Nutritional value of co-products from the tropical food industry and of novel feed ingredients

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ABSTRACT: High fiber co-products from the tropical food industry include copra and palm kernel products and rice co-products. The co-products from the copra and palm industries include copra meal, copra expellers, palm kernel meal, and palm kernel expellers. All 4 ingredients are very high in fiber and the energy value is relatively low when fed to pigs. The protein concentration is between 14 and 22% and the protein has a low biological value and a very high Arg:Lys ratio. Digestibility of most amino acids is less than in soybean meal but close to that in corn. Copra and palm kernel ingredients contain 0.5 to 0.6% P but the digestibility is low in palm kernel ingredients because of high concentration of phytate. Inclusion of copra meal should be less than 15% in diets fed to weanling pigs and less than 25% in diets for growing- finishing pigs. Palm kernel meal may be included by 15% in diets for weanling pigs and 25% in diets for growing and finishing pigs. The most common co-product from the rice milling industry is rice bran, which contains the pericarp and aleurone layers of brown rice that is removed before polished rice is produced. Rice bran contains approximately 25% NDF and 25 to 30% starch. Rice bran has a greater concentration of P than most other plant ingredients, but 75 to 90% of the P is bound in phytate. Inclusion of microbial phytase in the diets is, therefore, necessary if rice bran is used. Rice bran may contain 15 to 24% fat, but it may also have been defatted in which case the fat concentration is less than 5%. Concentrations of DE and ME are slightly less in full fat rice bran than in corn, but defatted rice bran contains less than 75% of the DE and ME in corn. The concentration of crude protein is 15 to 18% in rice bran and the protein has a high biological value and most amino acids are well digested by pigs. Inclusion of rice bran in diets fed to pigs has yielded variable results and inclusion levels should be less than 25 to 30% in diets for growing-finishing pigs, and likely less than 20% in diets for weanling pigs. Novel sources of protein that potentially may be used in diets for pigs include duckweed, microalgae, and single cell protein, but information about the nutritional value of these ingredients is very limited. However, it is likely that more information will be generated in the future and these sources of protein may, therefore, become more available for practical swine feeding in the future.

Keywords: copra meal, copra expellers, palm kernel meal, palm kernel expellers, rice bran

Copra Meal and Copra Expellers

The coconut palm (*Cocos nucifera*) is widely distributed throughout the tropics with major production in Indonesia, The Philippines, India, and in some South American countries. World production of copra meal and copra expellers is approximately 2 million metric tons (Soyatech, 2014).

Copra meal is produced by expeller extracting or solvent extracting the oil from dried coconut kernels. Copra meal is sometimes referred to as coconut meal or coconut oil meal. Although its protein content is less than that of conventional ingredients commonly used as protein sources, copra meal represents the largest quantity of locally available feed protein in many tropical areas (Creswell and Brooks, 1971). Variations in the nutrient composition of copra meal are mainly a function of the differences in residual oil concentration.

The residual oil in copra meal and copra expellers is mostly medium-chain, saturated fatty acids (lauric acid), which can lead to firmer carcass fat when high levels of copra meal are used in the diet (Thorne et al., 1988; 1992b). Quality problems such as rancidity and aflatoxin contamination may be an issue in copra meal, which may be attributed to the high moisture content of copra during drying and storage (Head et al., 1999).

Copra meal and copra expellers contain between 10 and 16% crude fiber and approximately 47% total dietary fiber (Jaworski et al., 2014). Concentrations of β-mannans, galactomannans, arabinoxylogalactans, and cellulose are relatively high (Balasubramaniam, 1976; Saittagaroon et al., 1983) and the water binding capacity of copra meal is much greater than that of palm kernel meal or palm kernel expellers (Jaworski et al., 2014). Protein levels of copra meal and copra expellers typically range from 20 to 26% (Table 1). The concentration of GE in copra meal is greater than in corn, but because of the high concentration of fiber in copra meal and copra expellers, concentrations of DE and ME are less than in corn (NRC, 2012; Sulabo et al. 2013).

Copra meal and copra expellers contain between 0.5 and 0.58% total P (NRC, 2012; Son et al., 2013; Almaguer et al., 2014), but only 40 to 50% of the P is bound to phytate. The standardized total tract digestibility of P, therefore, is relatively high in copra meal and copra expellers (Table 2; Son et al., 2013; Almaguer et al., 2014). However, if microbial phytase is included in the diets, the digestibility of phosphorus will increase (Almaguer et al., 2014).

The quality of the protein in copra meal is less than that of soybean meal and palm kernel products with Lys only being 1.91% of total CP and total indispensable AA being 33.92% of total CP. However, one specific characteristic of copra protein is that it is high in Arg and Arg is almost 10% of total CP and the Arg:Lys ratio is 2:1 (Table 3).

The standardized ileal digestibility of AA in copra meal and copra expellers fed to pigs ranges between 43 and 81% (Lekule et al., 1986; Thorne et al., 1992a; Sulabo et al., 2013; Son et al., 2014). The ileal digestibility of Lys in copra meal is also variable, ranging from 51 (Thorne et al., 1989; 1992a) to 73% (Sulabo et al., 2013), but the digestibility of all other indispensable amino acids is greater than of Lys indicating that the sources of copra meal used in these experiments may have been heat damaged because heat damage will reduce the digestibility of Lys more than that of other amino acids (Gonzalez-Vega et al., 2011; Almeida et al., 2013; 2014). The standardized ileal digestibility of Lys in copra expellers was reported at only 40% (Son et al., 2014), which was much less than for other indispensable amino acids indicating that this source was also heat damaged. The differences in amino acid digestibility among experiments may be due to differences in drying procedures, oil extraction procedures, and the degree and duration of heat processing that is used during oil extraction (Samson, 1971). Overall, the digestibility of protein and indispensable AA in copra expellers is less than in soybean meal, but similar to those in palm kernel meal (Table 4; Sulabo et al., 2013).

Copra meal may be included in diets fed to growing and finishing pigs by up to 30% without affecting growth performance (Grieve et al., 1966; Creswell and Brooks, 1971), but negative effects of increasing levels of copra meal in the diet have been reported (Lekule et al., 1986; Thorne et al. 1992b; O'Doherty and McKeon, 2000). However, Thorne et al. (1988) demonstrated that copra meal can be used by up to 50% in growing-finishing diets if diets are supplemented with synthetic AA or proteins with higher quality.

In diets fed to weanling pigs from 2 weeks post-weaning, performance was linearly reduced if copra meal was included in the diet and pigs fed diets containing 15% copra meal gained approximately 1 kg less over a 3-week period than pigs fed a control diet without copra meal (Jaworski et al., 2014). This result was obtained even though diets were balanced for digestible amino acids and metabolizable energy. It is possible that it is the high fiber concentration and the high water binding capacity of the fiber in copra meal that resulted in the pigs eating less and therefore gaining less. However, gain to feed ratio was also reduced over the 3-week feeding period if copra meal was used. It is, therefore, not recommended to include copra meal in diets fed to weanling pigs.

Palm Kernel Meal and Palm Kernel Expellers

Global production of palm kernel meal and palm kernel expellers has increased from approximately 5 million metric tons in 2005 to almost 7 million metric tons in 2012 (Soyatech, 2012). The reason for this increase is the increased demand for palm oil, which is often used in the biodiesel industry. Produced mainly in Southeast Asia and Africa, the oil palm fruit (*Elaeis guineensis*) yields palm oil extracted from the fleshy, outer mesocarp that surrounds the nut and palm kernel oil extracted from the kernel within the inner, hard shelled nut (Ravindran and Blair, 1992). Prior to oil extraction, the outer shell of the kernel is cracked open, separated, and subjected to steam conditioning. Mechanical extraction by screw pressing is the most common process in oil extraction from palm kernels, which results in production of palm kernel expellers. However, sometimes oil is removed via solvent extraction, and the resultant co-product is called palm kernel meal.

The nutrient concentration of palm kernel meal and palm kernel expellers depends on the method of oil extraction, the species of the palm nut, and the amount of shell remaining in the meal (O'Mara et al., 1999). Palm kernel expellers have a residual oil concentration of 6-8%, whereas solvent-extracted meals contain 1-2% residual oil (Table 1; Nwokolo et al., 1977; Onwudike, 1986). The concentration of crude fiber in palm kernel meal ranges between 7 and 20% (Babatunde et al., 1975), depending on the amount of shells and fruit removed from the palm kernel. More than 81% of the total carbohydrates in palm kernel meal are in the form of non-starch polysaccharides (Back Knudsen, 1997), mainly as β-(1,4)-D-mannans (Daud and Javis, 1992; Dusterhoft et al., 1992). Palm kernel meal also contains high amounts of lignin, which may be a result of contamination of nut shells (Back Knudsen, 1997), which contributes to its grittiness and fibrous texture. However, water binding capacity in palm kernel meal and palm kernel expellers is less than in copra meal (Jaworski et al., 2014). Because of the high concentration of insoluble dietary fiber, the energy in palm kernel meal and palm kernel expellers is poorly digested by pigs and concentrations of DE and ME in palm kernel meal and palm kernel expellers is less than 75% of that in soybean meal and corn (Table 1; NRC, 2012; Sulabo et al., 2013). However, energy digestibility in diets containing palm kernel expellers may be increased if beta-mannanase is added to the diet (Mok et al., 2013). The reason for this observation is most likely that beta-mannanase may help the pig digest some of the D-mannans that are present in palm kernel expellers.

The concentration of phosphorus in palm kernel meal and palm kernel expellers is between 0.5 and 0.65% (NRC, 2012; Son et al., 2013, Almaguer et al., 2014). However, between 60 and 75% of total P is bound to phytate and the standardized total tract digestibility of P in palm kernel meal and palm kernel expellers is, therefore, between 35 and 50% (Table 2; NRC, 2012; Son et al., 2013, Almaguer et al., 2014). However, because of the relatively high concentration of phytate in palm kernel products, the standardized total tract digestibility of P can be increased to between 60 and 75% if microbial phytase is added to the diets. As a consequence, the supply of digestible phosphorus from palm kernel meal and palm kernel expellers is similar to that of soybean meal if microbial phytase is added to the diet.

Relative to other oil meals, palm kernel meal has the lowest protein concentration ranging from 14 to 21% (Nwokolo et al., 1977; Sulabo et al., 2013). Palm kernel protein also has a low concentration of Trp, but 10% of the crude protein is made up of Arg (Table 3; Owusu-Domfeh et al., 1970; Sulabo et al., 2013). However, the Arg:Lys ratio is around 4:1 (Table 3) and as is the case with copra co-products, the supply of Arg is much greater than if other feed ingredients are used. The high concentration of Arg may suppress the digestibility of Lys because the 2 amino acids compete for the same transporter in the enterocytes. In general, the standardized ileal digestibility of amino acids in both palm kernel meal and palm kernel expellers is less than in Soybean meal but not different from copra meal (Table 4; Nwokolo et al., 1976; Février et al., 2001; Sulabo et al., 2013).

Palm kernel meal and palm kernel expellers are not always well-accepted by pigs (Gohl, 1981) and if included by more than 20% in the diet, palm kernel meal negatively affects growth performance and carcass quality of growing finishing pigs (McDonald et al., 1988; Rhule, 1996). Finishing pigs, however, have greater tolerance for palm kernel meal than nursery pigs (Babatunde et al., 1975). In experiments with weanling pigs, it was observed that if diets are formulated to contain similar concentrations of digestible amino acids and ME, feed conversion rates may be maintained if up to 15% palm kernel meal or palm kernel expellers are included in the diets (Jaworski et al., 2014). However, average daily gain may be slightly reduced if palm kernel products are used, which may be a result of reduced bulk density of the diet and increased water binding capacity (Jaworski et al., 2014). However, it may be economical to include up to 15% palm kernel meal or palm kernel expellers in diets fed to weanling pigs from 2 weeks post weaning.

Full Fat Rice Bran and Defatted Rice Bran

The global production of rice (*Oriza sativa*) exceeds 700 million metric tons per year and is the most produced cereal grain in the world after corn and wheat (FAOSTAT, 2012). Rice is produced primarily for human consumption and is the main carbohydrate source in human diets in many countries in the world. The largest rice producing countries are China and India followed by Indonesia, Vietnam, and Thailand (FAOSTAT, 2012). Annual production of rice in the United States is around 9 million metric tons, but the United States is 5th largest exporter of rice after Thailand, India, Vietnam, and Pakistan.

The main objective of producing rice is to produced polished white rice that is used for human consumption. However, paddy rice contains approximately 20% hulls that mainly consist of lignin and silica and therefore has very low nutritional value (Delcour and Hoseney, 2010). As a consequence, rice has to be de-hulled before consumption. Removal of the hulls results in production of brown rice that contains the bran layers, the germ, and the endosperm. Further processing is needed to remove the bran layers and endosperm and this results in production of rice bran, which may be used for animal feeding. After the bran has been removed, rice goes through several polishing steps before the final product, polished rice, is produced (Singh et al., 2013). On a quantitative basis, the rice bran is approximately 10% of the total weight of the paddy rice, which means that approximately 70 million metric tons of rice bran is produced annually and is available for animal feeding. There are other co-products produced from rice including brewers rice and rice mill feed, but these products are produced in much smaller quantities.

Rice bran includes the pericarp, the aleurone, and the subaleurone layers of rice, but depending on the type of milling, fractions of the endosperm may make up 20 to 25% of the bran product (Prakash and Ramaswamy, 1996). Rice bran, therefore, may contain up to 30% starch (Sauvant et al., 2004; NRC, 2012). The concentration of ether extract in rice bran is between 14 and 24% depending on the variety of rice that was grown and the type of milling used (Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012). However, because of the high concentration of lipase in rice bran, the fat may quickly oxidize and may become rancid (McCaskill and Orthoefer, 1994; Prakash and Ramaswamy, 1996). As a consequence, rice bran needs to be stabilized by use of heat treatment such as extrusion to deactivate the lipase and thus reduce the risk of oxidation (Hargrove, 1994). Alternatively, the fat may be removed from the rice bran using solvent extraction to produce defatted rice bran with a concentration of fat of 2 to 4%. Therefore, both full fat rice bran and defatted rice bran are available for animal feeding.

Full fat rice bran contains 20 to 30% NDF and the concentration of crude protein is approximately 15% (Sauvant et al., 2004; Kaufman et al., 2005; NRC, 2012). Values for DE in full fat rice bran have been reported between 3,000 and 3,100 kcal per kg and values for ME are approximately 100 kcal less than the DE values (Table 5; Sauvant et al., 2004; NRC, 2012). Concentrations of NDF and crude protein in defatted rice bran are 10 to 15% greater than in full fat rice bran because removal of the fat concentrates other nutrients in the bran. However, DE and ME values in defatted rice bran are much less than in full fat rice bran and values between 2,100 and 2,200 kcal per kg have been reported (Sauvant et al., 2004; NRC, 2012).

The concentration of phosphorus is greater in rice bran than in most other plant ingredients and values between 1.6 and 2.20% have been reported (Sauvant et al., 2004; NRC, 2012; Abelilla, 2014; Casas and Stein, 2015). However, 70 to 90% of the phosphorus is bound in phytate, and the digestibility of phosphorus in rice bran, therefore, is relatively low (Table 5; Abelilla, 2014; Casas and Stein, 2015). However, addition of microbial phytase will increase the digestibility of phosphorus.

The biological value of rice protein is high and the standardized ileal digestibility of most amino acids in polished rice is greater than that in most other cereal grains except wheat (Cervantes-Pahm et al., 2014). The protein in rice bran also has a relatively high concentration of Lys, Met, Trp, and Thr (Table 6). However, the standardized ileal digestibility of amino acids in both full fat and defatted rice bran is considerably less than in polished rice and for most indispensable amino acids, values between 70 and 85% have been reported (Table 6; Kaufman et al., 2005; NRC, 2012; Casas et al., 2015).

There are relatively few reports on effects of including rice bran in diets fed to weanling, growing, or finishing pigs. However, inclusion of 10% rice bran in diets fed to weanling pigs improved feed conversion rate because of increased colonic concentrations of bifidobacteria (Herfel et al., 2013), but it is not known what the maximum inclusion rate is. For growing and finishing pigs, reduced growth performance has been reported for inclusion of 30% full fat rice bran (Campos et al., 2006). Inclusion of 10% full fat rice bran in diets fed to growing pigs had no influence on the growth performance compared with pigs fed a corn-soybean meal control diet (Abelilla, 2014). In finishing diets, inclusion of 20% full fat rice bran improved performance compared with pigs fed defatted rice bran (Chae and Lee, 2002), and it has been suggested that the maximum inclusion rate of defatted rice bran in diets fed to growing-finishing pigs is 20% (Warren and Ferkel, 1990).

Novel and Non-traditional Protein Sources

Duckweed

Duckweeds (*Lemna spp.*) are small free floating aquatic plants that are grown on open waters worldwide (Archimede et al., 2011; Radic et al., 2011). They are of the botanical family *Lemnaceae* (Archimede et al., 2011) and contain 35-40% CP (Olorunfemi et al., 2006; Hasan and Chakrabarti, 2009). If plants are harvested and dehydrated, the resulting dehydrated Lemna plant may be included in diets fed to poultry and fish (Haustein et al., 1994; Bairagi et al., 2002). However the protein may also be extracted to produce a Lemna protein concentrate, which contains approximately 68% CP. The concentration of most indispensable AA in Lemna protein concentrate is greater than in soybean meal, but the concentration of phosphorus is less (Rojas et al., 2014). When fed to pigs, Lemna protein concentrate has a digestibility of AA that is close to that of soybean meal, whereas the digestibility of phosphorus in Lemna protein concentrate is greater than in soybean meal and the concentration of DE and ME in Lemna protein concentrate is similar to that in soybean meal (Rojas et al., 2014).

The plant tissue that is left after protein has been extracted is a high fiber product that has a composition that is similar to that of alfalfa meal. This ingredient is called Lemna meal and is mainly used in feeding of dairy cows. It is, however, likely that Leman meal also may be used in the feeding of gestating sows. However, for both Lemna protein concentrate and Lemna meal, experiments to evaluate effects of including these ingredients in diets fed to pigs are needed.

Microalgae

The annual global production of microalgae was recently estimated at approximately 10,000 metric ton dry matter (Becker, 2007). However, because some species of microalgae contains more than 20% crude fat, the interest in producing microalgae and use the oil in biodiesel production is increasing and it is, therefore, expected that the production of microalgae will increase in the future. There are more than 30,000 different species of microalgae and only a few hundred have been characterized in terms of chemical composition (Christaki et al., 2011). It has, however, been demonstrated that the concentration of nutrients vary significantly among different species, but the concentration of CP in many species is greater than 50% (dry matter basis). The AA composition of microalgae protein is similar to that in soybean protein (Christaki et al., 2011; Skrede et al., 2011). The digestibility of AA has not been determined when fed to pigs, but it has been demonstrated that when fed to mink, the digestibility of AA in microalgae is less than that of soybean meal and also variable among species (Skrede et al., 2011). The lipids in microalgae have a high concentration of polyunsaturated omega-3 fatty acids, which may contribute to improved animal health (Christaki et al., 2011). The concentration of ash is relatively high (up to 15%), but the concentration or digestibility of phosphorus has not been reported. Likewise, there are no reports on the concentration of DE and ME in microalgae fed to pigs. It has, however, been reported that inclusion of 2% microalgae in diets fed to weanling pigs has no negative effects on pig growth performance (Grinstead et al., 2000), and inclusion of microalgae in diets fed to finishing pigs may increase the concentration of long-chained polyunsaturated fatty acids in pork (Marriot et al., 2002; Sardi et al., 2006).

Single Cell Protein

Single cell protein may be produced by bacteria that utilize mainly methanol or methane as substrate. The protein has a concentration of CP between 40 and 70% and a relatively high concentration of indispensable AA. However, up to 19% of the protein may be in the form of nucleic acids, which limits the utilization of the protein in nutrition, but pigs do not seem to be negatively affected by the relatively high concentrations of nucleotides (Øverland et al., 2010). It is also possible to reduce the concentration of nucleotides in the protein by separating fractions with the greatest nucleotide content after production. The digestibility of AA in single cell protein is slightly less than in soybean meal and fish meal (Skrede et al., 1998).

The concentration of P in single cell protein is between 1 and 2% and the digestibility is greater than 75% (Kim et al., 2014). The concentration of gross energy in single cell protein is greater than in corn and soybean meal because of the greater concentration of ether extract in the meal. However, the digestibility of energy in single cell protein is less than in soybean meal and the concentration of DE and ME in single cell protein is not different from the concentration in soybean meal (Helwing et al., 2007; Kim et al., 2014).

There is a lack of information about the quantities of single cell protein that can be used in diets fed to pigs, but it is likely that single cell protein will mainly be used in diets fed to weanling pigs as a substitute for fish meal. However, production experiments to verify that single cell protein may replace fish meal are needed to fully evaluate this ingredient.

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APPENDICES

Table 1. Energy and nutrient composition and physical characteristics of copra and palm kernel ingredients (as-fed basis)[1]

	Ingredients				
Item	Copra Meal	Copra Expellers	Palm kernel Expellers	Palm kernel Meal	Soybean Meal
DM, %	92.90	89.90	91.90	91.90	90.00
Bulk density, g/L	502.40	-	634.10	401.00	-
Water binding capacity, g/g	4.18	-	1.83	2.17	-
GE, kcal/kg	4,445	4,308	4,482	4,250	4,256
DE, kcal/kg	3,430	3,785	2,892	2,669	3,619
ME, kcal/kg	3,248	3,617	2,786	2,542	3,294
CP, %	22.00	20.20	14.30	13.60	47.73
AEE, %	1.90	7.10	6.90	1.30	2.86
NDF, %	54.80	54.40	70.60	77.90	8.21
ADF, %	26.90	29.60	43.00	49.40	5.28
Insoluble dietary fiber, %	41.40	-	60.90	68.70	16.70
Soluble dietary fiber, %	5.50	-	2.60	2.20	-
Total dietary fiber, %	46.90	-	63.50	70.90	-

[1]Data from NRC (2012), Sulabo et al. (2013), Jaworski et al. (2014) and Son et al. (2014).

Table 2. Concentrations of calcium, phosphorus and phytate, and apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of phosphorus in copra and palm kernel ingredients (as-fed basis)[1]

Item	Ingredients				
	Copra Meal	Copra Expellers	Palm kernel Expellers	Palm kernel Meal	Soybean Meal
Ca, %	0.04	0.11	0.20	0.25	0.26
P, %	0.52	0.53	0.54	0.52	0.67
Phytate, %	0.79	0.78	1.12	1.29	1.55
Phytate P, %	0.22	0.22	0.32	0.35	0.44
Non-phytate P, %	0.30	0.31	0.22	0.16	0.23
P digestibility without phytase					
ATTD, %	60.80	46.00	48.90	30.00	41.10
STTD, %	70.60	56.50	57.90	39.80	49.60
P digestibility with phytase					
ATTD, %	80.80	-	64.10	58.20	72.20
STTD, %	90.30	-	73.50	68.10	81.10

[1]Data from NRC (2012), Son et al. (2013), and Almaguer et al. (2014).

Table 3. Amino acid composition in copra and palm kernel ingredients(as-fed basis)[1]

Item	Copra Meal		Copra Expellers		Palm Kernel Meal		Palm Kernel Expellers		Soybean Meal	
	%	% of CP	%	% of CP	%	% of CP	%	% of CP	%	% of CP
Crude Protein	22.00	-	20.20	-	13.60	-	14.30	-	47.70	-
Indispensable AA										
Arg	2.08	9.45	1.70	8.42	1.36	10.00	1.52	10.63	3.45	7.23
His	0.35	1.59	0.29	1.44	0.17	1.25	0.20	1.40	1.28	2.68
Ile	0.66	3.00	0.06	0.30	0.41	3.01	0.47	3.29	2.14	4.48
Leu	1.20	5.45	0.19	5.89	0.71	5.22	0.82	5.73	3.62	7.58
Lys	0.42	1.91	0.39	1.93	0.36	2.65	0.36	2.52	2.96	6.20
Met	0.27	1.23	0.24	1.19	0.22	1.62	0.25	1.75	0.66	1.38
Phe	0.79	3.59	0.79	3.91	0.47	3.46	0.53	3.71	2.40	5.03
Thr	0.55	2.50	0.57	2.82	0.33	2.43	0.37	2.59	1.86	3.90
Trp	0.15	0.68	0.15	0.74	0.05	0.37	0.12	0.84	0.66	1.38
Val	0.97	4.41	0.91	4.50	0.57	4.19	0.65	4.55	2.23	4.67
Total	7.44	33.82	6.29	31.14	4.65	34.19	5.29	39.99	21.26	44.54
Dispensable AA										
Ala	0.85	3.86	0.79	3.91	0.46	3.38	0.53	3.71	2.06	4.32
Asp	1.50	6.82	1.49	7.38	0.89	6.54	0.99	6.92	5.41	11.33
Cys	0.28	1.27	0.26	1.29	0.17	1.25	0.17	1.19	0.70	1.47
Glu	3.34	15.18	3.43	16.98	2.02	14.85	2.29	16.01	8.54	17.89
Gly	0.82	3.73	0.82	4.06	0.53	3.90	0.58	4.06	1.99	4.17
Pro	0.60	2.73	0.63	3.12	0.36	2.65	0.40	2.80	2.53	5.30
Ser	0.71	3.23	0.77	3.81	0.44	3.24	0.50	3.50	2.36	4.94
Tyr	0.41	1.86	0.54	2.67	0.29	2.13	0.29	2.03	1.59	3.33
Total	8.51	38.86	8.73	43.22	5.16	37.94	5.75	40.21	25.18	52.76
All AA										
Arg:Lys, %	4.95	-	4.36	-	3.78	-	4.22	-	1.17	-

[1]Data from NRC (2012), Sulabo et al. (2013), and Son et al. (2014).

Table 4. Standardized ileal digestibility (%) of amino acids in copra and palm kernel products and in soybean meal[1]

Item	Copra Meal	Copra Expellers	Palm Kernel Meal	Palm Kernel Expellers	Soybean Meal
Crude Protein	79.90	67.60	71.30	81.80	87.00
Indispensable AA					
Arg	91.20	90.00	88.30	90.40	94.00
His	82.50	73.20	80.80	83.60	90.00
Ile	81.60	76.70	80.40	83.50	89.00
Leu	81.60	78.50	79.70	82.40	88.00
Lys	72.80	40.30	71.10	76.50	89.00
Met	85.50	82.10	82.20	85.00	90.00
Phe	84.50	81.40	82.20	84.60	88.00
Thr	76.70	64.40	73.90	77.20	85.00
Trp	88.40	66.30	87.50	89.40	91.00
Val	79.00	77.80	77.20	81.00	87.00
Mean	82.60	73.07	80.30	83.40	89.10
Dispensable AA					
Ala	78.20	79.00	72.50	79.00	85.00
Asp	78.90	66.50	75.80	77.50	87.00
Cys	68.00	53.10	71.70	76.40	84.00
Glu	79.90	67.30	81.20	82.00	89.00
Gly	76.20	60.60	65.10	77.90	84.00
Pro	128.80	125.00	54.90	121.50	113.00
Ser	82.00	70.50	80.00	83.70	89.00
Tyr	82.80	58.00	80.10	82.70	88.00
Mean	83.70	72.50	75.20	83.70	89.90
Mean all AA	83.20	72.80	77.60	83.50	89.50

[1]Data from NRC (2012), Sulabo et al. (2013), and Son et al. (2014).

Table 5. Energy and nutrient composition of full fat rice bran and defatted rice bran (as-fed basis)[1]

Item	Ingredient	
	Full fat rice bran	Defatted rice bran
DM, %	91.60	91.35
Ash, %	14.80	11.51
GE, kcal/kg	4,772	4,056
DE, kcal/kg	3,100	2,199
ME, kcal/kg	2,997	2,081
CP, %	15.11	17.30
AEE, %	13.77	3.52
Starch	27.00	26.25
NDF, %	26.28	23.56
ADF, %	11.87	11.31
Calcium, %	0.22	0.10
Phosphorus, %	2.16	1.89
Phytate-P	1.74	1.61
Non-phytate P	0.42	0.28
ATTD2 of P without phytase	24.00	12.00
ATTD of P with phytase	62.00	-
STTD3 of P witout phytase	36.50	28.00
STTD of P with phytase	64.00	-

[1]Data from Sauvant et al., (2004), NRC (2012), and Abelilla et al. (2014).
[2]ATTD = apparent total tract digestibility.
[3]STTD = standardized total tract digestibility.

Table 6. Amino acid composition and standardized ileal digestibility (SID) of AA in full fat rice bran and defatted rice bran[1]

Item	Full fat rice bran			Defatted rice bran		
	%	% of CP	SID, %	%	% of CP	SID, %
CP	15.11	-	-	17.3	-	-
Indispensable AA						
Arg	1.24	8.21	89.00	1.57	9.08	83.00
His	0.42	2.78	87.00	0.55	3.18	75.00
Ile	0.51	3.38	69.00	0.62	3.58	75.00
Leu	1.04	6.88	70.00	1.25	7.23	75.00
Lys	0.67	4.43	78.00	0.80	4.62	70.00
Met	0.30	1.99	77.00	0.36	2.08	78.00
Phe	0.65	4.30	73.00	0.78	4.51	74.00
Thr	0.56	3.71	71.00	0.68	3.93	69.00
Trp	0.19	1.26	73.00	0.25	1.45	76.00
Val	0.78	5.16	69.00	0.94	5.43	73.00
Total	6.36	42.09	-	7.80	45.09	-

[1]Data from NRC (2012)