

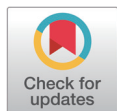
Rice as an alternative feed ingredient in swine diets

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Abstract

It has become important to explore alternative feed ingredients to reduce feed costs, which are burdensome for livestock production. In addition, it is desirable to find efficient and functional alternative ingredients for traditional feed ingredients in pig diets, considering the stress and sensitivity of disease of pig. Rice is produced around the world like corn that is the typical energy source in pig diets. 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-nutritional factors (ANFs) is also effective in improving digestibility and various polyphenols in rice can help modulation of immune responses, which can be beneficial to the gastrointestinal environment and health of pig. Many studies have been conducted on rice focusing on things such as degree of milling, substitution rates of corn, granule size, and processing methods. Most results have shown that rice can be partially or completely used to replace corn in pig 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 diets.

Keywords: Alternatives, Corn, Nutrient value, Pig, Rice

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 replace traditional feed ingredients in swine diets. There have been many attempts to find alternative feed ingredients as energy sources in pig diets with competitive feed costs [2–4]. As a result, several candidates including distillers dried grains with solubles, 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 advantages of being able to supply energy at efficient prices, they tend to contain numerous fibers that are difficult for pigs to digest and rely heavily on imports [7–9].

Post-weaning stress, a major challenging event in swine production, is one of the most important factors of high mortality and morbidity in nursery pigs [10,11]. The weaning stress also leads to reduced

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Availability of data and material

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Authors' contributions

Conceptualization: Kim S, Song M.
Writing - original draft: Kim S, Cho JH.
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Ethics approval and consent to participate

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feed intake, poor growth, and increased susceptibility to diseases [12,13] and causes dramatic changes in intestinal physiology and immunology [14–16]. Immaturity in the immune system of weaned pigs can act the immune responses insufficiently against various pathogens and increase the sensitivity of weaned pigs to disease [17]. Thus, it is necessary to develop diets that are not only highly digestible but one that also has functional ingredients.

Rice is a seed of grass species widely cultivated as a source of foods and 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 and contains higher starch and the most useful NSP for human than corn. However, it is more expensive than other grains [20,21] and thus the use of rice as an animal feed ingredient has been restricted.

Current changes in eating habits has led to increased consumption of bread, meat, and fruits instead of rice [22], but rice production has gradually increased with the development of agricultural technology. Due to the changes, the stock of rice has increased [23]. Therefore, there have been many attempts to use rice and their by-product as animal feed ingredients. It may be independent of import of main animal feed ingredients, such as corn and etc., and highly applicable to swine industry if rice can be used as an energy source in swine diets.

The types of rice differ depending on cultivation area and variety. The products produced 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 etc. [24]. Therefore, the nutritional value of rice in swine production will be reviewed in this study.

PHYSICOCHEMICAL FEATURES OF RICE

The physical structures of grains play an important role in preventing the loss/destruction of nutrients in the grains from internal and external factors during storage [25] and contribute to chemical properties and decomposition of nutrients during digestion [26,27].

The seed of rice is a form of wrapping caryopsis with palea and lemma, which is a husk (hull) with one spikelet [28]. The hull protects rice inside and prevents infestation of fungi and pests from outside. Whole grain rice consists of husk, seed coat, nucleus, endosperm, and embryo (germ) and brown rice is produced when the hull is removed from whole grain rice in first processing. After milling brown rice, germ and rice bran are removed and white starch layer remains, which is referred to as white rice (polished rice). When making the white rice from brown rice, 10% of rice weight is lost. The weight ratio of each part constituting rice is slightly different according to different types 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 region and cultivar. In addition, rice is available with a variety of colors such as white, red, purple, and black as the pigments in pericarp determines the colors of rice grain [28].

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

NUTRITIONAL COMPOSITION OF RICE

Nutritional composition of rice varies depending on subspecies (e.g., *Indica*, *Japonica*, and etc.), climate, soil, and cultivation methods. The amount of white rice, brown rice, germ, and bran

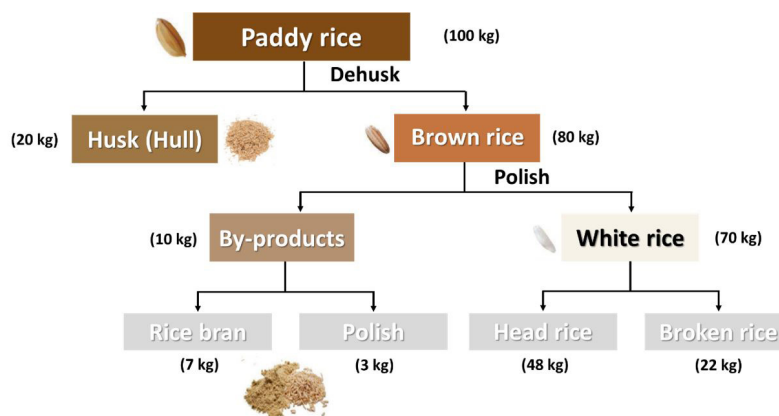


Fig. 1. Product fractions from standard milling process of rice (Source: modified from [31] with public domain).

produced from whole grain rice varies depending on degree of milling. Major nutrient components of brown rice and white rice are carbohydrates (70–90%), protein (7–8%), and fat (1–2%) and most of the carbohydrates are starch contents [33,34]. In addition, gross energy of brown rice and white rice is approximately 3,700 kcal per kilogram [34].

White rice contains high digestible nutrients with low fiber contents compared to other rice products. Compared to white rice, brown rice has been known to have relatively lower carbohydrates and higher protein, fat, and vitamins because it contains bran and germ [34].

Major components of rice bran are carbohydrates (35–40%), crude protein (10–15%), and crude fat (15–20%) [34] as well as vitamins and minerals, especially abundant vitamin B groups and phosphate [34]. However, there are many NSP in rice bran, which is difficult for pigs to digest [35]. Thus, in terms of digestion and utilization by pigs, white rice has almost 25% higher nutritional values than rice bran [36].

Rice germ contains approximately 28%, 20%, and 18% of carbohydrates, fat, and crude protein, respectively, and is rich in vitamin B groups and phosphate compounds [37,38]. Rice germ also has excellent nutritional values as a feed ingredient for swine diets, but occupies a very small portion in rice and has poor stability during storage due to the presence of highly active lipoxygenase [31]. Therefore, rice germ is stored by blocking contact with oxygen in the form of whole grains to minimize oxidative rancidity reaction and maintain the nutrients.

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 such as amylose (linear; α -1,4) and amylopectin (branched; α -1,4 and α -1,6). Depending on plants, starch generally consists of 70–80% amylopectin and 20–30% amylose [41]. The molecular size (chain length) of amylose composed α -1,4-glycosidic bonds is smaller than that of amylopectin [40] and easily hydrolyzed by the 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’ greater than approximately 40% [46]. In this result, the *Indica* subspecies are less viscous than the *Japonica* subspecies because amylose contents in the *Indica* species (25–30%) are higher than those in the *Japonica* subspecies (15–22%) [47]. Besides, the size of starch granules varies depending on

plant species [48]. The starch granules in rice are relatively small (approximately 2 μm), while potato starch granules are relatively large (more than 100 μm) [49].

Rice contains not only 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 as immune modulators by stimulating innate immunity [52–53]. Therefore, the use of rice as a feed ingredient in pig diets may give pigs therapeutic benefits for many gastrointestinal problems such as diarrhea, gut dysfunction, and inflammatory bowel diseases [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 anthocyanin is present as a pigment in rice bran and tocopherol exists in rice germ [37,55]. The ANFs in rice such as phytic acids, trypsin inhibitors, and lectin are low and usually present in rice bran and embryos, but they are easily separated during the milling process [56–58].

FEEDING VALUE OF RICE COMPARED TO CORN

In terms of various benefits of rice, rice starch has unique flavor and taste, small granules, hypo-allergenic property, and easy digestibility [21,59]. Starch granule size of rice can also influence its energy digestibility [60,61]. Generally, the larger the starch granules, the smaller the surface area to volume, which leads to less binding to enzymes and consequently reduces its hydrolysis [62–64]. It has been found that the size of starch granules in rice is smaller than that in corn [46,65]. 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 carbohydrate with low fiber contents and has high digestible nutrients compared with corn [36]. Due to these characteristics, white rice has the approximately feeding values 25% higher than rice bran and 12–15% higher than corn [36]. It seems, however, a waste to employ the white rice as a feedstuff for animals because the milling process requires higher cost and some nutrients including vitamins and fatty acids can be destroyed by the milling process. On the other hand, paddy rice has a low processing cost, but has too much fiber content that is difficult for pigs to digest. For these reasons, brown rice may be a better feedstuff for pigs than white rice [66]. Compared with corn, brown rice has similar concentrations of gross energy, crude protein, and ether extract and comparatively higher amount of starch, essential amino acids, and fatty [66–70] (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 diets (e.g., pigs, poultry). The studies have focused mainly on its particle size [71,72], processing methods [65,73], and substitution rates of corn [74]. Previous studies have shown that white rice can replace some proportions of corn in swine diets without negative effects on growth performance and nutrient digestibility of pigs [20,41,71,75]. However, several studies showed that the digestibility of rice was increased compared with that of other grains when rice was heat-treated and fed to pigs in a gelatinous form [59,65,76]. In particular, it has been known that cooked white rice can protect pigs from swine dysentery by reducing the substrates for bacterial fermentation in the large intestine [76]. It may have a significant impact on the gastrointestinal environments such as nutritional absorption and microbial balance and population. Similarly, a study showed that the pig removal and antibiotic treatment rate of pigs fed to rice was lower than those of corn [74]. Although previous studies have focused on white rice mainly, there has been some experiments with brown rice to replace corn in pig diets. Previous studies showed that the partial or complete replace-

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

Item	Corn ²	Brown rice ³	White rice ⁴
Gross energy (Mcal/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)

¹Each value is mean (SD).

²Adapted from [66–70].

³Adapted from [41,66,70].

⁴Adapted from [68,69].

ment of corn with brown rice in pig diets did not influence negatively growth performance and nutrient digestibility [21,65,66,77,78].

CONCLUSION

Feed alternatives are needed to stabilize supply and increase self-sufficiency by replacing corn in order to stabilize the rising production costs of pigs. Rice is produced around the world like corn that is the typical energy source in pig diets. Rice also contains more starch and less non-starch polysaccharides and anti-nutritive factors than corn and its structure and granule size are easier to digest than corn. In addition, rice has several components with physiological activities, such as polyphenols, that can be beneficial to the gastrointestinal environment and health of pigs. Based on the previous studies, rice can be partially or completely used to replace corn in pig diets without negatively influencing pig production. However, further studies are needed to verify how rice helps pigs to improve their health. From the points of view, rice can be a valuable feed ingredient for swine diets.

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