Amino Acid Composition of Different Varieties of Foxtail Millet (*Setaria italica*)

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The amino acid composition of glutinous and nonglutinous foxtail millet grains was determined by microbiological assay. There were no differences in amino acid composition between the glutinous and nonglutinous types. Based on the FAO/WHO pattern for selected nutritionally essential amino acids, the millet was deficient in lysine. There were positive correlations for leucine-phenylalanine, lysine-arginine, and phenylalanine-tyrosine and negative correlations for glycine–glutamic acid, leucine-lysine, and glutamic acid–lysine at the 1% level of probability. The crude protein content showed positive correlations with glutamic acid and proline contents and negative correlations with lysine, aspartic acid, and arginine contents at the 1% level of probability.

Foxtail millet (*Setaria italica*) is grown extensively in China, India, the East Indies, and other parts of Asia, temperate Europe, North Africa, Canada, and the United States. The grain is used for both food and feed, except in North America where it is grown as a forage crop because it is slightly less palatable. Very little work has been carried out on the amino acid composition of this millet. However, Baptist and Perera (1956), Mangay *et al.* (1957), and Taira (1962a) have reported that foxtail millet is deficient in lysine, and Taira (1962a) has suggested that glutinous and nonglutinous types of the millet may vary in lysine content. Therefore, investigations were undertaken to study the amino acid composition of glutinous and nonglutinous types of foxtail millet.

MATERIALS AND METHODS

Seeds of foxtail millet were collected from the Kikyogahara Branch of the Nagano Agricultural Experiment Station, Japan. Ten varieties, five each of nonglutinous and glutinous types, were obtained: Kumamoto-chima No. 1, Komemasari, Shinano No. 1, Daiohkoku, and Rikuu No. 1 (nonglutinous types) and Showa-mochi, Nekoashi, Takayama-shiromochi, Tsugaru-wase, and Shiroawa (glutinous types). All samples were dehulled by using conventional seed-cleaning equipment and were ground to pass a 40-mesh sieve. Total nitrogen was determined by the macro-Kjeldahl method (Association of Official Agricultural Chemists, 1965) and the crude protein value of samples was expressed as N × 6.25.

Each sample was sealed in a glass tube and was hydrolyzed by autoclaving with 4*N* hydrochloric acid at 121° C. for 6 hours. This acid hydrolyzate was used for evaluating all amino acids except tryptophan. For tryptophan analysis, hydrolysis was carried out by autoclaving at 121° C. for 16 hours with 4*N* sodium hydroxide in the presence of L-cysteine (Kuiken *et al.*, 1947). After autoclaving, acid hydrolyzates were adjusted to pH 4.0, filtered, and then adjusted to pH 6.8 (Horn *et al.*, 1955), while alkali hydrolyzates were filtered directly and adjusted to pH 6.8. Both hydrolyzates were made up to volume and assayed for amino acid.

The 18 amino acids were determined by microbiological assay, using the procedure described by Tamura *et al.* (1952). *Leuconostoc mesenteroides* P-60 ATCC 8042 was used for the determination of glycine, leucine, aspartic acid, lysine, arginine, phenylalanine, proline, methionine, cystine, and serine; *Lactobacillus arabinosus* 17-5 ATCC 8014 for valine, isoleucine, glutamic acid, and tyrosine; *Streptococcus faecalis* R ATCC 8043 for tryptophan and threonine; and *Leuconostoc citrovorum* ATCC 8081 for alanine and histidine.

RESULTS AND DISCUSSION

The protein content and amino acid composition of five varieties each of nonglutinous and glutinous types of foxtail millet are shown in Table I. The protein content on a dry basis ranged from 10.6 to 15.2% (Table II). The amino acid composition, expressed as per cent of protein, showed that the principal amino acids were glutamic acid, leucine, proline, and alanine. Comparison of the coefficients of variation of the amino acids (Table II) showed that proline, glycine, and lysine had the greatest variation, ranging from 10.96 to 13.59%. Coefficients of variation for the remaining amino acids ranged from 2.64 to 8.39%.

There were no differences in amino acid composition between nonglutinous and glutinous types of foxtail millet. The amino acid composition as reported in a previous paper (Taira, 1962a) and the present findings are in agreement with the data reported by Mangay *et al.* (1957) for essential amino acids, although the author's values are high for lysine and threonine and low for isoleucine. The amino acid pattern of foxtail millet belonging to the subfamily Panicoideae in the Gramineae classified by Stebbins and Crampton (1961) is generally similar to those of five other cereals—i.e., proso millet (*Panicum miliaceum*), Japanese barnyard millet (*Echinochloa crus-galli* var. *frumentacea*), pearl millet (*Pennisetum typhoideum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*), and 10 species belonging to the same subfamily

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Table I. Protein Content[a] and Amino Acid Composition[b] of Nonglutinous and Glutinous Foxtail Millet

	Nonglutinous Type					Glutinous Type				
	Kumamoto-chima No. 1	Komemasari	Shinano No. 1	Daioh-koku	Rikuu No. 1	Showa-mochi	Nekoashi	Takayama-shiromochi	Tsugaru-wase	Shiroawa
Glycine	3.9	3.4	2.5	2.9	3.2	3.3	3.0	3.1	2.9	2.6
Alanine	8.8	9.4	9.0	8.9	9.6	8.9	8.9	9.2	8.9	9.9
Valine	4.9	4.9	4.9	5.0	4.8	5.0	5.3	5.1	5.2	5.0
Isoleucine	3.9	4.1	4.1	4.0	4.1	4.2	4.2	4.1	4.1	4.4
Leucine	11.4	12.0	11.6	12.5	11.9	11.9	12.6	14.0	13.0	14.1
Aspartic acid	6.9	6.4	6.4	6.3	6.1	6.6	6.5	6.4	6.3	6.4
Glutamic acid	15.2	16.3	17.9	18.4	17.2	17.5	17.8	18.2	18.0	19.9
Lysine	2.4	1.8	1.9	1.8	1.8	1.9	2.0	1.5	1.8	1.5
Arginine	3.2	2.5	2.8	2.6	2.7	2.9	2.8	2.5	2.9	2.5
Histidine	2.0	1.7	1.8	1.9	1.7	1.8	1.8	1.8	1.9	1.8
Phenylalanine	4.6	4.8	4.8	5.1	4.7	4.8	5.0	5.4	5.2	5.2
Tyrosine	2.9	2.8	3.0	2.9	2.9	2.9	3.0	3.4	3.4	3.1
Proline	8.9	10.3	10.9	11.3	10.5	9.3	9.0	10.0	11.4	12.4
Tryptophan	1.8	1.8	1.7	1.7	1.9	1.5	1.7	1.7	1.9	1.9
Methionine	2.5	2.4	2.6	2.7	2.6	2.4	2.5	2.6	2.5	2.4
Cystine	1.5	1.5	1.4	1.5	1.4	1.6	1.5	1.4	1.5	1.4
Serine	5.8	5.7	5.5	6.2	5.9	5.5	5.6	5.9	6.0	6.0
Threonine	4.3	4.1	4.3	4.3	4.0	4.2	4.1	4.1	4.2	4.1
Protein	10.6	12.9	13.1	13.2	13.9	11.7	13.0	13.4	13.4	15.2

[a] % (N × 6.25) on dry basis. [b] % of protein.

(Taira, 1962b, 1963, 1966). The grains and seeds of Panicoideae especially show the amino acid pattern characterized by high alanine and leucine contents in marked contrast to those of other subfamilies in Gramineae. Comparison of the essential amino acid pattern of foxtail millet with that of whole hen's egg (Table III), as proposed by a Joint FAO/WHO Expert Group (World Health Organization, 1965), indicates that the millet is deficient in lysine but not in tryptophan, though corn belonging to the same subfamily is limited in both lysine and tryptophan.

Table II. Protein Content and Amino Acid Composition of Varieties of Foxtail Millet

Amino Acid	Per Cent of Protein: Extremes	Mean	Standard deviation	Coefficient of Variation, %
Glycine	2.6–3.9	3.08	0.40	12.99
Alanine	8.8–9.9	9.15	0.39	4.26
Valine	4.8–5.3	5.01	0.15	2.99
Isoleucine	3.9–4.4	4.12	0.13	3.16
Leucine	11.4–14.1	12.50	0.95	7.60
Aspartic acid	6.1–6.9	6.43	0.21	3.27
Glutamic acid	15.2–19.9	17.64	1.26	7.14
Lysine	1.5–2.4	1.84	0.25	13.59
Arginine	2.5–3.2	2.74	0.23	8.39
Histidine	1.7–2.0	1.82	0.09	4.95
Phenylalanine	4.6–5.4	4.96	0.26	5.24
Tyrosine	2.8–3.4	3.03	0.21	6.93
Proline	8.9–12.4	10.40	1.14	10.96
Tryptophan	1.5–1.9	1.76	0.13	7.39
Methionine	2.4–2.7	2.52	0.10	3.97
Cystine	1.4–1.6	1.47	0.07	4.76
Serine	5.5–6.2	5.87	0.23	3.92
Threonine	4.0–4.3	4.17	0.11	2.64
Protein[a]	10.6–15.2	13.03	1.22	9.36

[a] % (N × 6.25) on dry basis.

Correlation coefficients between amino acid pairs at the 1 and 5% levels of probability and also amino acid and crude protein contents in 10 varieties of foxtail millet are shown in Tables IV and V, respectively. There are positive correlations between leucine-phenylalanine, lysine-arginine, and phenylalanine-tyrosine, and negative correlations between glycine–glutamic acid, leucine-lysine, and glutamic acid–lysine at the 1% level of probability. The crude protein content shows positive correlations with glutamic acid and proline contents at the 1% level of probability and with alanine, leucine, and isoleucine contents at the 5% level of probability and negative correlations with lysine, aspartic acid, and arginine contents at the 1% level of probability and with glycine and cystine contents at the 5% level of probability. The amino acids, except isoleucine and cystine, showing correlation with crude protein con-

Table III. Essential Amino Acid Patterns[a]

A/E ratio. Milligrams per gram of total essential amino acids

Amino Acid	Hen's Egg	Foxtail Millet[b]	Corn[c]
Isoleucine	129	100	105
Leucine	172	302	295
Lysine	125	44	66
Total aromatic amino acids	195	193	242
Phenylalanine	114	120	103
Tyrosine	81	73	139
Total sulfur-containing amino acids	107	96	71
Methionine	61	61	42
Cystine	46	36	29
Threonine	99	101	91
Tryptophan	31	43	14
Valine	141	121	116

[a] Calculated as described by WHO (1965). [b] From mean amino acid content. [c] From Orr and Watt (1957).

Table IV. Correlation Coefficients between Amino Acid Pairs in 10 Varieties of Foxtail Millet

Amino Acid	Correlation Coefficient[a]
Leucine-phenylalanine	0.925**
Lysine-arginine	0.872**
Glycine-glutamic acid	−0.864**
Phenylalanine-tyrosine	0.797**
Leucine-lysine	−0.793**
Glutamic acid–lysine	−0.784**
Leucine–glutamic acid	0.759*
Histidine-threonine	0.753*
Lysine-phenylalanine	−0.748*
Glutamic acid–phenylalanine	0.743*
Isoleucine–glutamic acid	0.734*
Leucine-tyrosine	0.718*
Glycine-proline	−0.718*
Glutamic acid–proline	0.711*
Alanine-threonine	−0.697*
Aspartic acid–lysine	0.678*
Alanine-arginine	−0.663*
Lysine-proline	−0.659*
Arginine-histidine	0.650*
Aspartic acid–arginine	0.644*
Alanine-lysine	−0.638*

[a]* Significant at the 5% level. ** Significant at the 1% level.

Table V. Correlation Coefficient between Amino Acid and Protein Contents in 10 Varieties of Foxtail Millet

Amino Acid	Correlation Coefficient[a]
Glycine	−0.748*
Alanine	0.755*
Valine	0.111
Isoleucine	0.679*
Leucine	0.696*
Aspartic acid	−0.774**
Glutamic acid	0.815**
Lysine	−0.842**
Arginine	−0.765**
Histidine	0.500
Phenylalanine	0.590
Tyrosine	0.349
Proline	0.794**
Tryptophan	0.497
Methionine	0.074
Cystine	−0.634*
Serine	0.439
Threonine	−0.550

[a]* Significant at the 5% level. **Significant at the 1% level.

tents at the 1 and 5% levels of probability are characteristic of the amino acid pattern of prolamin in isolated proteins of foxtail millet (Taira, 1962c). Prolamin, as compared with albumin, globulin, and glutelin, shows that the positively correlated amino acids are higher and the negatively correlated amino acids are lower. Many workers (Flynn *et al.*, 1954; Frey, 1949, 1951; Hansen *et al.*, 1946; Showalter and Carr, 1922) have reported a positive correlation between zein (prolamin) and crude protein contents in corn. Accordingly, the correlation between crude protein and amino acid content of foxtail millet may be considered as due to positive correlation between the amount of the prolamin and crude protein.

It is, therefore, presumed that difference in lysine content of glutinous and nonglutinous types of foxtail millet reported previously (Taira, 1962a) may be mainly due not to the inherited character of two types, but to the negative correlation between crude protein and lysine contents, or to the positive correlation between crude protein and prolamin contents in the samples. However, it is necessary to extend the investigations to find out whether the variation of amino acid composition among the varieties is due to the individual characters, because the protein content of corn can be increased by selective breeding and controlled fertilization (Flynn *et al.*, 1954; Hamilton *et al.*, 1951; Mitchell *et al.*, 1952; Sauberlich *et al.*, 1953).

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LITERATURE CITED

Association of Official Agricultural Chemists, "Official Methods of Analysis," 10th ed., p. 16, 2.044, 1965.
Baptist, N. G., Perera, B. P. M., *Brit. J. Nutr.* **10,** 334 (1956).
Flynn, L. M., Zuber, M. S., Leweke, D. H., Grainger, R. B., Hogan, A. G., *Cereal Chem.* **31,** 217 (1954).
Frey, K. J., *Agron. J.* **41,** 113 (1949).
Frey, K. J., *Cereal Chem.* **28,** 123 (1951).
Hamilton, T. S., Hamilton, B. C., Johnson, B. C., Mitchell, H. H., *Cereal Chem.* **28,** 163 (1951).
Hansen, D. W., Brimhall, B., Sprague, G. F., *Cereal Chem.* **23,** 329 (1946).
Horn, M. J., Blum, A. E., Gersdorff, C. E. F., Warren, H. W., *Cereal Chem.* **32,** 64 (1955).
Kuiken, K. A., Lyman, C. M., Hale, F., *J. Biol. Chem.* **171,** 551 (1947).
Mangay, A. S., Pearson, W. N., Darby, W. J., *J. Nutr.* **62,** 377 (1957).
Mitchell, H. H., Hamilton, T. S., Beadles, J. R., *J. Nutr.* **48,** 461 (1952).
Orr, M. L., Watt, B. K., "Amino Acid Contents of Foods," Home Economics Research Report No. **4,** U. S. Department of Agriculture, Washington, D. C., 1957.
Sauberlich, H. E., Chang, W.-Y., Salmon, W. D., *J. Nutr.* **51,** 241 (1953).
Showalter, M. F., Carr, R. H., *J. Am. Chem. Soc.* **44,** 2019 (1922).
Stebbins, G. L., Crampton, B., *Recent Adv. Botany* **1,** 133 (1961).
Taira, H., *Eiyo To Shokuryo* **15,** 57 (1962a).
Taira, H., *Botan. Mag. Tokyo* **75,** 242 (1962b).
Taira, H., *Botan. Mag. Tokyo* **75,** 273 (1962c).
Taira, H., *Botan. Mag. Tokyo* **76,** 340 (1963).
Taira, H., *Botan. Mag. Tokyo* **79,** 36 (1966).
Tamura, G., Tsunoda, T., Kirimura, J., Miyazawa, S., *Nippon Nogei Kagaku Kaishi* **26,** 464 (1952).
World Health Organization, "Protein Requirement," WHO Tech. Rept. Ser. **301,** Joint FAO/WHO Expert Group, Rome, 1965.

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