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Amino Acid, Carbohydrate, and Fat Composition of Soybean Meals Prepared at 55 Commercial U.S. Soybean Processing Plants

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To quantify variation in U.S. soybean meals (SBM), samples were collected from 55 U.S. soybean (SB) processing plants located in seven of the geographic SB maturity zones at three time points. These samples were analyzed for crude and acid-hydrolyzed fat, oligosaccharide, and amino acid concentrations. Acid-hydrolyzed fat concentrations were poorly correlated ($r = 0.28$) to crude fat concentrations and were higher for SBM prepared in the southern zones (V−VII) as compared with the northern zones (I and II). Raffinose and verbascose concentrations were lowest ($P < 0.05$) for SBM prepared in northern maturity zones, while stachyose concentrations were highest for SBM prepared in central maturity zones (III and IV). Total essential, total nonessential, and total amino acid concentrations were lowest for SBM prepared in northern zones. There was variation in oligosaccharide and amino acid concentrations over time, probably due to variation in composition of SB arriving at the plants within maturity zone.

KEYWORDS: Soybean meal; fat; amino acids; oligosaccharides

INTRODUCTION

Large variation exists in environmental conditions in which soybeans (SB) are grown in the United States. These variations led to the classification of maturity zones based on geographic areas where SB are grown, with different genetic varieties bred for optimal growth in these zones. Additionally, SB varieties are categorized as northern (grown in zones 0−IV) or southern (grown in zones V−VIII) based on area of optimal growth (*1*). Differences in genetic varieties and environmental conditions usually result in lower protein and higher oil concentrations in northern than southern varieties and less variation in protein and oil concentrations in northern SB (*1*).

Additionally, differences in processing conditions used to prepare soybean meal (SBM), such as moisture, drying time, and toasting or drying temperature, can result in differences in SBM composition and quality. Differences in the amounts of oil refining byproducts added back to the SBM may result in differences in fat concentrations in the resultant SBM. Oligosaccharides found in SB are not removed during processing and can be concentrated, which can lead to decreased dry matter digestibilities and increased microbial growth and potentially improved gastrointestinal health (*2*). It is important to quantify the concentrations of key nutrients and antinutritional factors in SBM in order to determine their nutritional value for swine and poultry. Therefore, the objectives of this study were to determine concentrations of crude and acid-hydrolyzed fat, oligosaccharides, and amino acids in SBM produced at commercial SB processing plants located in maturity zones I−VII and to determine the relationship between crude and acid-hydrolyzed fat concentrations.

MATERIALS AND METHODS

Soybean Meals. Fifty-five SB processing plants located in SB maturity zones I (northern United States) through VII (southern United States) were used. A map of the maturity zones is presented by Grieshop et al. (*3*). Each plant was visited at approximately 2-week intervals over a 4-week period to collect a total of three samples from each plant. Samples from individual plants were not pooled but rather analyzed individually as a repeated measure within plant. During each visit, approximately 2 kg of SBM was collected for analysis. All samples were collected while the plants were running normally, and no processing information was collected.

Laboratory Analyses. Prior to analysis, SBM were ground through a 2-mm screen using a Wiley Mill, model 4 (Thomas-Wiley, Swedesboro, NJ). Acid-hydrolyzed fat content of the samples was determined by acid hydrolysis (*4*) followed by ether extraction according to Budde (*5*), while crude fat concentrations were determined according to AOAC (*6*). Oligosaccharide (raffinose, stachyose, and verbascose) concentrations of all samples were quantified by HPLC as described by Smiricky et al. (*7*). Soybean meal samples were prepared for amino acid analyses by using both acid hydrolysis (*8*) and oxidation methods (*9*). The amino acid concentrations then were determined using ion-exchange chromatography (*10*) on a GoldDV711 chromatograph (Beckman, Fullerton, CA). If the error between duplicates of a sample was greater than 5%,

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Table 1. Crude and Acid-Hydrolyzed Fat Concentrations (%, dry matter basis) of Soybean Meals Prepared at Commercial U.S. Soybean Processing Plants That Were Sampled at Three Collection Times

	soybean maturity zone						
item	1	2	3	4	5	6	7
n	4	10	21	6	3	4	2
			Crude Fat				
mean within zone	1.87	1.60	1.76	2.27	1.94	1.82	1.50
collection 1	1.45	1.55	1.85	2.03	1.89	2.53	1.26
collection 2	2.16	1.61	1.64	2.17	2.13	1.58	1.77
collection 3	2.00	1.63	1.80	2.60	1.82	1.36	1.48
SEM[a]	0.33	0.21	0.15	0.27	0.37	0.32	0.47
			Acid-Hydrolyzed Fat[b,c]				
mean within zone	3.92	3.62	3.79	4.07	4.03	4.20	4.27
collection 1	4.07	3.61	3.62	3.76	4.24	4.75	3.54
collection 2	4.44	3.67	4.05	4.48	4.05	4.06	4.58
collection 3	3.26	3.58	3.69	3.96	3.79	3.81	4.69
SEM	0.30	0.19	0.13	0.24	0.34	0.30	0.42

[a] SEM = pooled standard error of mean across collection times within a zone. [b] Interaction between maturity zone and collection time ($P < 0.05$). [c] Northern zones (I and II) vs southern zones (V–VII) ($P < 0.05$).

the assay was repeated in duplicate, with the exception of crude and acid-hydrolyzed fat where a variation of less than 10% was accepted.

Statistical Analysis. Statistical comparisons were made using the mixed models procedure of SAS (SAS Institute, Cary, NC). Because the variance and covariance matrix met the Huynh-Feldt condition, data were analyzed as a split-plot in time. The fixed effects of maturity zone, collection time, and the interaction between zone and collection time were examined. If the interaction was not significant ($P > 0.05$), then the main effects of zone and collection time were examined. Orthogonal polynomial contrasts were used to determine if there was a linear or quadratic effect of collection time. To make comparisons among maturity zones, the following contrasts were used: northern maturity zones (I and II) vs central zones (III and IV); northern zones (I and II) vs southern zones (V−VII); and central zones (III and IV) vs southern zones (V−VII). All data are presented as least squares means. The correlation coefficient for crude versus acid-hydrolyzed fat concentrations was determined using the correlation procedure of SAS (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Comparison of Acid Hydrolyzed Fat to Crude Fat Concentrations. There were no differences in crude fat concentrations among maturity zones or collection times (**Table 1**). Crude fat concentrations were much lower than 3.3%, the value reported by the NRC (*11*), but were similar to values reported by Grieshop et al. (*3*) for SBM collected from nine solvent extraction processing plants in the United States (range, 0.07−2.3% of dry matter) and Baize (*12*) for dehulled (1.48%) and nondehulled (1.67%) SBM produced at 18 and 20 U.S. processing plants, respectively. The difference between the NRC values and other published values may be due to variation in analytical procedures used.

An interaction existed ($P < 0.05$) between maturity zone and collection time for acid-hydrolyzed fat concentrations, indicating that changes in concentration among collection times were not consistent among maturity zones. These differences in acid-hydrolyzed fat concentrations among collection times is perhaps due to variation in composition of the SB reaching the processing plant as well as to processing conditions used. Additionally, acid-hydrolyzed fat concentrations were higher ($P < 0.05$) in SBM processed in southern maturity zones than in northern maturity zones. Acid-hydrolyzed fat concentrations

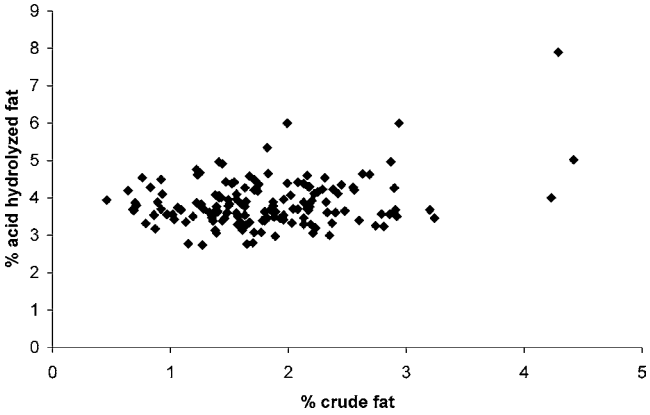

Figure 1. Correlation between crude fat and acid hydrolyzed fat concentrations (%, dry matter) in U.S. soybean meal samples ($y = 0.26x + 3.39$; $r = 0.28$).

of SBM in the current study were also similar to those (range, 3.3−4.5% of dry matter) of Grieshop et al. (*3*).

Crude fat and acid-hydrolyzed fat concentrations were poorly correlated ($r = 0.28$; **Figure 1**), with acid-hydrolyzed fat concentrations being 1.5−3.3 times higher than the corresponding crude fat concentration. Crude fat is the industry standard for fat measurement in the feed industry. However, crude fat analysis does not quantify phospholipids and sphingolipids. Acid-hydrolyzed fat analysis allows for measurement of all lipids, which is why it is the standard method of fat analysis used in the human and companion animal food industries. Gums and soapstocks commonly added to the SBM during processing contain fat in the forms of soaps, triglycerides, and phosphatides; therefore, a large percentage of the fat in these additives is not quantified by the crude fat procedure (*13*). However, the fat from these sources is partially available to meet the animal's energy needs. On the basis of the poor correlation between the two analytical procedures, it would be beneficial to analyze acid-hydrolyzed fat concentrations rather than crude fat concentrations in SBM in order to develop a more accurate database on this important ingredient.

Oligosaccharide Composition. Concentrations of the oligosaccharides, raffinose and verbascose, were lowest ($P < 0.05$) in northern maturity zones, while stachyose concentrations were highest in central maturity zones (**Table 2**). There was a significant interaction between maturity zone and collection time for stachyose concentrations, indicating differences in the variation of stachyose concentrations in SBM among collection times and maturity zones. There was a decrease ($P < 0.05$) in raffinose concentration over time with concentrations of 12.7, 12.0, and 11.9 mg/g for collections 1−3, respectively, most likely a result of variation in the SB arriving at the plant on specific collection days. Oligosaccharide concentrations were higher than those of 5.0−7.4, 30.8−41.3, and 1.2−1.7 mg/g found by Grieshop et al. (*3*) for raffinose, stachyose, and verbascose, respectively, in SBM from nine commercial solvent extraction processing plants in the United States. The higher concentrations found in the current study may be more representative of SBM oligosaccharide concentrations because a larger proportion of SBM processing plants were surveyed in the current study.

While SBM processed in northern maturity zones had lower concentrations of raffinose and verbascose, they also had higher concentrations of total dietary fiber (*3*), which would be less fermentable than oligosaccharides. This may indicate a lower digestibility SBM is available from processing plants located

Table 2. Oligosaccharide Concentrations (mg/g, dry matter basis) of Soybean Meals Prepared at Commercial U.S. Soybean Processing Plants That Were Sampled at Three Collection Times

	soybean maturity zone						
item	1	2	3	4	5	6	7
				Raffinose[a,b]			
mean within zone	10.52	10.81	12.71	12.33	12.52	13.79	13.47
collection 1	10.55	11.01	13.02	13.35	12.31	14.43	13.94
collection 2	9.91	10.76	12.61	11.84	12.98	13.75	13.46
collection 3	11.12	10.66	12.51	11.81	12.27	13.18	13.02
SEM[c]	1.11	0.70	0.48	0.90	1.28	1.11	1.56
				Stachyose[a,d,e]			
mean within zone	51.72	53.10	55.62	55.14	52.47	51.10	51.16
collection 1	51.77	52.82	56.36	56.76	47.47	45.93	51.34
collection 2	48.94	54.12	55.42	54.39	55.70	53.73	50.91
collection 3	54.45	52.36	55.07	54.27	54.24	53.65	51.24
SEM	1.77	1.12	0.77	1.44	2.04	1.77	2.50
				Verbascose[a,b,f]			
mean within zone	1.33	1.46	1.87	2.17	1.78	2.22	1.99
collection 1	1.38	1.44	1.90	2.40	1.59	2.49	2.09
collection 2	1.29	1.52	1.92	2.12	1.96	2.34	2.18
collection 3	1.31	1.42	1.80	2.00	1.81	1.85	1.71
SEM	0.14	0.09	0.06	0.11	0.16	0.14	0.18

[a] Northern zones (I and II) vs central zones (III and IV) ($P < 0.05$). [b] Northern zones (I and II) vs southern zones (V–VII) ($P < 0.05$). [c] SEM = pooled standard error of mean across collection times within a zone. [d] Interaction between maturity zone and collection time significant ($P < 0.05$). [e] Central zones (III and IV) vs southern zones (V–VII) ($P < 0.05$). [f] Linear effect of collection time ($P < 0.05$).

in the northern zones, potentially due to differences in carbohydrate deposition during SB seed development. Environmental differences in the northern maturity zones compared to the central and southern zones, such as cooler temperatures, shorter photoperiod, and shorter growing season, may result in different rates of fiber and oligosaccharide deposition.

Soy oligosaccharides are thought to be poorly digested, resulting in poor utilization of energy from SBM. Studies examining the effects of adding soy oligosaccharides on ileal nutrient digestibilities by swine resulted in equivocal outcomes. Addition of 3.50 or 4.78% soy oligosaccharides to purified swine diets containing casein as the protein source led to a 5% unit decrease in ileal dry matter and nitrogen digestibilities (*2*), while supplementation of 1.3% oligosaccharides to a swine diet containing SBM (3.74% total oligosaccharides) did not decrease digestibility of dry matter or nitrogen as compared to results obtained for swine fed semipurified diets containing SBM or soy protein isolate as the sole protein source (*7*). A 0.04 and 0.08 kg/d decrease in weight gain by weanling pigs was noted when 1 and 2% stachyose, respectively, was added to SBM-free diets, but growth rates were similar to when SBM was included in the diet (*14*). The results of these studies indicate that oligosaccharides at concentrations found naturally in a typical corn-SBM diet may have little effect on nutrient digestibilities.

Amino Acid Composition. Arginine, histidine, and methionine concentrations were different among SBM prepared in different maturity zones (**Table 3**). Concentrations of arginine and histidine were lowest ($P < 0.05$) for SBM processed in the northern zones (means, 3.77% arginine and 1.37% histidine for zones I and II vs 3.96 and 1.43% for zones III−VII). Concentrations in the SBM processed in the northern zones also were less than those reported by the NRC (*10*) for dehulled, solvent extracted SBM (3.87 and 1.42% of dry matter for arginine and histidine, respectively). Methionine concentrations in SBM processed in the central zones were highest (mean, 0.84% for zones III and IV vs 0.78% for zones I, II, V, VI, and VII) and were higher than the 0.74% value reported in the NRC (*11*).

Table 3. Concentrations (%, dry matter basis) of Individual Essential Amino Acids in Soybean Meals Prepared at Commercial U.S. Soybean Processing Plants That Were Sampled at Three Collection Times

	soybean maturity zone						
item	1	2	3	4	5	6	7
				Arginine[a,b]			
mean within zone	3.77	3.77	3.98	3.93	3.89	4.05	3.93
collection 1	3.69	3.67	3.88	3.72	3.90	4.03	3.75
collection 2	3.94	3.81	4.01	3.96	3.99	3.98	4.09
collection 3	3.69	3.85	4.05	4.10	3.79	4.15	3.96
SEM[c]	0.14	0.09	0.06	0.11	0.15	0.14	0.19
				Histidine[a,b,d]			
mean within zone	1.36	1.37	1.43	1.43	1.40	1.46	1.42
collection 1	1.34	1.31	1.39	1.34	1.37	1.42	1.36
collection 2	1.37	1.42	1.43	1.43	1.44	1.47	1.47
collection 3	1.36	1.38	1.47	1.53	1.39	1.49	1.43
SEM	0.05	0.03	0.02	0.04	0.05	0.05	0.06
				Isoleucine[e]			
mean within zone	2.28	2.28	2.37	2.33	2.32	2.37	2.36
collection 1	2.14	2.07	2.21	2.07	2.17	2.20	2.20
collection 2	2.34	2.37	2.39	2.36	2.43	2.41	2.44
collection 3	2.36	2.41	2.50	2.55	2.38	2.49	2.45
SEM	0.08	0.05	0.04	0.07	0.09	0.08	0.10
				Leucine[d]			
mean within zone	4.10	4.09	4.26	4.24	4.14	4.23	4.30
collection 1	4.05	3.95	4.15	4.01	4.09	4.01	4.04
collection 2	4.12	4.15	4.27	4.25	4.21	4.27	4.56
collection 3	4.14	4.18	4.36	4.46	4.12	4.41	4.29
SEM	0.13	0.08	0.06	0.10	0.14	0.12	0.17
				Lysine[d]			
mean within zone	3.23	3.23	3.31	3.36	3.30	3.37	3.30
collection 1	3.19	3.11	3.27	3.20	3.22	3.24	3.21
collection 2	3.21	3.28	3.17	3.33	3.36	3.39	3.37
collection 3	3.30	3.31	3.48	3.57	3.30	3.50	3.33
SEM	0.16	0.10	0.07	0.12	0.17	0.15	0.21
				Methionine[a,d,f]			
mean within zone	0.80	0.75	0.86	0.82	0.77	0.77	0.78
collection 1	0.82	0.62	0.81	0.71	0.60	0.60	0.61
collection 2	0.74	0.80	0.88	0.86	0.78	0.85	0.80
collection 3	0.84	0.84	0.90	0.88	0.93	0.86	0.94
SEM	0.06	0.04	0.03	0.05	0.07	0.06	0.08
				Phenylalanine			
mean within zone	2.66	2.59	2.67	2.68	2.61	2.73	2.69
collection 1	2.57	2.54	2.64	2.58	2.58	2.72	2.62
collection 2	2.76	2.62	2.70	2.67	2.70	2.67	2.78
collection 3	2.67	2.60	2.67	2.80	2.56	2.80	2.69
SEM	0.09	0.06	0.04	0.07	0.10	0.09	0.12
				Threonine[d]			
mean within zone	1.67	1.75	1.82	1.82	1.83	1.82	1.82
collection 1	1.54	1.63	1.75	1.56	1.87	1.72	1.74
collection 2	1.76	1.81	1.82	1.88	1.78	1.90	1.90
collection 3	1.73	1.81	1.88	2.02	1.84	1.85	1.81
SEM	0.08	0.05	0.04	0.07	0.10	0.08	0.11
				Valine[e]			
mean within zone	2.38	2.37	2.46	2.43	2.41	2.48	2.46
collection 1	2.24	2.15	2.31	2.16	2.26	2.35	2.29
collection 2	2.44	2.46	2.48	2.47	2.54	2.51	2.56
collection 3	2.46	2.48	2.60	2.66	2.43	2.58	2.53
SEM	0.09	0.06	0.04	0.07	0.10	0.09	0.11

[a] Northern zones (I and II) vs central zones (III and IV) ($P < 0.05$). [b] Northern zones (I and II) vs southern zones (V–VII) ($P < 0.05$). [c] SEM = pooled standard error of mean across collection times within a zone. [d] Linear effect of collection time ($P < 0.05$). [e] Quadratic effect of collection time ($P < 0.05$). [f] Central zones (III and IV) vs southern zones (V–VII) ($P < 0.05$).

Concentrations of histidine, isoleucine, leucine, lysine, methionine, threonine, and valine varied among collection times.

Table 4. Concentrations (%, dry matter basis) of Individual Nonessential Amino Acids in Soybean Meals Prepared at Commercial U.S. Soybean Processing Plants That Were Sampled at Three Collection Times

	soybean maturity zone						
item	1	2	3	4	5	6	7
			Alanine[a,b]				
mean within zone	2.27	2.28	2.41	2.38	2.32	2.43	2.40
collection 1	2.29	2.24	2.37	2.23	2.33	2.40	2.31
collection 2	2.27	2.30	2.39	2.40	2.34	2.40	2.48
collection 3	2.23	2.31	2.45	2.50	2.30	2.50	2.41
SEM[c]	0.07	0.04	0.03	0.05	0.08	0.07	0.10
			Aspartate				
mean within zone	6.09	6.15	6.39	6.40	6.29	6.43	6.28
collection 1	6.06	6.06	6.41	6.13	6.38	6.41	6.16
collection 2	6.17	6.20	6.37	6.40	6.35	6.38	6.50
collection 3	6.04	6.19	6.40	6.68	6.14	6.50	6.19
SEM	0.20	0.13	0.09	0.16	0.22	0.19	0.26
			Cysteine[a,d,e]				
mean within zone	0.86	0.81	0.92	0.87	0.83	0.85	0.83
collection 1	0.88	0.70	0.89	0.79	0.67	0.69	0.66
collection 2	0.80	0.86	0.94	0.90	0.86	0.94	0.87
collection 3	0.90	0.87	0.93	0.92	0.96	0.94	0.97
SEM	0.06	0.04	0.02	0.05	0.06	0.06	0.08
			Glutamate[a,b]				
mean within zone	9.39	9.48	9.98	9.97	9.71	10.15	9.97
collection 1	9.48	9.56	10.02	9.66	10.07	10.14	9.68
collection 2	9.35	9.44	9.97	9.97	9.67	9.99	10.25
collection 3	9.33	9.44	9.94	10.28	9.41	10.31	9.99
SEM	0.31	0.19	0.14	0.24	0.34	0.29	0.40
			Glycine[a,b]				
mean within zone	2.20	2.21	2.32	2.28	2.28	2.36	2.32
collection 1	2.20	2.18	2.32	2.26	2.33	2.35	2.25
collection 2	2.18	2.23	2.32	2.33	2.27	2.32	2.38
collection 3	2.21	2.25	2.32	2.26	2.23	2.41	2.33
SEM	0.06	0.04	0.03	0.05	0.07	0.06	0.08
			Proline[f]				
mean within zone	2.93	3.09	3.07	3.07	3.16	2.96	2.95
collection 1	2.84	2.85	2.95	2.86	2.86	2.89	2.78
collection 2	3.01	3.37	3.11	3.04	3.49	2.86	3.19
collection 3	2.93	3.06	3.15	3.30	3.12	3.12	2.90
SEM	0.15	0.09	0.07	0.12	0.16	0.14	0.19
			Serine[e]				
mean within zone	3.08	3.03	3.17	3.20	3.05	3.23	3.05
collection 1	3.23	3.15	3.27	3.30	3.15	3.29	3.06
collection 2	3.02	2.97	3.13	3.09	3.06	3.11	3.07
collection 3	2.98	2.97	3.10	3.19	2.94	3.30	3.02
SEM	0.13	0.08	0.06	0.10	0.14	0.12	0.17
			Tyrosine				
mean within zone	1.75	1.74	1.82	1.81	1.78	1.85	1.81
collection 1	1.70	1.73	1.80	1.74	1.82	1.89	1.75
collection 2	1.84	1.76	1.81	1.82	1.82	1.79	1.87
collection 3	1.71	1.73	1.84	1.87	1.71	1.88	1.81
SEM	0.07	0.04	0.03	0.05	0.07	0.07	0.08

[a] Northern zones (I and II) vs central zones (III and IV) ($P < 0.05$). [b] Northern zones (I and II) vs southern zones (V–VII) ($P < 0.05$). [c] SEM = pooled standard error of mean across collection times within a zone. [d] Central zones (III and IV) vs southern zones (V–VII) ($P < 0.05$). [e] Linear effect of collection time ($P < 0.05$). [f] Quadratic effect of collection time ($P < 0.05$).

Concentrations of histidine, leucine, lysine, methionine, and threonine increased linearly from collections 1−3, while isoleucine and valine concentrations were highest during collection 2. There was an interaction ($P < 0.05$) between maturity zone and collection time for methionine concentrations. The differences in concentrations between collection times is an indicator of variation in the composition of SB arriving at the same processing plants on different days. This variation could be due to variations in genetic variety of the SB and (or) to differences in management practices employed by the SB producer.

Table 5. Concentrations (%, dry matter basis) of Total Essential, Total Nonessential, and Total Amino Acids in Soybean Meals Prepared at Commercial U.S. Soybean Processing Plants That Were Sampled at Three Collection Times

	soybean maturity zone						
item	1	2	3	4	5	6	7
			Total Essential Amino Acids[a−c]				
mean within zone	22.3	22.2	23.2	23.0	22.7	23.7	23.0
collection 1	21.6	21.0	22.4	21.3	22.1	23.5	21.7
collection 2	22.7	22.7	23.2	23.2	23.2	23.4	24.0
collection 3	22.5	22.9	24.0	24.6	22.7	21.1	23.4
SEM[d]	0.68	0.43	0.30	0.55	0.75	0.68	0.96
			Total Nonessential Amino Acids[a,b]				
mean within zone	28.5	28.8	30.1	30.0	29.4	30.2	29.6
collection 1	28.7	28.5	30.0	29.0	29.6	30.0	28.5
collection 2	28.6	29.1	30.1	30.0	29.8	29.8	30.6
collection 3	28.3	28.8	30.2	31.0	28.8	31.0	29.6
SEM	0.88	0.56	0.39	0.69	0.96	0.88	1.24
			Total Amino Acids[a−c]				
mean within zone	50.8	51.0	53.3	53.0	52.1	53.9	52.6
collection 1	50.2	49.5	52.4	50.3	51.6	53.5	50.3
collection 2	51.3	51.8	53.3	53.2	53.1	53.2	54.6
collection 3	50.9	51.7	54.2	55.6	51.6	55.0	53.0
SEM	1.48	0.94	0.65	1.18	1.67	1.48	2.09

[a] Northern zones (I and II) vs central zones (III and IV) ($P < 0.05$). [b] Northern zones (I and II) vs southern zones (V–VII) ($P < 0.05$). [c] Linear effect of collection time ($P < 0.05$). [d] SEM = pooled standard error of mean across collection times within a zone.

As regards nonessential amino acids, concentrations of alanine, cysteine, glutamate, and glycine varied among maturity zones, with the lowest concentrations of alanine, glutamate, and glycine occurring for SBM processed in the northern zones and the highest concentrations of cysteine occurring for SBM processed in the central zones (**Table 4**). Additionally, concentrations of cysteine increased and serine decreased from collection times 1−3, and concentrations of proline were highest for collection time 2. The linear and quadratic effects of collection time on amino acid concentration are most likely due to changes in composition of the SB arriving at the processing plant over time rather than changes in processing conditions within the plant. Because the samples were collected at 2-week intervals, no major changes in processing conditions within the plant were likely to have occurred.

Concentrations of total essential (TEAA), total nonessential (TNEAA), and total amino acids (TAA) were lowest ($P < 0.05$) in northern maturity zones (**Table 5**). Additionally, concentrations of TEAA and TAA increased from collection times 1−3. Total essential amino acids concentrations in zones III−VII were similar to the 23.8% value reported in NRC (*11*).

Soybean seed protein concentrations can be affected by environmental conditions in which the SB are grown. Protein percentage increases linearly as the temperature in which the SB are grown increases above 28 °C, a temperature that is reached in the growing season in central and southern maturity zones. A sharp increase in SB protein and methionine concentrations from 34 to 42% and from 0.99 to 2.53%, respectively, was noted when daytime growing temperature was increased from 30 to 33 °C (*15*). Westgate et al. (*16*) noted that temperature had a direct effect on sucrose uptake and utilization by the plant. At high temperatures, the carbon from sucrose is incorporated into protein, while at lower temperatures, the carbon from sucrose is incorporated into oil within the seed. The differences in temperatures among maturity zones may play a role in the protein concentrations found in the SB and, therefore, in the resultant SBM. In addition, variation in

management practices used during SB growth (such as amount of nitrogen fertilizer applied, use of irrigation, and planting date) also may result in differences in protein and oil concentrations in the SB seed.

Differences in the proportions of the storage proteins, glycinin and β-conglycinin, of SB could result in differences in the proportions of amino acids found in the SB. β-Conglycinin is thought to be more nutritious as it contains higher amounts of the sulfur amino acids. Differences in proportion of glycinin and β-conglycinin and their subunits found in SB were noted among 14 different cultivars and among seven different growing locations within one maturity zone (*17*). Perhaps differences exist in the proportion and type of the storage proteins among cultivars grown within and among maturity zones, which would affect the amino acid composition of the SB and, therefore, the SBM.

Oligosaccharide and amino acid composition of SBM prepared at commercial soybean processing plants located in different maturity zones in the United States varied, both among maturity zones and over time. The SBM prepared in northern zones was somewhat unique as compared to that from the central and southern zones, having lower concentrations of raffinose and verbascose, higher concentrations of dietary fiber, and lower concentrations of total essential, total nonessential, and total amino acids. While variation in SB and SBM composition is to be expected, it is important that current data on the composition of SBM specific to each maturity zone be available for use in formulation of diets fed to nonruminants. By further characterizing composition of U.S. SBM, a more accurate description of its overall value in animal diets is possible. Additionally, it is important that accurate measures of compositional analysis be employed to ensure that the animal is provided the proper amounts of nutrients at the lowest cost to the producer.

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