9% and 18.0%, respectively (Sauvant et al., 2004). The concentration of fatty acids in diets affects the composition and fat quality of pigs (Wood et al., 2008) because the concentration of oleic and linoleic acids in pork cuts is related to a reduced melting point (Chae and Lee, 2002; Wood et al., 2008).

Inclusion of 20% FFRB or DFRB in diets for weanling pigs may improve average daily gain (**ADG**) and gain to feed ratio (**G:F**; Casas and Stein, 2016a), but effects of including FFRB or DFRB in diets for growing-finishing pigs on growth performance traits and longissimus muscle (**LM**) quality were inconclusive. Inclusion of 20% FFRB that was not stabilized increased ADG and G:F and had no effect on carcass yield or backfat thickness (Chae and Lee,

2002). In contrast, inclusion of 30% of FFRB decreased ADG, average daily feed intake (**ADFI**), and G:F (de Campos et al., 2006). Likewise, inclusion of 10% or 20% DFRB had no effect on growth performance, but inclusion of 30% increased ADFI, and reduced G:F (Warren and Farrell, 1990). However, because pigs do not need feed ingredients but instead need nutrients and energy, we hypothesized that FFRB or DFRB are not detrimental to growth performance and have no negative effects on carcass characteristics, LM quality, or fat quality when fed to growing-finishing pigs provided that diets are carefully formulated using values for digestible amino acids and phosphorus.

## MATERIALS AND METHODS

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

### *Animals and Housing*

Two blocks of 84 and 140 pigs, respectively, for a total of 224 pigs were allotted to 7 dietary treatments using a completely randomized block design. Pigs were the offspring of Line 359 boars mated to Camborough sows (Pig Improvement Company, Hendersonville, TN). There were 3 pens per treatment in block 1 and 5 pens per treatment in block 2 for a total of 8 pen replicates per treatment. Four pigs were housed in each pen with 2 barrows and 2 gilts in replicates 1 to 7 and 1 gilt and 3 barrows in replicate 8. Pigs had an average initial BW of 28.24 ± 4.1 kg, and pigs were housed in mechanically ventilated rooms in pens of 2.59 × 1.83 m to provide 1.18 $m^2$/pig. Pens had a single space dry-box feeder and a nipple drinker. The room temperature was maintained at a minimum of 18.5ºC.

### *Diets and Feeding*

Defatted rice bran was purchased from Riceland Foods (Stuttgart, AR), FFRB was donated by RiceBran Technologies (Scottsdale, AZ), and corn and soybean meal were sourced from the University of Illinois Feed Mill (Champaign, IL; Table 1).

A 3-phase feeding program was used and a basal diet containing corn and soybean meal, 3 diets containing 10, 20, or 30% FFRB, and 3 diets containing 10, 20, or 30% DFRB were formulated within each phase. Grower diets were fed from d 0 to 35 (Tables 2 and 3), early finisher diets were fed from d 36 to 70 (Tables 4 and 5), and late finisher diets were fed from d 70 to 97 (Tables 6 and 7). All diets were formulated to meet or exceed requirements for all nutrients by growing pigs (NRC, 2012). All diets contained 1,500 units per kg of phytase [Quantum Blue 5G (5,000 units per gram); AB Vista, Marlborough, UK]. Feed was provided on an ad libitum basis and water was available at all times. The amount of feed added to the feeders daily was recorded and the feed left in the feeders was recorded on the last day of each phase. Individual pig weights were recorded at the start of the experiment and at the conclusion of each phase.

### *Slaughter Procedures and Evisceration*

On the last day of the experiment, pig weights were recorded, and one pig per pen was transported to the University of Illinois Meat Science Laboratory (Urbana, IL). From replicates 1, 3, 5, and 7, the gilt with a BW closest to the average for the pen was selected, whereas from replicates 2, 4, 6, and 8, the barrow with a BW closest to the pen average was selected.

After arrival to the Meat Science Laboratory, pigs were held without feed, but with free access to water, for approximately 16 h. Pig weights were recorded before slaughter to determine

the ending live weight (**ELW**). Pigs were slaughtered using head-to-heart electrical immobilization followed by exsanguination. Weights of the heart, liver, and both kidneys were recorded. The weight of the full gastrointestinal tract (**GI**) was recorded immediately after evisceration. Each section of the GI tract (esophagus, stomach, small intestine, and large intestine) was rinsed with water to remove the digesta or fecal material. Mesenteric fat also was separated, and the weight of each section was recorded as described by Boler et al. (2014).

***Carcass Characteristics, Fresh Loin Quality, and Fat Quality***

Each carcass was weighed to determine hot carcass weight (**HCW)**, and then stored at 4ºC for 24 h. Carcasses were split down the midline and fresh LM quality was determined on the left side of the carcass. Fat depth was measured between the $10^{th}$ and the $11^{th}$ ribs, at three-fourths the distance of the LM from the dorsal side of the vertebral column. Visual color, instrumental color, ultimate pH, drip loss, cooking loss, and Warner Bratzler shear force (WBSF) evaluation were determined by trained University of Illinois personnel. Visual color, instrumental color and ultimate pH were measured by a single individual according to standards established by the National Pork Producers Council (NPPC, 1991), at the surface exposed by ribbing the carcass at the $10^{th}$ rib while the carcass was still suspended. Visual color was measured on the surface of the LM using a scale of 1 to 6, visual marbling was measured subjectively using a scale from 1 to 10, and firmness was scored using a subjective scale from 1 to 5. Instrumental color on the LM (L*, a*, and b*, CIE, 1978) was measured with 1 shot in center of the LM surface, taking care to avoid streaks of intramuscular fat, using a CR-400 Chroma meter (Minolta Camera Co., Ltd, Osaka, Japan) with a D65 light source and a 10º observed with an aperture size of 8 mm, using the procedure established by the National Pork Producers Council (NPPC, 1999). The longissimus muscle area (**LMA**) was measured by tracing

the surface of the LM on double-matted acetate paper. The images were digitized using a digitizer pad (Intuos Pro Digitizer Tablet and stylus; Wacom Technology Corporation, Vancouver, WA). Area of the LM was then measured using the magic wand tool of Adobe Photoshop CS6 (Adobe Systems Inc., San Jose, CA; (Overholt et al., 2016a). Ultimate pH was determined 24 h postmortem using a handheld MPI pH meter fitted with a glass electrode (MPI pH meter, Topeka, KS). A section of approximately 10 cm of LM was collected from each carcass posterior to the 10$^{th}$ rib, and 2 chops approximately 2.5 cm thick were vacuum packaged, aged for 14 d postmortem, and frozen and stored at -40ºC until thawed for evaluation of cooking loss, WBSF, and proximate analyses. An additional chop of 1.27 cm was used to measure drip loss. To determine drip loss, chops were weighed and suspended from a fish hook in a plastic bag for 24 h at 4ºC, and then weighed again and the difference was recorded as previously described (Boler et al., 2011). Cooking loss and WBSF were measured according to the procedure described by Overholt et al. (2016a) using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems Ltd., Godalming, UK) with a blade speed of 3.3 mm/s and a 100-kg load cell. Chops were cooked on one side to 35ºC and then flipped and cooked on the other side until they had reached an internal temperature of 70ºC. Chops were then allowed to cool to approximately 25ºC as described previously (Overholt et al., 2016a). Before proximate analyses of LM chops, subcutaneous fat tissue and all accessory muscles were removed and then the chop was homogenized in a food processor. The remaining homogenized samples were lyophilized (Gamma 1-16 LSCplus; IMA Life North America Inc. Tonawanda, NY).

Fresh belly weights were recorded and the flop distance, width, length, and thickness of each belly were measured according to procedures described by Overholt et al. (2016b).

Instrumental color of fat (L*, a*, and b*, CIE, 1978), were measured as described for LM, after peeling off the skin adjacent to the 10$^{th}$ rib. Efforts were made to evaluate the outer most layer of fat tissue. Fat tissue samples were collected from each belly from the dorsal edge of the anterior and samples were analyzed for crude fat and fatty acids according to Overholt et al., 2016a. All 3 fat layers were included in the fat samples used to determine fatty acid profiles.

***Chemical Analysis***

All diets and corn, soybean meal, FFRB, and DFRB were analyzed for dry matter (Method 930.15; AOAC Int., 2007) and gross energy was analyzed using an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) that used benzoic acid as the standard for calibration. Concentrations of crude protein (CP) were determined by combustion (Method 990.03; AOAC Int., 2007) using an Elementar Rapid N-cube Protein/Nitrogen apparatus (Elementar Americas Inc., Mt Laurel, NJ), and acid hydrolyzed ether extract (**AEE**) was analyzed using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by rapid determination of oil/fat utilizing high temperature solvent extraction (Procedure Am 5-04; AOCS, 2017) using an AnkomXT15 Extractor (Ankom Technology, Macedon, NY). Ash (Method 942.05; AOAC Int., 2007) was also analyzed in all diets and ingredients, and acid detergent fiber (**ADF**) and neutral detergent fiber (**NDF**) in these samples were determined using Ankom Technology method 12 and 13, respectively (Ankom2000 Fiber Analyzer, Ankom Technology, Macedon, NY). Diets also were analyzed for Ca and P using inductively coupled plasma spectroscopy (Method 985.01 A, B, and C; AOAC Int., 2007) and for amino acids [Method 982.30 95 E (a, b, c)].

The concentration of moisture in LM chops was determined by drying duplicate samples of 10 g of the fresh homogenized LM chop in an oven at 110ºC for at least 24 h (Boler et al.,

2014). The fat content of the LM was determined in the lyophilized sample by rapid determination of oil/fat utilizing high temperature solvent extraction (Procedure Am 5-04; AOCS, 2017) using an AnkomXT15 Extractor (Ankom Technology, Macedon, NY). Crude fat also was determined in diets, ingredients, and belly samples by ether extraction (Method 920.39 (A); AOAC Int., 2007). Methyl esters of fatty acids were extracted from diets, ingredients, and belly samples (Method Ce-266; AOCS, 2017), and the concentration of fatty acids in these samples was measured using a capillary gas liquid chromatography (Method 996.06; AOAC Int., 2007).

***Calculation and Statistical Analysis***

The standardized fat free lean (**SFFL**) was calculated using the equation developed by Burson and Berg (2001): SFFL, % = ([8.588 + (0.465 × (0.465 × HCW, lb) – (21.896 × $10^{th}$ rib backfat, in.) + (3.005 ×$10^{th}$ LMA, $in^2$)] ÷ HCW, lb) ×100. Iodine values (**IV**) were calculated from the fatty acid profiles using the AOCS (1998) equation: IV = [16:1 (0.95) + 18.1 (0.86) + 18.2 (1.732) + 18:3 (2.616) + 20:1 (0.785) + 22:1 (0.723)].

Data were summarized to calculate ADG, ADFI, and G:F. Percentage of organs were calculated by dividing the weight of the organ by ELW and multiplied by 100. Outliers were identified and removed using the PROC BOXPLOT option of SAS (SAS Institute Inc., Cary, NC). Normality of data among treatments was confirmed using the UNIVARIATE procedure. Data were analyzed using the MIXED procedure of SAS with a model that included diet as main effect and block and replicate within block as random effects. Mean values were calculated using the LSMeans statement. Contrast statements were used to determine the linear and quadratic effects of inclusion level of FFRB or DFRB on all response variables using appropriate coefficients for equally spaced treatments. A contrast statement was also used to compare values

between FFRB and DFRB. The pen was the experimental unit for all analyses and an alpha value of 0.05 was used to assess significance among means; tendencies were considered at $0.05 \leq P < 0.10$.

## RESULTS

### *Growth Performance*

The analyzed composition of all diets concurred with calculated values. Final BW of pigs was not affected by dietary treatments in any of the 3 phases (Table 9.8). In all phases, ADFI was greater ($P < 0.05$) and G:F was less ($P < 0.05$) in pigs fed diets containing DFRB than in pigs fed diets containing FFRB. During the grower phase, increased inclusion of FFRB or DFRB did not affect ADFI or ADG, but G:F tended to decrease (linear, $P = 0.079$) as the inclusion of DFRB increased in the diet. In the early finisher phase, the ADFI of pigs fed diets containing FFRB tended to increase at the 10% inclusion level, and then tended to decrease at greater inclusion levels (quadratic, $P = 0.083$). In contrast, the ADFI of pigs fed diets containing DFRB increased (linear, $P < 0.05$) as the inclusion of DFRB increased in the diet. The ADG was not affected by treatment in the early finisher phase, but G:F decreased (linear, $P < 0.05$) as the inclusion of DFRB increased in the diets.

The ADFI in the late finisher phase decreased (linear, $P < 0.05$) as the inclusion of FFRB increased, whereas ADFI of pigs fed diets containing DFRB decreased at 10% inclusion and then increased (quadratic, $P < 0.05$). The ADG of pigs fed diets containing DFRB tended to decrease linearly ($P = 0.064$) as the inclusion of DFRB increased in the diets. The G:F for pigs fed diets containing FFRB tended to increase linearly ($P = 0.061$), whereas G:F in pigs fed diets containing DFRB increased at 10% inclusion, and then decreased (quadratic, $P < 0.05$).

For the overall phase, ADG was not affected by dietary treatments, but ADFI decreased (linear, $P < 0.05$) and G:F increased linearly ($P < 0.05$) in pigs fed diets containing increasing levels of FFRB. In contrast, for pigs fed diets containing increasing levels of DFRB, ADFI increased linearly ($P < 0.05$), but G:F decreased (linear, $P < 0.05$).

***Organs Weights***

The weight or percentage of the esophagus, stomach, small intestine, mesenteric fat, or heart, were not affected by dietary treatments (Table 9.9), but the weight and percentage of the full GI tract, gut fill, and of the large intestine was greater ($P < 0.05$) in pigs fed diets containing DFRB than in pigs fed diets containing FFRB. Also, the weight of liver and the percentage of kidneys tended to increase, if pigs were fed diets containing up to 20% DFRB, but then decreased at 30% inclusion (quadratic, $P = 0.078$ and 0.062; respectively), but the percentage of liver increased (linear and quadratic, $P < 0.05$) as the inclusion of DFRB increased in the diets.

***Carcass Characteristics and Loin and Fat Composition***

There were no effects of dietary treatments on ELW, HCW, carcass yield, LMA, $10^{th}$ rib back fat, or SFFL (Table 9.10). Values for L* and a* in back fat were not affected by inclusion of FFRB or DFRB in the diets, but b* decreased (linear, $P < 0.05$) as the inclusion of DFRB increased in the diets and tended to decrease (linear, $P = 0.095$) as FFRB was included in the diets.

Marbling score decreased (linear, $P < 0.05$) as the inclusion of FFRB or DFRB increased in the diets, but loins from pigs fed diets containing DFRB had greater ($P < 0.05$) marbling scores than pigs fed diets containing FBRB (Table 9.11). The L* values in loins from pigs fed diets containing DFRB tended to increase at 20% of inclusion, but decreased at 30% inclusion (quadratic, $P = 0.085$), and the L* values were grater ($P < 0.05$) for pigs fed diets containing

DFRB than for pigs fed diets containing FFRB. Likewise, the percentage of cooking loss was greater ($P < 0.05$) in LM from pig fed diets containing DFRB than for pigs fed diets containing FFRB. There were no effects of dietary treatments on percentage or water and ash, but the percentage of protein increased (linear, $P < 0.05$) as FFRB or DFRB increased in the diet. In contrast, the percentage of lipids in LM decreased (linear, $P < 0.05$) as FFRB or DFRB increased in the diets.

There were no effects of treatments on weight, width, or thickness of bellies or on instrumental color of fat in bellies (Table 9.12). However, the length of the bellies decreased (linear, $P < 0.05$) as the inclusin of FFRB increased in the diets, whereas the length of bellies decreased at 10% inclusion of DFRB, but increased at 20% (quadratic, $P < 0.05$). Likewise, the flop distance of bellies from pigs fed diets containing FFRB or DFRB increased until 20% inclusion and then decreased (quadratic, $P < 0.05$).

***Fatty Acid Profile of Belly Adipose Tissue***

The concentration of crude fat in bellies increased (linear, $P < 0.05$) as the inclusion of FFRB or DFRB increased in the diets (Table 9.13). The concentration of crude fat tended ($P = 0.07$) to be greater in adipose tissue from pigs fed diets containing DFRB than in pigs fed diets containing FFRB.

The concentration of C14:0, C16:0, C16:1, C17:0, C18:0, C18:1, total SFA, and total MUFA, decreased (linear, $P < 0.05$) and the concentration of C18:2, C18:3, and PUFA increased (linear, $P < 0.05$) as the inclusion of FFRB increased in the diets, but this was not the case if the inclusion of DFRB increased. The concentration of C14:0, C14:1, C16:0, C16:1, C17:0, C18:0, C18:1, and total SFA was greater ($P < 0.05$) in bellies from pigs fed diets containing DFRB compared with pigs fed diets containing FFRB, but the concentration of C18:2, C18:3, and total

PUFA was greater ($P < 0.05$) in bellies from pigs fed diets containing FFRB than in pigs fed diets containing DFRB. The IV of belly fat increased (linear, $P < 0.05$) as the inclusion of FFRB increased in the diet and the IV was greater ($P < 0.05$) in belly fat from pigs fed diets containing FFRB compared with pigs fed diets containing DFRB.

## DISCUSSION

### *Chemical Composition of Ingredients*

The analyzed proximate composition of corn and soybean meal concurs with reported values, except for concentration of crude protein in soybean meal, which was greater than reported by NRC (2012). Likewise, concentrations of crude protein, ash, neutral detergent fiber, and acid detergent fiber in FFRB and DFRB were within the range of reported values (NRC, 2012; Sauvant et al., 2004; Casas and Stein, 2017), and concentrations of most fatty acids in all ingredients were within the range of reported values (NRC, 2012; Lee et al., 2013).

Rice bran contains pericarp, seed coat, germ and aleurone layers of rice, which are the fractions of the grain that contain most of the lipids (Juliano, 1983; Zhou et al., 2012). Lipids in the bran may be extracted from FFRB using expeller or chemical processes to produce rice oil and DFRB (Serna-Saldivar, 2010). The concentration of acid hydrolyzed ether extract in FFRB used in this experiment was 18.8%, which is slightly greater than previously reported (Sauvant et al., 2004; NRC, 2012; Casas and Stein, 2017), whereas the concentration of acid hydrolyzed ether extract in DFFB was 2.6%, which is less than reported values (Sauvant et al., 2004; Rostagno et al., 2011). Variation in the content of fat in FFRB is a result of differences in the quality of rice milling, and different types of milling may result in different concentrations of starch from the endosperm in FFRB and DFRB (Juliano, 1983; Saunders, 1985; Rosniyana et al.,

2007). The process used for extraction of oil from FFBR also affects the concentration of fat in DFRB, because solvent extraction of fat results in less residual fat in DFRB compared with DFRB produced from mechanical extraction of fat (Saunders, 1985; Serna-Saldivar, 2010). Rice oil contains approximately 41 and 34% MUFA and PUFA, respectively (Juliano, 1983; Saunders, 1985, Faria et al., 2012), and the high concentration of MUFA and PUFA as well as the presence of lipases and oxidases cause rapid oxidation of fat in FFRB if it is not stabilized immediately after production (Saunders, 1985; Rosniyana et al., 2009). Stabilization of FFRB is usually achieved by dry heating, extrusion, or cooking (Saunders, 1985; Chae and Lee, 2002; Faria et al., 2012; Thanonkaew et al., 2012). The FFRB used in this experiment was stabilized by heating to prevent oxidation of oil.

***Growth Performance***

To our knowledge, no previous experiments have evaluated growth performance of pigs fed either FFRB or DFRB over the entire growing-finishing period, although data for the growing period (Warren and Farrell, 1990) or the finishing period (Chae and Lee, 2002; de Campos et al., 2006) have been reported. However, the present results indicate that responses to inclusion of FFRB or DFRB in diets for growing-finishing pigs are primarily related to the ME of the diets. Thus, the linear reduction in ADFI and the increased G:F that was observed as FFRB increased in the diets is likely a result of the greater ME in FFRB than in corn and soybean meal (Casas and Stein, 2017), which resulted in greater ME in the diets as FFRB inclusion increased. It is also possible that the greater concentration of fat in diets containing FFRB increased the digestibility of other nutrients (Cervantes-Pahm and Stein, 2008). Likewise, the increased ADFI and reduced G:F by pigs fed diets containing DFRB are likely a result of the reduced ME of DFRB compared with corn and soybean meal (Casas and Stein, 2017) with a

subsequent reduction in ME of the diets as DFRB inclusion increased. Results obtained in this experiment are in agreement with results for growth performance of weanling pigs fed diets containing FFRB or DFRB (Casas and Stein, 2016b) and indicate that FFRB or DFRB do not affect ADG of pigs. However, due to differences in ME among FFRB, DFRB, corn, and soybean meal, ADFI and G:F will be affected by the inclusion of FFRB or DFRB in the diets.

***Organ Weights, Carcass Characteristics, and Loin and Fat Quality***

Weights of the organs observed in this experiment were less than reported from previous experiments (Casas et al., 2009; Boler et al., 2014), but in agreement with data reported by Overholt et al. (2016a). However, the weight of the organs such as heart, liver, lungs, and kidneys depends on the BW of the pigs, whereas the weight of the stomach, small intestine, and large intestine are also influenced by feed intake and concentration of fiber in the diet (van Milgen and Noblet, 2003). Thus, the increased weight of the large intestine of pigs fed diets containing DFRB was likely a result of the greater feed intake by those pigs. Chae and Lee (2002) reported no effects on carcass yield or back fat thickness of feeding diets containing 20% FFRB compared with pigs fed a control diet containing DFRB, corn, and animal fat, and data from this experiment are in agreement with this observation.

The proximate composition of LM that was determined in this experiment concurs with data from previous studies (Kim et al., 2008; Boler et al., 2014). However, the decrease in the concentration of fat in LM that was observed in this experiment as FFRB or DFRB were included in the diets is in contrast with previous data indicating an increased concentration of fat in cuts from forelegs of pigs fed diets containing 30% FFRB (de Campos et al., 2006). Differences in lipid and carbohydrate metabolism in the muscle fibers of the LM compared with forelegs muscle may explain the difference between this study and previous data (Leseigneur-

Meynier and Gandemer, 1991; Monziols et al., 2007). Likewise, no effects on pH of loin chops were reported as FFRB was added to diets for finishing pigs (de Campos et al., 2006) and a similar observation was made in this experiment. Thus, it appears that FFRB or DFRB may be included in diets for growing-finishing pigs without influencing carcass characteristics or LM quality.

***Fatty Acid Profile of Belly Adipose Tissue***

The belly represents 12.0 to 16.7% of the carcass weight of pigs and is the most valuable cut in the U.S. because of the high value of bacon (Soladoye et al., 2015). The quality of the belly is influenced by concentration and composition of dietary fat (Rosenvold and Andersen, 2003; Wood et al., 2008). Greater concentration of unsaturated fatty acids results in softer bellies, reduced slicing efficiency, and shorter shelf life (Kloareg et al., 2007; Soladoye et al., 2015). However, for health reasons, consumers prefer less saturated fat and more unsaturated fatty acids (Shackelford et al., 1990; Webb and O'Neill, 2008).

Values for belly weight, length, and thickness observed in this experiment are within the range of previous data (Overholt et al., 2016b). The drop in the flop distance observed when pigs were fed diets containing 30% FFRB or DFRB, likely is a result of the greater concentrations of PUFA in the adipose tissue.

The concentration of fat in FFRB is greater than in corn and DFRB, and increased inclusion of FFRB in the diets, therefore, increased the concentration of fat and total concentration of fatty acids in the bellies. Pigs are able to synthetize SFA and MUFA de novo, but they do not synthesize PUFA (Shackelford et al., 1990; Kloareg et al., 2007). As a consequence, even though diets had different concentrations of crude fat, the concentration of fat in the bellies was not different. De novo synthesis of fat likely is the reason pigs fed diets

containing DFRB had greater concentration of SFA and MUFA, specifically C18:0 and C18:1, compared with pig fed FFRB. However, because FFRB contains more C18:2 and C18:3, the adipose tissue of pigs fed diets FFRB, had increased concentration of PUFA. Results observed in this experiment concur with data reported by de Campos et al. (2006) for pigs fed diets containing 30% FFRB.

In conclusion, 30% FFRB included in diets for growing-finishing pigs may improve G:F of pigs without affecting carcass characteristics or LM quality with the exception that concentration of PUFA in bellies will increase. However, inclusion of DFRB in diets will reduce G:F without affecting LM quality or composition of the bellies. The differences in results between FFRB and DFRB are primarily a consequence of differences in ME and in the concentration of fat between FFRB and DFRB.

## TABLES

**Table 9.1**. Analyzed composition of corn, soybean meal, full fat rice bran (FFRB), and defatted rice bran (DFRB), as is basis

| Item | Corn | Soybean meal | FFRB | DFRB |
|---|---|---|---|---|
| GE, kcal/kg | 3,872 | 4,340 | 4,832 | 3,796 |
| DM, % | 84.29 | 90.22 | 93.36 | 86.98 |
| CP, % | 6.33 | 54.87 | 14.36 | 16.47 |
| AEE[1], % | 3.21 | 0.56 | 18.88 | 2.69 |
| Ash, % | 0.68 | 6.35 | 9.23 | 12.27 |
| ADF, % | 2.34 | 4.46 | 11.16 | 9.99 |
| NDF, % | 7.44 | 7.39 | 13.85 | 19.22 |
| Fatty acids[2,3] | | | | |
| Crude fat, % | 1.46 | 0.30 | 17.52 | 1.81 % |
| C14:0 | 0.06 | 0.11 | 0.31 | 0.50 |
| C16:0 | 14.61 | 17.78 | 16.41 | 17.87 |
| C16:1 | 0.15 | 0.14 | 0.18 | 0.24 |
| C17:0 | 0.10 | 0.19 | 0.05 | 0.08 |
| C18:0 | 1.91 | 4.04 | 1.95 | 1.82 |
| C18:1 | 25.94 | 11.57 | 40.40 | 35.83 |
| C18:2 | 50.95 | 50.45 | 33.46 | 32.35 |
| C18:3 | 1.28 | 7.06 | 1.17 | 1.19 |
| C20:0 | 0.42 | 0.30 | 0.80 | 0.64 |
| C20:1 | 0.27 | 0.17 | 0.60 | 0.45 |

**Table 9.1.** Cont.

| Item | Corn | Soybean meal | FFRB | DFRB |
|---|---|---|---|---|
| C22:0 | 0.19 | 0.40 | 0.45 | 0.78 |
| C22:1 | 0.04 | N.D.[4] | 0.06 | N.D. |
| C24:0 | 0.27 | 0.30 | 0.92 | 2.25 |
| C24:1 | 0.09 | N.D. | 0.03 | N.D. |
| Total SFA[5] | 17.28 | 22.93 | 20.00 | 21.75 |
| Total MUFA[6] | 26.40 | 11.88 | 41.24 | 36.52 |
| Total PUFA[7] | 52.22 | 57.51 | 34.62 | 33.53 |
| IV[8] | 114.26 | 116.06 | 96.43 | 90.52 |

[1]AEE = acid hydrolyzed ether extract.

[2]C14:1, C15:0, C20:4, C20:5, C22:5, and C22:6 were analyzed, but not detected in any ingredients.

[3]Fatty acids are expressed as percent of crude fat.

[4]N.D. = not detected

[5]Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[6]Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

[7]Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 +C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

[8]Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of total fat (AOCS, 1998).

**Table 9.2**. Ingredient and analyzed composition of grower diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Ingredient, % | | | | | | | |
| Ground corn | 70.18 | 62.32 | 55.22 | 46.24 | 62.36 | 55.77 | 45.91 |
| Soybean meal | 24.00 | 22.00 | 19.00 | 18.00 | 22.00 | 18.5 | 18.5 |
| Rice coproducts | - | 10.0 | 20.00 | 30.00 | 10.0 | 20.00 | 30.00 |
| Soybean oil | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| L-Lys HCl | 0.27 | 0.29 | 0.34 | 0.33 | 0.28 | 0.34 | 0.27 |
| DL-Met | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.02 |
| L-Thr | 0.06 | 0.07 | 0.09 | 0.09 | 0.06 | 0.08 | 0.05 |
| Ground limestone | 1.16 | 1.59 | 1.61 | 1.61 | 1.57 | 1.58 | 1.55 |
| Dicalcium phosphate | 0.60 | - | - | - | - | - | - |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Phytase premix[1] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Vitamin-mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | | | | | |
| DM, % | 88.81 | 89.26 | 89.08 | 90.22 | 55.48 | 87.95 | 87.6 |
| GE, kcal/kg | 4,076 | 4,174 | 4,179 | 4,261 | 3,975 | 3,983 | 3,964 |
| ME, kcal/kg[3] | 3,378 | 3,345 | 3,305 | 3,267 | 3,255 | 3,124 | 2,997 |
| NE, kcal/kg[3] | 2,553 | 2,530 | 2,505 | 2,473 | 2,458 | 2,364 | 2,256 |
| CP, % | 18.10 | 17.89 | 16.8 | 17.77 | 17.51 | 17.16 | 17.92 |
| AEE, %[4] | 4.41 | 6.07 | 7.54 | 9.23 | 4.69 | 5.23 | 5.43 |
| ADF, % | 2.18 | 3.22 | 3.92 | 4.21 | 3.12 | 3.98 | 4.69 |
| NDF, % | 7.45 | 7.95 | 8.58 | 9.32 | 8.22 | 9.67 | 10.09 |
| Ash, % | 5.75 | 4.96 | 5.7 | 6.45 | 5.32 | 6.5 | 6.91 |
| Ca, % | 0.70 | 0.71 | 0.80 | 0.61 | 0.97 | 1.06 | 1.03 |

**Table 9.2.** Cont.

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| P, % | 0.47 | 0.54 | 0.68 | 0.82 | 0.55 | 0.71 | 0.89 |
| Indispensable AA, % | | | | | | | |
| Arg | 1.09 | 1.08 | 1.10 | 1.10 | 1.13 | 1.13 | 1.15 |
| His | 0.46 | 0.44 | 0.44 | 0.44 | 0.46 | 0.45 | 0.45 |
| Ile | 0.77 | 0.73 | 0.73 | 0.70 | 0.77 | 0.73 | 0.71 |
| Leu | 1.52 | 1.42 | 1.43 | 1.36 | 1.50 | 1.42 | 1.39 |
| Lys | 1.30 | 1.12 | 1.19 | 1.20 | 1.24 | 1.20 | 1.19 |
| Met | 0.29 | 0.27 | 0.33 | 0.28 | 0.27 | 0.28 | 0.29 |
| Phe | 0.89 | 0.84 | 0.82 | 0.79 | 0.86 | 0.82 | 0.80 |
| Thr | 0.78 | 0.76 | 0.68 | 0.69 | 0.70 | 0.69 | 0.65 |
| Trp | 0.21 | 0.22 | 0.22 | 0.21 | 0.20 | 0.20 | 0.21 |
| Val | 0.85 | 0.83 | 0.85 | 0.83 | 0.87 | 0.86 | 0.86 |
| Dispensable AA, % | | | | | | | |
| Ala | 0.87 | 0.85 | 0.87 | 0.86 | 0.86 | 0.85 | 0.87 |
| Asp | 1.69 | 1.62 | 1.63 | 1.61 | 1.70 | 1.61 | 1.62 |
| Cys | 0.25 | 0.25 | 0.26 | 0.26 | 0.25 | 0.26 | 0.26 |
| Glu | 3.14 | 2.94 | 2.95 | 2.82 | 3.11 | 2.90 | 2.83 |
| Gly | 0.72 | 0.71 | 0.73 | 0.73 | 0.72 | 0.71 | 0.73 |
| Pro | 1.05 | 0.99 | 1.00 | 0.95 | 1.04 | 0.92 | 0.94 |
| Ser | 0.75 | 0.73 | 0.74 | 0.73 | 0.78 | 0.73 | 0.73 |
| Tyr | 0.56 | 0.54 | 0.52 | 0.51 | 0.55 | 0.53 | 0.52 |

[1]The phytase premix was prepared by mixing 30 g of microbial phytase [Quantum Blue 5G (5,000 units per gram), AB Vista; Marlborough, UK] with 970 g of ground corn. The premix, therefore, contained 150,000 units of phytase per kilogram, and at 1% inclusion, 1,500 units of phytase were included per kilogram of complete feed.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin

**Table 9.2.** Cont.

$D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

[3]ME and NE values were calculated (NRC, 2012) rather than analyzed.

[4]AEE = acid hydrolyzed ether extract.

**Table 9.3.** Concentration of crude fat and fatty acids in grower diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis[1,2]

| Item, % | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Crude fat | 3.44 | 5.32 | 6.53 | 8.36 | 3.7 | 4.01 | 4.47 |
| C14:0 | 0.56 | 0.49 | 0.49 | 0.47 | 0.56 | 0.56 | 0.58 |
| C16:0 | 18.31 | 17.50 | 17.58 | 17.19 | 17.96 | 17.75 | 18.13 |
| C16:1 | 0.87 | 0.68 | 0.62 | 0.55 | 0.82 | 0.77 | 0.76 |
| C17:0 | 0.23 | 0.18 | 0.16 | 0.14 | 0.23 | 0.20 | 0.20 |
| C18:0 | 6.88 | 5.55 | 5.03 | 4.46 | 6.27 | 5.89 | 5.97 |
| C18:1 | 28.35 | 31.82 | 34.34 | 35.80 | 30.45 | 31.18 | 32.43 |
| C18:2 | 36.73 | 36.13 | 33.82 | 33.74 | 35.75 | 35.66 | 33.43 |
| C18:3 | 1.57 | 1.43 | 1.36 | 1.36 | 1.37 | 1.36 | 1.28 |
| C20:0 | 0.30 | 0.46 | 0.54 | 0.58 | 0.38 | 0.41 | 0.43 |
| C20:1 | 0.50 | 0.53 | 0.57 | 0.58 | 0.52 | 0.51 | 0.54 |
| C20:4 | 0.14 | 0.09 | 0.07 | 0.08 | 0.10 | 0.10 | 0.09 |
| C22:0 | 0.14 | 0.22 | 0.28 | 0.31 | 0.22 | 0.27 | 0.33 |
| C22:1 | 0.07 | 0.04 | 0.11 | 0.09 | N.D. | 0.08 | 0.10 |
| C24:0 | 0.17 | 0.35 | 0.50 | 0.57 | 0.38 | 0.56 | 0.74 |
| C24:1 | N.D. | 0.03 | N.D. | 0.03 | 0.03 | 0.03 | 0.03 |
| Total SFA[4] | 26.48 | 24.43 | 24.13 | 23.19 | 25.66 | 25.13 | 25.69 |
| Total MUFA[5] | 29.78 | 33.07 | 35.66 | 37.02 | 31.79 | 32.56 | 33.87 |
| Total PUFA[6] | 38.43 | 37.65 | 35.25 | 35.18 | 37.22 | 37.12 | 34.81 |
| IV[7] | 93.36 | 94.77 | 92.77 | 93.83 | 92.86 | 93.31 | 90.37 |

[1]Fatty acids are expressed as percent of crude fat.

[2]Diets were also analyzed for C14:1, C15:0, C20:5, C22:5, and C22:6, but these fatty acids were not detected in any diets.

[3]N.D. = not detected.

[4]Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

**Table 9.3.** Cont.

[5]Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

[6]Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 +C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

[7]Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

**Table 9.4.** Ingredient and analyzed composition of early finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Ingredients, % | | | | | | | |
| Ground corn | 77.05 | 68.56 | 59.68 | 50.87 | 69.64 | 61.65 | 53.17 |
| Soybean meal | 17.50 | 16.00 | 15.00 | 13.8 | 15.00 | 13.00 | 11.50 |
| Rice coproducts | - | 10.0 | 20.00 | 30.00 | 10.0 | 20.00 | 30.00 |
| Soybean oil | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| L-Lys HCl | 0.24 | 0.24 | 0.22 | 0.21 | 0.26 | 0.26 | 0.25 |
| L-Thr | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Ground limestone | 1.06 | 1.4 | 1.35 | 1.37 | 1.35 | 1.34 | 1.33 |
| Dicalcium phosphate | 0.40 | 0.05 | - | - | - | - | - |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Phytase premix[1] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Vitamin-mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | | | | | |
| DM, % | 86.09 | 88.17 | 88.43 | 89.33 | 87.23 | 86.25 | 87.33 |
| GE, kcal/kg | 4,020 | 4,097 | 4,235 | 4,257 | 4,097 | 4,235 | 4,257 |
| ME, kcal/kg[3] | 3,397 | 3,359 | 3,325 | 3,286 | 3,271 | 3,142 | 3,013 |
| NE, kcal/kg[3] | 2,601 | 2,571 | 2,541 | 2,509 | 2,506 | 2,406 | 2,304 |
| CP, % | 14.11 | 14.6 | 15.54 | 14.83 | 14.74 | 14.58 | 15.13 |
| AEE[4], % | 4.74 | 6.18 | 7.67 | 9.52 | 4.73 | 5.35 | 5.43 |
| ADF, % | 2.81 | 3.32 | 4.11 | 4.42 | 3.82 | 4.65 | 4.75 |
| NDF, % | 8.50 | 9.29 | 10.12 | 9.07 | 8.25 | 10.27 | 10.00 |
| Ash, % | 4.13 | 4.88 | 4.23 | 6.26 | 4.82 | 5.61 | 7.01 |
| Ca, % | 0.68 | 0.68 | 0.18 | 0.60 | 0.67 | 0.86 | 0.93 |
| P, % | 0.40 | 0.48 | 0.63 | 0.80 | 0.48 | 0.68 | 0.88 |

**Table 9.4.** Cont.

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Indispensable AA, % | | | | | | | |
| Arg | 0.87 | 0.88 | 0.91 | 0.96 | 0.91 | 0.94 | 0.93 |
| His | 0.39 | 0.38 | 0.38 | 0.38 | 0.39 | 0.39 | 0.38 |
| Ile | 0.61 | 0.57 | 0.58 | 0.61 | 0.62 | 0.60 | 0.57 |
| Leu | 1.35 | 1.23 | 1.24 | 1.23 | 1.31 | 1.29 | 1.24 |
| Lys | 0.95 | 1.02 | 0.88 | 1.09 | 0.93 | 0.99 | 0.87 |
| Met | 0.22 | 0.22 | 0.22 | 0.23 | 0.23 | 0.22 | 0.24 |
| Phe | 0.72 | 0.69 | 0.70 | 0.72 | 0.73 | 0.71 | 0.68 |
| Thr | 0.60 | 0.55 | 0.56 | 0.56 | 0.55 | 0.56 | 0.55 |
| Trp | 0.21 | 0.19 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |
| Val | 0.70 | 0.68 | 0.71 | 0.73 | 0.72 | 0.73 | 0.73 |
| Dispensable AA, % | | | | | | | |
| Ala | 0.78 | 0.76 | 0.78 | 0.78 | 0.79 | 0.79 | 0.80 |
| Asp | 1.33 | 1.29 | 1.29 | 1.32 | 1.32 | 1.31 | 1.25 |
| Cys | 0.22 | 0.22 | 0.24 | 0.23 | 0.24 | 0.23 | 0.25 |
| Glu | 2.63 | 2.42 | 2.43 | 2.39 | 2.53 | 2.47 | 2.36 |
| Gly | 0.61 | 0.62 | 0.64 | 0.64 | 0.64 | 0.65 | 0.66 |
| Pro | 0.95 | 0.90 | 0.87 | 0.87 | 0.94 | 0.85 | 0.87 |
| Ser | 0.64 | 0.62 | 0.63 | 0.60 | 0.61 | 0.61 | 0.60 |
| Tyr | 0.47 | 0.45 | 0.45 | 0.47 | 0.47 | 0.47 | 0.45 |

[1]The phytase premix was prepared by mixing 30 g of microbial phytase [Quantum Blue 5G (5,000 units per gram), AB Vista; Marlborough, UK] with 970 g of ground corn. The premix, therefore, contained 150,000 units of phytase per kilogram, and at 1% inclusion, 1,500 units of phytase were included per kilogram of complete feed.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg;

**Table 9.4.** Cont.

riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

[3]ME and NE values are calculated values (NRC, 2012).

[4]AEE = acid hydrolyzed ether extract.

**Table 9.5.** Concentration of crude fat and fatty acids in early finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis[1,2]

| Item, % | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Crude fat | 3.15 | 4.86 | 6.69 | 8.18 | 3.8 | 3.99 | 3.82 |
| C14:0 | 0.47 | 0.46 | 0.45 | 0.46 | 0.50 | 0.50 | 0.55 |
| C:15:0 | 0.04 | 0.05 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 |
| C16:0 | 17.18 | 17.13 | 17.36 | 17.40 | 17.48 | 17.38 | 17.51 |
| C:16:1 | 0.74 | 0.64 | 0.56 | 0.54 | 0.74 | 0.72 | 0.74 |
| C17:0 | 0.21 | 0.17 | 0.16 | 0.13 | 0.20 | 0.20 | 0.19 |
| C:18:0 | 6.09 | 5.20 | 4.64 | 4.41 | 5.98 | 5.66 | 5.74 |
| C18:1 | 26.02 | 29.69 | 32.19 | 35.29 | 27.99 | 29.09 | 30.75 |
| C18:2 | 42.14 | 39.50 | 36.89 | 33.81 | 39.62 | 38.18 | 36.26 |
| C18:3 | 1.32 | 1.31 | 1.20 | 1.28 | 1.25 | 1.22 | 1.17 |
| C20:0 | 0.38 | 0.44 | 0.53 | 0.58 | 0.40 | 0.42 | 0.43 |
| C20:1 | 0.41 | 0.46 | 0.53 | 0.58 | 0.44 | 0.49 | 0.47 |
| C20:4 | 0.09 | 0.08 | 0.07 | 0.06 | 0.10 | 0.09 | 0.09 |
| C22:0 | 0.16 | 0.22 | 0.28 | 0.31 | 0.21 | 0.32 | 0.35 |
| C22:1 | 0.06 | 0.07 | N.D. | 0.09 | 0.08 | 0.05 | 0.05 |
| C24:0 | 0.18 | 0.36 | 0.49 | 0.56 | 0.39 | 0.61 | 0.78 |
| C24:1 | 0.04 | 0.02 | 0.03 | 0.04 | 0.04 | 0.05 | N.D. |
| Total SFA[4] | 24.54 | 23.66 | 23.46 | 23.33 | 24.81 | 24.53 | 24.81 |
| Total MUFA[5] | 27.23 | 30.86 | 33.30 | 36.51 | 29.25 | 30.35 | 32.01 |
| Total PUFA[6] | 43.54 | 40.90 | 38.15 | 35.15 | 40.98 | 39.49 | 37.52 |
| IV[7] | 99.87 | 98.40 | 95.66 | 93.28 | 97.07 | 95.43 | 93.42 |

[1]Fatty acids are expressed as percent of crude fat.

[2]Diets were also analyzed for C14:1, C15:0, C20:5, C22:5, and C22:6, but these fatty acids were not detected in any diets.

[3]N.D. = not detected.

[4]Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

**Table 9.5.** Cont.

[5]Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

[6]Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 +C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

[7]Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

**Table 9.6**. Ingredient and analyzed composition of late finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis

| Item | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Ingredients, % | | | | | | | |
| Ground corn | 78.45 | 69.52 | 61.02 | 52.02 | 70.04 | 62.04 | 54.04 |
| Soybean meal | 16.50 | 15.50 | 14.00 | 13.00 | 15.00 | 13.00 | 11.00 |
| Rice coproducts | - | 10.0 | 20.00 | 30.00 | 10.0 | 20.00 | 30.00 |
| Soybean oil | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| L-Lys HCl | 0.11 | 0.10 | 0.10 | 0.08 | 0.10 | 0.11 | 0.12 |
| Ground limestone | 1.04 | 1.18 | 1.18 | 1.20 | 1.16 | 1.15 | 1.14 |
| Dicalcium phosphate | 0.20 | - | - | - | - | - | - |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Phytase premix[1] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Vitamin-mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | | | | | |
| DM, % | 88.57 | 88.98 | 89.36 | 90.01 | 87.59 | 88.63 | 88.33 |
| GE, kcal/kg | 3,975 | 4,101 | 4,169 | 4,292 | 3,998 | 4,003 | 3,961 |
| ME, kcal/kg[3] | 3,412 | 3,375 | 3,337 | 3,298 | 3,285 | 3,156 | 3,026 |
| NE, kcal/kg[3] | 2,618 | 2,586 | 2,556 | 2,523 | 2,517 | 2,417 | 2,317 |
| CP, % | 13.85 | 13.68 | 14.37 | 14.33 | 13.62 | 13.99 | 13.85 |
| AEE[4], % | 4.50 | 5.83 | 7.82 | 9.90 | 4.95 | 4.94 | 4.38 |
| NDF, % | 9.61 | 9.47 | 9.96 | 12.48 | 8.50 | 9.40 | 10.92 |
| ADF, % | 2.46 | 3.22 | 3.96 | 4.64 | 3.47 | 4.11 | 4.86 |
| Ash, % | 4.42 | 4.53 | 5.44 | 5.89 | 4.23 | 4.56 | 5.87 |
| Ca, % | 0.69 | 0.69 | 0.63 | 0.73 | 0.61 | 0.70 | 0.77 |
| P, % | 0.36 | 0.49 | 0.66 | 0.80 | 0.50 | 0.69 | 0.86 |

**Table 9.6** Cont.

| | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Indispensable AA, % | | | | | | | |
| Arg | 0.86 | 0.89 | 0.89 | 0.94 | 0.91 | 0.89 | 0.88 |
| His | 0.37 | 0.37 | 0.37 | 0.38 | 0.38 | 0.37 | 0.36 |
| Ile | 0.59 | 0.59 | 0.56 | 0.57 | 0.58 | 0.57 | 0.53 |
| Leu | 1.21 | 1.19 | 1.14 | 1.17 | 1.19 | 1.12 | 1.09 |
| Lys | 0.84 | 0.83 | 0.85 | 0.85 | 0.83 | 0.83 | 0.77 |
| Met | 0.21 | 0.21 | 0.22 | 0.24 | 0.22 | 0.22 | 0.22 |
| Phe | 0.69 | 0.69 | 0.67 | 0.69 | 0.69 | 0.66 | 0.61 |
| Thr | 0.51 | 0.51 | 0.50 | 0.52 | 0.52 | 0.50 | 0.48 |
| Trp | 0.19 | 0.17 | 0.18 | 0.19 | 0.18 | 0.18 | 0.18 |
| Val | 0.68 | 0.69 | 0.69 | 0.71 | 0.70 | 0.67 | 0.68 |
| Dispensable AA, % | | | | | | | |
| Ala | 0.73 | 0.73 | 0.73 | 0.78 | 0.75 | 0.74 | 0.73 |
| Asp | 1.32 | 1.32 | 1.28 | 1.32 | 1.32 | 1.26 | 1.19 |
| Cys | 0.22 | 0.22 | 0.23 | 0.24 | 0.22 | 0.22 | 0.22 |
| Glu | 2.46 | 2.40 | 2.29 | 2.33 | 2.42 | 2.23 | 2.13 |
| Gly | 0.61 | 0.63 | 0.63 | 0.65 | 0.64 | 0.64 | 0.60 |
| Pro | 0.90 | 0.87 | 0.84 | 0.84 | 0.88 | 0.84 | 0.81 |
| Ser | 0.60 | 0.59 | 0.58 | 0.61 | 0.61 | 0.58 | 0.54 |
| Tyr | 0.44 | 0.45 | 0.44 | 0.43 | 0.44 | 0.43 | 0.39 |

[1]The phytase premix was prepared by mixing 30 g of microbial phytase [Quantum Blue 5G (5,000 units per gram), AB Vista; Marlborough, UK] with 970 g of ground corn. The premix, therefore, contained 150,000 units of phytase per kilogram, and at 1% inclusion, 1,500 units of phytase were included per kilogram of complete feed.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg;

**Table 9.6.** Cont.

riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin $B_{12}$, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

[3]ME and NE values are calculated values (NRC, 2012).

[4]AEE = acid hydrolyzed ether extract.

**Table 9.7**. Concentration of crude fat and fatty acids in late finisher diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB), as fed basis[1,2]

| Items, % | Basal | FFRB | | | DFRB | | |
|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 10% | 20% | 30% |
| Crude fat | 2.93 | 4.29 | 6.03 | 7.88 | 3.0 | 2.61 | 2.7 |
| C14:0 | 0.44 | 0.44 | 0.45 | 0.45 | 0.51 | 0.50 | 0.57 |
| C:15:0 | 0.06 | 0.05 | 0.05 | 0.04 | 0.06 | 0.05 | 0.06 |
| C16:0 | 18.01 | 17.66 | 17.75 | 16.80 | 17.76 | 17.47 | 18.51 |
| C16:1 | 0.71 | 0.62 | 0.57 | 0.51 | 0.76 | 0.75 | 0.80 |
| C17:0 | 0.20 | 0.16 | 0.15 | 0.13 | 0.21 | 0.19 | 0.21 |
| C18:0 | 5.91 | 5.02 | 4.61 | 4.22 | 5.69 | 5.49 | 6.13 |
| C18:1 | 28.61 | 31.60 | 33.81 | 35.44 | 29.33 | 29.93 | 31.06 |
| C18:2 | 38.66 | 36.85 | 34.30 | 34.94 | 38.11 | 38.13 | 34.71 |
| C18:3 | 1.40 | 1.33 | 1.23 | 1.13 | 1.34 | 1.34 | 1.27 |
| C20:0 | 0.34 | 0.47 | 0.57 | 0.65 | 0.47 | 0.38 | 0.39 |
| C20:1 | 0.41 | 0.51 | 0.55 | 0.57 | 0.48 | 0.46 | 0.50 |
| C20:4 | 0.09 | 0.08 | 0.06 | 0.06 | 0.10 | 0.10 | 0.09 |
| C22:0 | 0.16 | 0.23 | 0.29 | 0.34 | 0.25 | 0.19 | 0.24 |
| C22:1 | 0.06 | 0.08 | 0.06 | 0.07 | 0.06 | 0.06 | 0.04 |
| C24:0 | 0.20 | 0.39 | 0.50 | 0.59 | 0.33 | 0.41 | 0.57 |
| C24:1 | N.D.[3] | 0.04 | 0.04 | 0.03 | N.D. | 0.04 | N.D. |
| Total SFA[4] | 25.12 | 24.02 | 23.87 | 22.62 | 24.93 | 24.27 | 26.11 |
| Total MUFA[5] | 29.79 | 32.80 | 34.98 | 36.59 | 30.63 | 31.20 | 32.39 |
| Total PUFA[6] | 40.15 | 38.26 | 35.59 | 36.13 | 39.55 | 39.57 | 36.07 |
| IV[7] | 96.28 | 95.52 | 92.71 | 94.94 | 95.88 | 96.40 | 91.30 |

[1]Fatty acids are expressed as percent of crude fat.

[2]Diets were also analyzed for C14:1, C15:0, C20:5, C22:5, and C22:6, but these fatty acids were not detected in any diets.

[3]N.D. = not detected.

[4]Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[5]Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1 + C22:1.

**Table 9.7.** Cont.

[6]Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 +C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

[7]Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

**Table 9.8.** Growth performance of pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1]

| Item | Diets | | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[2] | Linear | Quad[2] | |
| Growing, d 0 to 35 | | | | | | | | | | | | | |
| Initial BW, kg | 27.8 | 28.0 | 28.3 | 28.1 | 28.3 | 28.2 | 28.1 | 1.76 | 0.855 | 0.907 | 0.903 | 0.855 | 0.964 |
| ADFI, kg | 1.79 | 1.81 | 1.74 | 1.68 | 1.82 | 1.96 | 1.88 | 0.08 | 0.149 | 0.543 | 0.159 | 0.406 | 0.008 |
| ADG, kg | 0.856 | 0.833 | 0.836 | 0.820 | 0.832 | 0.882 | 0.851 | 0.03 | 0.345 | 0.864 | 0.753 | 0.900 | 0.211 |
| G:F | 0.477 | 0.462 | 0.484 | 0.489 | 0.462 | 0.451 | 0.454 | 0.01 | 0.209 | 0.314 | 0.079 | 0.353 | 0.008 |
| Final BW, kg | 57.9 | 57.3 | 57.7 | 56.9 | 57.5 | 58.1 | 58.0 | 1.93 | 0.773 | 0.974 | 0.913 | 0.938 | 0.721 |
| Early finishing, d 36 to 70 | | | | | | | | | | | | | |
| ADFI, kg/d | 2.69 | 2.81 | 2.67 | 2.58 | 2.73 | 2.97 | 2.87 | 0.13 | 0.110 | 0.083 | 0.005 | 0.258 | 0.001 |
| ADG, kg | 1.00 | 1.04 | 1.02 | 1.00 | 0.98 | 1.02 | 0.99 | 0.02 | 0.863 | 0.192 | 0.820 | 0.809 | 0.283 |
| G:F | 0.374 | 0.371 | 0.383 | 0.387 | 0.358 | 0.347 | 0.346 | 0.02 | 0.142 | 0.629 | 0.006 | 0.292 | < 0.001 |
| Final BW, kg | 92.8 | 93.6 | 93.4 | 91.8 | 91.6 | 93.9 | 92.6 | 2.19 | 0.753 | 0.590 | 0.855 | 0.978 | 0.912 |
| Late finishing, d 70 to 97 | | | | | | | | | | | | | |
| ADFI, kg/d | 3.52 | 3.45 | 3.23 | 3.22 | 3.25 | 3.44 | 3.71 | 0.31 | 0.007 | 0.723 | 0.067 | 0.004 | 0.028 |
| ADG, kg | 1.02 | 1.02 | 1.03 | 1.00 | 1.00 | 0.98 | 0.93 | 0.02 | 0.821 | 0.574 | 0.064 | 0.533 | 0.083 |
| G:F | 0.291 | 0.300 | 0.322 | 0.311 | 0.311 | 0.291 | 0.259 | 0.04 | 0.061 | 0.315 | 0.010 | 0.009 | 0.004 |
| Final BW, kg | 120.0 | 120.9 | 121.1 | 118.6 | 118.4 | 120.3 | 117.4 | 2.34 | 0.703 | 0.472 | 0.581 | 0.791 | 0.437 |

**Table 9.8.** Cont.

| Item | Diets | | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[2] | Linear | Quad[2] | |
| Overall, d 0 to 97 | | | | | | | | | | | | | |
| ADFI, kg/d | 2.60 | 2.61 | 2.49 | 2.42 | 2.54 | 2.73 | 2.73 | 0.13 | 0.009 | 0.430 | 0.019 | 0.684 | 0.001 |
| ADG, kg | 0.95 | 0.96 | 0.96 | 0.93 | 0.93 | 0.95 | 0.92 | 0.02 | 0.471 | 0.362 | 0.364 | 0.838 | 0.253 |
| G:F | 0.368 | 0.370 | 0.386 | 0.388 | 0.367 | 0.349 | 0.342 | 0.02 | 0.007 | 0.987 | 0.001 | 0.607 | < 0.001 |

[1]Data are least squares means of 8 observations for all diets.

[2]Quad = quadratic effect.

**Table 9.9.** Organs weights for pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1]

| Item | Diets | | | | | | | SEM | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | | Linear | Quad[2] | Linear | Quad[2] | - |
| Full GI[3] tract, kg | 7.521 | 6.830 | 7.433 | 7.480 | 7.797 | 8.178 | 7.871 | 0.295 | 0.670 | 0.148 | 0.208 | 0.250 | 0.001 |
| Full GI tract, %[4] | 6.577 | 5.960 | 6.575 | 6.621 | 6.746 | 7.189 | 6.808 | 0.268 | 0.448 | 0.136 | 0.250 | 0.214 | 0.005 |
| Gut Fill, kg[5] | 2.175 | 1.756 | 2.207 | 2.223 | 2.265 | 2.695 | 2.463 | 0.222 | 0.486 | 0.255 | 0.133 | 0.399 | 0.010 |
| Gut Fill, % | 1.919 | 1.546 | 1.973 | 1.967 | 1.957 | 2.369 | 2.134 | 0.201 | 0.453 | 0.282 | 0.169 | 0.422 | 0.023 |
| Esophagus, kg | 0.077 | 0.072 | 0.075 | 0.069 | 0.078 | 0.080 | 0.069 | 0.006 | 0.405 | 0.953 | 0.374 | 0.287 | 0.433 |
| Esophagus, % | 0.067 | 0.063 | 0.066 | 0.061 | 0.068 | 0.071 | 0.060 | 0.005 | 0.450 | 0.952 | 0.315 | 0.229 | 0.531 |
| Stomach, kg | 0.606 | 0.575 | 0.576 | 0.535 | 0.609 | 0.624 | 0.547 | 0.035 | 0.167 | 0.889 | 0.286 | 0.245 | 0.265 |
| Stomach, % | 0.530 | 0.503 | 0.510 | 0.476 | 0.530 | 0.551 | 0.475 | 0.030 | 0.248 | 0.899 | 0.279 | 0.204 | 0.359 |
| Small intestine, kg | 1.647 | 1.492 | 1.648 | 1.588 | 1.640 | 1.620 | 1.534 | 0.090 | 0.955 | 0.564 | 0.333 | 0.637 | 0.747 |
| Small intestine, % | 1.444 | 1.298 | 1.465 | 1.416 | 1.425 | 1.433 | 1.332 | 0.078 | 0.801 | 0.517 | 0.335 | 0.587 | 0.950 |
| Large intestine, kg | 1.645 | 1.631 | 1.542 | 1.637 | 1.730 | 1.702 | 1.770 | 0.072 | 0.720 | 0.441 | 0.274 | 0.898 | 0.027 |
| Large intestine, % | 1.437 | 1.428 | 1.362 | 1.461 | 1.499 | 1.507 | 1.539 | 0.061 | 0.982 | 0.379 | 0.254 | 0.801 | 0.054 |
| Mesenteric fat, kg | 1.351 | 1.283 | 1.366 | 1.407 | 1.457 | 1.438 | 1.468 | 0.132 | 0.585 | 0.597 | 0.473 | 0.714 | 0.230 |

**Table 9.9.** Cont.

| Item | Basal | Diets | | | | | | SEM | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | | Linear | Quad[2] | Linear | Quad[2] | - |
| Mesenteric, fat, % | 1.177 | 1.120 | 1.196 | 1.237 | 1.264 | 1.256 | 1.266 | 0.115 | 0.512 | 0.574 | 0.506 | 0.661 | 0.278 |
| Heart, kg | 0.331 | 0.354 | 0.331 | 0.340 | 0.331 | 0.339 | 0.344 | 0.011 | 0.949 | 0.509 | 0.312 | 0.754 | 0.644 |
| Heart, % | 0.289 | 0.310 | 0.294 | 0.302 | 0.288 | 0.300 | 0.299 | 0.009 | 0.581 | 0.446 | 0.322 | 0.988 | 0.345 |
| Liver, kg | 1.568 | 1.630 | 1.675 | 1.619 | 1.685 | 1.789 | 1.682 | 0.064 | 0.482 | 0.347 | 0.114 | 0.078 | 0.131 |
| Liver, % | 1.371 | 1.423 | 1.481 | 1.432 | 1.466 | 1.579 | 1.460 | 0.044 | 0.205 | 0.237 | 0.049 | 0.015 | 0.107 |
| Kidneys, kg | 0.386 | 0.390 | 0.380 | 0.367 | 0.389 | 0.408 | 0.366 | 0.015 | 0.280 | 0.554 | 0.511 | 0.114 | 0.431 |
| Kidneys, % | 0.337 | 0.340 | 0.338 | 0.325 | 0.339 | 0.361 | 0.317 | 0.013 | 0.440 | 0.483 | 0.475 | 0.062 | 0.628 |

[1]Data are least squares means of 8 observations for all diets.

[2]Quad = quadratic effect.

[3]GI = gastrointestinal tract.

[4]Percent of ending live weight.

[5]Gut fill = full intestinal tract wt. – (empty small intestine + empty large intestine + empty stomach + esophagus + mesenteric fat).

**Table 9.10.** Carcass characteristics of pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1]

| Item | Diets | | | | | | | SEM | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | | Linear | Quad[2] | Linear | Quad[2] | - |
| ELW[3], kg | 114.48 | 114.45 | 112.94 | 112.83 | 115.07 | 113.34 | 115.27 | 2.619 | 0.425 | 0.981 | 0.935 | 0.711 | 0.434 |
| HCW, kg | 90.78 | 90.72 | 89.27 | 88.56 | 90.41 | 87.83 | 90.61 | 2.267 | 0.269 | 0.842 | 0.669 | 0.333 | 0.944 |
| Carcass yield, % | 79.31 | 79.29 | 78.76 | 78.81 | 78.87 | 78.12 | 78.63 | 0.433 | 0.195 | 0.919 | 0.071 | 0.185 | 0.161 |
| LM area, $cm^2$ | 54.48 | 55.19 | 56.39 | 53.74 | 54.39 | 52.12 | 55.43 | 2.552 | 0.901 | 0.360 | 0.943 | 0.354 | 0.451 |
| $10^{th}$-rib fat depth, cm | 1.60 | 1.50 | 1.47 | 1.73 | 1.45 | 1.45 | 1.61 | 0.219 | 0.638 | 0.337 | 0.964 | 0.397 | 0.657 |
| Standardized fat free lean[4], % | 56.61 | 57.21 | 58.38 | 56.16 | 57.33 | 57.21 | 56.83 | 1.261 | 0.967 | 0.154 | 0.903 | 0.572 | 0.874 |
| Back fat L* | 75.07 | 74.99 | 75.07 | 74.44 | 75.25 | 74.86 | 75.82 | 1.119 | 0.357 | 0.538 | 0.346 | 0.372 | 0.186 |
| Back fat a*[5] | 4.96 | 4.95 | 4.59 | 4.62 | 4.74 | 5.07 | 4.57 | 0.411 | 0.354 | 0.952 | 0.569 | 0.672 | 0.789 |
| Back fat b*[5] | 4.19 | 3.60 | 3.87 | 3.49 | 4.08 | 3.65 | 3.43 | 0.449 | 0.095 | 0.674 | 0.015 | 0.821 | 0.744 |
| Back fat Lightness, L*[5] | 75.07 | 74.99 | 75.07 | 74.44 | 75.25 | 74.86 | 75.82 | 1.119 | 0.357 | 0.538 | 0.346 | 0.372 | 0.186 |

[1]Data are least squares means of 8 observations for all diets.

[2]Quad = quadratic effect.

[3]ELW = ending live weight.

[4]Standardized fat free lean = {[8.588 + (0.465 × HCW, lb) – (21.896 × $10^{th}$-rib fat depth, in) + (3.005 × $10^{th}$-rib LMA, $in^2$)] / HCW × 100 (Burson and Berg, 2001).

**Table 9.10**. Cont.

[5]L* = measure of lightness (greater value indicates a lighter color), a* = measure of redness (greater value indicates a redder color), and b* = measure of yellowness (greater value indicates a more yellow color).

**Table 9.11.** Loin quality of growing pigs fed basal diets or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB) [1]

| Item | Diets | | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[2] | Linear | Quad[2] | - |
| Color[3] | 2.44 | 2.44 | 2.31 | 2.13 | 2.19 | 1.94 | 2.13 | 0.174 | 0.178 | 0.592 | 0.133 | 0.214 | 0.149 |
| Marbling[3] | 1.88 | 1.13 | 1.13 | 1.00 | 1.50 | 1.50 | 1.25 | 0.176 | 0.002 | 0.082 | 0.021 | 0.724 | 0.025 |
| Firmness[4] | 2.50 | 2.13 | 1.63 | 2.13 | 2.25 | 2.00 | 2.00 | 0.298 | 0.217 | 0.139 | 0.184 | 0.669 | 0.601 |
| L*[5] | 50.46 | 50.26 | 51.01 | 50.04 | 51.89 | 54.09 | 51.55 | 1.678 | 0.921 | 0.735 | 0.283 | 0.085 | 0.029 |
| a*[5] | 9.56 | 10.20 | 9.95 | 10.06 | 9.55 | 9.04 | 9.63 | 0.652 | 0.567 | 0.582 | 0.896 | 0.546 | 0.101 |
| b*[5] | 2.28 | 2.40 | 2.01 | 1.73 | 2.27 | 2.53 | 2.35 | 0.531 | 0.348 | 0.671 | 0.817 | 0.861 | 0.395 |
| Ultimate pH | 5.60 | 5.61 | 5.57 | 5.57 | 5.58 | 5.56 | 5.55 | 0.093 | 0.257 | 0.981 | 0.110 | 0.865 | 0.363 |
| Drip loss, % | 3.49 | 3.23 | 3.40 | 3.97 | 3.42 | 3.84 | 4.69 | 0.650 | 0.584 | 0.523 | 0.173 | 0.481 | 0.397 |
| Cook loss, % | 26.04 | 24.85 | 25.12 | 24.53 | 26.74 | 27.61 | 28.14 | 0.988 | 0.365 | 0.765 | 0.131 | 0.932 | 0.002 |
| WBSF[6], kg | 3.24 | 3.05 | 2.96 | 2.94 | 3.05 | 3.02 | 3.22 | 0.219 | 0.324 | 0.708 | 0.926 | 0.390 | 0.540 |
| Moisture, % | 73.61 | 73.48 | 73.99 | 73.80 | 73.18 | 73.62 | 73.75 | 0.232 | 0.307 | 0.910 | 0.411 | 0.229 | 0.212 |
| Protein, % | 23.38 | 24.32 | 24.49 | 25.01 | 24.48 | 24.41 | 25.32 | 0.884 | 0.023 | 0.664 | 0.010 | 0.848 | 0.743 |
| Lipid, % | 2.36 | 2.07 | 1.61 | 1.74 | 2.33 | 1.99 | 1.64 | 0.203 | 0.014 | 0.295 | 0.008 | 0.421 | 0.280 |
| Ash, % | 2.59 | 2.39 | 2.21 | 2.34 | 2.34 | 2.41 | 2.35 | 0.151 | 0.130 | 0.210 | 0.283 | 0.458 | 0.638 |

[1]Data are least squares means of 8 observations for all diets.

[2]Quad = quadratic effect.

**Table 9.11** Cont.

[3]National Pork Producers Council (1999). NPPC color (1 = pale pink to 6 = dark purplish red). NPPC marbling (1 = 1% intramuscular lipid to 10 = ≥ 10% intramuscular lipid).

[4]National Pork Producers Council (1991). NPPC firmness (1 = very soft to 5 = very firm).

[5]L* = measure of lightness (greater value indicates a lighter color), a* = measure of redness (greater value indicates a redder color), and b* = measure of yellowness (greater value indicates a more yellow color).

[6]WBSF = Warner Bratzler shear force.

**Table 9.12**. Characteristics of bellies from pigs fed basal diet or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB) [1]

| Item | Diets | | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[2] | Linear | Quad[2] | - |
| Belly wt, kg | 6.24 | 5.93 | 6.32 | 5.94 | 6.02 | 6.58 | 6.19 | 0.204 | 0.589 | 0.860 | 0.645 | 0.680 | 0.239 |
| Belly length, cm | 68.89 | 66.51 | 66.06 | 66.16 | 64.16 | 66.13 | 66.03 | 1.149 | 0.025 | 0.145 | 0.084 | 0.008 | 0.245 |
| Belly width, cm | 27.69 | 26.83 | 28.16 | 26.67 | 27.27 | 28.07 | 26.96 | 0.451 | 0.400 | 0.485 | 0.492 | 0.443 | 0.568 |
| Belly thickness, cm,[3] | 2.83 | 2.77 | 3.11 | 2.99 | 3.14 | 3.25 | 3.12 | 0.184 | 0.326 | 0.882 | 0.236 | 0.246 | 0.162 |
| Flop distance, cm | 7.53 | 8.58 | 11.91 | 7.75 | 10.11 | 12.58 | 7.88 | 1.45 | 0.450 | 0.032 | 0.507 | 0.003 | 0.423 |

[1]Data are least squares means of 8 observations for all diets.

[2]Quad = quadratic effect.

[3]Thickness is the average of measurements measured at 8 locations from the anterior to posterior, with 4 measurements on each of the dorsal and ventral edges.

**Table 9.13**. Fatty acid profile of belly adipose tissue (% of total fat) of pig fed basal diets or diets containing full fat rice bran (FFRB) or defatted rice bran (DFRB)[1,2]

| Item | Diet | | | | | | | | *P*-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad[3] | Linear | Quad | - |
| Crude fat | 74.07 | 71.56 | 78.08 | 81.47 | 78.55 | 82.05 | 81.35 | 3.43 | 0.007 | 0.198 | 0.025 | 0.292 | 0.070 |
| C14:0 | 1.21 | 1.21 | 1.09 | 1.06 | 1.24 | 1.18 | 1.25 | 0.043 | 0.002 | 0.646 | 0.750 | 0.606 | 0.002 |
| C15:0 | 0.07 | 0.05 | 0.07 | 0.06 | 0.08 | 0.06 | 0.06 | 0.006 | 0.886 | 0.616 | 0.269 | 0.351 | 0.266 |
| C16:0 | 22.89 | 21.92 | 19.89 | 19.85 | 22.20 | 21.62 | 21.80 | 0.404 | < 0.001 | 0.229 | 0.036 | 0.274 | < 0.001 |
| C16:1 | 2.18 | 1.78 | 1.63 | 1.36 | 2.20 | 1.87 | 2.07 | 0.210 | < 0.001 | 0.373 | 0.054 | 0.240 | < 0.001 |
| C17:0 | 0.48 | 0.36 | 0.38 | 0.30 | 0.44 | 0.44 | 0.39 | 0.027 | < 0.001 | 0.426 | 0.018 | 0.675 | < 0.001 |
| C18:0 | 11.30 | 11.35 | 9.30 | 8.97 | 10.39 | 11.03 | 10.74 | 0.719 | < 0.001 | 0.641 | 0.582 | 0.457 | 0.015 |
| C18:1 | 44.13 | 42.26 | 42.65 | 41.98 | 43.85 | 44.50 | 44.11 | 1.548 | 0.016 | 0.273 | 0.812 | 0.920 | < 0.001 |
| C18:2 | 13.05 | 16.33 | 19.90 | 21.39 | 14.52 | 14.36 | 14.32 | 1.063 | < 0.001 | 0.229 | 0.275 | 0.309 | < 0.001 |
| C18:3 | 0.47 | 0.56 | 0.68 | 0.72 | 0.51 | 0.49 | 0.49 | 0.036 | < 0.001 | 0.494 | 0.823 | 0.526 | < 0.001 |
| C20:0 | 0.18 | 0.23 | 0.21 | 0.21 | 0.19 | 0.21 | 0.20 | 0.011 | 0.086 | 0.044 | 0.070 | 0.432 | 0.070 |
| C20:1 | 0.84 | 0.80 | 0.82 | 0.83 | 0.85 | 0.86 | 0.86 | 0.030 | 0.878 | 0.355 | 0.606 | 0.993 | 0.108 |
| C20:4 | 0.30 | 0.33 | 0.37 | 0.33 | 0.33 | 0.33 | 0.34 | 0.021 | 0.104 | 0.073 | 0.191 | 0.476 | 0.534 |
| C22:5 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.003 | 0.446 | 0.802 | 0.458 | 0.909 | 0.710 |
| Total SFA[4] | 36.17 | 35.16 | 30.99 | 30.50 | 34.63 | 34.57 | 34.86 | 1.091 | < 0.001 | 0.734 | 0.241 | 0.228 | < 0.001 |

**Table 9.13.** Cont.

| Item | Diets | | | | | | | | P-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | FFRB | | | DFRB | | | | FFRB | | DFRB | | FFRB vs. DFRB |
| | - | 10% | 20% | 30% | 10% | 20% | 30% | SEM | Linear | Quad3 | Linear | Quad | - |
| Total MUFA[5] | 47.19 | 44.88 | 45.13 | 44.31 | 46.94 | 47.31 | 47.08 | 1.780 | 0.003 | 0.215 | 0.986 | 0.982 | < 0.001 |
| Total PUFA[6] | 13.89 | 17.29 | 21.03 | 22.51 | 15.45 | 15.25 | 15.22 | 1.102 | < 0.001 | 0.229 | 0.286 | 0.317 | < 0.001 |
| IV[7] | 64.58 | 68.47 | 75.16 | 77.14 | 67.02 | 66.96 | 66.72 | 1.140 | < 0.001 | 0.406 | 0.219 | 0.244 | < 0.001 |

[1]Data are least squares means of 8 observations for all diets.

[2]C14:1, C20:5, C22:0, C22:1, C22:1, C22:6, C24:0, and C24:1 were analyzed, but concentrations were below 0.03% in all samples.

[3]Quad = quadratic effect.

[4]Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[5]Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1n9 + C22:1.

[6]Total PUFA = C18:2 + C18:3 + C20:2 + C20:3 +C20:4 + C20:3 + C22:4 + C22:5 + C22:6.

[7]IV = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific fatty acids as a percentage of crude fat (AOCS, 1998).

## LITERATURE CITED

AOAC Int. 2007. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. In: W. Hortwitz and G. W. Latimer, Jr., editors. AOAC Int., Gaithersburg, MD.

AOCS. 1998. Official methods and recommended practice of the AOCS. 5th ed. AOCS, Champaign, IL, USA.

AOCS. 2017. Official methods and recommended practices of the AOCS. 7th ed. Am. Oil Chem. Soc., Champaign, IL.

Boler, D. D., L. W. Kutzler, D. M. Meeuwse, V. L. King, D. R. Campion, F. K. McKeith, and J. Killefer. 2011. Effects of increasing lysine on carcass composition and cutting yields of immunologically castrated male pigs. J. Anim. Sci. 89:2189-2199. doi:10.2527/jas.2010-3640

Boler, D. D., C. L. Puls, D. L. Clark, M. Ellis, A. L. Schroeder, P. D. Matzat, J. Killefer, F. K. McKeith, and A. C. Dilger. 2014. Effects of immunological castration (Improvest) on changes in dressing percentage and carcass characteristics of finishing pigs. J. Anim. Sci. 92:359-368. doi:10.2527/jas.2013-6863

Burson, D., and E. Berg. 2001. Procedures for esimating pork carcass composition. Pork facts. Natl. Pork Prod. Counc., Des Moines, IA.

Casas, G. A., G. Afanador, and D. Rodriguez. 2009. Componentes anatómicos y coeficientes alométricos en cerdos machos castrados desde el nacimiento. Rev. Colomb. Cienc. Pecu. 22:156-167.

Casas, G. A., and H. H. Stein. 2016a. Effects of full fat or defatted rice bran on growth performance and blood characteristics of weanling pigs. J. Anim. Sci. 94:4179-4187. doi:10.2527/jas.2016-0565

Casas, G. A., and H. H. Stein. 2016b. Effects of microbial xylanase on digestibility of dry matter, organic matter, neutral detergent fiber, and energy and the concentrations of digestible and metabolizable energy in rice coproducts fed to weanling pigs. J. Anim. Sci. 94:1933-1939. doi:10.2527/jas2015-0064

Casas, G. A., and H. H. Stein. 2017. Gestating sows have greater digestibility of energy in full fat rice bran and defatted rice bran than growing gilts regardless of level of feed intake. J. Anim. Sci. 95:3136-3142. doi:10.2527/jas.2017.1585

Cervantes-Pahm, S. K., and H. H. Stein. 2008. Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs. J. Anim. Sci. 86:1841-1849. doi:10.2527/jas.2007-0721

Chae, B. J., and S. K. Lee. 2002. Rancid rice bran affects growth performance and pork quality in finishing pigs. Asian-australas. J. Anim. Sci. 15:94-101. doi:10.5713/ajas.2002.94

CIE. 1978. Recomendations on uniform color spaces-color equations, psychometric color terms. No. Suppl. No. 2 to CIE Publication No. 15 (E-1.3L, 1971, 9TC-1-3), CIE, Paris, France. Commission Internationale de L'eclairage.

de Blas, C., G. G. Mateos, and P. García-Rebollar. 2010. Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos. (In spanish). 3rd. ed. Fund. Esp. Desarrollo Nutr. Anim., Madrid, Spain.

de Campos, R. M. L., E. Hierro, J. A. Ordoñez, T. M. Bertol, and L. Hoz. 2006. A note on partial replacement of maize with rice bran in the pig diet on meat and backfat fatty acids. J. Anim. Feed Sci. 15:427-433. doi:10.22358/jafs/66913/2006

Faria, S. A. S. C., P. Z. Bassinello, and M. V. C. Penteado. 2012. Nutritional composition of rice bran submitted to different stabilization procedures. Braz. J. Phar. Sci. 48:651-657.

Juliano, B. O. 1983. Lipid in rice and rice processing. In: P. J. Barnes, editor, Lipids in cereal Technology. Academic Press, London. p. 305-330.

Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. He, M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. Can. J. Anim. Sci. 85:355-363. doi:10.4141/A04-084

Kim, J. H., P. N. Seong, S. H. Cho, B. Y. Park, K. H. Hah, L. H. Yu, D. G. Lim, I. H. Hwang, D. H. Kim, J. M. Lee, and C. N. Ahn. 2008. Characterization of nutritional value for twenty-one pork muscles. Asian-Australas. J. Anim. Sci. 21:138-143. doi:10.5713/ajas.2008.70208

Kloareg, M., J. Noblet, and J. van Milgen. 2007. Deposition of dietary fatty acids, de novo synthesis and anatomical partitioning of fatty acids in finishing pigs. Br. J. Nutr. 97:35-44. doi:10.1017/S0007114507205793

Lee, J. W., D. Y. Kil, B. D. Keever, J. Killefer, F. K. McKeith, R. C. Sulabo, and H. H. Stein. 2013. Carcass fat quality of pigs is not improved by adding corn germ, beef tallow, palm kernel oil, or glycerol to finishing diets containing distillers dried grains with solubles. J. Anim. Sci. 91:2426-2437. doi:10.2527/jas.2012-5328

Leseigneur-Meynier, A., and G. Gandemer. 1991. Lipid composition of pork muscle in relation to the metabolic type of the fibres. Meat Sci. 29:229-241. doi:10.1016/0309-1740(91)90052-R

Monziols, M., M. Bonneau, A. Davenel, and M. Kouba. 2007. Comparison of the lipid content and fatty acid composition of intermuscular and subcutaneous adipose tissues in pig carcasses. Meat Sci. 76:54-60. doi:10.1016/j.meatsci.2006.10.01

NPPC. 1991. Procedures to evaluate market hogs. Natl. Pork Prod. Counc., Des Moines, IA.

NPPC. 1999. Official color and marbling standards. Natl. Pork Prod. Counc., Des Moines, IA.

NRC. 2012. Nutrient requirements of swine. 11 th rev. ed. Natl. Acad. Press, Washington, DC.

Overholt, M. F., J. E. Lowell, E. K. Arkfeld, I. M. Grossman, H. H. Stein, A. C. Dilger, and D. D. Boler. 2016a. Effects of pelleting diets without or with distillers' dried grains with solubles on growth performance, carcass characteristics, and gastrointestinal weights of growing-finishing barrows and gilts. J. Anim. Sci. 94:2172-2183. doi:10.2527/jas2015-0202

Overholt, M. F., J. E. Lowell, K. B. Wilson, R. J. Matulis, H. H. Stein, A. C. Dilger, and D. D. Boler. 2016b. Effects of feeding pelleted diets without or with distillers dried grains with solubles on fresh belly characteristics, fat quality, and commercial bacon slicing yields of finishing pigs. J. Anim. Sci. 94:2198-2206. doi:10.2527/jas.2015-0203

Rosenvold, K., and H. J. Andersen. 2003. Factors of significance for pork quality—a review. Meat Sci. 64:219-237. doi:10.1016/S0309-1740(02)00186-9

Rosniyana, A., M. A. Hashifah, and S. A. Shariffah-Norin. 2009. Nutritional content and storage stability of stabilised rice bran – MR 220. J. Trop. Agric. and Food Sc. 37:163-170.

Rosniyana, A., M. A. Hashifah, and S. A. Sharuffah-Norin. 2007. The physico-chemical properties and nutritional composition of rice bran produced at different milling degrees of rice. J. Trop. Agric. Food Sc. 35:99-105.

Rostagno, H. S., L. F. T. Albino, J. L. Donzele, P. C. Gomes, R. F. de Oliveira, D. C. Lopes, A. S. Ferreira, S. L. T. Barreto, and R. F. Euclides. 2011. Brazilian tables for poultry and swine. Composition of feedstuffs and nutritional requirements. 3rd ed. Universidade Federal de Viçosa, Viçosa, Brazil.

Saunders, R. M. 1985. Rice bran: Composition and potential food uses. Food Rev. Int. 1:465-495. doi:10.1080/87559128509540780

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Academic Publishers, The Netherlands.

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. CRC Press, Boca Raton, FL.

Shackelford, S. D., M. F. Miller, K. D. Haydon, N. V. Lovegren, C. E. Lyon, and J. O. Reagan. 1990. Acceptability of bacon as influenced by the feeding of elevated levels of monounsaturated fats to growing-finishing swine. J. Food Sci. 55:621-624. doi:10.1111/j.1365-2621.1990.tb05191.x

Soladoye, P. O., P. J. Shand, J. L. Aalhus, C. Gariépy, and M. Juárez. 2015. Review: Pork belly quality, bacon properties and recent consumer trends. Can. J. Anim. Sci. 95:325-340. doi:10.4141/cjas-2014-121

Thanonkaew, A., S. Wongyai, D. J. McClements, and E. A. Decker. 2012. Effect of stabilization of rice bran by domestic heating on mechanical extraction yield, quality, and antioxidant properties of cold-pressed rice bran oil (Oryza saltiva L.). LWT - Food Sci. Technol. 48:231-236. doi:10.1016/j.lwt.2012.03.018

van Milgen, J., and J. Noblet. 2003. Partitioning of energy intake to heat, protein, and fat in growing pigs. J. Anim. Sci. 81:E86-E93. doi:10.2527/2003.8114_suppl_2E86x

Warren, B. E., and D. J. Farrell. 1990. The nutritive value of full-fat and defatted Australian rice bran. II. Growth studies with chickens, rats and pigs. Anim. Feed Sci. Technol. 27:229-246. doi:10.1016/0377-8401(90)90085-m

Webb, E. C., and H. A. O'Neill. 2008. The animal fat paradox and meat quality. Meat Sci. 80:28-36. doi:10.1016/j.meatsci.2008.05.029

Wood, J. D., M. Enser, A. V. Fisher, G. R. Nute, P. R. Sheard, R. I. Richardson, S. I. Hughes, and F. M. Whittington. 2008. Fat deposition, fatty acid composition and meat quality: A review. Meat Sci. 78:343-358. doi:10.1016/j.meatsci.2007.07.019

Zhou, Z., K. Robards, S. Helliwell, and C. Blanchard. 2002. Composition and functional properties of rice. Int. J. Food Sci. Technol. 37:849-868. doi:10.1046/j.1365-2621.2002.00625.x

## GENERAL CONCLUSION

Rice is widely grown around the world with China and India leading the global production of paddy rice and white rice. Different varieties of rice are produced as a result of different climatic conditions. Milling processing methods may differ among regions, resulting in variability in composition and nutritional value of rice coproducts that are available as ingredients for animal feeding. The main coproducts produced from rice milling include broken rice, full fat rice bran, brown rice, defatted rice bran, and rice mill feed. The composition of these 5 rice coproducts obtained in the U.S. was determined, and digestibility values for GE, DM, NDF, and the concentration of DE and ME by weanling pigs, growing gilts, and gestating sows were calculated. The standardized ileal digestibility (SID) of CP and AA, and the standardized total tract digestibility (STTD) of P, also were calculated, and effects of addition of microbial xylanase on apparent total tract digestibility (ATTD) of GE and nutrients and effects of supplementation of diets with microbial phytase on STTD of P were determined. In addition, effects on growth performance of including rice bran in diets of weanling pigs and growing-finishing pigs were determined, and effects of rice bran on LM and belly fat quality were evaluated.

Results of this research demonstrated that broken rice contained more starch and less CP and fiber than did other rice coproducts, whereas FFRB and DFRB contained more fiber and CP than broken rice. Arabinoxylan was the main polysaccharide in the fiber fraction of rice coproducts except for rice mill feed where the main fraction was cellulose. It also was demonstrated that *in vitro* digestibility of DM is a good predictor of ATTD of DM *in vivo*, but the IVDMD in rice coproducts is reduced as the concentration of NSP is increased.

It was established that apparent ileal digestibility (AID) and SID of CP and AA in broken rice was greater than in FFRB and DFRB, but because of greater concentrations of CP and AA in FFRB and DFRB, these ingredients contained more SID CP and AA. In addition, it was demonstrated that in weanling pigs, addition of microbial xylanase increased the concentration of DE and ME of FFRB and DFRB, but this was not the case if xylanase was added to broken rice or brown rice. It is likely that the low concentration of arabinoxylan in broken rice and brown rice was the reason for the lack of response of xylanase in these ingredients. The ATTD of GE and DM and the concentration of DE and ME were greater in broken rice and brown rice than in FFRB and DFRB if microbial xylanase was not added to the diets. However, if microbial xylanase was used, the concentration of DE and ME in FFRB was not different from the concentration of DE and ME in broken rice and brown rice. It also was demonstrated that gestating sows had greater ATTD of GE and, therefore, obtained more DE and ME from FFRB and DFRB than did growing gilts, but these differences did not appear to be a result of increased fermentation of fiber in sows compared with gilts. In addition, results indicated that the level of intake of feed by gestating sows did not affect the ATTD of GE, DM, OM, or NDF, or the concentration of DE or ME, of FFRB or DFRB. Concentrations of DE in the basal diet and diets containing FFRB or DFRB obtained *in vivo* (3,346, 3,531, and 3,082 kcal/kg; respectively) were in agreement with values predicted from prediction equations (Eq. 29, Noblet and Perez, 1993) using the chemical composition of the diets (3,393, 3559, and 3,082 kcal/kg; respectively).

Full fat rice bran and DFRB contained more P than did other feed ingredients, but more than 70% of the P was bound to phytate. The ATTD and STTD of P in broken rice were greater than in brown rice, FFRB, DFRB, and rice mill feed because of less phytate in broken rice. Addition of microbial phytase to rice coproducts increased the ATTD and STTD of P and

decreased the excretion of P from pigs fed diets containing all rice coproducts. Addition of microbial phytase to rice coproducts also reduced the excretion of Ca and increased the ATTD of Ca in diets containing rice coproducts.

Increased inclusion of FFRB or DFRB in diets fed to weanling pigs decreased ADFI, but if FFRB was used, G:F was improved compared with pigs fed a corn-soybean meal control diet. Pigs fed diets containing FFRB also had greater G:F than pigs fed diets containing DFRB, and ADG increased if 10 or 20% FFRB or DFRB was included in the diets. Inclusion of 30% FFRB in diets for growing-finishing pigs improved G:F without affecting LM quality or carcass characteristics with the exception that concentration of PUFA in bellies increased. However, inclusion of DFRB in diets reduced G:F without affecting LM quality or composition of the bellies. Iodine values calculated from the concentration of fatty acids in belly fat increased as the inclusion of FFRB increased in the diets. Likewise, iodine values estimated for jowl fat, using the concentration of essential fatty acids in the diets (K-State Iodine Value Predictor, 2014) were close to the iodine values calculated using the concentration of fatty acids in the belly, indicating that both approaches may be used to estimate the iodine values.

In conclusion, results of these experiments indicate that rice coproducts may be used as a source of energy, AA, and P in diets of pigs. Full fat rice bran or DFRB may be included in diets of weanling pigs at the 20% inclusion level without negatively affecting growth performance. In addition, FFRB may be included the 30% inclusion level in diets of growing-finishing pigs without negatively affecting growth performance, although belly fat quality may be reduced as a consequence of increased PUFA. Inclusion of DFRB in diets of growing-finishing pigs may reduce G:F, but has no effects on LM quality or composition of the bellies.