Efficacy of white rice-based diets in nursery pigs

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ABSTRACT

Rice is a staple cereal consumed by much of the world's population but has received relatively little attention as a potential feedstuff for the animal industries in many parts of the world. It may be because its price is relatively high and only a small amount of rice produced is traded (6.2%). India, Thailand and Vietnam play a major role in the world rice export market. Rice is characterized by its high starch content, low fat and dietary fiber content, and lower crude protein content in comparison to other cereals. Rice-based diets have a higher apparent digestibility of nutrients than corn-based diets. Complete replacement of corn with rice in weaned pig diets does not affect growth performance, but feed efficiency is improved when corn is replaced with brown rice. Heat processing of rice does not influence digestibility and growth performance of pigs. Due to rice's high digestibility and low fiber content, pigs fed rice-based diets have lower concentrations of volatile fatty acids and viscosity of intestinal digesta compared to other cereal-based diets. Moreover, rice has been shown to have potential to ameliorate diarrhea, colonization of pathogens, severity of enteric bacterial diseases, and pig removals. The mechanism for this protective function is not fully understood, but it may be, to a certain extent, related to lower fiber content and high digestibility of rice and a so-called "rice factor". In practice, when availability and cost of rice permits, pork producers can benefit from the use of rice-based diets for piglets.

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1. Introduction

Rice is a staple cereal consumed by much of the world's population, and a plethora of studies exist investigating the physical and chemical properties of cooked rice for man. Most of these studies relate to the starch properties of rice, presumably because starch constitutes more than 75% of rice's composition (Pluske et al., 2007; Stein et al., 2016), and hence forms the major carbohydrate consumed. The high starch content of cooked rice coupled with a very low non-starch polysaccharide (NSP) level makes cooked rice a ready source of absorbable glucose, and hence energy, for the human population. More recently, there is interest in the use of rice-based oral rehydration formulas for controlling enteric diseases in children (Iyngkaran & Yadav, 1998; Ramakrishna et al., 2000; Gregorio et al., 2016) and animals (Hampson et al., 2001).

In contrast, there is less information pertaining to the feeding of rice to animals, especially the pig, with respect to effects on production and intestinal "health", which incorporates enteric disease. This is predominately because other cereal sources, such as wheat, barley, corn, and sorghum, are used in pig production and can be fed to pigs cheaper than rice. Nevertheless, given the information available from the human literature with respect to the cooking and milling properties of rice, potential exists for the use of processed (cooked) rice in certain diets for pigs, especially the young pig. This is particularly when the intestine is compromised by enteric pathogens such as *Escherichia coli*, the agent of post-weaning colibacillosis (PWC) or, as it is more commonly recognized, post-weaning diarrhea (PWD). Incorporation of processed rice into such diets has potential to add value to the world rice industry and reduce the pig industry's reliance on the use of growth promoting antibiotics. Furthermore, spin-offs into the biomedical field in the control of human enteric pathogens may be possible.

Antimicrobial agents are presently the main tool used for control of PWD, and are provided to pigs to treat overt disease, to provide prophylaxis in situations where disease is liable to occur, and to improve growth rates in the absence of disease. However, problems are arising over the use of antimicrobials in the pig industry. Their long-term use eventually selects for the survival of resistant bacterial species or strains, and genes encoding this resistance also can be transferred to other formerly susceptible bacteria. Currently, a variety of bacterial pathogens of pigs are showing resistance to a range of antimicrobial drugs. Not only is this reducing the number of antimicrobials available to control bacterial diseases in pigs, but this resistance also poses risks to human health. Risks include the transfer of multidrug resistant zoonotic pathogens (e.g., *Salmonella* spp. and *Campylobacter* spp.) from pigs to humans, the direct or indirect transfer of resistance genes from the porcine intestinal microflora to human bacterial strains, and the presence of antimicrobial drug residues in pig meat (Hampson et al., 2001). Public concern about these issues is leading to reduced availability or the complete banning of certain antimicrobial agents for use in pig production, as has occurred in certain parts of Europe. Although there are currently no total bans on the use of growth promoting antibiotics in the Vietnam pig industry, it is imperative to develop alternative means, such as the use of nutrition, both of controlling bacterial infections and promoting growth in pigs without recourse to the use of antimicrobials.

Swine rations usually contain a large amount of cereal grains such as corn, barley, wheat, oat, and rice. Among these ingredients, corn is the cereal grain preferred by most pork producers in Vietnam and many regions of the world. However, other cereal grains may be considered, at times, due to their lowered costs or their positive effects on growth performance and health of young pigs. Cereal grains have different carbohydrate composition which may affect the health of the digestive tract by providing different substrates for microbial activity (Jensen & Jorgensen, 1994; Bach Knudsen et al., 2012). Unfortunately, there are few reliable data to support intelligent selection of the most appropriate cereals for the health of young pigs. Oat, wheat, and barley are ingredients with high content of non-starch polysaccharides which can stimulate the growth of commensal gut flora (Bach Knudsen, 1991), leading to a healthy digestive tract. In other words, studies of McDonald et al. (1999 & 2001), Hopwood et al. (2004), and Mateos et al. (2006) indicate benefits of rice, which contains almost no fiber. Apparently, more information is needed on both the practical and physiological effects of various cereal grains in the diet of young pigs.

The aim of this paper is to review the effects of rice-based diets on growth performance, digestibility, gastrointestinal parameters, and health of weaned pigs in comparison to other cereal-based diets.

2. Global Rice Production and Trade

Rice is widely grown all over the world and a staple food for humans. Approximately 673.8 million metric tons (MMT) of rice are produced annually in the world, with overwhelming majority of this entering the human food markets. Only about 6.2% of rice produced is traded in the global markets. As with most crops, China has a major role in rice production and use, but a minor role in trade. In the 2016 marketing year China accounted for 31.0% of world production of 673.8 MMT (Table 1). The second largest rice producer is India, with a total production of 165.2 MMT in 2016. It may be surprising that India is now emerging as the world's largest rice exporter with an amount of 10.1 MMT. With a large population, strong economic growth and internal food price pressures, China could quickly disappear from the rice export market. In contrast, Thailand and Vietnam, though with smaller amounts of rice production as compared to China, play a major role in the world rice export market. The second largest rice exporter is Thailand at 9.9 MMT for 2016. Vietnam is the third rice exporter at 6.1 MMT, 15.8% of the world total in 2016.

Most of the current price problems are related to exporters withdrawing supplies from the market and the general rise in all commodity prices. The longer-term structural question of who will produce rice for international markets will continue to influence market prices for years to come. It appears that India, Thailand and Vietnam are more committed to export markets.

3. Chemical Composition of Rice

Rice is characterized by its high starch content, low fat and dietary fiber content, and lower crude protein content in comparison to other cereals (Table 2). In term of crude protein, rice (8.1-8.6%) is comparable to corn (8.1%), even with a better balanced essential amino acid profile (Figure 1). Both brown rice and white rice has a higher concentration of essential amino acids, except for histidine and leucine, than corn. Piao et al. (2002) and Li et al. (2002), however, found that the balance between isoleucine and leucine is better in brown rice than that in corn. Barley (10.8%), oat (11.3%), and wheat (14.0%) have a greater content of crude protein than corn and rice.

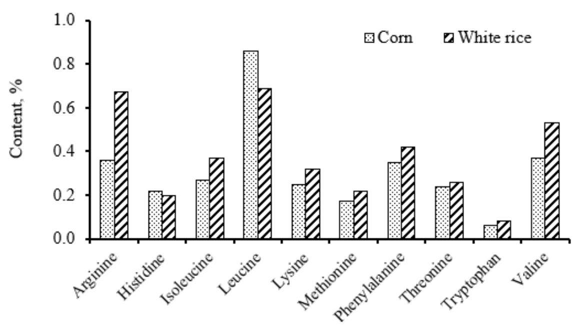

Figure 1. Essential amino acids in corn and white rice. Data from: Bach Knudsen (1997); Kim et al. (2007); Che et al. (2012).

Apart from high contents of crude protein, other cereals also contain a considerable amount of total dietary fiber (> 9.0%) which is much higher than that (1.2%) in rice (Table 2). In contrast, rice contains a significantly higher level of starch (75.3-87.4%) than other cereals. Regarding the energy content, rice has a higher level (3.54 Mcal/kg) of metabolizable energy (ME) than barley, oat, and wheat. In comparison to corn, although both rice and corn have the same gross energy content (Li et al., 2002; Vicente et al., 2008), the ME of rice is lightly greater than that of corn. The higher ME content of rice might be resulted from its higher digestibility. In addition, other cereals, particularly barley, oat and corn, have higher lipid content than white rice.

Because of its low fiber content and high starch content, rice might be a good alternative to other cereals in the pig's diet immediately after weaning. It may have a major impact on the digestibility of dietary nutrients and the microbial populations through providing fewer substrates for bacterial fermentation in the intestinal tract (Pluske et al., 2003; Montagne et al., 2004; Vicente et al., 2008). This in turn may prevent the proliferation of pathogenic bacteria. The interaction between the components of diet (e.g. fiber) and the development of intestinal bacteria and gut is complex. Thus, a rice-based diet does have an important role to play in intestinal disease and health of young pigs.

4. Effects on Growth Performance

Replacement of other cereals with rice in weaning diets for pigs has been conducted by several researchers, but most of the research has focused on comparing the effect of substituting rice for corn in the weaned pig's diet. In a series of experiments carried out at the same commercial farm testing whether corn, barley, rolled oat, or rice as the main energy source in the diet for weaned pigs affects growth performance, Che et al. (2012) reported that average daily gain (ADG) of pigs fed the rice diet was significantly higher than that of pigs fed barley or rolled oat diets, but not different from that of pigs fed the corn diet (Table 3). No difference in feed/gain (F/G) was seen among the treatment diets. Average daily feed intake (ADFI) of pigs fed corn, rolled oat, and rice diets were similar, but was significantly higher than that of pigs fed barley diet. In the second experiment, Che et al. (2012) investigated effects of complete replacement of corn with rice in diets and length of rice feeding on growth performance of weaned pigs (Table 3). The results showed that there were no significant differences in ADG, ADFI, and F/G. This suggests that rice can substitute for corn in the diet for weaned pigs, reared under commercial conditions, without affecting the growth performance of pigs.

However, with studies conducted at the univer-

Table 1. Top paddy rice producers-2016 and rice exporting countries worldwide in 2016[1]

Producers	Amount		Exporters	Amount	
	Million metric ton	%		Million metric ton	%
China	208.7	31.0	India	10.1	24.3
India	165.2	24.5	Thailand	9.9	23.9
Indonesia	72.7	10.8	Vietnam	6.1	14.7
Bangladesh	52.1	7.7	Pakistan	4.0	9.6
Vietnam	43.6	6.5	USA	3.3	8.0
Thailand	32.6	4.8	Myanmar	1.4	3.4
Myanmar	28.6	4.2	Cambodia	1.2	2.9
Philippines	18.5	2.7	Uruguay	0.9	2.2
Japan	10.7	1.6	Brazil	0.6	1.4
Brazil	10.6	1.6	Argentina	0.5	1.2
Pakistan	10.3	1.5	Others	3.5	8.4
USA	10.2	1.5			
Cambodia	10.0	1.5			
World total	673.8	100.0		41.5	100.0

[1]Data from FAO (2017).

Table 2. Chemical composition of cereal grains (as fed)

	Barley[1]	Oat[1]	Wheat[1]	Corn[3]	Rice[2]	Rice[3]
Protein, %	10.8	11.3	14.0	8.1	8.1	8.6
Ether extract, %	3.0	4.0	1.1	2.9	0.9	2.4
Starch, %	49.7	40.1	57.6	62.1	75.3-87.4	n.a.
Dietary fiber, %	18.8	22.8	9.8	9.5	1.2	n.a.
Ash, %	4.1	2.6	2.0	1.4	0.5	1.1
ME, Mcal/kg	2.91	2.60	3.30	3.39	3.54	n.a.

[1]Stein et al. (2016).
[2]Pluske et al. (2007); Stein et al. (2016).
[3]n.a.: not available; Li et al. (2002).

Table 3. Effects of cereals on growth performance of pigs from d 0 to 42 post-weaning[1]

Experiment 1	Dietary treatments			
	Corn	Barley	Rolled oat	Rice
ADG, g	331[a]	307[c]	323[bc]	337[a]
ADFI, g	495[a]	462[b]	489[a]	504[a]
F:G, g/g	1.49	1.49	1.52	1.49
Experiment 2	**Dietary treatments[2]**			
	Corn (6 wk)	Rice (1 wk)	Rice (2 wk)	Rice (4 wk)
ADG, g	307	315	318	307
ADFI, g	455	459	468	446
F:G, g/g	1.35	1.33	1.33	1.33

[1]12 pens of 21 pigs/treatment. Data from Che et al. (2012).
[2]Pigs were fed rice diets for 1, 2 or 4 weeks and then on a corn diet until the end of experiment.
[a-c]Means within a row with different superscripts differ ($P < 0.05$).

sity research farms, better performance of weaned pigs has been often reported. Mateos et al. (2006) showed that pigs fed the cooked-rice diet grew faster (12.3%) than those fed the cooked-corn diet. In another experiment using brown rice, Li et al. (2002) found that 50% or complete replacement of corn with brown rice in nursery diets improved the feed efficiency. In comparison to wheat, pigs fed rice-based diets from 46-63 days of age, regardless of low or high dietary protein, ate more, gained faster, and had better feed efficiency than those fed the wheat-based diets (Bonet et al., 2003).

Rice has a high level of starch, thus gelatinization of the starch portion of the grains might improve nutrient utilization and thereby resulting in a better growth performance. Vicente et al. (2008) evaluated effects of cooked-flaked corn, raw-ground rice, cooked-ground rice, and cooked-flaked rice on performance of weaned pigs for 28 days post-weaning (Table 4). They showed that pigs fed rice consumed more feed (678 vs. 618 g/d), grew faster (466 vs. 407 g/d), and tended to have lower F/G than those fed corn. No differences in growth performance due to heat processing of rice were observed. This suggests that heat processing does not affect growth performance of pigs fed rice-based diets.

5. Effects on Nutrient Digestibility

Rice-based diets have a higher apparent total tract digestibility of nutrients than corn-based diets. Mateos et al. (2006) found that the digestibility of GE, OM, DM, and fat was higher for rice- than for corn-based diets (Table 5), which agrees with the results of Li et al. (2002), Piao et al. (2002) and Vicente et al. (2008). It was also shown that heat processing did not affect the digestibility of nutrients in the rice-based diets (Table 6). A similar result was obtained when corn was replaced with 50% or 100% of brown rice in the diets. The corn-based diet had a significant lower apparent digestibility of dietary components than the brown rice-based diet or the diet with 50% replacement of corn. The higher digestibility of a rice-based diet would be likely to explain the improved growth performance in weaned pigs fed rice diets compared to corn diets. It is pointed out that fewer substrates for bacterial fermentation might be resulted from a rice-based diet, but ileal digestibility of rice vs. other cereal diets needs to be determined.

6. Gastrointestinal Effects

With high digestibility of nutrients and low fiber content, rice-based diets may greatly influence activity of microbial fermentation and intestinal environment. Hopwood et al. (2004) reported that the barley-based diet or the diet with high inclusion level of barley fed to pigs caused a significant decrease in pH of distal colon and feces compared to pigs fed the rice-based diet (Table 7). However, no differences were observed in digesta pH in duodenum and ileum of pigs among the treatments. It is obvious that a diet containing high fiber ingredients, like barley, increases the pH in the large intestine via providing fermentable substrates to the microbial activity as compared to the rice-based diet. In another experiment, different types of fiber such as high-amylose corn starch, lupin isolate, or a combination of both included in a rice-based diet reduced the digesta pH in cecum, proximal colon, and distal colon (Table 8). Further, a rice-based diet resulted in a numerically higher pH in the large intestine as compared to a wheat-based commercial diet (Pluske et al., 2003). The inclusion of animal or plant protein in a rice-based diet also significantly influenced the digesta pH of the large intestine. The rice diet with animal protein had a higher cecum and colon pH than that with plant protein.

The increase in pH is likely to be because of the increased pool of volatile fatty acid (VFA) through the high activity of microbial fermentation in the large intestine. The rice-based diet had a lower total pool of VFA than that with increasing levels of barley. It was further indicated that rice-based diets with inclusion of various types of fiber sources produced different amounts of pooled VFA (Table 9). In order to prove that the fiber components added to rice diets increase the production of VFA, McDonald et al. (2001) added a viscous but unfermentable component, carboxymethylcellulose (CMC) to a rice-based diet. They found that no differences in concentration of VFA of digesta in the large intestine of pigs.

The high level of fiber in the cereals, e.g. barley, caused not only an elevated total pool of VFA and decreased pH but also an increased viscosity. The rice-based diets with different inclusion levels of barley resulted in an increase in viscosity in the small intestine of pigs (Figure 2). The viscosity in pigs fed the rice-based diet was lower than that in those fed the barley-based diet or the diet with the inclusion of 500 g/kg of barley. Hopwood et al. (2004) reported that the intake of non-starch polysaccharide was positively

Table 4. Effects of cereals and heating processing on performance of pigs from d 0 to 28 post-weaning[1]

Item	Corn	Rice		
	Cooked-flaked	Raw-ground	Cooked-ground	Cooked-flaked
ADG, g[2]	407	459	482	456
ADFI, g[2]	618	680	680	672
F:G, g/g	1.52	1.49	1.41	1.47

[1]8 pens of 5 pigs/treatment. Data from Vicente et al. (2008).
[2]Corn vs. mean of the 3 rice treatments ($P < 0.01$).

Table 5. Effects of cereals on total tract apparent digestibility of dietary components[1]

Item	Cereal source	
	Cooked rice	Cooked corn
DM, %	83.8[a]	80.6[b]
OM, %	86.2[a]	82.9[b]
GE, %	82.7[a]	79.0[b]
Ether extract, %	60.9[a]	58.8[b]
CP, %	72.9	72.9
Starch, %	99.2	99.4

[1]8 pens of 4 pigs/treatment; Average of d 6 & 16 post-weaning. Data from Mateos et al. (2006).
[a-b]Means within a row with different superscripts differ ($P < 0.05$).

Table 6. Effects of cereals and heat processing on apparent total tract digestibility of dietary components[1]

Item	Corn	Rice		
	Cooked-flaked	Raw-ground	Cooked-ground	Cooked-flaked
DM, %	86.7[a]	88.1[b]	88.8[b]	88.3[b]
OM, %	88.6[a]	90.6[b]	91.1[b]	90.8[b]
GE, %	86.5[a]	88.4[b]	89.3[b]	88.8[b]
CP, %	80.8	80.9	81.6	81.0

[1]8 pens of 5 pigs/treatment; Average of d 5, 14 & 28 post-weaning. Data from Vicente et al. (2008).
[a-b]Means within a row with different superscripts differ ($P < 0.05$).

Table 7. Digesta pH in various sections of the intestinal tract in pigs fed rice-based diet with different levels of barley[1]

Item[2]	Rice:barley (g/kg)			
	703:0	497:250	275:500	0:750
Duodenum	5.7	5.9	5.7	5.8
Ileum	6.7	6.3	6.6	6.1
Distal colon	6.8[a]	6.6[a]	6.1[b]	5.7[b]
Feces	6.9[a]	6.9[a]	6.5[b]	6.4[b]

[1]6 pigs/treatment; [2]10 d after weaning. Data from Hopwood et al. (2004).
[a-b]Means within a row with different superscripts differ ($P < 0.05$).

correlated with the viscosity of small intestinal content of pigs. The viscosity of digesta is also dependent on, in addition to fiber sources, types of fiber combined in the diet. Addition of high-amylose corn starch and lupin isolate combined to the rice-based diet greatly increased the vis-

Table 8. Digesta pH in different sections of the intestinal tract in pigs fed rice-based diets[1]

	Diet				
	R+AP	R+HACS	R+LI	R+HACS+LI	Com
Ileum	7.1	7.1	7.3	7.4	6.8
Cecum	6.2[a]	5.3[b]	5.5[bc]	5.4[b]	5.8[ac]
Proximal colon	6.3[a]	5.2[b]	5.4[b]	5.3[b]	6.0[a]
Distal colon	6.6[a]	5.7[b]	6.0[b]	6.1[b]	7.0[bc]

[1]6 pigs/treatment. Data from Pluske et al. (2003).
R = rice, AP = animal protein; HACS = high-amylose corn starch, LI = lupin isolate, Com = commercial diet containing wheat.
[a-c]Means within a row with different superscripts differ ($P < 0.05$).

Table 9. Pools of VFA of digesta in the large intestine in pigs fed rice-based diets[1]

VFA pool (mmol per pig)	Diet				
	R+AP	R+HACS	R+LI	R+HACS+LI	Com
Cecum	8	18	15	12	11
Colon	19[a]	45[b]	45[b]	27[ac]	36[bc]

[1]6 pigs/treatment. Data from Pluske et al. (2003).
R = rice, AP = animal protein; HACS = high-amylose corn starch, LI = lupin isolate, Com = commercial diet containing wheat.
[a-c]Means within a row with different superscripts differ ($P < 0.05$).

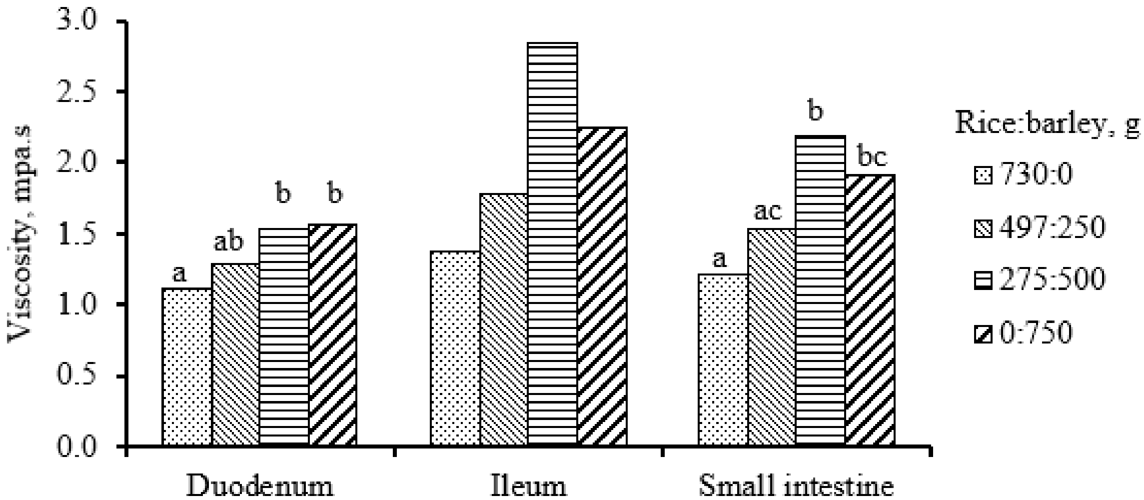

Figure 2. Viscosity of intestinal contents of pigs fed rice-based diets containing different levels of pearl barley. 6 pigs/treatments; 10 d after weaning. Bars with different superscripts differ ($P < 0.05$). Data from Hopwood et al. (2004).

cosity of ileal digesta if compared to diets with the inclusion of high-amylose corn starch or lupin isolate individually (Pluske et al., 2003).

7. Effects on Pig Health and Diarrhea

Rice, when compared to other cereals, has been shown to reduce the diarrhea, intestinal colonization of pathogens, and the severity of enteric bacterial diseases when pigs were challenged with enterotoxigenic *Escherichia coli* (ETEC) or *Brachyspira pilosicoli*. Hopwood et al. (2004) investigated the effect of rice-based diet with high inclusion level of barley with or without NSP enzyme supplementation. They showed that the fecal DM did not differ among dietary groups (Table 10), but the post-infection fecal consistency score was different, with pigs receiving the rice-only diet having firmer and better-formed feces than pigs fed either of barley diets. Mateos et al. (2006) reported that pigs fed the cooked-rice diet had a lower diarrhea score than those fed the cooked-corn diet. This indicates that under normal or disease conditions rice-based diets fed to pigs reduce the moisture content of feces. When pigs challenged with ETEC, the ADG for the experimental period was negative for those pigs consuming diets with barley, and positive for those fed the rice-only diet (Table 11). The intestinal viscosity was also greater in infected pigs fed 500 g/kg of barley compared with those fed the rice-based diet. In another ETEC challenge study, Montagne et al. (2004) showed that ileal and cecal viscosity of pigs fed rice-based diets with animal or plant protein was lower than that of pigs fed wheat-based diet with plant protein.

In term of intestinal colonization of pathogens, culture of mucosal scrapings revealed greater proliferation of ETEC within the small and large intestines of pigs consuming diets containing barley than those eating the rice-only diet (Table 12). In addition, the ETEC were more dominant within the microbiota of pigs eating barley compared with that within pigs eating rice. At each of the intestinal sites swabbed there were more ETEC on the culture plates from pigs eating the barley diets compared with those not receiving barley. With *Brachyspira pilosicoli* inoculation (Figure 3), the period of fecal excretion ranged from 1 to 25 days. The pigs fed the rice diet excreted *Brachyspira pilosicoli* for a significantly shorter period than those fed the standard diet containing wheat and barley, regardless of diet forms. They also observed that a higher incidence of fecal excretion in all the groups fed the standard diet was accompanied by a significantly higher number of pigs showing clinical signs of disease compared to the pigs fed the rice diet. A similar protective effect of rice-based diets has been seen in pigs experimentally infected with the intestinal spirochete *Brachyspira hyodysenteriae*, the agent of swine dysentery (Pluske et al., 1996) and *Brachyspira pilosicoli*, the agent of porcine intestinal spirochetosis (Hampson et al., 2000).

The protective effect of such a diet against bacterial infection has been attributed in part to the high digestibility of its protein and carbohydrates (Siba et al., 1996; Pluske et al., 1998). In piglets,

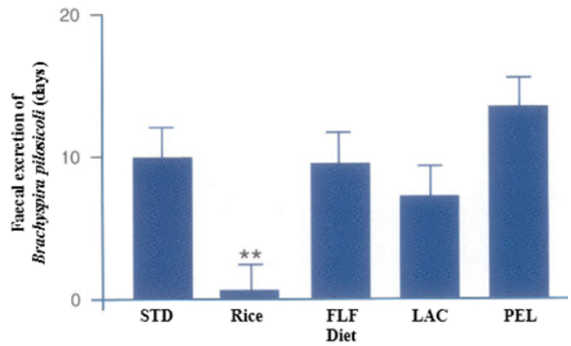

Figure 3. Fecal excretion of *Brachyspira pilosicoli* by pigs fed various diets and infected experimentally in 2 trials. STD=standard diet containing barley and wheat, FLF=fermented liquid feed, LAC=STD + lactic acid, PEL=pelleted STD; 6 pigs/treatment. Adapted from Lindecrona et al. (2004).

it is generally thought that diets containing less fiber and highly digestible ingredients, thereby limiting the quantity of fermentable substrates entering the large intestine, are associated with a decrease in the incidence of PWC (Montagne et al., 2003). Such diets may result in less accumulation of potential bacterial substrate in the upper small intestine, the primary site of proliferation of the pathogenic *E. coli* causing PWC (Francis, 2002).

One of the primary mechanisms by which toxin-producing bacteria, such as *E. coli* or *Salmonella*, initiate secretory diarrhea is the increase of water secretion by the small intestinal crypt cells, by a pathway involving cAMP (Keely et al., 2009). In young pigs, the large intestine is incompletely developed and may not be capable of absorbing enough fluid to prevent clinical diarrhea and dehydration. A component of boiled white rice recently identified and named the rice factor has been shown to block the secretory response of intestinal crypt cells to cAMP in guinea pigs (Macleod et al., 1995; Mathews et al., 1999). A potential effect of this rice factor has not been demonstrated in other animal species; however, boiled rice has been used for many years in the treatment of diarrhea in humans and is included in various oral rehydration products (Gregorio et al., 2016).

The reduction in diarrhea and intestinal colonization of enteric pathogens may help prevent infections and improve the pig health. In a series of experiment conducted by Che et al. (2012)

Table 10. Fecal dry matter and consistency score in weaned pigs infected with enterotoxigenic *Escherichia coli* and fed different diets

Item	Rice:barley, g/kg[1]		
	703:0	275:500	275:500 + Enzyme
Fecal DM (g/kg)			
Over 6d post-weaning	304	295	299
Post-infection	301	292	277
Fecal consistency score[2]			
Pre-infection	1.5	1.8	1.7
Post-infection	2.9^{a}	3.6^{b}	3.7^{b}

[1]n = 11, 13, & 12 for 0, 500, & 500+NSP Enzyme groups, respectively. Data from Hopwood et al. (2004).
[2]Score 0-5.
[a-b]Means within a row with different superscripts differ ($P < 0.05$).

Table 11. Growth and digesta viscosity of weaner pigs killed 3-4 d after infection with enterotoxigenic *Escherichia coli*

Item	Rice:barley, g/kg[1]		
	703:0	275:500	275:500 + Enzyme
Gain, g/d	10.5	-7.8	-27.0
Viscosity, mpa.s			
Duodenum	1.8	2.1	2.6
Ileum	1.6^{a}	2.3^{b}	2.2^{ab}
Small intestine	1.7	2.2	2.6

[1]n = 11, 13, & 12 for 0, 500, & 500+NSP Enzyme groups, respectively. Data from Hopwood et al. (2004).
[a-b]Means within a row with different superscripts differ ($P < 0.05$).

Table 12. Proportion of β-hemolytic enterotoxigenic *Escherichia coli* (ETEC) cultured from intestinal swabs in weaner pigs infected with ETEC and fed different diets

Item	Rice:barley, g/kg[1]		
	703:0	275:500	275:500 + Enzyme
Viable CFU/g ($\log_{10}$)[2]			
Mid-small intestine	1.0^{a}	4.1^{b}	3.5^{b}
Proximal colon	2.3^{a}	5.2^{b}	6.0^{b}
ETEC (%), intestinal swabs			
Duodenum	7.5	22.1	26.5
Ileum	11.0^{a}	47.6^{b}	21.4^{ab}
Cecum	16.5^{a}	53.2^{b}	53.0^{b}
Feces	27.9	44.5	38.8

[1]n=11, 13, & 12 for 0, 500, & 500+NSP Enzyme groups, respectively. Data from Hopwood et al. (2004).
[a-b]Means within a row with different superscripts differ ($P < 0.05$).

at the same commercial pig farm, feeding rice-based diets to weaned pigs significantly reduced the pig removal by half, even when pigs were fed rice diets for only one week immediately after weaning (Figure 4). Furthermore, Pluske et al. (2003) showed that the number of antibiotic treatments of pigs was also reduced in pigs fed the rice-only diet compared to a commercial diet and rice-based diets with the inclusion of various fiber sources. Obviously, feeding a rice-based diet improves pig health with evidence of reduced pig removal and number of antibiotic treatment.

8. Conclusions

Rice, widely grown over the world, is a highly digestible ingredient and has high potential to be a good feed ingredient for animals. Rice can sub-

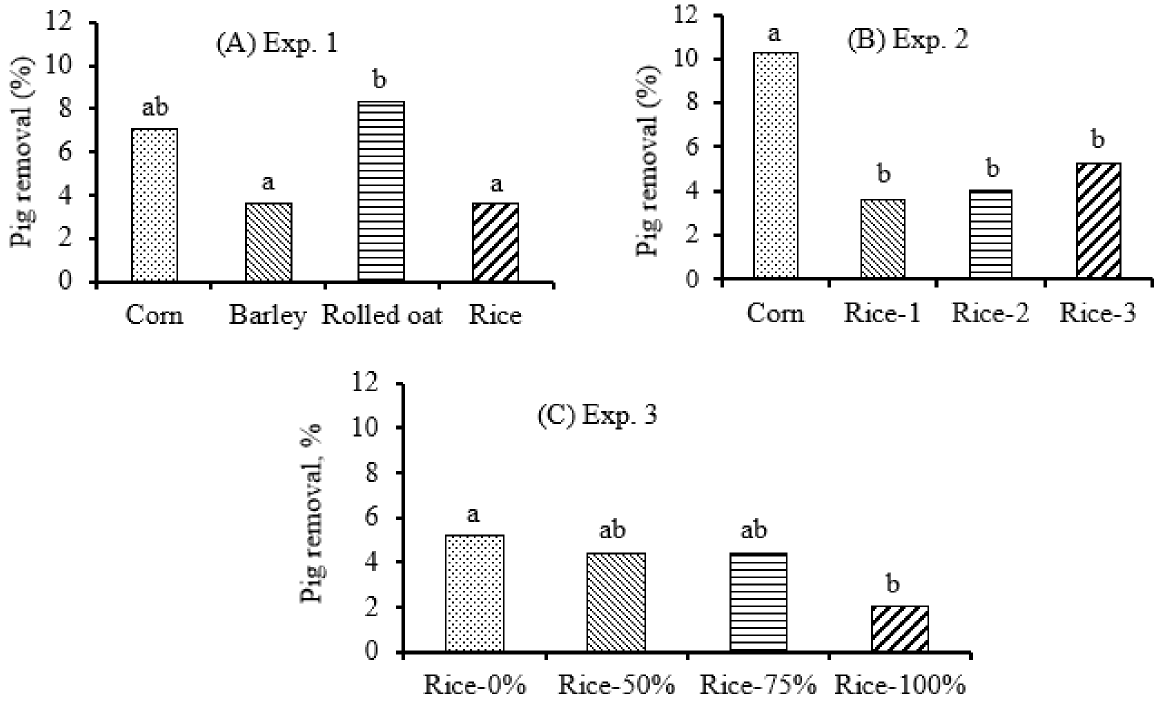

Figure 4. Effect of different cereal-based diets on pig removals 6 weeks post-weaning. (A) Pigs fed diets with different cereals as a main source of energy for 6 weeks post-weaning. (B) Pigs fed corn-based diets for 6 weeks or rice-based diets for 1 (Rice-1), 2 (Rice-2) or 4 (Rice-3) weeks post-weaning. (C) Effects of feeding rice with 0 (Rice-0%), 50 (Rice-50%), 75 (Rice-75%), and 100% (Rice-100%) replacement of corn in diets for 1 week on the overall pig removal over 6 weeks post-weaning. 252 pigs/treatment. [a-b]Means with different superscript letters within each experiment differ ($P < 0.05$). Data from Che et al. (2012).

stitute for corn in diets for weaned pigs without affecting the pig's performance. The rice-based diet appears to be better in growth performance and feed efficiency than a barley- or wheat-based diet. Rice included in diets makes feces less moist and reduces the incidence of diarrhea. Inclusion of rice in diets causes less viscous digesta and appears to prevent the proliferation of pathogens. Feed ingredients in weaning diets that excessively increase the viscosity of the intestinal digesta may be detrimental to pig and production. Rice appears to improve pig health with evidence of reduced pig removal and antibiotic treatment.

9. Implications And Recommendations

Reduced viscosity, diarrhea, and proliferation of pathogens by rice would be likely due to its low fiber content, high digestibility, and rice factor. In practice, when availability and cost of rice permits, pork producers can benefit from inclusion of rice in diets for pigs immediately after weaning.

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