한국가금학회지 제 49권 제 2호, 79～87 (2022)
Korean J. Poult. Sci. Vol.49, No.2, 79～87 (2022)
https://doi.org/10.5536/KJPS.2022.49.2.79

Variation of Crude Protein and Amino Acids Concentrations in Corn, Wheat, and Barley from Different Countries

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ABSTRACT The objective of this study was to investigate the variability in crude protein (CP) and amino acids (AA) content in cereal grains imported from different origins in Korea from 2006 to 2015. The values of CP and AA contents in corn, wheat, and barley were obtained from 430 and 325 samples from six countries, 83 and 56 samples from seven countries, and 60 and 58 samples from three countries, respectively. The CP concentrations in corn, wheat, and barley ranged from 7.12 (Brazil) to 7.68% (India), 10.55 (Ukraine) to 13.26% (Brazil), and 9.46 (India) to 10.49% (Ukraine), respectively. The Lys concentrations in the corn, wheat, and barley ranged from 0.18 (Argentina) to 0.24% (China), 0.26 (India) to 0.34% (China), and 0.23 (India) to 0.31% (Australia), respectively. The concentrations of CP and AA varied among different countries of origin ($P<0.05$), except for Met in wheat and CP in barley. The coefficients of variation for CP were 3.26, 9.06, and 5.36 from corn, wheat, and barley, respectively. The correlation coefficients (r) between CP and Lys concentrations in corn, wheat, and barley were positively correlated and were 0.322, 0.277, and 0.542, respectively. In conclusion, CP and AA concentrations varied not only from different countries of origins but also within the same country due to the geographic region in which they are produced.

(Key words: nutritional content, cereal grain, protein, amino acids, origin)

INTRODUCTION

Information on nutrient composition in feed ingredients is the most critical factor affecting accurate feed formulation to meet the nutrient requirements of poultry and swine to maximize productivity and to minimize the excretion of excessive nutrients from the livestock.

Cereal grains such as corn, wheat, and barley are commonly used for poultry and swine diets (Schnepf, 2011; Woyengo et al., 2014; Velayudhan et al., 2015). Dietary protein is supplied by meals from oilseeds such as soybean and canola, and cereal grains are used as energy sources. However, in general, the portion of cereal grains in feed formulation accounted for over 60% of the total, thus these supply a considerable amount of protein to the diet (Lilburn et al., 1999). Also, even within the same ingredient, the amino acids (AA) compositions of the same feed ingredient may have a different value. Therefore, the CP and AA profiles of cereal grains are important to accurate feed formulation.

The protein quality of cereal grains differs depending on the genetic background or diverse environmental conditions (Triboï et al., 2003; Ball et al., 2013). The growing conditions of feed ingredients might affect nutrient availability. Finally, the changes in nutrient concentrations in cereal grain by the environmental condition can influence the price of feed ingredients and animal diets. Therefore, the variability of nutrient concentrations according to origin take into account when the nutritional profile of feed ingredients was used for feed formulation. For these reasons, the consideration of the geographic difference of grains is important to estimate the dietary nutrient concentrations in feed formulation. The objective of this study was to compare the variability of the CP and AA concentrations in the cereal grains among different countries.

MATERIALS AND METHODS

1. Data Collection

Samples of three cereal grains (corn, wheat, and barley)

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known to be imported to Korea from different countries were selected and analyzed by the CP and AA from 2006 to 2015 (Nonghyup analysis center, Anseong, Korea). A total of 430 and 325 corn samples from 6 countries (Argentina, Brazil, China, India, Ukraine, and the USA), 83 and 56 wheat samples from 7 countries (Australia, Brazil, Canada, China, India, Ukraine, and the USA), and 60 and 58 samples of barley from 3 countries (Australia, India, and Ukraine) for CP and AA were used in the present study, respectively. The analyzed values of CP and AA including Lys, Met, Cys, and Thr were used to test the variability in nutrient concentration within and among countries of origins. All of the analyzed values were presented as an as-is basis. Also, the AA to Lys ratio was calculated to compare the relative AA concentrations on the Lys concentration.

2. Chemical Analysis

The present study was conducted by using data from laboratories of major feed companies in Korea to understand the variations in nutrients of cereal grains imported to Korea from different countries. All the cereal grain samples were analyzed in duplicate for CP and AA including Lys, Met, Cys, and Thr. Crude protein was analyzed with Dumas combustion method (N × 6.25) by an N analyzer (Leco FP-528, St. Joseph, MI, USA). The AA was analyzed after acid hydrolysis using high-performance liquid chromatography (HPLC; Agilent 1200, Santa Clara, CA, USA), except for sulfur-containing AA. Methionine and cysteine were oxidized to methionine sulfone and cysteic acid by reaction with performic acid before acid hydrolysis and analyzed by HPLC.

3. Statistical Analysis

All data for each ingredient were analyzed by the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, USA). Data for the CP and AA concentrations were examined by one-way ANOVA, and the origin was determined as the fixed effect. The interquartile range (IQR) method was used to identify and remove the outliers. Data points with values larger than 1.5 times IQR were considered as outlier. The average nutrient concentration of CP and AA values and coefficient of variation (CV) of each grain samples were calculated. A correlation and regression analyses were used to determine the relationship between AA and CP concentrations in the grains used in the present study. The significance was determined at $P<0.05$.

RESULTS

The average values of CP and AA for corn is given in Table 1. Samples obtained from India and Brazil had the lowest and greatest values 7.12 and 7.68%, respectively. The CV of CP had the lowest and greatest in samples obtained

Table 1. Variability of crude protein (CP) and amino acids among six origins of corn (%, as-is basis)

Origin	Amino acids (%)							
	CP	Lys	Met	Cys	Thr	Met:Lys	Cys:Lys	Thr:Lys
Within country								
Argentina								
n[1]	30	18	18	18	18	18	18	18
Average	7.25	0.18	0.12	0.15	0.22	0.67	0.82	1.25
CV[2]	4.51	19.21	14.49	16.53	11.18	13.99	16.92	13.22
Brazil								
n[1]	57	34	34	34	34	34	34	34
Average	7.12	0.21	0.12	0.15	0.24	0.60	0.76	1.17
CV[2]	2.92	13.13	23.22	14.27	7.89	18.09	15.02	8.56
China								

Table 1. Continued

Origin	Amino acids (%)							
	CP	Lys	Met	Cys	Thr	Met:Lys	Cys:Lys	Thr:Lys
n[1]	56	56	56	56	56	56	56	56
Average	7.60	0.24	0.14	0.17	0.27	0.62	0.71	1.16
CV[2]	2.88	14.91	13.68	10.13	8.43	17.54	14.51	15.15
India								
n[1]	11	11	11	11	11	11	11	11
Average	7.68	0.22	0.14	0.16	0.26	0.64	0.76	1.17
CV[2]	5.2	11.2	17.7	14.5	6.6	25.9	23.0	9.5
Ukraine								
n[1]	25	14	14	14	14	14	14	14
Average	7.43	0.21	0.13	0.14	0.25	0.63	0.69	1.18
CV[2]	5.03	14.23	14.88	8.90	10.31	11.66	12.11	11.96
USA								
n[1]	251	192	192	192	192	192	192	192
Average	7.17	0.21	0.13	0.16	0.25	0.63	0.74	1.16
CV[2]	5.25	15.11	16.56	13.08	7.95	18.00	14.70	10.58
NRC (2012)								
n[1]	163	132	130	112	129			
Average	8.24	0.25	0.18	0.19	0.28	0.71	0.76	1.12
INRA (2003)								
n[1]	2,634	2,634	2,634	2,634	2,634			
Average	8.10	0.24	0.17	0.20	0.30	0.71	0.83	1.25
Among countries								
n	430	325	325	325	325	325	325	325
Minimum	7.12	0.18	0.12	0.14	0.22	0.60	0.69	1.16
Maximum	7.68	0.24	0.14	0.17	0.27	0.67	0.82	1.25
Average[3]	7.14	0.22	0.13	0.16	0.25	0.63	0.74	1.17
CV[2]	3.26	8.72	7.43	5.90	6.73	4.05	5.98	2.95
SEM[4]	0.338	0.032	0.022	0.020	0.021	0.112	0.113	0.135
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.490	0.002	0.099

[1] Values represent the number of observations of nutrient contents in corn to the corresponding country of origins or the publications.
[2] CV=coefficient of variation.
[3] Average values are calculated as a weighted average.
[4] SEM=standard error of the mean.

from China (7.09% to 8.11%, CV=2.88%) and USA (6.10% to 8.77%, CV=5.25%). For AA, the Met and Thr had the lowest and greatest, respectively. The Met contents in corn ranged from 0.12% to 0.14%; Thr ranged from 0.22% to 0.27% values 0.12% and 0.22%, respectively. And the CV for AA had ranged from 5.90% (Cys) to 8.72% (Lys). The

Lys, Met, Cys, and Thr concentration in samples obtained from Argentina (0.18, 0.12, 0.15, and 0.22%) and China (0.24, 0.14, 0.17, and 0.27%) had the lowest and greatest, respectively. The samples obtained from Argentina (19.21, 16.53, and 11.18%) had the greatest CV of AA (Lys, Cys, and Thr), except for Met. The Cys to Lys ratio differed (*P*=0.002) by countries of origin.

The average values of CP and AA for wheat is shown in Table 2. For AA (Lys, Met, Cys, and Thr), samples obtained from China had the greatest values of 0.34, 0.17, 0.29, and 0.33%, respectively. The samples obtained from India had the lowest Lys (0.26%) and Met (0.14%). And the lowest Cys and Thr found in samples obtained from Canada (0.23%) and the USA (0.28%), respectively. The samples obtained from the USA had the lowest CV of Lys (4.17%), Met (7.86%), Cys (8.87%), and Thr (4.92%), respectively. Among AA, the Met and Lys had the lowest and greatest, respectively. The Met contents in wheat ranged from 0.14% to 0.17%; Lys ranged from 0.26% to 0.34%, respectively, and the CV for AA had ranged from 6.34% (Thr) to 10.04% (Lys). The Thr

Table 2. Variability of crude protein (CP) and amino acids among seven origins of wheat (%, as-is basis)

Origin	Amino acids (%)							
	CP	Lys	Met	Cys	Thr	Met:Lys	Cys:Lys	Thr:Lys
Within country								
Australia								
n[1]	12	8	8	8	8	8	8	8
Average	11.70	0.27	0.16	0.23	0.30	0.59	0.89	1.13
CV[2]	11.77	6.69	15.03	10.95	5.04	15.80	12.44	4.11
Brazil								
n[1]	15	9	9	9	9	9	9	9
Average	13.26	0.29	0.17	0.26	0.32	0.57	0.89	1.12
CV[2]	8.55	12.31	19.21	12.83	14.42	10.89	3.91	9.29
Canada								
n[1]	7	5	5	5	5	5	5	5
Average	12.76	0.28	0.16	0.23	0.33	0.56	0.83	1.15
CV[2]	8.78	13.32	20.07	9.84	12.76	21.94	13.69	5.18
China								
n[1]	11	11	11	11	11	11	11	11
Average	13.10	0.34	0.17	0.29	0.33	0.51	0.83	0.98
CV[2]	2.79	7.2	13.5	13.4	12.8	11.0	10.7	14.7
India								
n[1]	13	6	6	6	6	6	6	6
Average	11.70	0.26	0.14	0.24	0.30	0.54	0.93	1.17
CV[2]	3.94	16.22	10.21	13.12	11.09	11.27	8.92	6.70
Ukraine								
n[1]	13	10	10	10	10	10	10	10
Average	10.55	0.30	0.16	0.25	0.29	0.55	0.86	0.99

Table 2. Continued

Origin	Amino acids (%)							
	CP	Lys	Met	Cys	Thr	Met:Lys	Cys:Lys	Thr:Lys
CV	9.92	17.32	15.81	15.74	10.04	20.36	15.31	10.78
USA								
n[1]	12	7	7	7	7	7	7	7
Average	10.83	0.27	0.14	0.24	0.28	0.54	0.90	1.07
CV[2]	7.23	4.17	7.86	8.87	4.92	9.40	12.00	5.09
NRC (2012)								
n[1]	64	34	29	26	32			
Average	14.46	0.39	0.22	0.33	0.40	0.56	0.85	1.03
INRA (2003)								
n[1]	7,068	7,068	7,068	7,068	7,068			
Average	10.50	0.31	0.17	0.26	0.32	0.55	0.84	1.03
Among countries								
n	83	56	56	56	56	56	56	56
Minimum	10.55	0.26	0.14	0.23	0.28	0.51	0.83	0.98
Maximum	13.26	0.34	0.17	0.29	0.33	0.59	0.93	1.17
Average[3]	11.95	0.29	0.16	0.25	0.31	0.55	0.87	1.07
CV[2]	9.06	10.04	8.23	7.56	6.34	4.74	4.02	7.05
SEM[4]	0.961	0.034	0.024	0.032	0.035	0.082	0.100	0.098
P-value	<0.001	<0.001	0.053	0.011	0.024	0.475	0.506	0.001

[1] Values represent the number of observations of nutrient contents in wheat to the corresponding country of origins or the publications.
[2] CV=coefficient of variation.
[3] Average values are calculated as a weighted average.
[4] SEM=standard error of the mean.

to Lys ratio differed (P=0.001) by countries of origin.

Samples obtained from India and Ukraine had the lowest and greatest values 9.46 and 10.49%, respectively (Table 3). The samples obtained from Ukraine (10.05% to 11.09%, CV=4.00%) and Australia (7.22% to 14.82%, CV=20.02%) had the lowest and greatest CV of CP. For AA (Lys, Met, Cys, and Thr), samples obtained from 0.23, 0.11, 0.16, and 0.25% and 0.31, 0.13, 0.20, and 0.30%, respectively. In the case of a CV of AA (Lys, Met, Cys, and Thr), the samples obtained from Ukraine (3.30, 7.27, 7.92, and 4.03%) had the lowest, and Australia (21.33, 13.62, 13.61%) had the greatest except for Lys. Met and Lys had the lowest and greatest, respectively. The Met contents in barley ranged from 0.11% to 0.13%; Lys ranged from 0.23% to 0.31%, respectively, and the CV for AA had ranged from 8.94% (Met) to 15.21% (Lys). The Thr to Lys ratio differed (P<0.001) by countries of origin.

The nutrient composition in corn, wheat, and barley varied not only among the country of origins but within origins (P<0.05). Concentrations of CP and AA in cereal grains differed (P<0.05) among countries, except for Met in wheat and CP in barley. The concentrations of CP and AA in barley

Table 3. Variability of crude protein (CP) and amino acids among three origins of barley (%, as-is basis)

Origin	Amino acids (%)							
	CP	Lys	Met	Cys	Thr	Met:Lys	Cys:Lys	Thr:Lys
Within country								
Australia								
n[1]	34	34	34	34	34	34	34	34
Average	9.82	0.31	0.13	0.20	0.30	0.43	0.65	0.95
CV[2]	20.02	12.31	21.33	13.62	13.61	19.59	13.58	5.65
India								
n[1]	19	17	17	17	17	17	17	17
Average	9.46	0.23	0.11	0.16	0.25	0.50	0.68	1.10
CV[2]	4.72	16.55	13.53	12.43	7.91	12.89	9.69	10.09
Ukraine								
n[1]	7	7	7	7	7	7	7	7
Average	10.49	0.30	0.13	0.20	0.30	0.45	0.67	1.02
CV[2]	4.00	3.30	7.27	7.92	4.03	5.28	6.97	2.64
NRC (2012)								
n[1]	76	38	35	34	37			
Average	11.33	0.40	0.20	0.26	0.36	0.50	0.65	0.90
INRA (2003)								
n[1]	2,739	2,739	2,739	2,739	2,739			
Average	10.0	0.38	0.17	0.23	0.35	0.49	0.66	1.00
Among countries								
n	60	58	58	58	58	58	58	58
Minimum	9.46	0.23	0.11	0.16	0.25	0.43	0.65	0.95
Maximum	10.49	0.31	0.13	0.20	0.30	0.50	0.68	1.10
Average[3]	9.79	0.29	0.13	0.19	0.29	0.45	0.66	1.01
CV[2]	5.36	15.21	8.94	13.52	10.07	8.41	2.94	7.45
SEM[4]	1.523	0.040	0.026	0.026	0.039	0.067	0.071	0.070
P-value	0.308	<0.001	0.040	<0.001	<0.001	0.002	0.186	<0.001

[1] Values represent the number of observations of nutrient contents in barley to the corresponding country of origins or the publications.
[2] CV=coefficient of variation.
[3] Average values are calculated as a weighted average.
[4] SEM=standard error of the mean.

had relatively wide variations rather than corn and wheat samples.

The concentrations of Lys, Met, Cys, and Thr in corn, wheat, and barley were positively correlated with the CP concentrations (Table 4). The concentrations of Thr had relatively high positive correlations ($P<0.001$) with the CP

Table 4. Correlation coefficients (r) between crude protein (CP) and amino acids in corn, wheat, and barley (as-is basis)[1,2]

Item	Correlation coefficient (r)				
	CP	Lys	Met	Cys	Thr
Corn					
CP	-	0.322	0.288	0.267	0.393
Lys		-	0.369	0.475	0.548
Met			-	0.681	0.332
Cys				-	0.389
Thr					-
Wheat					
CP	-	0.277	0.397	0.362	0.505
Lys		-	0.349	0.518	0.576
Met			-	0.677	0.352
Cys				-	0.332
Thr					-
Barley					
CP	-	0.542	0.559	0.476	0.741
Lys		-	0.660	0.819	0.902
Met			-	0.832	0.744
Cys				-	0.801
Thr					-

[1] All data have shown significant difference ($P<0.001$).
[2] The number of observations of corn, wheat, and barley are 325, 56, and 58, respectively.

and Lys 0.393 and 0.548, 0.505 and 0.576, and 0.741 and 0.902 in corn, wheat, and barley, respectively. On the contrary, correlation coefficients between CP and AA for corn, wheat, and barley were weak at of 0.267 (Cys), 0.277 (Lys), and 0.476 (Cys), respectively.

DISCUSSION

It is important to know information on the accurate nutritional profile in the feed ingredients when the feed formulating. However, it is difficult to analyze the nutrient concentrations of all the feed ingredients used in feed formulation. For this reason, the data presented in publications is used for feed formulation (McDonald et al., 2002; Sauvant et al., 2004; AMINODat®4.0, 2010; Rostagno et al., 2011; NRC, 2012). Among the reference lists, NRC was the most commonly used for citing the nutrient composition of feed ingredients (Cromwell et al., 1999). In this study, the values from NRC (2012) and Sauvant et al. (2004) were used to compare with the analyzed average value. Average values of CP in corn, wheat, and barley (7.14, 11.95, and 9.79%) were less than that listed in NRC (8.24, 14.50, and 11.30%), respectively. Sauvant et al. (2004) (8.10, 10.50, and 10.0%) showed relatively high CP concentrations in corn and barley but less than in wheat compared with the CP values in the present study. There are differences in CP concentration of cereal grains between studies but the values of respective AA to Lys ratio of corn, wheat, and barley were similar to table values of NRC (2012) and Sauvant et al. (2004).

Protein composition of cereal grains has been used as criteria of feeding quality of feed ingredient and affects the cost of feed ingredients. However, the CP and AA concentrations depend primarily on the genotype; it is also significantly affected by growing conditions (Skogerson et al., 2010; Ray et al., 2015). Some studies on the environmental conditions in which it was grown have been shown to affect CP concentrations in wheat (Triboï et al., 2003) and barley (Torp et al., 1981). The environmental-related conditions, including temperature (Ray et al., 2015), drought (Lilburn et al., 1999; Triboï et al., 2003), and N application (Li et al., 2016) can alter nutritional composition and grain yield (Simmonds, 1994; Ray et al., 2015). The change in CP concentration of cereal grains under heat and drought stress is mainly caused by the altered quantity of total nitrogen (N) accumulated during growth of wheat (Triboï et al., 2003). In addition, the application of N increases protein concentrations of cereal grains, but there was no beneficial effect on its nutritional value for chicks (Cromwell et al., 1983). According to Li et al. (2016), on the other hand, the N application up to 225 kg/ha increased CP concentration and *in vitro* dry matter digestibility of wheat improved with increasing N application up to 225 kg/ha. These previous results can be possibly explained that the nutritional composition and nutrient availability of cereal grains are affected by various growing conditions, and the change of nutritional composition of grains can be easily affected by the growing conditions. Therefore, for accurate feed formulation, not only the information on nutritional concentration of the feed ingredients but also the efficacy of feed ingredients by the animal should be evaluated.

The chemical analysis to measure AA concentrations is time-consumed and costly, but AA estimation using a prediction equation is relatively simple. We analyzed possible relationships among CP, Lys, Met, Cys, and Thr to estimate respective AA concentration using prediction equation. Some studies (Cromwell et al., 1999; Brandt et al., 2000; Olukosi and Adebiyi, 2013) developed the prediction models for estimation of AA concentrations in the cereal grains by using CP concentration. The positive correlation was shown between CP and AA concentrations. The observed results from this study were in agreement with earlier published (Cromwell et al., 1999). However, some studies (Brandt et al., 2000; Belyea et al., 2004) showed a negative correlation between CP and AA concentration. We do not show the equation to estimate AA concentrations using the CP concentration of cereal grains because most correlation coefficient (r^2) values of prediction equations are lower than 0.5. It might be due to the low tendency of AA concentration to change in CP concentration or the concentrated samples in a certain country. Therefore, further study is needed to generate the prediction equation for estimate the AA concentration in a large number of observations.

The results from this study confirmed the variability of CP and AA concentrations dependent on not only the across the country but also on within the same country, the trends of AA to Lys ratio of corn and barley were similar to the values of within and across countries. This result represents that the concentrations of CP and AA in cereal grains from different countries can vary depending on growing conditions both among and within counties. Therefore, in conclusion, when the animal diet is formulated, the information on nutritional composition of cereal grains should be taking into account their country of origins.

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Received Mar. 10, 2022, Revised May 26, 2022, Accepted May 30, 2022