Determination of chemical composition, energy content, and amino acid digestibility in different wheat cultivars fed to growing pigs[1]

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ABSTRACT: This study was conducted to determine the DE, ME, and apparent (**AID**) and standardized ileal digestibility (**SID**) of AA in different wheat cultivars fed to growing pigs. In Exp. 1, twelve crossbred growing barrows were allotted to a replicated 6 × 6 Latin square design to determine the DE and ME contents of 12 different wheat cultivars. In Exp. 2, twelve growing barrows with a simple T-cannula were used to determine the AID and SID of AA in 10 different wheat cultivars. Pigs were randomly allotted to a replicated 6 × 6 Latin square design and fed one nitrogen-free diet and 10 different cultivars of wheat diets. Among different wheat cultivars, the concentrations of GE, CP, NDF, ADF, and starch ranged from 4,385 to 4,458 kcal/kg, 12.95% to 18.14%, 9.16% to 13.89%, 1.93% to 2.92% and 60.81% to 70.77%, respectively (DM basis). There were significant differences ($P < 0.05$) in the DE, ME values, and the ATTD of GE in 12 different cultivars of wheat in Exp. 1. The DE and ME contents and the ATTD of GE ranged ($P < 0.05$) from 3,922 to 4,067 kcal/kg DM, 3,759 to 3,941 kcal/kg DM and 88.14% to 90.31%, respectively. The best prediction equations of DE and ME for different cultivars of wheat cultivars were DE = −2,738 – (40.8 × % ADF) + (1.7 × GE) – (51.5 × % Xylans) – (95.7 × % Ash) + (22.3 × % EE), R^2 = 0.98, and ME = −2,990 + (1.7 × GE) – (50.2 × % Xylans) – (87.6 × % Ash), R^2 = 0.88, respectively. There were also differences ($P < 0.05$) in the AID and SID of CP and indispensable AA, expect for His, in 10 wheat cultivars in Exp. 2. The AID and SID of CP, Lys, and Met ranged ($P < 0.05$) from 82.02% to 89.46%, 74.13% to 84.73%, 87.35% to 92.49% and 87.56% to 94.04%, 80.56% to 89.89%, 89.56% to 94.45%, respectively. In conclusion, the chemical composition, energy contents, and most AA digestibility in different cultivars of wheat varied widely.

Key words: amino acids, digestibility, energy, pigs, prediction equation, wheat

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INTRODUCTION

Wheat (*Triticum aestivum*) is the primary cereal grain produced in the world, particularly in the European Union (FAO, 2015). Wheat can be classified according to seedtime (spring or winter), hardness (soft or hard), and color (white or red). Additional categories are used in the United States for wheat classification, and these comprise six classes including hard red winter, hard red spring, soft red winter, durum, soft white, and hard white (McFall and Fowler, 2009). In diets for pigs, wheat is primarily used as an important energy component due to its high starch content ranging from 50% to 80% (Lin et al., 1987; Zijlstra et al., 1999; Black, 2001). The variation in energy and nutrient content among different wheat cultivars has been reported previously (Regmi et al., 2009; Jha et al., 2011). In addition, due to its high dietary

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inclusion level, ranging from 30% to 70%, wheat provides significant amounts of AA to pig, supplying up to 60% of the pig requirement for total AA (Myrie et al., 2008). However, little information is available for AA digestibility in different cultivars of wheat (Haydon and Hobbs, 1991).

China is a big producer of wheat with an annual output of about 125 million tons (FAO, 2015). It is very important and necessary for feed formulation precisely in pig industry to use the energy content and nutrients digestibility of Chinese wheat cultivars, because the published data (NRC, 2012; CVB, 2007) for energy content and AA digestibility of wheat is always differ from the values of wheat in China. Considering the development of prediction equations saves time and money, improves the efficiency of estimating energy values, and has been widely used to determine the DE and ME of feed ingredients (Powles et al., 1995). The other aim of our study is providing prediction equations for energy content according to the chemical composition of wheat for many farmers in China. Therefore, two experiments were conducted to evaluate the DE and ME values and apparent (**AID**) and standardized (**SID**) ileal digestibility of AA in different cultivars of wheat, and to develop prediction equations for DE and ME based on chemical characteristics of wheat.

MATERIALS AND METHODS

All protocols in this study were approved by the Institutional Animal Care and Use Committee of China Agricultural University (Beijing, China). Two experiments were conducted in Fengning Animal Experimental Base of China Agricultural University (Hebei, China).

Collection of Wheat Samples

A total of 16 cultivars of wheat were collected from different areas of China known mainly for wheat production, including 10 white winter wheat samples from different provender mills which are in Shandong, Henan, Jiangsu, and Hebei provinces, and six red spring wheat samples from Heilongjiang and Liaoning provinces, and the name of wheat cultivars were also showed in Table 1. In this study, pigs were crossbred (Duroc × Landrace × Yorkshire) barrows and obtained from Fengning Animal Experimental Base. They were placed in individual stainless-steel metabolism crates (1.4 m × 0.7 m × 0.6 m) in a temperature-controlled room (22.0 ± 2 °C). Mash feeds were supplied daily at a level of 4% of their BW (Adeola, 2001) and divided into two equal-sized meals at 0800 and 1700 hours. All pigs had free access to water. The chemical compositions and AA contents of the 16 wheat cultivars are shown in Table 2 (DM basis).

Table 1. Sources of wheat cultivars used in the experiments

Number	Sources	Variety	Chinese name of cultivars
1	Shandong	Winter wheat	Lumai 21
2	Shandong	Winter wheat	Yannong 24
3	Shandong	Winter wheat	Luomai 9
4	Shandong	Winter wheat	Jimai 22
5	Shandong	Winter wheat	Lumai 15
6	Jiangsu	Winter wheat	Taishan 22
7	Liaoning	Spring wheat	Liaochun 10
8	Heilongjiang	Spring wheat	Kenjiu 10
9	Heilongjiang	Spring wheat	Kehan 16
10	Heilongjiang	Spring wheat	Longmai 30
11	Heilongjiang	Spring wheat	Longmai 26
12	Heilongjiang	Spring wheat	Beimai 4
13	Henan	Winter wheat	Zhengmai 9023
14	Henan	Winter wheat	Aikang 58
15	Henan	Winter wheat	Yumai 7036
16	Hebei	Winter wheat	Shimai 8

Experiment 1: Energy Contents

This experiment was conducted to determine the DE and ME values and the apparent total tract digestibility (**ATTD**) of GE in different wheat cultivars fed to growing pigs. Twelve barrows with initial BW of 50.1 ± 2.8 kg were randomly allotted to a replicated 6 × 6 Latin square design and fed the 12 different wheat diets selected from 16 wheat cultivars according to their breeding system in different growing regions. The experimental diets were formulated to contain one of the 12 different wheat cultivars at an inclusion level of 97.0% (Table 3). The chemical composition of the experimental diets in Exp. 1 is presented in Table 4.

Experiment 1 included six periods, and each period lasted for 15 d with 10 d of diet adaptation followed by 5 d total feces and urine collection. During the 5 d collection period, feces were collected into a plastic bag every 4 h and then stored at −20 °C. At the end of experiment, the 5 d fecal collection from each pig was pooled, mixed, and weighed; a 700-g subsample was taken and dried in a forced-draft oven at 65 °C for 72 h. After drying and grinding through a 1-mm screen, fecal subsamples were stored at −20 °C for further chemical analysis. Total urine was collected into plastic buckets attached to funnels located under the metabolism cages at the same time as the fecal collection. Approximately 50 mL of 6 N HCl were added to

Table 2. Analyzed composition of the 16 wheat cultivars (DM basis)[1]

Items	Wheat cultivars number[3]																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Max	Min	Mean	CV
GE, kcal/kg	4,432	4,420	4,405	4,401	4,385	4,430	4,458	4,395	4,409	4,408	4,405	4,393	4,412	4,425	4,425	4,393	4,458	4,385	4,412	1.65
CP, %	14.22	13.65	13.59	13.94	14.65	14.50	17.46	12.95	17.24	13.75	18.14	16.25	14.41	14.43	14.62	16.02	18.14	12.95	14.99	10.17
Starch, %	64.24	64.35	64.15	66.14	64.17	70.77	61.28	67.91	63.16	63.68	61.21	60.81	65.26	69.49	68.80	70.24	70.77	60.81	65.35	5.09
EE, %[2]	1.38	1.22	1.27	1.41	1.51	1.75	1.82	2.82	1.39	1.69	1.50	2.73	1.38	1.34	1.00	1.21	2.82	1.00	1.59	31.61
NDF, %	13.08	13.66	12.50	10.71	12.38	12.88	12.58	13.89	11.22	12.63	13.54	12.33	10.37	9.16	10.29	11.03	13.89	9.16	12.02	11.59
ADF, %	2.34	2.69	2.51	1.94	2.29	2.44	2.43	2.92	2.04	2.63	2.68	2.43	2.22	1.93	2.23	2.53	2.92	1.93	2.39	11.63
Ash, %	1.77	1.74	1.88	1.83	1.78	1.97	2.05	1.80	1.78	1.87	2.21	1.96	1.70	1.78	2.02	1.83	2.21	1.70	1.87	6.93
Ca, %	0.16	0.13	0.03	0.03	0.03	0.03	0.11	0.02	0.04	0.03	0.06	0.06	0.08	0.06	0.11	0.07	0.16	0.02	0.07	61.64
P, %	0.17	0.22	0.18	0.17	0.19	0.34	0.27	0.25	0.27	0.17	0.34	0.25	0.14	0.19	0.20	0.08	0.34	0.08	0.21	32.44
Xylans, %	4.64	5.00	4.74	4.14	5.65	4.63	6.24	5.52	5.33	4.61	5.61	5.04	5.50	4.60	4.91	5.12	6.24	4.14	5.08	10.23
Bulk weight, g/L	907.7	890.6	917.2	924.7	869.4	922.1	919.2	868.6	917.9	953.3	880.8	938.5	905.3	951.6	951.4	905.1	953.3	868.6	914.0	2.8
Indispensable AA, %																				
Arg	0.60	0.65	0.56	0.61	0.63	0.64	0.74	0.53	0.68	0.54	0.73	0.65	0.61	0.61	0.69	0.68	0.74	0.53	0.63	9.53
His	0.49	0.47	0.39	0.40	0.48	0.47	0.55	0.37	0.50	0.47	0.60	0.53	0.46	0.46	0.50	0.51	0.60	0.37	0.48	11.94
Ile	0.48	0.50	0.48	0.51	0.52	0.53	0.58	0.44	0.61	0.47	0.64	0.56	0.50	0.48	0.53	0.56	0.64	0.44	0.52	10.08
Leu	1.01	1.04	0.96	1.01	1.06	1.07	1.20	0.91	1.27	0.98	1.33	1.17	1.01	0.99	1.07	1.10	1.33	0.91	1.07	10.50
Lys	0.47	0.50	0.35	0.38	0.50	0.51	0.52	0.35	0.44	0.47	0.56	0.50	0.50	0.47	0.60	0.52	0.60	0.35	0.48	14.58
Met	0.20	0.20	0.22	0.25	0.24	0.22	0.28	0.19	0.26	0.19	0.26	0.23	0.23	0.23	0.24	0.24	0.28	0.19	0.23	11.12
Phe	0.56	0.74	0.69	0.70	0.72	0.74	0.87	0.52	0.87	0.54	0.95	0.73	0.73	0.55	0.66	0.78	0.95	0.52	0.71	17.53
Thr	0.37	0.39	0.35	0.39	0.40	0.40	0.45	0.34	0.46	0.36	0.47	0.41	0.38	0.37	0.42	0.41	0.47	0.34	0.40	9.65
Trp	0.17	0.16	0.18	0.17	0.19	0.18	0.22	0.15	0.20	0.18	0.19	0.21	0.19	0.15	0.22	0.22	0.22	0.15	0.19	13.09
Val	0.62	0.67	0.67	0.61	0.69	0.80	0.88	0.87	0.91	0.88	0.94	0.65	0.75	0.63	0.61	0.67	0.94	0.61	0.74	15.33
Dispensable AA, %																				
Ala	0.58	0.61	0.59	0.65	0.61	0.61	0.69	0.67	0.62	0.57	0.72	0.64	0.59	0.59	0.63	0.62	0.72	0.57	0.62	12.88
Asp	0.68	0.74	0.77	0.76	0.75	0.75	0.82	0.80	0.77	0.71	0.82	0.77	0.79	0.71	0.89	0.88	0.89	0.68	0.77	13.21
Cys	0.43	0.39	0.40	0.47	0.43	0.41	0.52	0.43	0.45	0.41	0.47	0.36	0.37	0.39	0.40	0.42	0.52	0.36	0.42	11.13
Glu	4.14	4.19	4.21	4.08	4.14	4.29	5.06	4.13	4.44	4.34	5.82	4.50	4.01	3.99	3.77	3.99	5.82	3.77	4.32	9.69
Gly	0.58	0.59	0.65	0.62	0.59	0.60	0.68	0.59	0.61	0.59	0.72	0.56	0.59	0.59	0.59	0.60	0.72	0.58	0.61	11.37
Pro	1.61	1.56	1.58	1.68	1.59	1.73	1.71	1.64	1.81	1.63	2.17	1.60	1.63	1.59	1.48	1.77	2.17	1.48	1.67	10.89
Ser	0.61	0.63	0.66	0.68	0.62	0.64	0.61	0.61	0.73	0.61	0.80	0.65	0.61	0.57	0.63	0.63	0.80	0.57	0.64	11.65
Tyr	0.04	0.09	0.06	0.08	0.07	0.09	0.11	0.05	0.08	0.05	0.17	0.06	0.05	0.02	0.02	0.09	0.17	0.02	0.07	16.72

[1]Analysis conducted in duplicate.

[2]EE = ether extract.

[3]Sources of wheat cultivars are described in Table 1.

each bucket to limit microbial growth and reduce loss of ammonia. Urine volume was recorded daily and a subsample of 10% was collected and stored at −20 °C. At the end of collection period, urine samples were pooled within each pig and a subsample (about 100 mL) was stored at −20 °C for further analysis.

Experiment 2: AA Digestibility

This experiment was conducted to determine the AID and SID of AA in 10 wheat cultivars selected from 16 wheat cultivars according to the differences in their chemical composition and energy contents. Twelve crossbred barrows with initial BW of 46.2 ± 2.1 kg were fitted with a T-cannula in the distal ileum and allotted to a replicated 6 × 6 Latin square design. Dietary treatments included one nitrogen-free diet and 10 test feedstuff diets formulated to contain 96.70% of each respective wheat cultivar as the sole source of CP and AA (Table 3). The N-free diet was used to determine the endogenous losses of nitrogen and 0.30% chromic oxide was included in each diet as an indigestible marker to determine AA digestibility. The procedures for equipping pigs with a simple T-cannula at the distal ileum were as described by Stein et al. (1998). The analyzed composition of the experimental diets in Exp. 2 is presented in Table 5.

Exp. 2 included six periods, and each period lasted 7 d with a 5 d of adaptation to the diets followed by 2 d of ileal digesta collection from 0800 to 1700 hours using the procedures described by Stein et al. (1998). Digesta was collected in a plastic bag, and the bags were changed every 30 min and then stored at −20 °C. Ileal digesta samples were thawed and mixed within pig and diet, and a subsample was taken and lyophilized in a vacuum-freeze dryer (Tofflon Freezing Drying Systems, Minhang District, Shanghai, China) and ground through a 1-mm screen for further chemical analysis.

Table 3. Ingredient composition of the experimental diets (%, as-fed basis)

	Exp. 1	Exp. 2	
Ingredient	Wheat diet	Wheat diet	N-free diet
Wheat	97.00	96.70	—
Corn starch	—	—	74.00
Sucrose	—	—	15.00
Acetate cellulose[1]	—	—	4.00
Soybean oil	—	—	3.00
Limestone	0.30	0.40	1.00
Dicalcium phosphate	1.80	1.70	1.40
Sodium chloride	0.30	0.30	0.30
Chromic oxide	—	0.30	0.30
Potassium carbonate	—	—	0.30
Magnesium oxide	—	—	0.10
Choline chloride	0.10	0.10	0.10
Premix[2]	0.50	0.50	0.50
Total	100.00	100.00	100.00

[1]Made by Chemical Reagents Company (Beijing, China).

[2]Premix provided the following per kilogram of complete diet: vitamin A as retinyl acetate, 5,512 IU; vitamin D_3 as cholecalciferol, 2,200 IU; vitamin E as DL-alpha-tocopheryl acetate, 30 IU; vitamin K_3 as menadione nicotinamide bisulfite, 2.2 mg; vitamin B_{12}, 27.6 µg; riboflavin, 4 mg; pantothenic acid as DL-calcium pantothenate, 14 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; thiamin as thiamine mononitrate, 1.5 mg; pyridoxine as pyridoxine hydrochloride, 3 mg; biotin, 44 µg; Mn as MnO, 40 mg; Fe as $FeSO_4$ H_2O, 75 mg; Zn as ZnO, 75 mg; Cu as $CuSO_4$ $5H_2O$, 100 mg; I as KI, 0.3 mg; Se as Na_2SeO_3, 0.3 mg.

Chemical Analysis

The chemical analysis of all samples was tested in duplicate. Wheat samples were analyzed for DM (procedure 930.15; AOAC 2006), CP (procedure 984.13; AOAC 2006), starch (procedure 979.10; AOAC 2006), ether extract (**EE**; Thiex et al., 2003), ash (procedure, 942.05; AOAC, 2006), calcium (procedure 968.08; AOAC, 2006), and phosphorus (procedure 946.06; AOAC, 2006). Ion chromatography

Table 4. Analyzed composition of the experimental diets in Exp. 1 (%, as-fed basis)[1]

	Wheat diets[2]											
Items	1	2	3	4	5	6	7	8	9	10	11	12
DM	90.96	90.26	91.10	90.36	90.64	90.04	89.36	88.99	89.98	90.09	89.41	89.47
CP	14.81	13.29	13.91	14.02	14.21	14.02	13.29	12.00	16.59	13.28	17.28	15.75
Ash	3.45	3.35	3.57	3.34	3.53	3.47	3.29	3.27	3.21	3.30	3.48	3.50
Ca	0.42	0.45	0.50	0.46	0.47	0.52	0.42	0.44	0.43	0.40	0.40	0.47
P	0.41	0.38	0.47	0.46	0.46	0.42	0.46	0.47	0.50	0.32	0.32	0.43
NDF	13.83	13.41	12.33	11.93	12.91	12.27	12.01	12.84	11.95	12.21	12.66	13.02
ADF	3.29	3.22	2.87	2.32	2.87	2.81	2.96	3.05	2.55	2.69	2.81	2.70
GE, kcal/kg	3,912	3,864	3,902	3,845	3,888	3,857	3,864	3,821	3,900	3,802	3,879	3,867

[1]Analysis conducted in duplicate.

[2]Sources of wheat cultivars are described in Table 1.

Table 5. Analyzed composition of the experimental diets in Exp.2 (%, as-fed basis)[1]

Items	Wheat diets[2]										N-free diet
	1	2	5	6	7	11	13	14	15	16	
DM	88.35	88.32	88.63	89.54	87.93	88.67	88.84	89.32	88.07	89.26	89.04
CP	13.64	13.10	13.85	13.87	16.29	16.23	14.19	13.56	12.66	14.92	0.49
Ca	0.52	0.57	0.51	0.55	0.51	0.41	0.52	0.50	0.50	0.52	0.51
P	0.43	0.54	0.54	0.50	0.51	0.40	0.48	0.50	0.48	0.41	0.31
NDF	9.57	10.57	9.97	8.89	9.04	8.96	10.84	9.53	9.66	8.45	3.47
ADF	2.10	2.39	2.28	1.81	2.13	2.11	2.37	2.22	2.31	1.91	5.34
Indispensable AA											
Arg	0.55	0.55	0.59	0.52	0.62	0.59	0.63	0.53	0.55	0.61	0.01
His	0.41	0.39	0.4	0.42	0.42	0.47	0.43	0.37	0.41	0.45	0.01
Ile	0.43	0.40	0.43	0.44	0.49	0.50	0.45	0.40	0.41	0.48	0.02
Leu	0.88	0.85	0.89	0.89	1.01	1.02	0.91	0.84	0.84	0.96	0.03
Lys	0.37	0.35	0.39	0.42	0.36	0.45	0.47	0.37	0.43	0.44	0.01
Met	0.19	0.17	0.19	0.19	0.21	0.22	0.18	0.18	0.18	0.20	0.10
Phe	0.47	0.56	0.49	0.62	0.67	0.74	0.65	0.48	0.52	0.51	0.02
Thr	0.32	0.31	0.34	0.33	0.37	0.36	0.35	0.32	0.32	0.35	0.00
Trp	0.16	0.14	0.17	0.15	0.18	0.16	0.16	0.17	0.13	0.15	0.01
Val	0.56	0.53	0.57	0.57	0.63	0.62	0.58	0.58	0.54	0.60	0.01
Dispensable AA											
Ala	0.51	0.50	0.53	0.51	0.58	0.57	0.54	0.50	0.50	0.55	0.01
Asp	0.59	0.60	0.66	0.61	0.68	0.65	0.69	0.62	0.63	0.69	0.03
Cys	0.35	0.35	0.38	0.38	0.43	0.40	0.37	0.35	0.34	0.41	0.05
Glu	3.57	3.43	3.49	3.49	4.23	4.29	3.60	3.42	3.17	3.82	0.06
Gly	0.50	0.48	0.51	0.49	0.57	0.55	0.53	0.51	0.48	0.52	0.01
Pro	1.36	1.27	1.36	1.38	1.63	1.57	1.39	1.35	1.23	1.52	0.03
Ser	0.52	0.51	0.53	0.50	0.59	0.59	0.55	0.51	0.50	0.54	0.01
Tyr	0.05	0.05	0.04	0.03	0.03	0.12	0.09	0.03	0.48	0.05	0.08

[1]Analysis conducted in duplicate.

[2]Sources of wheat cultivars are described in Table 1.

(Dionex ICS-3000, Sunnyvale, CA) was used to measure xylan content in wheat cultivars, and ingredients were hydrolyzed with 11 N sulfuric acid at 120 ℃ for 3 h. The modified procedures of van Soest et al. (1991) were followed to determine NDF and ADF concentrations. The concentration of NDF was analyzed using heat stable α-amylase and sodium sulfite without correction for insoluble ash (Ankom Technology, Macedon, NY). The ADF fraction was analyzed in a separate sample. The GE of wheat cultivars, diets, feces, and urine samples was analyzed using an adiabatic oxygen bomb calorimeter (Parr Instruments Co., Moline, IL).

Wheat samples, diets, and ileal digesta in Exp. 2 were analyzed for AA contents by the standard method (AOAC, 2006). With the exception of Met, Cys, and Trp, the AA contents were determined after hydrolysis with 6 N HCl at 110 °C for 24 h using an AA analyzer (Hitachi L-8900, Tokyo, Japan). Methionine and Cys were determined as methionine sulfone and cysteic acid using an AA analyzer (Hitachi L-8900, Tokyo, Japan) after cold performic acid oxidation overnight and hydrolyzing with 7.5 N HCl at 110 °C for 24 h. Tryptophan was determined using High Performance Liquid Chromatography (Agilent 1200 Series, Santa Clara, CA) after LiOH hydrolysis for 22 h at 110 °C. The chromium concentration in diets and digesta was determined using a polarized Zeeman Atomic Absorption Spectrometer (Hitachi Z2000, Tokyo, Japan) after nitric acid–perchloric acid wet ash sample preparation. Bulk weight of different wheat cultivars was also analyzed (Li et al., 2014).

Calculations

In Exp. 1, the DE and ME contents and the ATTD of GE of the 12 wheat cultivars were calculated using the method as described by Adeola (2001):

$$DE_d = \left(GE_i - GE_f\right) / F_i$$

$$DE_w = DE_d / 0.97$$

$$ME_d = \left(GE_i - GE_f - GE_u\right) / F_i$$

$$ME_w = ME_d / 0.97$$

$$ATTD = (GE_i - GE_f) / GE_i$$

where DE_d and ME_d are the DE and ME values in each diet (kcal/kg of DM), GE_i is the total GE intake of each pig (kcal of DM), and F_i which was the actual feed intake over the 5-d collection period. GE_f and GE_u are the GE content in feces and urine of each pig (kcal/kg of DM) over the 5-d collection period. DE_w and ME_w are the DE and ME values in each wheat cultivar (kcal/kg of DM) and 0.97 is the percentage of wheat cultivars in the diet.

In Exp. 2, the AID, SID, and endogenous losses of CP and AA in diets were calculated according to the equations described by Stein et al. (2007). The AID for each AA in the test diet was calculated using the following equation:

$$AID\ (\%) = \begin{bmatrix} 1 - (AA_{digesta} / AA_{diet}) \\ \times (Cr_{diet} / Cr_{digesta}) \end{bmatrix} \times 100\%$$

where $AA_{digesta}$ and $Cr_{digesta}$ are the concentrations of AA and chromium in the ileal digesta (g/kg of DM), while AA_{diet} and Cr_{diet} are the concentrations of AA and chromium in the test diets (g/kg of DM). The basal ileal endogenous loss of each AA (IAA, g/kg of DM intake; DMI) was determined for pigs fed the N-free diet using the following equation:

$$IAA = AA_{digesta} \times (Cr_{diet} / Cr_{digesta})$$

The SID of each AA was calculated using the following equation:

$$SID\ (\%) = AID + (IAA / AA_{ingredient}) \times 100\%$$

where $AA_{ingredient}$ is the concentrations of AA in the wheat cultivars (g/kg of DM).

Statistical Analysis

All the data were checked for normality, and outliers were detected using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). No outliers were found. All data were analyzed using the MIXED procedure of SAS 9.2 with pig as the experimental unit. The statistical model included the fixed effect of diet and the random effects of period and animal. Correlation coefficients between chemical characteristics and DE of wheat cultivars were analyzed using the PROC CORR procedure of SAS 9.2. Prediction equations for DE and ME in the wheat cultivars were developed using PROC REG of SAS 9.2 using stepwise regression procedures. Statistical differences among the treatments were separated by Tukey's multiple range test. Treatment means were calculated using the LSMEANS statement. Difference was considered significant if $P < 0.05$. The R^2 and residual SD (**RSD**) were used to define the best-fit equations. The equations with the greatest R^2 and the smallest RSD were chosen as the best-fit models for the prediction equations (Dong et al., 2014).

RESULTS AND DISCUSSION

Chemical Composition and Characteristics of Wheat Cultivars

In the present study, the bulk weight of 16 different wheat cultivars ranged from 868.6 to 953.3 g/L with a mean value of 914.0 g/L. A lesser bulk weight ranging from 788.8 to 809.2 g/L was observed among five different wheat cultivars reported by Anderson and Bell (1983a) and Jha et al. (2011b) indicated the density of 12 wheat cultivars varied from 767.0 to 840.0 g/L for Canadian spring, winter, and durum wheat. However, a lower bulk weight (495.3 to 759.2 g/L) was obtained with 15 varieties of wheat damaged by frost (Anderson and Bell, 1983b). Similarly, Zijlstra et al. (1999) indicated frost-damaged wheat had low density from 578.0 to 776.0 g/L, and the durum wheat had a density of 454.0 g/L. Wiseman et al. (2000) reported the bulk weight ranged from 695.0 to 815.0 g/L of 18 different cultivars of wheat grown at seven different sites. The differences in bulk weight of wheat were caused by different varieties, growing condition and regions. In the present study, the starch content varied from 60.81% to 70.77%, and this result was similar to published data (Kim et al., 2003). In previous studies, starch content ranged from 50.4% to 79.5% (Sibbald and Price, 1976; Lin et al., 1987; Zijlstra et al., 1999). The main reasons for the variation of starch contents in wheat cultivars are the variety (e.g., soft or hard), growing region, and growing season (e.g., rainfall or drought; Kim et al., 2003). Meanwhile, in view of the raising demand for wheat as a renewable source for biofuel production, efforts aimed at breed wheat cultivars with high starch content could be of increasing interest as starch is the principal grain component providing sugars for fermentation (Kindred et al., 2008). In addition, wheat cultivars contained less concentration of NDF and ADF in our study compared with previous literatures, in which NDF and ADF contents of wheat with different cultivars and harvest time ranged from 19.40% to 25.10% and 2.70%

to 5.10% (Zijlstra et al., 1999; Wiseman et al., 2000; Kim et al., 2003; Widyaratne and Zijlstra, 2008). In the present study, winter wheat cultivars showed lower NDF and ADF concentrations compared with spring wheat cultivars. Therefore, the variety and growing region of wheat may have a profound effect on the fiber content of wheat (Kim et al., 2005a). Moreover, within different cultivars of wheat, there were large variations in the CP (12.95% to 18.14%) and AA contents. This large variation may reflect the importance of varying climatic conditions on the protein content of the kernel rather than soil or genetic factors (Posner, 2000; Brown, 2010). It was discussed that abundant rainfall and low temperatures during the period from seeding to maturity results in lower protein content, whereas warm weather conditions cultivate wheat containing a high CP content (Smith and Gooding, 1999). Another reason may be the preferential breeding of protein-rich wheat for breadmaking, whereas wheat used as feed ingredient or as renewable source for biofuel production eventually contains relatively more carbohydrate, in particular starch (Kindred et al., 2008; Shewry, 2009). The AA concentrations in wheat cultivars in the present study were similar with those values in some previous studies (Anderson and Bell, 1983a; Peterson et al., 2008; Jha et al., 2011b; NRC, 2012).

Energy Contents of 12 Cultivars of Wheat

Significant differences were observed among the DE and ME contents and the ATTD of GE of 12 wheat cultivars ($P < 0.01$), ranging from 3,922 to 4,067 kcal/kg DM, 3,759 to 3,941 kcal/kg DM and 88.14% to 90.31%, respectively (Table 6). The DE content of winter wheat cultivars showed was greater ($P < 0.05$) that spring wheat cultivars. The lesser DE and ME content in wheat cultivar No. 5 may be due to lower GE. A low starch content and high ADF content in wheat cultivar No. 10 may account for its lower DE and ME contents. The DE and ME contents of wheat is highly dependent on the digestibility of carbohydrates as they are the largest contributors to the energy supply from grains (Kim et al., 2005a). The DE contents of wheat cultivars in our study were similar to the range reported in a previous study from 3,868 to 4,058 kcal/kg DM for five different classes of Canada western red spring wheat (Jha et al., 2011b). However, the DE contents in the present study were higher (3,922 to 4,067 kcal/kg vs. 3,177 to 3,798 kcal/kg) than the values in NRC (2012), Wiseman et al. (2000), and Zijlstra et al. (1999). Wiseman et al. (2000) studied

Table 6. The DE, ME, and the ATTD of GE of the 12 wheat cultivars fed to growing pigs in Exp. 1 (as DM basis)[1]

	Wheat cultivar number (n = 12)[2]													*P*-value	
Items	1	2	3	4	5	6	7	8	9	10	11	12	SEM	Wheat cultivates	Spring vs. Winter
DE, kcal/kg	4,010^{abcd}	3,948^{def}	4,015^{abc}	3,989^{bcde}	3,934^{ef}	3,974^{cdef}	4,060^{a}	3,965^{cdef}	4,067^{a}	3,922^{f}	4,010^{abcd}	4,044^{ab}	14.35	< 0.01	0.03
ME, kcal/kg	3,890^{abc}	3,838^{bcde}	3,890^{abc}	3,855^{bcd}	3,795^{de}	3,840^{bcde}	3,941^{a}	3,826^{cde}	3,914^{ab}	3,759^{e}	3,874^{abcd}	3,893^{abc}	16.74	< 0.01	0.35
ME/DE, %	97.04	97.22	96.91	96.63	96.52	96.58	97.11	96.47	96.24	95.90	96.60	96.33	0.12	0.59	0.46
ATTD of GE, %	89.41^{abc}	88.72^{bc}	89.65^{abc}	90.31^{a}	88.14^{c}	89.42^{abc}	89.54^{abc}	89.21^{abc}	90.20^{a}	89.02^{abc}	89.01^{abc}	90.04^{ab}	0.20	0.01	0.12

[1]Means in a row without a common superscript differ, $P < 0.05$.

[2]Sources of wheat cultivars are described in Table 1. Numbers 1 to 6 of wheat cultivars are winter wheat, and numbers 7 to 12 are spring wheat.

18 wheat cultivars at seven different growing areas and concluded the content of DE was affect by the variety and site of wheat. Therefore, the different results for a large variation in DE and ME contents of wheat cultivars may cause by wheat variety and growing conditions, such as locality, rainfall, and frost damage received during growth of wheat (Black, 2001; Kim et al., 2005a).

Correlation Among Physical, Chemical Characteristics and DE

For fiber components, NDF and ADF were not significantly correlated with DE content, respectively (Table 7), and this may be caused by the small variation in ADF and NDF content. Similar to our study, no significant relationship was found between NDF or ADF and DE value in wheat cultivars (Kim et al., 2004), but ADF and NDF had a significantly negative correlation with DE in other studies because of the decreased nutrient digestibility caused by fiber fraction (Batterham et al., 1980; Zijlstra et al., 1999). Consistent with our result, fiber components were negatively correlated with bulk weight in previous studies (Zijlstra et al., 1999), and the reason may be relative to the physical characteristics of fiber fractions, such as expansibility. Starch showed a high positive correlation with GE, and CP content in wheat had a positive correlation with GE and DE. These results were consistent with Noblet and Perez (1993) who reported starch and CP were the main components for providing energy

Prediction Equations for DE and ME

Several prediction equations were obtained after analyzing the data by stepwise regression analyses (Table 8), and most equations included GE and xylans. For prediction of DE, two equations (Nos. 1 and 2) were based on a single predictor, and the estimation based on CP was not as precise as that based on GE (RSD = 33.1 and 29.7, respectively). The precision of the equations was improved after including a second predictor, such as ADF, bulk weight, or xylans, and the three equations (Nos. 3, 4, and 5) with two predictors had similar precision (RSD = 24.5, 24.8, and 24.2, respectively). Introducing a third or fourth variable in the equations improved the prediction of DE with the RSD ranging from 16.3 to 21.1. Equation 11 had the best prediction for DE (R^2 = 0.98, RSD = 9.4), with the positive contributions of GE and EE and the negative contributions of ADF, xylans, and ash. This was in agreement with Batterham et al. (1980) who reported that GE and fiber components accounted for the variation in DE content in eight wheat cultivars, and King and Taverner (1975) reported that DE was precisely predicted by the equation including NDF and GE because of the small variations in CP, EE, and ash contents. In addition, high concentrations of fiber components could decrease the digestibility of nutrients, thus fiber fraction was usually considered as the best predictor in most published equations (Noblet and Perez 1993; Zijlstra et al., 1999). Xylans are the main structural carbohydrate in the cell wall of wheat (Nortey et al., 2008). Similar to our study, Zijlstra et al. (1999) reported that xylans were the best single predictor for DE content in 16 wheat cultivars, and Kim et al. (2004) reported that insoluble xylans content had a negative contribution to DE content with nine Australian wheat cultivars for weaning pigs. The digestibility of xylans is low for pigs due to the lack of endogenous enzyme, leading to a negative contribution to DE and ME. Prediction

Table 7. Correlation coefficients among chemical compositions and DE in the wheat cultivars (Exp. 1)

Items	DE	CP	EE	Starch	Ash	*P*	NDF	ADF	Xylans	GE	Bulk weight
DE	1.00										
CP	0.76**	1.00									
EE[1]	0.07	−0.13	1.00								
Starch	0.46	−0.68*	0.06	1.00							
Ash	−0.06	0.10	0.03	−0.12	1.00						
P	0.32	0.48	0.26	0.07	0.05	1.00					
NDF	−0.21	−0.18	0.16	−0.12	0.30	−0.13	1.00				
ADF	−0.15	−0.20	0.04	0.01	0.13	0.03	0.77**	1.00			
Xylans	0.29	0.46	0.26	−0.43	−0.05	0.48	0.04	0.31	1.00		
GE	0.81**	0.80**	0.30	0.62*	0.14	0.41	0.07	0.24	0.18	1.00	
Bulk weight	0.24	0.13	−0.01	−0.14	−0.12	−0.22	−0.42	−0.46	−0.49	0.14	1.00

[1]EE = ether extract.

*, ** represent $P < 0.05$ and $P < 0.01$, respectively.

equations for the ME of wheat cultivars were also developed. Two equations with a single predictor were obtained, and the equation with GE was more precise than that with CP (RSD, 29.8 vs. 39.3). The content of CP was considered as one of the best predictors for energy values (Noblet and Perez, 1993; Zijlstra et al., 1999). In the present study, CP was highly correlated with GE resulting in inclusion of GE in most equations instead of CP. Estimation precision for ME was improved when concentration of xylans was included as the second predictive factor along with GE (R^2 = 0.83, RSD = 23.1). The best equation was obtained after inclusion of GE, xylans, and ash (R^2 = 0.88, RSD = 21.1). The precision of the predictive equations obtained in our study was also tested using previously published data (Table 9). Interestingly, the equations with higher R^2 (equations 10 and 11) did not predict the DE accurately compared with lower R^2 (equations 3 and 4). In addition, the precision of the predictive equations obtained in our study was tested using previously published data (Lin et al., 1987; Zijlstra et al., 1999; Wiseman, 2000; Widyaratne and Zijlstra, 2008). However, limited data were available to test all equations because xylans were not determined in most studies (Table 9).

Table 8. Prediction equations for DE and ME (kcal/kg DM) in wheat from the physical and chemical characteristics[1]

No.	Regression equation[2]	R^2	RSD	*P*-value
1	DE = 3,665 + (21.2 × % CP)	0.57	33.1	<0.01
2	DE = -514 + (1.0 × GE)	0.66	29.7	<0.01
3	DE = -829 – (58.4 × % ADF) + (1.1 × GE)	0.79	24.5	<0.01
4	DE = -1,384 + (1.1 × GE) + (0.65 × bulk weight)	0.79	24.8	<0.01
5	DE = -2,261+ (1.5 × GE) – (41.9 × % Xylans)	0.79	24.2	<0.01
6	DE = -2,324 + (1.6× GE) – (48.1 × % Xylans) – (103.7 × % Ash)	0.86	21.1	<0.01
7	DE = -2,226 – (48.1 × % ADF) + (1.6 × GE) – (34.8× % Xylans)	0.88	19.6	<0.01
8	DE = -2,636 – (46.9 × % ADF) + (1.6 × GE) – (44.0 × % Xylans) + (20.3 × % EE)	0.92	16.7	<0.01
9	DE = -2,800 + (1.7 × GE) – (58.9 × % Xylans) – (111.1 × % Ash) + (23.4 × % EE)	0.92	17.2	<0.01
10	DE = -2,284 – (42.6 × % ADF) + (1.6 × GE) – (40.9 × % Xylans) – (87.9 × % Ash)	0.93	16.3	<0.01
11	DE = -2,738 – (40.8 × % ADF) + (1.7 × GE) – (51.5 × % Xylans) – (95.7 × % Ash) + (22.3 × % EE)	0.98	9.4	<0.01
12	ME = 3,543 + (20.4 × % CP)	0.47	39.3	0.01
13	ME = -1,063 + (1.1 × GE)	0.69	29.8	<0.01
14	ME = -2,936 + (1.6 × GE) – (44.9 × % Xylans)	0.83	23.1	<0.01
15	ME = -2,990 + (1.7 × GE) – (50.2 × % Xylans) – (87.6 × % Ash)	0.88	21.1	<0.01

[1]Regression equations were developed by stepwise regression analyses.

[2]EE = ether extract; RSD = residual standard deviation.

Table 9. Evaluation the accuracy of prediction equations for DE (kcal/kg DM) in wheat samples

Equation	Determined value[1]	Predicted value[2]	Difference	Reference
3	3,899	4,092	193	Zijlstra et al. (1999
3	3,806	4,028	222	Widyaratne and Zijlstra (2008)
3	3,908	4,013	105	Morgan et al. (1982)
3	3,748	3,978	230	Lin et al. (1987)
3	3,736	3,637	99	NRC (2012)
4	3,899	4,049	150	Zijlstra et al. (1999)
4	3,748	3,679	−69	Wiseman (2000)
5	3,899	4,226	327	Zijlstra et al. (1999)
5	3,806	4,102	296	Widyaratne and Zijlstra (2008)
8	3,899	4,195	296	Zijlstra et al. (1999)
8	3,806	4,123	317	Widyaratne and Zijlstra (2008)
10	3,899	4,374	475	Zijlstra et al. (1999)
10	3,806	4,274	468	Zijlstra et al. (1999)
11	3,899	4,415	516	Zijlstra et al. (1999)
11	3,806	4,310	504	Widyaratne and Zijlstra (2008)

[1]Determined value was the published data in previous references.

[2]Predicted value was calculated by the predictive equation in the present study.

The AID and SID of AA

Significant differences ($P < 0.05$) were observed in the AID values of CP and indispensable AA except for His among 10 different cultivars of wheat (Table 10). Similar to the AID values, significant differences ($P < 0.05$) were observed in the SID value of CP and indispensable AA except for His and Leu among the 10 different wheat cultivars (Table 11). There were differences in the AID and SID of CP and most indispensable AA among different cultivars of wheat, and the differences may be caused by the different concentrations of fiber fraction, CP, and AA balances in wheat cultivars. In the present study, wheat cultivars Nos. 1, 2, and 13 had lower AID and SID of AA than sample No. 11 due to their high NDF concentration, because fiber fraction has a negative effect on AA digestibility by increasing the evacuation rate and decreasing the retention time of digasta in the intestine (De Vries et al., 2012). The AID and SID of CP and most AA in our study were similar with values in the literature (Yin et al., 2008; Hackl et al., 2010), but these values were 3% to 7% and 2% to 5% (except for Trp) higher than NRC (2012). A previous study reported low AID values for indispensable AA (52.0% to 87.0%) in soft winter wheat (Haydon and Hobbs, 1991), and the result for the low AA digestibility may be caused by the high albumin, globulin, and gliadin protein, which contain low contents of AA and decrease AA digestibility (Shewry and Halford, 2002; Liu, 2011b). In the present study, Lys and Thr were the least digestible indispensable AA, which was in agreement with previous studies for Lys (Pedersen et al., 2007; Hennig et al., 2008) and Thr (Widyaratne and Zijlstra, 2008). The reason for the low SID of Lys is because the main portion of Lys is in the aleurone fraction of wheat which is known for its low digestibility (Green et al., 1987). A low SID value for Thr mainly resulted from its relatively high concentration of endogenous losses in comparison to other AA, instead of the cultivars of wheat (Sauer et al., 1981; Fan et al., 1993).

In a word, there were considerable differences in the chemical composition, DE and ME content as well as the AID and SID of CP and most AA among different wheat cultivars in China. The differences in chemical composition, especially the concentration of starch, fiber, and CP among the wheat cultivars may be responsible for the variability in the nutritive value of wheat samples. Therefore, the chemical composition of different wheat cultivars should be taken into consideration when formulating feeds for swine.

Table 10. The AID (%) of CP and AA in 10 wheat cultivars fed to growing pigs[1]

	Wheat cultivars (n = 10)[3]											*P*-value	
Items	1	2	5	6	7	11	13	14	15	16	SEM	Wheat clutivars	Spring vs. winter
CP	82.61^{cd}	82.02^{d}	88.54^{ab}	84.91^{abcd}	87.18^{abc}	89.46^{a}	84.75^{bcd}	85.74^{abcd}	86.42^{abcd}	86.70^{abc}	1.10	<0.01	<0.01
Indispensable AA													
Arg	87.92^{bc}	86.74^{c}	91.91^{a}	88.95^{abc}	90.68^{ab}	91.81^{a}	88.83^{abc}	86.74^{c}	90.82^{ab}	90.66^{ab}	2.11	0.01	0.14
His	88.57	86.86	90.32	88.63	88.57	91.33	88.16	91.06	89.72	90.93	3.25	0.12	0.43
Ile	84.32^{c}	83.64^{c}	89.85^{ab}	87.81^{ab}	88.67^{ab}	90.40^{a}	86.22^{bc}	88.27^{ab}	88.73^{ab}	88.66^{ab}	1.25	0.01	0.04
Leu	86.43^{c}	86.16^{c}	91.14^{ab}	89.03^{abc}	90.16^{ab}	91.55^{a}	87.88^{bc}	90.35^{ab}	90.36^{ab}	89.73^{ab}	1.03	0.01	0.09
Lys	76.86^{cd}	74.13^{d}	83.36^{a}	81.83^{abc}	77.35^{bcd}	84.73^{a}	80.42^{abc}	82.67^{ab}	83.75^{a}	82.13^{abc}	1.88	0.01	0.70
Met	89.71^{bc}	87.35^{d}	91.92^{ab}	90.33^{abc}	90.65^{ab}	92.49^{a}	88.06^{cd}	90.21^{abc}	92.42^{a}	91.14^{ab}	2.18	0.01	0.26
Phe	86.94^{d}	88.75^{cd}	92.03^{ab}	91.83^{ab}	91.67^{ab}	93.92^{a}	91.25^{b}	90.96^{bc}	92.10^{ab}	90.75^{bc}	1.42	0.01	0.07
Thr	72.37^{b}	72.18^{b}	83.42^{a}	79.35^{a}	81.78^{a}	83.51^{a}	77.64^{ab}	80.01^{a}	80.52^{a}	80.33^{a}	2.13	0.01	0.02
Trp	84.23^{b}	78.82^{c}	90.65^{a}	85.01^{ab}	87.06^{ab}	89.37^{ab}	85.07^{ab}	86.95^{ab}	84.94^{b}	85.29^{ab}	1.98	0.01	0.25
Val	80.74^{bc}	78.89^{c}	87.83^{a}	84.68^{ab}	84.74^{ab}	86.82^{a}	83.17^{abc}	87.15^{a}	80.74^{bc}	85.02^{ab}	1.36	0.01	0.43
Dispensable AA													
Ala	78.43	77.34	84.96	82.02	82.67	84.74	80.43	80.62	84.90	82.66	2.06	0.12	0.33
Asp	78.73^{c}	77.63^{c}	85.89^{a}	82.67^{ab}	83.11^{ab}	85.05^{a}	82.04^{ab}	81.06^{abc}	85.89^{a}	84.27^{ab}	1.32	0.02	0.03
Cys	86.74^{c}	86.63^{c}	91.52^{a}	88.78^{abc}	90.22^{ab}	91.43^{a}	87.67^{bc}	89.78^{abc}	90.89^{ab}	90.24^{ab}	1.24	0.04	0.01
Glu	94.75	94.35	96.24	95.56	95.89	96.42	94.45	95.22	96.05	95.56	0.52	0.08	0.02
Gly	79.36	76.75	85.67	81.03	84.23	85.24	79.06	77.54	83.56	84.05	2.54	0.11	0.22
Pro	89.64	91.82	94.23	91.56	94.24	94.13	90.78	83.22	88.89	93.89	3.08	0.29	0.11
Ser	86.15	85.43	90.56	88.01	89.78	90.89	87.45	87.33	90.04	88.67	1.40	0.09	0.12
Tyr	87.56	88.03	90.89	94.78	91.24	98.25	94.22	81.23	91.78	95.56	2.70	0.68	0.41

[1]Means in a row without a common superscript differ, $P < 0.05$.

[2]Sources of wheat cultivars are described in Table 1.

[3]Numbers 7 and 11 of wheat cultivars belong to spring wheat, and the other cultivars of wheat are winter wheat.

Table 11. The SID (%) of CP and AA in 10 wheat cultivars fed to growing pigs[1]

	Wheat cultivars (n = 10)[3]											*P*-value	
Items	1	2	5	6	7	11	13	14	15	16	SEM	Wheat clutivars	Spring vs. winter
CP	88.02^{bc}	87.56^{c}	93.89^{a}	90.33^{abc}	91.56^{abc}	94.04^{a}	90.05^{abc}	90.12^{abc}	92.13^{abc}	92.44^{ab}	1.54	0.02	0.05
Indispensable AA													
Arg	90.67^{bc}	89.54^{c}	94.56^{a}	91.89^{abc}	93.11^{abc}	94.52^{a}	91.24^{abc}	89.78^{c}	93.56^{ab}	94.04^{ab}	1.91	0.01	0.07
His	91.78	90.25	93.56	91.89	91.56	94.13	91.24	93.32	92.89	93.78	1.75	0.33	0.53
Ile	88.53^{bc}	88.14^{c}	94.03^{a}	92.05^{ab}	92.22^{ab}	94.03^{a}	90.21^{abc}	91.15^{abc}	93.12^{a}	92.43^{ab}	1.25	0.01	0.07
Leu	90.21	90.14	93.23	92.89	93.42	94.78	91.54	93.03	93.11	93.34	1.13	0.07	0.02
Lys	83.04^{bc}	80.56^{c}	89.23^{ab}	87.41^{ab}	83.56^{abc}	89.89^{a}	85.42^{abc}	86.03^{abc}	89.01^{ab}	87.34^{ab}	0.88	0.02	0.59
Met	91.78^{bcde}	89.56^{e}	93.89^{ab}	92.42^{abcd}	92.45^{abcd}	94.22^{ab}	90.31^{de}	91.42^{cde}	94.45^{a}	93.02^{abc}	1.18	0.01	0.09
Phe	90.56^{c}	91.78^{bc}	95.56^{a}	94.67^{a}	94.24^{ab}	96.02^{a}	93.89^{ab}	93.78^{ab}	95.41^{a}	94.24^{ab}	1.04	0.01	0.17
Thr	80.54^{b}	80.52^{b}	90.14^{a}	87.41^{a}	88.89^{a}	90.78^{a}	85.20^{ab}	85.67^{ab}	88.78^{a}	87.89^{a}	1.13	0.01	0.03
Trp	89.23^{ab}	84.42^{b}	94.56^{a}	90.33^{a}	91.56^{a}	94.24^{a}	89.89^{a}	89.67^{a}	91.14^{a}	90.61^{a}	1.02	0.02	0.06
Val	85.89^{bc}	84.32^{c}	92.89^{a}	89.78^{ab}	89.30^{abc}	91.41^{a}	88.12^{abc}	90.13^{ab}	91.12^{ab}	89.78^{ab}	1.76	0.02	0.33
Dispensable AA													
Ala	84.31	83.33	90.51	87.89	87.72	90.01	85.89	86.62	90.81	88.04	2.16	0.17	0.28
Asp	84.72^{c}	83.52^{c}	91.32^{a}	88.56^{abc}	88.31^{abc}	90.52^{ab}	87.21^{bc}	86.78^{bc}	91.52^{a}	89.42^{ab}	1.12	0.03	0.02
Cys	90.63	90.61	95.14	92.53	93.43	94.78	91.52	93.67	95.05	93.56	1.63	0.07	0.22
Glu	96.04	95.61	97.53	96.89	96.89	97.43	95.78	96.63	97.42	96.78	1.31	0.11	0.09
Gly	87.73	85.53	94.02	89.78	91.71	93.04	87.14	86.02	92.54	92.33	2.24	0.16	0.11
Pro	94.32	96.92	98.89	96.33	98.12	98.22	95.53	88.04	94.11	98.21	2.68	0.38	0.36
Ser	90.31	89.74	94.67	92.32	93.43	94.53	91.51	91.62	94.33	92.72	1.83	0.15	0.17
Tyr	90.60	91.02	94.21	99.52	96.14	99.41	95.82	86.21	95.52	98.67	5.70	0.81	0.43

[1]Means in a row without a common superscript differ, $P < 0.05$.

[2]Sources of wheat cultivars are described in Table 1.

[3]Numbers 7 and 11 of wheat cultivars belong to spring wheat, and the other cultivars of wheat are winter wheat.

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