JAST (Journal of Animal Science and Technology) TITLE PAGE
Upload this completed form to website with submission

ARTICLE INFORMATION	Fill in information in each box below
Article Type	Review article
Article Title (within 20 words without abbreviations)	Rice as an alternative feed ingredient in swine diet
Running Title (within 10 words)	Rice as an alternative feed ingredient in swine diet
Author	Sheena Kim[1#], Jin Ho Cho[2#], Hyeun Bum Kim[1], Minho Song[3]
Affiliation	1 Department of Animal Resources Science, Dankook University, Cheonan 31116, Korea 2 Division of Food and Animal Science, Chungbuk National University, Cheongju, Chungbuk, 28644, Korea 3 Division of Animal and Dairy Science, Chungnam National University, Daejeon 34134, Korea # These authors contributed equally to this work.
ORCID (for more information, please visit https://orcid.org)	Sheena Kim (https://orcid.org/ 0000-0002-5410-1347) Jin Ho Cho (https://orcid.org/0000-0001-7151-0778) Hyeun Bum Kim (https://orcid.org/0000-0003-1366-6090) Minho Song (https://orcid.org/0000-0002-4515-5212)
Competing interests	No potential conflict of interest relevant to this article was reported. The authors declare that they have no competing interests.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	This work was supported by the Individual Basic Science & Engineering Research Program (No. NRF- 2019R1F1A1059662) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education of the Republic of Korea.
Acknowledgements	This work was supported by the Individual Basic Science & Engineering Research Program (No. NRF- 2019R1F1A1059662) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education of the Republic of Korea.
Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.
Authors' contributions Please specify the authors' role using this form.	Conceptualization: Kim S. Song M. Writing - original draft: Kim S. Cho JH Writing - review & editing: KIM HB. Song M.
Ethics approval and consent to participate	This article does not require IRB/IACUC approval because there are no human and animal participants.

CORRESPONDING AUTHOR CONTACT INFORMATION

For the corresponding author (responsible for correspondence, proofreading, and reprints)	Fill in information in each box below
First name, middle initial, last name	Minho Song
Email address – this is where your proofs will be sent	mhsong@cnu.ac.kr
Secondary Email address	mhsong6@gmail.com
Address	Division of Animal and Dairy Science, Chungnam National University, Daejeon 34134, Korea
Cell phone number	+82-10-9254-0931

Office phone number	+82-42-821-5776
Fax number	+82-42-825-9754

For the corresponding author (responsible for correspondence, proofreading, and reprints)	**Fill in information in each box below**
First name, middle initial, last name	Hyeun Bum Kim
Email address – this is where your proofs will be sent	hbkim@dankook.ac.kr
Secondary Email address	
Address	Department of Animal Resources Science, Dankook University, Cheonan 31116, Korea
Cell phone number	+82-10-3724-3416
Office phone number	+82-41-550-3653
Fax number	+82-41-565-2949

Rice as an alternative feed ingredient in swine diet

Sheena Kim[1#], Jin Ho Cho[2#], Hyeun Bum Kim[1*], Minho Song[3*]

[1] Department of Animal Resources Science, Dankook University, Cheonan, South Korea

[2] Division of Food and Animal Science, Chungbuk National University, Cheongju, South Korea

[3] Division of Animal and Dairy Science, Chungnam National University, Daejeon, South Korea

# Equal contributors

* Corresponding authors

Hyeun Bum Kim

Department of Animal Resources Science, Dankook University, Cheonan, South Korea

Tel: +82-41-550-3653

Email: hbkim@dankook.ac.kr

Minho Song

Division of Animal and Dairy Science, Chungnam National University, Daejeon, South Korea

Tel: +82-42-821-5776

Email: mhsong@cnu.ac.kr

Abstract

Rising feed costs have made it important to explore and study alternative feed ingredients for cost-effective animal production. In addition to this, it is desirable to find efficient and functional alternative ingredients for traditional feed ingredients in pig feed, considering the stress of the pig and the sensitivity of the disease. Rice is produced around the world, like corn, the energy source in typical pig feed. Although the nutritional quality varies depending on the degree of milling, rice, except whole grains (paddy rice), contains more starch than corn, and its structure and granule size are easier to digest than corn. In addition, the fact that rice has fewer non-starch polysaccharides(NSP) and anti-nutritive factors is also effective in improving digestibility, and various polyphenols can help improve immune response, which can be beneficial to the gastrointestinal environment and pig health. Many studies have been conducted on rice focusing on things such as degree of milling, substitution rate of corn, size, and processing methods. Most results have shown that rice can be partially or completely used to replace corn in diets without negatively affecting pig growth and production. While further research should focus on the precise biological mechanisms at play, it was confirmed that the use of rice could reduce the use of antibiotics and pig removal, and protect pigs from gastrointestinal diseases, including diarrhea. From this point of view, rice can be evaluated as a valuable feed ingredient for swine diet.

Keywords (3 to 6): Alternatives, nutrition value, rice, pig

Introduction

In the animal production industry, it has become important to explore and research alternative feedstock for cost-effective animal production due to the rising cost of feed [1]. It is needed to find efficient alternative ingredients to traditional feed ingredients in swine diets. There have been many attempts to find alternative feed ingredients as energy sources in pig diet with competitive feed costs [2 - 4]. As a result, several candidates, including distillers dried grains with solubles (DDGS), copra meal, palm kernel expellers, and other by-products have been identified as alternatives to replace corn [5, 6]. While the proposed alternatives have the advantage of being able to supply energy at an efficient price, they tend to contain numerous fibers that are difficult for pigs to digest and in addition, they rely heavily on imports [7 - 9].

Post-weaning stress, a major challenging event in pig production is one of the most important factors of high mortality and morbidity in nursery pigs [10, 11]. Weaning stress may lead to reduced feed intake, poor growth, and increased susceptibility to disease [12, 13] and in addition, also causes dramatic changes in intestinal physiology and immunology [14 - 16]. Immaturity in the immune system in the weaned pigs can reduce the immune response to the pathogens and increase the sensitivity of weaned pigs to disease [17]. Thus, it is necessary to develop a diet that is not only highly digestible but one that also has functional ingredients.

Rice is a seed of grass species widely cultivated as a source of food and, Asia has a suitable climate for producing rice, which is richer than other grains. Rice is the world's third most grown staple crop, with 741.5 million tons being produced annually, providing 50 percent of the world's calories along with corn and wheat [18, 19]. Rice is an excellent source of carbohydrates, has a higher starch content than corn, contains the most useful -NSP for humans, and is more expensive than other grains [20, 21]. Therefore, the use of rice as animal feed has been restricted.

Current changes in eating habits has led to increased consumption of wheat, meat, and fruits instead of rice [22]. With the development of agricultural technology, rice production in Asia has gradually increased; thus, the decrease in rice consumption increases the stock of rice [23]. Therefore, there have been many attempts to use rice and their by-product as feed ingredients. In addition, if rice is used as an energy ingredient in swine diet, it is independent of import and has been shown to be highly applicable to the swine industry.

The type of rice differs depending on the cultivation area and variety. The products generated according to the processing stage are largely divided into whole grain (paddy rice), unpolished rice, polished rice, and their byproducts including rice bran, broken rice, and rice mill produced during the milling process as feed [24]. Therefore, in this study, the nutritional value of rice in swine production will be reviewed.

Physicochemical Features of Rice

The physical structure of grain plays an important role in preventing the loss/destruction of nutrients in the grain from internal and external factors during storage [25]. In the end, the structural characteristics of grains also contribute to the chemical properties and decomposition of nutrients during digestion [26, 27].

The seeds of rice, are a form of wrapping caryopsis with palea and lemma, which is a husk(hull) with one spikelet [28]. The hull protects the rice inside and prevents the infestation of fungi and pests from outside. The whole grain rice is consisted of husk, seed coat, nucleus, endosperm, and embryo (germ) and the brown rice is produced when hull is removed from whole grain rice in first processing. When milling brown rice, the germ and rice bran are removed and the white starch layer remains, which is referred to as white rice (polished rice). When making white rice from brown rice, 10% of the rice weight is lost. The weight ratio of each part constituting rice is slightly different according to the type of cultivar. In general, paddy rice consists of rice hull (16%-26%), germ (1.5%-2.5%), bran (3.8%-6.7%), and endosperm (64.8%-79.7%) [29]. There are variations of rice depending on the region and cultivar. In addition, rice is available in a variety of colors such as white, red, purple, and black as the pigments in the pericarp determines the color of rice grain [28].

Rice appears to be used as a feedstuff since rice includes more starch compared with other conventional cereal grains [30]. However, paddy rice cannot be a food or feed ingredient in mono-gastric animals since 20 % of the weight of paddy rice consist of rice hulls, which are composed of considerable amounts of crude fiber: lignin and silica [31, 32] (Figure 1).

Nutritional Composition of Rice

The nutritional composition of rice varies slightly, depending on the subspecies (e.g., *Indica*, *Japonica*), climate, soil, and cultivation methods. In general, rice hulls account for 20% of the weight of paddy rice and is composed of a considerable number of fibrous components, such as lignin and silica [32]. The amount of white rice, brown rice, germ, and bran produced from whole grain rice varies depending on the degree of milling. The major nutrient components of brown rice and white rice are carbohydrates (70%-90%), proteins (7%-8%), and fats (1%-2%), and most of the carbohydrates are starch [33], [34]. The gross energy values per 100g of brown rice and white rice are approximately 370 kcal [34].

White rice is a rich and digestible concentrate with low fiber content and high digestible nutrients compare to other rice products. Compared to white rice the brown rice has been known to have relatively lower carbohydrates, but higher protein, fat, and vitamins because the brown rice contained bran and germ.

The major components of rice bran are carbohydrates (35%-40%), crude protein (10%-15%), crude fat (15%-20%), and in addition phosphate and vitamin B groups are also abundant [34]. As such, rice bran contains excellent sources of protein, vitamins and minerals. However, there are many NSP in rice bran, which is difficult for pigs to digest [35]. Thus, in terms of digestion and utilization, white rice has a nutritional value almost 25% higher than rice bran [36].

The rice germ contains approximately 28%, 20%, and 18% of carbohydrates, fat, and crude protein, respectively[37], so the ratio of main nutrients is much higher than that of rice or rice byproducts, and in addition the germ is also rich in vitamin B and phosphate compounds[37, 38]. The rice germ has excellent nutritional value as a feed ingredient for swine diet, but it occupies a very small portion in rice, and has poor stability during storage due to the presence of highly active lipoxygenase [31]. Therefore, to minimize oxidative rancidity reaction and maintain nutrients, it is stored by blocking contact with oxygen in the form of whole grains.

Starch is a natural polymeric carbohydrate in which many glucose units are connected by α-glycoside bond [39, 40]. It is essentially made from two structurally different polymers: amylose (linear; α-1,4) and amylopectin (branched; α-1,4 and α-1,6). Depending on the plants, starch generally consists of 70%-80% amylopectin and 20%-30% amylose [41], whose molecular number is smaller than that of amylopectin [40]. In addition, amylose composed of α-1,4 glycosidic bonds is easily hydrolyzed by animal digestive enzymes e.g. α-amylase [39, 43, 44]. Unlike starch, structural polysaccharides such as chitin, cellulose, and peptidoglycan are bound by β-glycosidic bonds and are highly resistant to hydrolysis. Therefore, it requires microbial enzymes to breakdown [45].

Characteristics of different varieties of rice differ due to the ratio of amylose and amylopectin. The 'waxy' starches contain less than 15% amylose, 'normal' 20%–35% and 'high amylose' amylose starches greater than approximately 40% [46]. In this result, *Indica* is less viscous because amylose contents in *Indica* (25%-30%) is higher than in *Japonica* (15%-22%) [47]. Besides, the size of the starch granules varies depending on plant species [48]. The starch granules in rice are relatively small (apporoximately 2 μm), while potato starch granules are relatively large (more than 100 μm) [49].

Hence rice contains various polyphenols (e.g. tocopherol, tocotrienol, and γ-oryzanol) having an antioxidant function but also γ-aminobutyric acid which has been known to a bio-active compound. [50, 51]. These compounds have been reported to have the effect of improving immune responses by stimulating innate immunity [52-53]. Therefore, the use of rice as a feed ingredient has therapeutic benefits for many gastrointestinal diseases such as diarrhea, gut health, and inflammatory bowel diseases in human nutrition [54]. The antioxidant and physiologically active ingredients are known to be more present in pigmented rice including brown rice, purple rice, and black rice than in white rice [55]. Because for example, anthocyanin is present as a pigment in rice bran, and tocopherol exists in rice germ [37, 55]. White rice is obtained after milling both rice bran and rice germ.

Anti-nutrient factors in rice such as phytic acids, trypsin inhibitors, and lectin, are is low, and they are usually present in rice bran and embryos [56-57]. Phytic acid binds to minerals such as zinc, copper, iron, magnesium, niacin and calcium preventing their absorption. Trypsin inhibitors make it difficult to digest proteins. Lectin (Haemagglutinin-lectin) binds to specific carbohydrate receptor sites in the intestinal lining and impede nutritional absorption. However, since lectin and trypsin inhibitors are heat sensitive, they are deactivated during the heating process. They are usually present in rice bran and can be easily separated during the milling process [56, 58].

Feeding Value of Rice Compared to Corn

Rice is an excellent source of carbohydrates, contains more starch and low NSP compared with corn, known as a traditional feed ingredient, but it more useful for humans and more expensive than corn [20, 21]. This is because starch, which has the highest proportion of rice, has a high nutritional value [20]. In terms of various benefits, especially in the case of rice starch, characteristics such as unique flavor, taste, small granules, hypo-allergenic property, and digestibility [21, 59]. Starch granule size could also affect the digestibility of energy [60, 61]. It has been found that the size of starch is smaller in rice than in corn [46, 62]. The larger the starch granules, the smaller the surface area to volume, which leads to less binding to the enzyme and consequently reduce the potential for hydrolysis [63 - 65]. Therefore, the digestibility values are supportive of better performance of pigs fed rice than those fed corn [21, 39]. White rice is a rich and digestible concentrate with low fiber content and high digestible nutrients than corn [36]. Therefore, white rice has approximately a feeding value 25% higher than rice bran and 12%-15% higher than corn [36].

It seems, however, a waste to employ white rice as feedstuff for animals because the milling process requires higher cost, and some nutrients including vitamins and fatty acids can be destroyed after the milling process. On the other hand, paddy rice has a low processing cost, but it has too much fiber content that is difficult for pigs because of the rice hulls. For the above reasons, Li reported that brown rice, could be the best to be feedstuff to pigs [66].

Compared with corn, brown rice has similar concentrations of gross energy, crude protein, and ether extract, but, in fact, the amount of starch, essential amino acids, and fatty acids in brown rice are comparatively higher than corn [66-71] (Table 1).

Application of Rice for Swine Diets

Compared to various rice by-products, white rice has been studied extensively as a feed component of animal diet (eg, pigs, poultry).- Studies have focused mainly on the particle size [72, 73], processing methods [65, 74], and substitution rate of corn [75] . Many studies have shown that white rice can replace a proportion of corn in swine diets without negative effect in pigs [20, 72]. Yang et al. (1992) reported that there was no negative effect on the growth performance and carcass composition when rice was fed instead of corn in growing-finishing pigs [76].

Previous studies have shown that the digestibility of nutrients in pigs fed to rice was improved over those fed corn [77]. Furthermore, digestibility was found to increase when the rice was heat-treated and fed to pigs in a gelatinous form , created through gelatinization, which is conducted at a higher temperature for rice than other raw grains [59, 65, 78]. In particular, Pluske et al. (1996) have shown that cooked white rice could protect pigs from swine dysentery [78]. They explained that by reducing the substrate for bacterial fermentation in the large intestine, it may have a significant impact on the gastrointestinal environment such as nutritional absorption, and microbial balance and population. Similarly, according to Che et al., the pig removal and antibiotic treatment rate of pigs fed to rice was lower than that of corn [75].

Although previous studies have focused on white rice mainly, in some countries, such as China and the United States, there has been some experiments with brown rice to replace corn in pig diets. Studies have shown that the partial or complete replacement of corn with brown rice in pig diets has no negative impacts on what?[66, 70, 79], but can improve feed efficiency and growth performance through improved apparent total tract digestibility [21, 65]. Interestingly, Kim et al. (2007) reported that the variety of rice had no effect on digestible energy (DE) [80]. Moreover, Liu et al. (2016) found that there was no difference in the value of DE regardless of the milling process of rice [81].

Conclusion

Alternatives are needed to stabilize supply and increase self-sufficiency by replacing corn in order to stabilize the rising production costs of pigs. Asia has a climate more suitable for growing rice than corn, and the recently the inventory of rice has been increasing. Thus, it is worth examining the value of rice a feed ingredient.

Various rice byproducts are already being used for animal feed, but their nutritional value is less than that of corn. However, rice grains are more suitable as alternatives as they have similar nutritional levels to corn. In the case of whole grains (paddy rice), the fiber content is high and while white rice has lower fiber content, the processing cost is high. Considering the processing costs and nutritional value, brown rice was found to be suitable for comparison with corn.

Further studies should be conducted, however several studies that evaluated growth and digestion rates have already suggested that a portion or complete replacement of corn with brown rice is possible. From this perspective, rice could be evaluated as a sufficiently valuable alternative as a swine feed ingredient.

Acknowledgments

This work was supported by the Individual Basic Science & Engineering Research Program (No. NRF-2019R1F1A1059662) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education of the Republic of Korea.

References

[1] Wickramasuriya SS, Yi YJ, Yoo J, Kang NK, Heo JM. A review of canola meal as an alternative feed ingredient for ducks. J Anim Sci Technol. 2015;57(1):1–9. http://dx.doi.org/10.1186/s40781-015-0062-4

[2] Robison WL. Substitute for corn for growing and fattening pigs. Ohio Agricultural Experiment Station; 1939.

[3] Stein HH, Shurson GC. Board-invited review: The use and application of distillers dried grains with solubles in swine diets. J Anim Sci. 2009;87(4):1292-1303. https://doi.org/10.2527/jas.2008-1290

[4] Son AR, Shin SY, Kim BG. Standardized total tract digestibility of phosphorus in copra expellers, palm kernel expellers, and cassava root fed to growing pigs. Asian-Australasian J Anim Sci. 2013;26:1609-1613. https://doi.org/ 10.5713/ajas.2013.13517

[5] Wachenheim C, Novak P, DeVuyst E, Lambert DK. Demand estimation for agricultural processing coproducts. Great Plains Res. 2006;16:85-94.

[6] Hoffman LA, Baker A. Estimating the substitution of distillers' grains for corn and soybean meal in the U.S/ feed complex. U.S. Department of Agriculture; 2011. Feed outlook No.: FDS-11I01. 62 p.

[7] Agunbiade J, Wiseman J, Cole DJ. Energy and nutrient use of palm kernels, palm kernel meal and palm kernel oil in diets for growing pigs. Anim Feed Sci Technol. 1999;80(3–4):165–81. https://doi.org/10.1016/S0377-8401(99)00070-X

[8] Kim BG, Lee JH, Jung HJ, Han YK, Park KM, Han IK. Effect of partial replacement of soybean meal with palm kernel meal and copra meal on growth performance, nutrient digestibility and carcass characteristics of finishing pigs. Asian-Australas J Anim Sci. 2001; 14:821-830. https://doi.org/10.5713/ajas.2001.821

[9] Son AR, Hyun Y, Htoo JK, Kim BG. Amino acid digestibility in copra expellers and palm kernel expellers by growing pigs. Anim Feed Sci Technol. 2014; 187:91-97. https://doi.org/10.1016/j.anifeedsci.2013.09.015

[10] Lallès JP, Bosi P, Smidt H, Stokes CR. Weaning—a challenge to gut physiologists. Livest Sci. 2007;108(1-3):82-93. https://doi.org/10.1016/j.livsci.2007.01.091

[11] Lallès JP. Long term effects of pre- and early postnatal nutrition and environment on the gut. J Anim Sci. 2012;90(4):421-429. https://doi.org/10.2527/jas.53904

[12] Spreeuwenberg MAM, Verdonk JMAJ, Gaskins HR, Verstegen MWA. Small intestine epithelial barrier function is compromised in pigs with low feed intake at weaning. J Nutr. 2001;131(5):1520-1527. https://doi.org/10.1093/jn/131.5.1520

[13] Stokes CR, Bailey M, Haverson K, Harris C, Jones P, Inman C. Postnatal development of intestinal immune system in piglets: Implications for the process of weaning. Anim Res. 2004;53(4):325-334. https://doi.org/10.1051/animres:2004020

[14] Pluske JR, Hampson DJ, Williams IH. Factors influencing the structure and function of the small intestine in the weaned pig: A review. Livest Prod Sci. 1997;51(1):215-236. https://doi.org/10.1016/S0301-6226(97)00057-2

[15] Blecha F, Kelley KW. Effects of cold and weaning stressors on the antibody-mediated immune response of pigs. J Anim Sci. 1981; 53(2):439-447. https://doi.org/10.2527/jas1981.532439x

[16] Hampson DJ. Alterations in piglet small intestinal structure at weaning. Res Vet Sci. 1986;40(1):32-40. https://doi.org/10.1016/s0034-5288(18)30482-x

[17] Guevarra RB, Lee JH, Lee SH, Seok MJ, Kim DW, Kang BN, Johnson TJ, Isaacson RE, Kim HB. 2019. Piglet gut microbial shifts early in life: causes and effects. J Anim S ci. Biotechnol 10:1 http://doi.org/10.1186/s40104-018-0308-3

[18] Nadeem M, Anjum FM, Amir RM, Khan MR, Hussain S, Javed MS. An Overview of Anti-nutritional factors in cereal grains with special reference to wheat-a review. Pakistan J food Sci. 2010;20(1–4):54–61.

[19] Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. Annals of the new york Academy of Sciences, 1324(1), 7-14.

[20] Hopwood DE, Pethick DW, Pluske JR, Hampson DJ. Addition of pearl barley to a rice-based diet for newly weaned piglets increases the viscosity of the intestinal contents, reduces starch digestibility and exacerbates post-weaning colibacillosis. Br J Nutr. 2004; 92(3):419-427. https://doi.org/10.1079/bjn20041206

[21] Vicente B, Valencia DG, Pérez-Serrano M, Lázaro R, Mateos GG. 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. 2008; 53(4):325-334. https://doi.org/10.2527/jas.2006-697

[22] Abdullah, A. B., Ito, S., & Adhana, K. (2006, March). Estimate of rice consumption in Asian countries and the world towards 2050. In Proceedings for Workshop and Conference on Rice in

the World at Stake (Vol. 2, pp. 28-43).

[23] Korea Rural Economic Institute (KREI). Monthly international grain observation. 2019. http://aglook.krei.re.kr/jsp/pc/front/observe/monthlyReport.jsp?ovr_item_code=OVR0000000073&prt_ovr_item_code=OVR0000000071

[24] Farrell DJ, Hutton K. Rice and rice milling byproducts. In: Nontraditional feed sources for use in swine production (Ed. P. A. Thacker and R. N. Kirkwood). 1990. Butterworth & Co. (Publishers) Ltd. pp. 339-353

[25] Prakash BG, Raghavendra KV, Gowthami R, et al. Indigenous practices for eco-friendly storage of food grains and seeds. Adv Plants Agric Res. 2016;3(4):101-107. DOI: 10.15406/apar.2016.03.00101

[26] Bornhorst GM, Chang LQ, Rutherfurd SM, Moughan PJ, Singh RP. Gastric emptying rate and chyme characteristics for cooked brown and white rice meals in vivo. J Sci Food Agric. 2013;93(12):2900–8. https://doi.org/10.1002/jsfa.6160

[27] Bornhorst GM, Kostlan K, Singh RP. Particle size distribution of brown and white rice during gastric digestion measured by image analysis. J Food Sci. 2013;78(9). https://doi.org/10.1111/1750-3841.12228

[28] Juliano B, Bechtel D. The rice grain and its gross composition. In: B. Juliano, Ed., Rice Chemistry and Technology, 2nd Edition, American Association of Cereal Chemists, St. Paul, 1985.p. 17-58

[29] Juliano, B. Rice in human nutrition. Int. Rice Res. Inst. 26. 1993

[30] Knudsen KEB. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim Feed Sci Technol. 1997;67(4):319-338. https://doi.org/10.1016/s0377-8401(97)00009-6

[31] Malekian F, Rao RM, Prinyawiwatkul W. Lipase and Lipoxygenase Activity , Functionality , And Nutrient Losses in Rice Bran During Storage Lipase and Lipoxygenase Activity , Functionality , And Nutrient Losses in Rice Bran During Storage. 2010

[32] Serna-Saldivar, Dry-milling operations. Cereal grains: Properties, processing and nutritional attributes. CRC Press. 2010

[33] Marsono Y, and Topping DL. Complex carbohydrates in australian rice products-influence of microwave cooking and food processing. Food Sci Technol. 1993;26(4):364–370. https://doi.org/10.1006/fstl.1993.1072

[34] Saleh, A. S. M., Wang, P., Wang, N., Yang, L., & Xiao, Z. (2019). Brown Rice Versus White Rice: Nutritional Quality, Potential Health Benefits, Development of Food Products, and Preservation

Technologies. Comprehensive Reviews in Food Science and Food Safety, 18. https://doi.org/10.1111/1541-4337.12449

[35] Marsono, Y., Illman, R. J., Clarke, J. M., Trimble, R. P., & Topping, D. L. (1993). Plasma lipids and large bowel volatile fatty acids in pigs fed on white rice, brown rice and rice bran. The British Journal of Nutrition, 70(2), 503–513. https://doi.org/10.1079/BJN19930144

[36] Bray CI. Rice and rice byproducts for fattening swine. LSU Agricultural Experiment Station Reports. 64.1943

[37] Moongngarm, A., Daomukda, N., & Khumpika, S. (2012). Chemical Compositions, Phytochemicals, and Antioxidant Capacity of Rice Bran, Rice Bran Layer, and Rice Germ. APCBEE Procedia, 2, 73–79. https://doi.org/10.1016/j.apcbee.2012.06.014

[38] Rondanelli, M., Miccono, A., Peroni, G., Nichetti, M., Infantino, V., Spadaccini, D., Alalwan, T. A., Faliva, M. A., & Perna, S. (2019). Rice germ macro- and micronutrients: a new opportunity for the nutraceutics. Natural Product Research, 0(0), 1–5. https://doi.org/10.1080/14786419.2019.1660329

[39] Singh J, Dartois A, Kaur L. Starch digestibility in food matrix: a review. Trends Food Sci Technol. 2010;21:168–80. doi:10.1016/j.tifs.2009.12.001.

[40] Tortoe C, Akonor PT, Koch K, Menzel C, Adofo K. Amylose and amylopectin molecular fractions and chain length distribution of amylopectin in 12 varieties of Ghanaian sweet potato (Ipomoea batatas) flours. Int J Food Prop [Internet]. 2017;20(12):3225–33. Available from: https://doi.org/10.1080/10942912.2017.1283326

[41] Zhang D, Li D, Piao XS, Han IK, Yang CJ, Shin IS, et al. Effects of replacing corn with brown rice or brown rice with enzyme on growth performance and nutrient digestibility in growing pigs. Asian-Australasian J Anim Sci. 2002;15(9):1334–40.

[42] Martens BMJ, Gerrits WJJ, Bruininx EMAM, Schols HA. Amylopectin structure and crystallinity explains variation in digestion kinetics of starches across botanic sources in an in vitro pig model. J Anim Sci Biotechnol. 2018;9(1):1–13.

[43] Bornhorst GM. Breakdown and Mixing of Brown and White Rice during Gastric Digestion In Vivo. 2010;1–193.

[44] Svihus B, Uhlen AK, Harstad OM. Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. Anim Feed Sci Technol. 2005;122(3–4):303–20.

[45] Black JL. Nutritional Value of Cereal Grains for Animals. 1999;7–9.

[46] Tester RF, Karkalas J, Qi X. Starch - Composition, fine structure and architecture. J Cereal Sci. 2004;39:151–65. https://doi.org/10.1016/j.jcs.2003.12.001

[47] Liu, Q., Wang, Z., Chen, X., Cai, X., Tang, S., Yu, H., Zhang, J., Hong, M., & Gu, M. (2003). Stable inheritance of the antisense waxy gene in transgenic rice with reduced amylose level and improved quality. Transgenic Research, 12(1), 71–82. https://doi.org/10.1023/A:1022148824018

[48] Shih C-H, Lee T-T, Kuo WH-J, Yu B. Growth Performance and Intestinal Microflora Population of Broilers Fed Aged Brown Rice. Ann Anim Sci [Internet]. 2014;14(4):897–909. Available from: http://www.degruyter.com/view/j/aoas.2014.14.issue-4/aoas-2014-0048/aoas-2014-0048.xml

[49] Puncha-arnon S, Pathipanawat W, Puttanlek C, Rungsardthong V, Uttapap D. Effects of relative granule size and gelatinization temperature on paste and gel properties of starch blends. Food Res Int. 2008;41(5):552-561. https://doi.org/10.1016/j.foodres.2008.03.012

[50] Kang BR, Park MJ, Lee HS. Germination dependency of antioxidative activities in brown Rice. J Korean Soc Food Sci Nutr. 2006;35(4):389-394. https://doi.org/10.3746/jkfn.2006.35.4.389

[51] Cho MK, Kim MH, Kang MY. Application of rice polishing by-products to processed rice Food (Ⅱ) - Processing Aptitude of Rice Embryo. 2008;18(3):331-336

[52] Teltathum, T. (2004). Effect of Gamma Oryzanol in purple glutinous rice bran on immune response in male mice (Mus musculus) Master thesis. Chiang Mai University, Chiang Mai, Thailand. 155 p.

[53] Shin SY, Kim HW, Jang HH, et al. γ-Oryzanol-rich black rice bran extract enhances the innate immune response. J Med Food. 2017;20(9):855-863. https://doi.org/10.1089/jmf.2017.3966

[54] Ronald Ross Watson, Victor R. Preedey, Sherma Zibadi. Wheat and rice in disease prevention and health: benefits, risks and mechanisms of whole grains in health promotion. 2014. https://doi.org/10.1016/C2012-0-00472-3

[55] Boonsit P, Pongpiachan P, Julsrigival S, Karladee D. Gamma oryzanol content in glutinous purple rice landrace varieties. CMUJ Nat Sci 2010;9(1):151-158

[56] Popova A, Mihaylova D. Antinutrients in plant-based foods: A review. Open Biotechnol J. 2019;13(1)68-76. https://doi.org/10.2174/1874070701913010068

[57] Samtiya M., Aluko RE, Dhewa T. Plant food anti-nutritional factors and their reduction strategies: an overview. Food Prod Process and Nutr. 2020;2(6). https://doi.org/10.1186/s43014-020-0020-5

[58] Villalobos H, Maria E, Espinoza E, Ana M. Anti-nutritional factors present in raw, polished rice. Rev. costarric. salud pública. 2007;16(31):8-12

[59] Samtiya M, Aluko RE, Dhewa T. Plant food anti-nutritional factors and their reduction strategies: an overview. Food Prod Process and Nutr. 2020;2(6). https://doi.org/10.1186/s43014-020-0020-5

[60] Langworthy CF, Deuel HJ. Digestibility of raw rice, arrowroot, canna, cassava, taro, tree-fern, and potato starches. J Biol Chem. 1922;52:251-261.

[61] Kaur L, Singh J, McCarthy OJ, Singh H. Physico-chemical, rheological and structural properties of fractionated potato starches. J. Food Eng. 2007;82(3):383–394. https://doi.org/10.1016/j.jfoodeng.2007.02.059

[62] Ai Y, Jane JL. Understanding starch structure and functionality. Elsevier Ltd; 2017. doi:10.1016/B978-0-08-100868-3.00003-2.

[63] MacGregor AW, Ballance DL. Hydrolysis of large and small starch granules from normal and waxy barley cultivas by alpha-amylases from barley malt.pdf. 1980;:397–402.

[64] Tester RF, Qi X, Karkalas J. Hydrolysis of native starches with amylases. Anim Feed Sci Technol. 2006;130:39–54.

[65] Mateos GG, López E, Latorre MA, Vicente B, Lázaro RP. The effect of inclusion of oat hulls in piglet diets based on raw or cooked rice and maize. Anim Feed Sci Technol. 2007;135(1-2):100-112. https://doi.org/10.1016/j.anifeedsci.2006.07.006

[66] Li D, Zhang DF, Piao XS, Han IK, Yang CJ, Li JB, et al. Effects of replacing corn with chinese brown rice on growth performance and apparent fecal digestibility of nutrients in weanling pigs. Asian-Australasian J Anim Sci. 2002; 15(8):1191-1197. https://doi.org/10.5713/ajas.2002.1191

[67]Hongtrakul K, Goodband RD, Behnke KC, Nelssen JL, Tokach MD, Bergström JR, Nessmith WB , Kim IH. The effects of extrusion processing of carbohydrate sources on weanling pig performance. J Anim Sci. 1998;76(12):3034-3042. http://doi.org/10.2527/1998.76123034x

[68] Nutrient Requirements of Swine. Nutrient Requirements of Swine. 2012. https://doi.org/10.17226/13298

[69] Stein HH, Lagos LV, Casas GA. Nutritional value of feed ingredients of plant origin fed to pigs. Anim Feed Sci Technol. 2016;218:33–69. http://dx.doi.org/10.1016/j.anifeedsci.2016.05.003

[70] Zhang D, Li D, Piao XS, Han IK, Yang CJ, Shin IS, et al. Effects of replacing corn with brown rice or brown rice with enzyme on growth performance and nutrient digestibility in growing pigs. Asian-Australasian J Anim Sci. 2002;15:1334-1340. https://doi.org/10.5713/ajas.2002.1334

[71] Li XL, Yuan SL, Piao XS, Lai CH, Zang JJ, Ding YH, et al. The nutritional value of brown rice and maize for growing pigs. Asian-Australasian J Anim Sci. 2006; 19(6): 892-897.

https://doi.org/10.5713/ajas.2006.892

[72] Marsono Y, Topping DL. Effects of Particle Size of Rice on Resistant Starch and SCFA of the Digesta in Caecostomised Pigs. Indones Food Nutr Prog. 1999;6(2):44–50.

[73] Ebling PD, Kessler AM, Villanueva AP, Pontalti GC, Farina G, Ribeiro AML. Rice and soy protein isolate in pre-starter diets for broilers. Poult Sci [Internet]. 2015;94(11):2744–52. Available from: http://dx.doi.org/10.3382/ps/pev279

[74] Sittiya J, Yamauchi K, Takata K. Effect of replacing corn with whole-grain paddy rice and brown rice in broiler diets on growth performance and intestinal morphology. J Anim Physiol Anim Nutr (Berl). 2016 Apr;100(2):381-90. doi: 10.1111/jpn.12357. Epub 2015 Jun 30. PMID: 26122821.

[75] Che TM, Perez VG, Song M, Pettigrew JE. Effect of rice and other cereal grains on growth performance, pig removal, and antibiotic treatment of weaned pigs under commercial conditions. J Anim Sci. 2012; 90(13):4916-4924. https://doi.org/10.2527/jas.2011-4916

[76] Yang LF, Chen DT, and Hsu A. Effect of rice grain on performance, carcass characteristics and nutrient digestibility on growing-finishing pig feed pellet diet. J. Livest. Res. Taiwan. 1992;25:189-96.

[77] Brestenský M, Nitrayová S, Patráš P, Heger J. Utilization of Amino Acids of Broken Rice in Growing Pigs. J Microbiol Biotechnol Food Sci. 2020;9(6):347-9.

[78] Pluske JR, Siba PM, Pethick DW, Durmic Z, Mullan BP, Hampson DJ. The incidence of swine dysentery in pigs can be reduced by feeding diets that limit the amount of fermentable substrate entering the large intestine. J Nutr. 1996;126: 2920-2933. https://doi.org/10.1093/jn/126.11.2920

[79] Cromwell GL, Henry BJ, Scott AL, Gerngross MF, Dusek DL, Fletcher DW. Glufosinate herbicide-tolerant (LibertyLink) rice vs. conventional rice in diets for growing-finishing swine. J Anim Sci. 2005; 83:1068-1074. https://doi.org/10.2527/2005.8351068x

[80] Kim JC, Mullan BP, Hampson DJ, Rijnen MMJA, Pluske JR. The digestible energy and net energy content of two varieties of processed rice in pigs of different body weight. Anim Feed Sci Technol. 2007;134:316–325. doi:10.1016/j.anifeedsci.2006.09.016.

[81] Liu H, Wan H, Xu S, Fang Z, Lin Y, Che L, et al. Influence of extrusion of corn and broken rice on energy content and growth performance of weaning pigs. Anim Sci J. 2016; 87(11):1386-1395. https://doi.org/10.1111/asj.12578

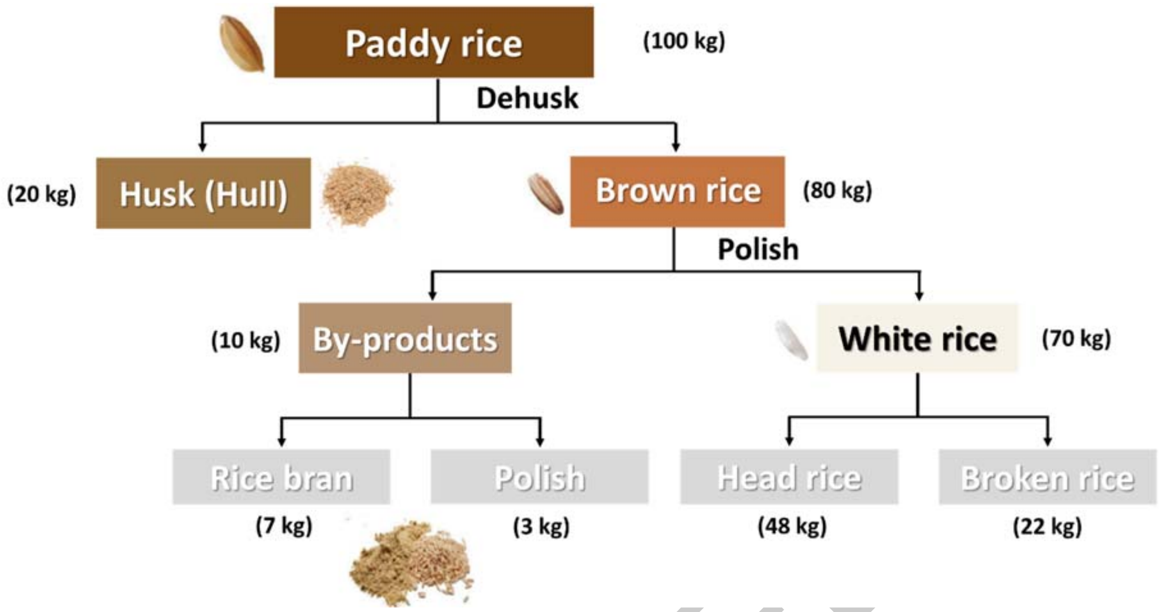

Figure 1. Product fractions from standard milling process of rice (Source: modified from [31]).

Table 1. Proximate composition of corn, brown rice, and white rice (as-fed basis).

Item[1]	Corn[2]	Brown rice[3]	White rice[4]
Gross energy, MJ/kg	3,930 (38.08)	3,810 (112.39)	3,976 (155.13)
Crude protein, %	8.33 (0.36)	8.31 (0.39)	8.05 (0.07)
Ether extract, %	3.10 (0.39)	2.44 (0.26)	1.16 (0.36)
Acid detergent fiber, %	2.90 (0.01)	1.31 (0.00)	1.85 (1.77)
Crude ash, %	1.19 (0.13)	1.05 (0.15)	0.66 (0.22)
Total starch, %	60.96 (1.58)	72.40 (0.00)	79.45 (5.86)
Calcium, %	0.02 (0.00)	0.03 (0.00)	0.04 (0.00)
Total phosphorus, %	0.28 (0.02)	0.33 (0.01)	0.18 (0.00)
Moisture, %	12.07 (0.26)	12.10 (0.00)	12.55 (0.64)
Essential amino acids (%)			
Arginine	0.39 (0.03)	0.77 (0.00)	0.62 (0.14)
Histidine	0.26 (0.02)	0.16 (0.06)	0.22 (0.05)
Isoleucine	0.30 (0.02)	0.38 (0.00)	0.37 (0.04)
Leucine	1.02 (0.07)	0.75 (0.00)	0.71 (0.05)
Lysine	0.27 (0.01)	0.35 (0.00)	0.37 (0.10)
Methionine	0.19 (0.01)	0.20 (0.00)	0.20 (0.03)
Phenylalanine	0.43 (0.04)	0.51 (0.00)	0.43 (0.05)
Threonine	0.29 (0.02)	0.32 (0.00)	0.31 (0.07)
Tryptophan	0.12 (0.11)	0.25 (0.12)	0.10 (0.00)
Valine	0.38 (0.04)	0.45 (0.00)	0.56 (0.09)

[1] Value are mean ± S.D

[2] Adapted from [66 – 71]

[3] Adapted from [66, 70, 71]

[4] Adapted from [68, 69]