Published online June 22, 2017

Concentrations of minerals in pig feed ingredients commonly used in China[1]

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ABSTRACT: Mineral concentrations were determined in 13 different feed ingredients commonly used in swine diets. Ingredients included corn and 4 corn co-products: corn gluten feed, corn gluten meal, corn germ meal, and corn distillers dried grains with solubles (DDGS). Wheat, wheat bran, and wheat shorts were also included, and 5 oilseed meals including soybean meal, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal were used as well. Corn grain contained 88.7% dry matter (DM) and 0.46% K (DM basis). Greater concentrations of DM, ash, Ca, P, nonphytate P, Cu, Fe, Mn, and Zn were observed in corn gluten feed, corn DDGS, and corn germ meal compared with corn grain ($P < 0.05$). In general, minerals in corn DDGS were approximately three times greater than in corn grain and about 90% of the total P in corn DDGS was in the nonphytate bound form. Corn gluten meal had the least concentrations ($P < 0.05$) of most minerals, but the greatest ($P < 0.05$) concentrations of Fe (373.55 mg/kg, DM basis), Cu (11.88 mg/kg, DM basis), and Se (0.92 mg/kg, DM basis). On a DM-basis, concentrations of DM, Ca, P, phytate bound P, and Fe in wheat grain were 88.2%, 0.10%, 0.34%, 0.16%, and 53.48 mg/kg, respectively. Wheat bran contained more ($P < 0.05$) K, Mg, Cl, Fe, Zn, and Mn compared with wheat and wheat shorts. On a DM-basis, 2.72% K was observed in soybean meal, which was more ($P < 0.05$) than in the other oilseed meals. However, rapeseed meal had the greatest ($P < 0.05$) concentration of ash (9.37%), Ca (1.01%), P (1.05%), and Fe (526.49 mg/kg) among the oilseed meals, but only 16.2% of the total P in rapeseed meal was non-phytate P. In contrast, more than 50% of the P in soybean meal and peanut meal was non-phytate P. The least ($P < 0.05$) concentration of Cu (6.73 mg/kg, DM basis) was observed in rapeseed meal and the greatest ($P < 0.05$) concentration (32.75 mg/kg) was analyzed in sunflower meal. Concentrations of most minerals in soybean meal, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal varied considerably compared with published values. In conclusion, the concentration of minerals in 13 commonly used feed ingredients were analyzed and results indicated considerable variation among and within feed ingredients for most minerals, which for some minerals may be a result of differences in minerals in the soil in which the ingredients were grown, but processing likely also contributes to differences among ingredients.

Key words: corn, corn co-products, minerals, oilseed meals, wheat, wheat co-products

Transl. Anim. Sci. 2017.1:126–136
doi:10.2527/tas2017.0013

INTRODUCTION

Minerals are inorganic elements that are essential for growth and performance in pigs, although most are required in relatively small quantities (NRC, 2012). Determination of accurate mineral concentration of feed ingredients is important because incorrect assumptions about mineral composition in feed ingredients may result in under-supplementation of minerals causing deficiencies, poor growth, and production losses (Liesegang et al., 2002). In contrast, if minerals are added in excess of the requirement, toxicities, poor growth performance, increased excretion, and possibly increased pollution of the environment may be the consequences (NRC, 2005).

[1]The current work was supported by Special Fund for Agro-scientific Research in the Public Interest (grant number 201303079). The authors want to thank anhong Liu for her help with data analysis.

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Received January 10, 2017.
Accepted February 26, 2017.

China is the largest producer of pigs and pig feed in the world, but there are no central feed composition tables available for Chinese feed ingredients. Instead, values from the U.S. or Europe are used in diet formulations in China. Many factors including climate, soil conditions, plant variety, and processing may influence nutrient composition of a feed ingredient (Engström and Lindén, 2009; Zhang et al., 2010; Radulov et al., 2012; Pedersen et al., 2014). In particular, concentrations of minerals in feed ingredients are influenced by the soil in which plants are grown and may also be influenced by plant variety and processing method (Mahan et al., 2005; Zhang et al., 2010; Kraler et al., 2014). It is, therefore, possible that feed ingredients that are grown and (or) processed in China have a different mineral composition than ingredients used in other parts of the world. If that is the case, then diets may be incorrectly formulated if U.S. or European feed ingredient tables are used in Chinese production systems. As a consequence, there is a need for determining mineral concentration of feed ingredients produced in China. Therefore, the objective of this work was to determine the mineral concentration of 13 commonly used feed ingredients that were grown and (or) processed in China.

MATERIALS AND METHODS

Feed Ingredients

Thirteen feed ingredients commonly used in China were analyzed. Ingredients included corn and 4 corn co-products: corn gluten feed, corn gluten meal, corn germ meal, and corn distillers dried grains with solubles (DDGS). Wheat, wheat bran, and wheat shorts were also included, and 5 oilseed meals including soybean meal, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal were used as well.

Corn gluten feed is a co-product from the corn wet milling industry and is a combination of corn bran, screenings, distiller solubles, and other residual after the separation of corn starch (Rausch and Belyea, 2006; Almeida et al., 2011; Anderson et al., 2012; Rojas et al., 2013; Wang et al., 2014). Corn gluten meal is a high-protein ingredient that is produced by separating protein and starch after centrifugation of the bran-free part of corn in the wet milling process (Almeida et al., 2011; Anderson et al., 2012; Ji et al., 2012; NRC, 2012; Rojas et al., 2013). Corn germ meal is another co-product from the corn wet milling process where corn is cleaned and steeped and oil is extracted from the germ, resulting in production of corn germ meal (Rojas et al., 2013). Corn DDGS is produced after fermentation of corn to produce ethanol from the starch, and consists of the resulting wet distillers grain as well as at least 75% of the solubles from the whole stillage, which are dried to produce DDGS (Pahm et al., 2009; Almeida and Stein, 2012; Anderson et al., 2012; Rojas et al., 2013). Wheat bran and wheat shorts are produced from commercial milling of wheat. Wheat bran is the coarse outer covering of the wheat kernel, which is separated from cleaned and scoured wheat (Wilfart et al., 2007; AAFCO, 2011). Wheat shorts consists of fine particles of wheat bran, wheat germ, wheat flour, and tailings, and contains less than 7% crude fiber (AAFCO, 2011) and 5 to 20% CP (Huang et al., 1999).

Soybean meal is the product obtained by grinding the soybean grain residual after removal of most of the oil from soybeans by solvent extraction and contains less than 7.0% crude fiber (AAFCO, 2011). Rapeseed meal is produced after the mechanically pressed rapeseed expellers have been solvent extracted to remove the majority of the residual oil. Cottonseed meal contains 34 to 54% CP and is produced after the oil has been removed from cotton seed via solvent extraction (Li et al., 2012). The AA composition of cottonseed meal is less favorable and AA have a lower digestibility compared with soybean meal (Knabe et al., 1989; Cromwell, 1998; González-Vega and Stein, 2012), but cottonseed meal is sometimes used as an alternative protein source in diets for pigs because the cost is usually less compared with soybean meal. Sunflower meal is produced after oil has been solvent extracted from sunflower seeds. Sunflower meal has a high concentration of fiber, but is sometimes used in swine diets (Chiba, 2013; González-Vega and Stein, 2012). Peanut meal is the ground product of the shelled and de-oiled peanuts, composed primarily of the kernels and a portion of the hulls of peanuts and the concentration of crude fiber is less than 7% (Li et al., 2014a).

Samples of corn and wheat were collected directly from producers' fields in different regions of China. The 10 yellow dent corn samples included the following varieties: Xianyu 335, Xianyu 696, Xianyu 32D22, Wugu 702, Zhengdan 958, Changcheng 799, Lihe 16, Suiyu 7, and Demeiya. These samples were collected in Hebei, Shandong, Jilin, Henan, and Heilongjiang provinces in China with 2 samples collected in each province.

Twenty different samples of wheat were collected from the main wheat producing provinces including Shandong, Shanxi, Henan, Liaoning, and Hebei provinces with 4 samples collected in each province. The varieties of wheat included Longmai 30, Lumai 21, Yannong 24, Lumai 15, Beimai 4, Jimai 22, Kehan 16, Taishan 22, Longmai 26, and Kenjiu 10.

Ten samples of each of the 5 oilseed meals were collected from commercial feed mills. Likewise, 10 source of corn gluten meal and corn DDGS and 11 sources of corn gluten feed and corn germ meal and 10 sources of each wheat co-product were collected

Table 1. Origin of ingredients used in this research

Ingredient	Hebei	Henan	Shandong	Shanxi	Jilin	Liaoning	Xinjiang	Sichuan	Hubei	Gansu	Heilongjiang	Hunan	Total
Corn	2[1]	2	2	–	2	–	–	–	–	–	2	–	10
Corn gluten feed	2	2	2	2	2	1	–	–	–	–	–	–	11
Corn gluten meal	9	–	–	–	1	–	–	–	–	–	–	–	10
Corn germ meal	–	1	2	2	2	2	–	–	–	–	2	–	11
Corn DDGS[2]	–	5	–	–	5	–	–	–	–	–	–	–	10
Wheat	4	4	4	4	–	4	–	–	–	–	–	–	20
Wheat bran	–	2	3	–	–	3	–	–	–	2	–	–	10
Wheat shorts	2	1	–	2	–	2	1	1	1	1	–	–	11
Soybean meal	2	2	2	2	1	–	1	–	–	–	–	–	10
Rapeseed meal	–	–	–	–	–	–	–	–	5	–	–	5	10
Sunflower meal	3	–	–	1	–	3	3	–	–	–	–	–	10
Cottonseed meal	1	1	1	1	–	1	3	1	1	–	–	–	10
Peanut meal	3	3	4	–	–	–	–	–	–	–	–	–	10

[1]Number of ingredients acquired from a province.

[2]DDGS = distillers dried grains with solubles.

from commercial feed mills. The origins of the corn, wheat and the co-products from corn and wheat, and the oilseed meals are indicated in Table 1. All samples were stored at –20°C after collection.

Chemical Analysis

Analyses for minerals in all samples were conducted at the Ministry of Agriculture Feed Potency and Safety Supervision and Testing Center located at the Ministry of Agriculture Feed Industry Centre, Beijing, China.

All ingredients were analyzed for dry matter (DM; method 934.01), ash (method 942.05), Ca and P (method 985.01) according to the procedures of the AOAC (2005). Chlorine was analyzed by using the method (method 943.01) described in AOAC (2000). Phytate concentration in the ingredients was determined by using the method described by Akinmusire and Adeola (2009). The concentration of phytate-bound P in ingredients was calculated as 28.2% of analyzed phytate (Tran and Sauvant, 2004). Selenium in ingredients was analyzed using an inductively coupled plasma–mass spectrometer (ICP–MS) described by Bou et al. (2004). Samples were analyzed for I using the method described by Sullivan and Zywicki (2012). Potassium, Na, Mg, Fe, Zn, Cu, and Mn were determined using an inductively coupled plasma–mass spectrometer (Agilent 7500 series, Santa Clara, CA) as described by Duan et al. (2013).

Calculations and Statistical Analysis

The concentration of phytate bound P in samples was calculated as 28.2% of analyzed phytate (Tran and Sauvant, 2004). Nonphytate bound P was calculated as the difference between total P and phytate bound P. The minimum, maximum, and the average value of each mineral was calculated. The standard deviation (SD) of the concentration of each mineral in ingredients was also calculated.

Data were analyzed within 3 groups: corn and corn co-products, wheat and wheat co-products, and oilseed meals. For each group, data were analyzed using the PROC Mixed of SAS (SAS Inst. Inc., Cary, NC) with a completely randomized design. The model included ingredient as fixed effect and the source of each ingredient as the experimental unit. The Least Significant Difference Test was used to separate means. An α level of 0.05 was used to assess significance among means and P-values between 0.05 and 0.10 were considered a trend.

RESULTS AND DISCUSSION

Corn and Corn Co-products

Corn is the most commonly used cereal grains in swine diets due to its high nutritional value (Sauber and Owens, 2001; Gwirtz and Garcia-Casal, 2014). Ground corn may be fed directly to pigs, but corn may also be processed industrially using wet milling, dry milling, or dry grinding technologies (NRC, 2012; Gwirtz and Garcia-Casal, 2014). The primary objectives of the processing is to produce corn starch, corn syrup, corn oil, corn flour, ethanol, etc., but these processes also result in production of a number of co-products that may be used in animal feeding (Serna-Saldivar, 2010; NRC, 2012). Corn gluten feed, corn gluten meal, corn germ meal, and DDGS are the main co-products that are generated during corn processing.

The concentration of ash in Chinese corn is relatively low (Table 2) and this observation is in agreement with observations from other countries (Sauvant et al., 2004; CVB, 2007; NRC, 2012). However, as corn

Table 2. Mineral composition of 10 sources of corn, 11sources of corn gluten feed, 10 sources of corn gluten meal, 11 sources of corn germ meal, and 10 sources of corn distillers dried grains with solubles (DDGS), dry matter (DM) basis

	DM[1]	Ash	Ca	P	Phy-P	NPhy-P[2]	K	Mg	Na	Cl	Co	Cu	Fe	I	Mn	Se	Zn
Item	%	%	%	%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Corn																	
Avg	88.7^{c3}	1.29^{d}	0.03^{c}	0.21^{c}	0.14^{bc}	0.07^{b}	0.46^{b}	0.12^{c}	ND[4]	0.05^{c}	ND	2.02^{d}	34.84^{c}	ND	5.74^{c}	0.04^{c}	20.03^{c}
SD	0.90	0.10	0.02	0.05	0.03	0.02	0.05	0.01	ND	0.01	ND	0.20	8.64	ND	0.67	0.04	3.02
Min	87.5	1.17	0.01	0.15	0.10	0.04	0.38	0.10	ND	0.04	ND	1.73	22.87	ND	4.95	0.01	15.54
Max	90.5	1.43	0.06	0.29	0.19	0.10	0.54	0.14	ND	0.08	ND	2.26	46.63	ND	7.02	0.15	24.97
Corn gluten feed																	
Avg	91.9^{a}	6.64^{a}	0.25^{a}	0.86^{a}	0.38^{a}	0.48^{a}	1.68^{a}	0.45^{a}	0.03	0.30^{a}	0.38	4.65^{c}	163.37^{b}	ND	24.87^{a}	0.05^{a}	68.93^{ab}
SD	1.37	2.05	0.14	0.20	0.15	0.14	0.60	0.11	0.02	0.13	0.12	1.03	54.50	ND	7.27	0.02	11.97
Min	89.7	3.72	0.10	0.51	0.13	0.31	0.34	0.25	0.01	0.11	0.26	3.35	69.86	ND	17.00	0.02	55.90
Max	94.7	10.04	0.62	1.18	0.58	0.72	2.51	0.61	0.06	0.57	0.61	6.78	259.02	ND	36.17	0.08	100.16
Corn gluten meal																	
Avg	91.6^{a}	1.76^{d}	0.02^{c}	0.12^{c}	0.07^{c}	0.05^{b}	0.07^{c}	0.03^{c}	0.01	0.14^{b}	0.03	11.88^{a}	373.55^{a}	ND	4.66^{c}	0.92^{c}	12.70^{c}
SD	1.45	0.37	0.03	0.04	0.03	0.02	0.04	0.02	0.00	0.09	0.02	1.63	107.01	ND	1.43	0.38	4.08
Min	88.9	1.05	0.01	0.05	0.03	0.01	0.03	0.01	0.01	0.02	0.01	8.32	238.81	ND	2.88	0.68	9.05
Max	93.5	2.23	0.09	0.18	0.13	0.08	0.14	0.07	0.02	0.24	0.06	13.59	564.19	ND	6.85	1.95	19.43
Corn germ meal																	
Avg	90.9^{ab}	3.11^{c}	0.17^{b}	0.62^{b}	0.22^{b}	0.40^{a}	0.63^{b}	0.32^{b}	0.04	0.09^{bc}	ND	5.71^{c}	176.88^{b}	ND	14.88^{b}	0.04^{c}	52.96^{b}
SD	1.48	0.95	0.11	0.46	0.12	0.36	0.50	0.27	0.03	0.06	ND	1.06	80.75	ND	10.15	0.01	25.87
Min	88.85	2.11	0.06	0.36	0.09	0.11	0.17	0.06	0.01	0.03	ND	3.94	108.55	ND	4.77	0.02	26.23
Max	93.31	5.01	0.43	1.87	0.52	1.34	1.85	0.86	0.08	0.20	ND	7.45	322.47	ND	37.03	0.05	113.19
Corn DDGS																	
Avg	90.4^{b}	5.32^{b}	0.12^{b}	0.59^{b}	0.08^{c}	0.53^{a}	1.55^{a}	0.38^{ab}	0.13	0.30^{a}	0.18	9.69^{b}	208.98^{b}	0.39	17.85^{b}	0.42^{b}	83.64^{a}
SD	1.34	0.64	0.05	0.18	0.06	0.20	0.24	0.04	0.10	0.05	0.09	2.49	182.95	0.41	5.92	0.31	40.82
Min	88.8	4.10	0.04	0.28	0.03	0.17	1.15	0.29	0.05	0.22	0.06	5.68	10.79	0.15	9.58	0.08	47.48
Max	92.5	6.53	0.21	0.84	0.21	0.79	1.98	0.44	0.35	0.38	0.28	14.4	448.31	0.86	29.31	0.95	190.54
SEM[5]	0.41	0.34	0.03	0.08	0.03	0.06	0.12	0.04	0.01	0.03	-[6]	0.45	33.01	–	1.96	0.07	6.96
P-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	–	< 0.01	< 0.01	–	< 0.01	< 0.01	< 0.01

[a–d]Averages (Avg) with different superscripts within the same column differ ($P < 0.05$).

[1]DM = dry matter.

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

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

[4]ND, not detectable.

[5]SEM = pooled standard error of the mean.

[6]Not compared because mineral was not detectable in some ingredients.

is processed and starch and other nutrients are removed, the concentration of ash is concentrated in the co-products, which is the reason for the increased concentration of ash in corn gluten feed, DDGS, and corn germ. In contrast, the concentration of ash in corn gluten meal was not different from the concentration in corn indicating that some of the ash was removed along with removal of gluten and fat from the corn. The concentration of ash was greater ($P < 0.05$) in corn gluten feed than in all other co-products indicating that some of the product streams that are included in corn gluten feed may contain relatively large proportions of ash.

The concentration of Ca in corn grown in China is very low, which has also been reported in previous research with Chinese corn (Liu et al., 2013; Li et al., 2014b) and with corn from other countries (Sauvant et al., 2004; CVB, 2007; NRC, 2012). The concentrations of Ca in corn gluten feed and corn germ meal observed in this experiment were greater ($P < 0.05$) than in corn and also greater than reported by NRC (2012). This observation indicates that limestone or other Ca-rich compounds possibly are added during or after processing to produce corn gluten feed and corn germ meal in China. The concentration of Ca in corn gluten meal was also very low, whereas the greater ($P < 0.05$) concentration of Ca in corn DDGS compared with corn is in agreement with previous data (NRC, 2012; Li et al., 2015).

The concentration of P in the Chinese corn was less than reported by Sauvant et al. (2004) and NRC (2012), but in good agreement with values reported for other sources of Chinese corn (Liu et al., 2013). This may indicate that some areas of China have lower soil concentrations of P compared with corn-growing areas in other parts of the world. The concentrations of P in corn germ meal and corn DDGS observed in this study were greater ($P < 0.05$) than in corn, but also less than reported by NRC (2012). Corn gluten feed also contained more ($P < 0.05$) P than corn, but the value obtained in this experiment was close to values published by Sauvant et al. (2004) and NRC (2012). In contrast, the concentration of P in corn gluten meal observed in this study was not different from the concentration in corn, but much less than values reported by Sauvant et al. (2004) and NRC (2012). These observations indicate that production processes used in the corn wet milling industry in China may be different from the processes used in other parts of the world and that different product streams may be included in the ingredients called corn gluten feed and corn gluten meal.

In agreement with previous reports (Sauvant et al., 2004; NRC, 2012; Almeida and Stein, 2012; Rojas et al., 2013), the majority of the P in corn was bound to phytate. However, for all the corn co-products, the majority of the P was not phytate bound, which is likely a consequence of these co-products being produced from the wet milling industry or via fermentation because fermentation or steeping in water results in release of P from the phytate molecule (Carlson and Poulsen, 2003; Lyberg et al., 2006; Rojas and Stein, 2012; Rojas et al., 2013). The relatively low concentration of phytate-bound P in corn DDGS is in agreement with data from Almeida and Stein (2012) and Rojas et al. (2013) and illustrates that the fermentation process used to produce DDGS results in hydrolysis of the phytate molecule. In contrast, the low concentrations of phytate bound P in corn germ meal and in corn gluten meal that were observed in this experiment are in contrast to previous values (Sauvant et al., 2004; Rojas et al., 2013) and indicate that these ingredients may have been steeped at some point during processing.

All ingredients contained more K than any other mineral, and the concentrations of K and Mg in corn, corn gluten feed and corn DDGS were somewhat greater than previously published values (Sauvant et al., 2004; NRC, 2012). These observations may be a result of differences in soil concentrations of K and Mg among corn producing areas of the world. However, concentrations of K and Mg in corn gluten meal analyzed in this study were less than reported (Sauvant et al., 2004; NRC, 2012), which is likely a result of the low ash concentration in the corn gluten meals included in this study.

Sodium was not detectable in the corn used in this study, and concentrations were low in all the corn co-products. The concentration of Cl was also low in corn, corn gluten meal, and corn germ meal, but somewhat greater in corn gluten feed and corn DDGS. The values for both Na and Cl in all ingredients are in agreement with values reported by NRC (2012).

Values for Cu, Fe, Mn, and Zn in corn and corn DDGS observed in this experiment are in agreement with values published by Sauvant et al. (2004) and NRC (2012). There are very few published values for concentrations of micro minerals in corn gluten feed, corn gluten meal, and corn germ meal. As an example, the values published by NRC (2012) for Cu, Fe, Mn, and Zn are based on only one observation per ingredient. Thus, the current data based on analysis of 10 or 11 different sources of each of these ingredients provide a more robust database for these minerals than what has previously been available. The observation that the concentration of Fe is the most variable among the ingredients may have been caused by differences in the Fe concentration in the water used in the wet milling of corn, but differences in soil concentrations of Fe may also have contributed to these differences.

Iodine was not detected in any of the ingredients except in corn DDGS. To our knowledge, concentrations of I in corn and corn co-products have not previously been reported. However, the observation that I is present in corn DDGS, but not in the other ingredients is difficult to explain because we are not aware of any addition of I during processing that would explain the appearance of I in DDGS.

Large variations in the concentration of Se in corn has been described because of variations in soil Se concentrations (Mahan et al., 2005; 2014) and the concentration of Se in corn that was determined in this experiment is within the wide range of previously reported values (Mahan et al., 2014). A much greater concentration of Se in corn DDGS compared with corn grain has also been reported (Sauvant et al., 2004; NRC, 2012; Kim et al., 2014), and results of the present study is in agreement with these observations. Likewise, the observation that the concentration of Se in corn gluten meal was greater ($P < 0.05$) than in all other ingredients is in agreement with NRC (2012). However, the values for Se in corn gluten feed and corn germ meal observed in this experiment are less than reported by Sauvant et al. (2004).

Cobalt was not detected in corn or in corn germ meal, but concentrations in corn gluten feed, corn gluten meal, and corn DDGS were detectable. There are very few published data for the concentration of Co in corn and corn co-products, but the current values based on analysis of 10 or 11 different ingredients indicate that corn DDGS and corn gluten feed may provide some Co to the diets. This is, however, of limited value in the feeding of pigs, but when fed to ruminant animals, Co may be used in the synthesis of vitamin B_{12}.

Wheat and Wheat Co-products

On a DM basis, the concentration of ash (1.82%) in wheat was greater than the value reported by CVB (2007), but less compared with the value reported by NRC (2012; Table 3). Fan et al. (2008) reported that the concentrations of minerals in wheat grain have decreased over the last 160 yr, but the concentration of most minerals in wheat that were analyzed in this study were greater than reported book values, which may be due to the different origins of the wheat samples. Whereas all samples used in this study were from China, samples from many countries in the world are included in most other databases (Ficco et al., 2009; Zhang et al., 2010, NRC, 2012). Many other factors, including varieties, growing environment, and soil conditions also affect mineral compositions of wheat grain (Peterson et al., 1983; Anglani, 1998; Hawkesford and Zhao, 2007).

Wheat bran contained more ash (5.45%, DM basis) than reported by NRC (2012), but less compared with values reported by Sauvant et al. (2004) and CVB (2007). More Ca was observed in wheat, wheat bran, and wheat shorts compared with values reported by Ficco et al. (2009), Zhang et al. (2010), Sauvant et al. (2004), CVB (2007), and NRC (2012). Greater concentrations of DM, P, phytate bound P, Fe, but less Se, were also observed in wheat, wheat bran, and wheat shorts compared with previous values (Sauvant et al., 2004, CVB, 2007; NRC, 2012).

The wheat kernel mainly consists of bran, endosperm, and germ. Wheat bran is the outer layer of the grain and contains 50 to 80% of the minerals of the whole wheat grain, which is the primary reason for the greater ($P < 0.05$) concentrations of most minerals in wheat bran compared with wheat grain and wheat shorts (Underwood and Suttle, 1999; Suttle, 2010). Because most of the starch is removed in the milling process, nutrient densities including mineral concentration, in wheat shorts is generally greater than in wheat. However, wheat bran has greater ($P < 0.05$) concentrations of minerals than wheat shorts because of the higher amount of seed coat in wheat bran compared with wheat shorts.

Oilseed Meals

The concentration of DM in cottonseed meal was greater ($P < 0.05$) than in soybean meal (Table 4). No differences in DM concentrations were observed between rapeseed meal, cottonseed meal, sunflower meal, and peanut meal. Greater ($P < 0.05$) concentration of ash was observed in rapeseed meal than in soybean meal, but there were no differences in ash concentrations between soybean meal, cottonseed meal, peanut meal, and sunflower meal. The Ca concentration in sunflower meal was greater ($P < 0.05$) than in soybean meal, but less ($P < 0.05$) compared with rapeseed meal.

The DM, ash, Ca, P, K, Na, Mg, Mn, and Zn concentrations in soybean meal were within the range of values published previously (Sauvant et al., 2004; CVB, 2007; NRC, 2012), but there was less ($P < 0.05$) phytate bound P in soybean meal compared with the values reported by Sauvant et al. (2004) and NRC (2012). This indicates that the digestibility of P in the soybean meal analyzed in this work may be greater than suggested by Sauvant et al. (2004) and NRC (2012). Less Fe and Cu was also analyzed in soybean meal compared with the values reported by Sauvant et al. (2004), CVB (2007), and NRC (2012).

Rapeseed meal contained 1.01% Ca (DM-basis), which is the greatest ($P < 0.05$) among the 5 oilseed meals analyzed in this work. On a DM basis, rapeseed meal also contained more ($P < 0.05$) P (1.05%) than the other oilseed meals, but the concentration of non-phytate P (0.17%) was the least ($P < 0.05$) in rapeseed meal, which indicates that the P in rapeseed meal has a lower di-

Table 3. Mineral composition of 20 sources of wheat, 10 sources of wheat bran, and 10 sources of wheat shorts, dry matter (DM) basis

	DM[1]	Ash	Ca	P	Phy-P[2]	NPhy-P[3]	K	Mg	Na	Cl	Co	Cu	Fe	I	Mn	Se	Zn
Item	%	%	%	%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Wheat																	
Avg	88.2^{b}	1.82^{c}	0.10^{a}	0.34^{c}	0.16^{c}	0.18^{b}	0.50^{b}	0.18^{b}	ND[4]	0.05^{b}	ND	5.75^{c}	53.48^{b}	ND	44.99^{b}	0.04^{b}	33.15^{b}
SD	0.89	0.15	0.05	0.04	0.06	0.09	0.04	0.07	ND	0.01	ND	1.63	20.71	ND	11.38	0.01	9.14
Min	86.7	1.44	0.03	0.28	0.05	0.06	0.43	0.09	ND	0.01	ND	3.78	19.96	ND	30.55	0.02	21.08
Max	89.9	2.23	0.16	0.42	0.27	0.35	0.59	0.30	ND	0.07	ND	11.01	97.17	ND	72.76	0.05	65.13
Wheat bran																	
Avg	89.4^{a}	5.45^{a}	0.10^{a}	0.91^{a}	0.57^{a}	0.34^{a}	1.46^{a}	0.55^{a}	0.01	0.08^{a}	ND	13.66^{a}	137.20^{a}	ND	129.25^{a}	0.46^{a}	94.71^{a}
SD	0.74	0.50	0.02	0.20	0.10	0.18	0.15	0.08	0.00	0.03	ND	0.54	56.77	ND	23.41	0.27	12.21
Min	88.32	4.74	0.08	0.54	0.41	0.09	1.32	0.45	0.01	0.05	ND	12.82	54.68	ND	87.74	0.11	62.25
Max	90.50	6.49	0.14	1.16	0.72	0.65	1.85	0.75	0.03	0.16	ND	14.63	248.92	ND	154.12	1.03	106.51
Wheat shorts																	
Avg	88.2^{b}	2.53^{b}	0.06^{b}	0.44^{b}	0.24^{b}	0.20^{b}	0.51^{b}	0.15^{b}	0.02	0.05^{b}	ND	8.56^{b}	69.24^{b}	1.13	5.87^{c}	0.59^{a}	33.58^{b}
SD	0.67	0.96	0.02	0.16	0.12	0.19	0.18	0.06	0.01	0.01	ND	3.75	37.15	0.65	2.77	0.19	16.44
Min	87.03	1.34	0.03	0.26	0.01	0.05	0.22	0.05	0.01	0.04	ND	3.33	15.40	0.40	1.48	0.31	8.84
Max	89.30	3.97	0.10	0.72	0.42	0.63	0.79	0.24	0.03	0.06	ND	14.52	117.40	2.20	9.23	1.00	61.75
SEM[5]	0.33	0.15	0.01	0.04	0.03	0.04	0.03	0.02	-[6]	0.01	–	0.63	10.44	–	4.05	0.05	3.44
P-value	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01	–	< 0.01	–	< 0.01	< 0.01	–	< 0.01	< 0.01	< 0.01

[a–c]Averages (Avg) with different superscripts within the same column differ ($P < 0.05$).
[1]DM = dry matter.
[2]Phytate P, calculated as 28.2% of phytate (Tran and Sauvant, 2004).
[3]Nonphytate P, calculated as the difference between total P and phytate P.
[4]ND, not detectable.
[5]SEM = pooled standard error of the mean.
[6]Not compared because mineral was not detectable in some ingredients.

Table 4. Mineral composition of 10 sources of soybean meal, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal, DM basis

	DM[1]	Ash	Ca	P	Phy-P[2]	NPhy-P[3]	K	Mg	Na	Cl	Co	Cu	Fe	I	Mn	Se	Zn
Item	%	%	%	%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Soybean meal																	
Avg	88.8^{b}	7.05^{b}	0.30^{c}	0.69^{c}	0.21^{d}	0.49^{a}	2.72^{a}	0.35^{d}	0.04^{a}	ND[4]	0.52	16.48^{bc}	151.77^{c}	0.20	42.94^{c}	ND	54.55^{b}
SD	0.75	0.40	0.05	0.06	0.04	0.05	0.23	0.03	0.02	ND	0.18	2.85	80.69	0.06	5.22	ND	3.92
Min	87.5	6.63	0.22	0.55	0.15	0.38	2.25	0.32	0.02	ND	0.34	13.27	47.74	0.11	32.52	ND	47.66
Max	90.1	7.79	0.36	0.81	0.28	0.57	3.03	0.41	0.07	ND	1.01	22.41	319.72	0.29	52.17	ND	59.45
Rapeseed meal																	
Avg	89.8^{a}	9.37^{a}	1.01^{a}	1.05^{a}	0.88^{a}	0.17^{c}	1.78^{b}	0.62^{ab}	0.01^{bc}	0.13	ND	6.73^{d}	526.49^{a}	ND	75.28^{b}	0.59	81.23^{a}
SD	0.84	0.42	0.09	0.09	0.10	0.04	0.12	0.03	0.01	0.10	ND	0.32	243.88	ND	8.24	0.44	6.40
Min	88.7	8.70	0.89	0.90	0.70	0.12	1.47	0.55	0.01	0.05	ND	6.37	291.27	ND	64.40	0.16	63.93
Max	91.7	10.11	1.21	1.22	1.02	0.22	1.90	0.65	0.03	0.31	ND	7.27	998.64	ND	87.56	1.60	87.01
Sunflower meal																	
Avg	90.2^{a}	6.54^{b}	0.51^{b}	1.03^{a}	0.54^{b}	0.49^{a}	1.60^{cd}	0.61^{b}	0.01^{c}	0.10	0.36	32.75^{a}	310.23^{b}	ND	39.53^{c}	0.25	77.64^{a}
SD	1.21	0.85	0.08	0.19	0.14	0.04	0.10	0.10	0.00	0.02	0.13	5.53	64.74	ND	5.80	0.02	15.26
Min	89.0	4.64	0.32	0.59	0.20	0.39	1.36	0.35	0.01	0.08	0.25	19.09	239.68	ND	25.05	0.20	48.89
Max	92.8	7.40	0.59	1.21	0.68	0.54	1.72	0.67	0.01	0.12	0.66	37.6	428.02	ND	42.99	0.28	104.22
Cottonseed meal																	
Avg	90.4^{a}	7.09^{b}	0.34^{c}	0.71^{bc}	0.41^{c}	0.31^{b}	1.72^{bc}	0.70^{a}	0.02^{bc}	0.08	0.27	13.88^{c}	170.09^{c}	ND	128.22^{a}	0.78^{a}	51.88^{b}
SD	1.72	1.08	0.24	0.28	0.10	0.27	0.16	0.19	0.01	0.03	0.16	3.57	140.58	ND	59.54	0.16	14.05
Min	88.4	5.84	0.17	0.37	0.28	0.01	1.44	0.51	0.01	0.04	0.15	7.81	17.57	ND	17.00	0.51	35.13
Max	94.1	9.95	1.02	1.02	0.53	0.69	1.93	1.05	0.05	0.13	0.69	19.08	477.7	ND	175.14	1.03	77.14
Peanut meal																	
Avg	90.0^{a}	6.89^{b}	0.27^{c}	0.83^{b}	0.35^{c}	0.48^{a}	1.54^{d}	0.47^{c}	0.03^{ab}	ND	ND	18.77^{b}	381.14^{b}	ND	58.67^{bc}	0.10^{b}	72.56^{a}
SD	0.68	0.71	0.03	0.04	0.05	0.04	0.08	0.03	0.03	ND	ND	3.00	163.83	ND	15.18	0.04	7.02
Min	89.1	5.67	0.22	0.78	0.30	0.42	1.43	0.42	0.01	ND	ND	13.18	147.22	ND	39.52	0.07	56.92
Max	91.4	8.11	0.34	0.93	0.43	0.54	1.69	0.50	0.10	ND	ND	22.52	580.49	ND	91.27	0.20	78.74
SEM[5]	0.35	0.23	0.04	0.05	0.03	0.04	0.05	0.03	0.01	-[6]	–	1.09	47.5	–	8.66	–	3.21
P-value	< 0.05	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	–	–	< 0.01	< 0.01	–	< 0.01	–	< 0.01

[a–d]Averages (Avg) with different superscripts within the same column differ ($P < 0.05$).

[1]DM = dry matter.

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

[3]Nonphytate P, calculated as the difference between total P and phytate P.

[4] ND, not detectable.

[5]SEM = pooled standard error of the mean.

[6] Not compared because mineral was not detectable in some ingredient.

gestibility than P in the other oilseed meals. The greatest ($P < 0.05$) concentrations of K and Na were observed in soybean meal, but the least ($P < 0.05$) K and Na concentrations were detected in peanut meal and sunflower meal. Sunflower meal contained more Ca and P compared with the values reported by Liu et al. (2015), but there was less phytate-bound P in sunflower meal compared with values reported by Sauvant et al. (2004) and NRC (2012).

The concentration of P in cottonseed meal was in agreement with the value reported by Li et al. (2012), but less compared with values from Sauvant et al. (2004), CVB (2007), and NRC (2012). Cottonseed meal also contained less Fe, Zn, and Cu, but more Mn compared with values reported by Sauvant et al. (2004), CVB (2007), and NRC (2012). The greatest ($P < 0.05$) concentration of Mn among the 5 oilseed meals was observed in cottonseed.

The concentrations of Ca and P in sunflower meal were greater than the values reported by Liu et al. (2015) and a lower percentage of the P was bound to phytate compared with values from Sauvant et al. (2004) and NRC (2012). As is the case for the soybean meal analyzed in this study, the lower percentage of phytate bound P in sunflower meal likely will result in a greater digestibility of P in Chinese sunflower meal compared with sunflower meal produced in other parts of the world. Concentrations of all other minerals in sunflower meal were within the range of values previously reported (Sauvant et al., 2004; CVB, 2007; NRC, 2012) although the concentration of ash was less than reported in these 3 feed databases.

The concentrations of DM, ash, Ca, and P in peanut meal were in agreement with values reported by Li et al. (2014a), but less compared with values reported by NRC (2012) except that more P was observed in peanut meal analyzed in this study. Peanut meal contained more K, Mg, Fe, Zn, Cu, and Mn compared with the values from NRC (2012). The average concentration of P in peanut meal was greater ($P < 0.05$) than in soybean meal, but less ($P < 0.05$) compared with rapeseed meal. However, the proportion of the P in peanut meal that was bound in phytate was much less ($P < 0.05$) than in rapeseed meal, and it is, therefore, likely that the digestibility of P is greater in peanut meal than in rapeseed meal. The concentration of Fe in peanut meal was also greater ($P < 0.05$) than in soybean meal, but less ($P < 0.05$) than in rapeseed meal, but there was no difference in Fe concentration between peanut meal and sunflower meal.

Nutrient concentrations in oilseed meals may be affected by the soil in which the oilseeds are grown and the variety of the oilseed used for meal production. Although the soybean meal, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal that were analyzed in the current work were all produced by the solvent extraction method, differences among crushing plants in China and plants in other countries may exist, which may also have contributed to some of the differences in mineral composition that were observed.

In conclusion, compared with corn and wheat grain, corn gluten feed, corn germ meal, corn DDGS, wheat bran, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal had a greater concentration of Fe and most other micro minerals. The greatest concentration of Ca and the greatest percentage of phytate bound P versus total P (83.8%, DM basis) were observed in rapeseed meal whereas soybean meal had the greatest concentration of K. No differences were observed for most minerals between corn gluten meal and corn and between wheat and wheat shorts. The greatest variation in Se concentration was observed in corn. Concentrations of most minerals in corn, corn gluten feed, corn gluten meal, corn germ meal, corn DDGS, wheat, wheat bran, wheat shorts, soybean meal, rapeseed meal, sunflower meal, cottonseed meal, and peanut meal were different compared with databases published elsewhere. As a consequence, the current results, if used in formulation of pig feed ingredients in China, may result in more accurate diet formulations.

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