Note

Some Properties of Starch from Foxtail Millet (*Setaria italica* BEAUV.)

Shuzo FUJITA,[†] Li DONGHUI,*
Yoshimi SUGIMOTO,** Naoyoshi INOUCHI***
and Hidetsugu FUWA****

Division of Food, Mie Municipal College,
Isshinden, Tsu-shi, Mie 514-01, Japan

*Foxtail Millet Research Institute,
Academy of Agricultural and Forestry Science,
Hebei Province, China

**Department of Home Science, Mukogawa Women's
University, Nishinomiya, Hyogo 663, Japan

***Division of Food, Sakurai Women's College,
Sakurai, Nara 630, Japan

****Department of Food and Nutrition,
Osaka City University, Osaka 558, Japan

Received October 17, 1988

Foxtail millet (or italian millet, *Setaria italica* BEAUV.) has been extensively cultivated in Eurasia as food and forage.^{1~4)} In Japan today, millet is only consumed as a sweetstuff such as "Awa-okoshi" and a millet cake called "Awa-mochi," or as birdseed. In China, however, it has been widely used for more than 2,000 years as nutritional gruel or soup for pregnant and nursing women, and has recently been applied to food therapy.⁵⁾

The main component of this millet is starch and protein.⁶⁾ Two types of foxtail millet starch have been recognized, namely the waxy and non-waxytypes. Taira investigated the amylose content of millet starches,⁷⁾ and Lorenz reported that the amylographic viscosity of foxtail and proso millet starches was higher than that of rye and wheat starches.⁸⁾ However, many more details still remain to be clarified. In the present study, we examined the structure and properties of foxtail millet starches to reveal the detail characteristics of starches obtained from several varieties of this millet.

Thirteen different varieties of foxtail millet cultivated in China were examined (see Table I). They were either typical representatives of varieties cultivated in China or those having special characteristics. The YOUZHI group has superior qualities; for example, YOUZHI-1 and -4 show higher contents of protein, each having 16.2 and 17.4%, respectively. JIQU was produced by irradiating of ⁶⁰Co and has an improved protein quality, while SHUQU and GAOLIANGQU were produced by crossing with

proso millet and sorghum, respectively. Starch granules were prepared by the slightly modified method of Adkins and Greenwood,⁹⁾ and were refluxed by 85% methanol for defatting. The absorption spectrum of starch-iodine complexes was measured by scanning from 700 to 500 nm.¹⁰⁾ For fractionation of the debranched materials, starch was hydrolyzed with crystalline *Pseudomonas* isoamylase by the method of Ikawa¹¹⁾ and the materials were fractionated by gel filtration on a Sephadex G-75 column. The starch granules and distilled water (1:2 by weight) were sealed in an aluminum pan for thermographic analysis, the thermogram being measured on a Rigaku Denki 8240 differential scanning calorimeter (DSC) with water as the reference.¹²⁾

Table I shows the wavelength at the maximum absorbance of the iodine absorption spectrum ($A_{\max}$) and the "blue value" (BV) at 680 nm. $A_{\max}$ value for YOUZHI-2 and -4 were 535 and 536 nm, respectively, and were in the range of 587 to 606 nm for the others. The BVs for the non-waxytypes were in the wide range of 0.340 to 0.518, GAOLIANGQU, the foxtail millet-sorghum hybrid, showing the lowest BV among the non-waxytypes. Ikawa reported that the BV of sorghum starch was in the range of 0.20 to 0.34¹³⁾; therefore, the result suggests that GAOLIANGQU starch may be affected by the sorghum background. JIQU starch may be a high amylose type because its BV was 0.518.

From gel filtration of the debranched materials on a Sephadex, the amylose content and distribution of the linear α -1,4 chains of amylopectin are shown in Table I. The YOUZHI-2 and -4 starches, presumed to be the waxytype from their iodine absorption curves, contained 1.3 and 2.7% of fraction 1 (*i.e.*, the amylose fraction), respectively, and approximately 3% of the carbohydrates were eluted in the intermediate fraction of both the millets. Taira reported that the varieties of the waxytype of foxtail millet could be divided into two groups by their amylose content (*i.e.*, 0.82 and 4.20% groups on the average).⁷⁾ The ratio of fraction 2 to 3 of YOUZHI-2 was as high as 4.1, and similar figures have also been observed for starches of adlay¹⁴⁾ and dull mutant of corn.¹¹⁾ In the non-waxytype of millet, fraction 1 contents were in the range of 17.4 (LUMIQING) and 24.0% (JIQU). LUMIQING endosperm contains oligosaccharides, and therefore its soup or gruel has a sweet taste. The ratio of fraction 2 to 3 of the non-waxytype of starches was in the range of 2.6 to 3.5.

From the DSC characteristics and pasting characteristics by DSC, SHUQU, the foxtail millet-proso millet hybrid, showed the lowest temperatures for gelatinization among the examined samples (Table II), the onset (To), peak (Tp) and conclusion (Tc) temperatures for gelatinization being higher than those of wheat and rye starches.⁸⁾ JIQU, GAOLIANGQU and two waxytype millets (YOUZHI-2 and -4) showed higher temperatures for gelatinization. A waxytype of starch has, in general, a

[†] To whom inquiries should be addressed.

Table 1. IODINE ABSORPTION SPECTRA AND GEL FILTRATION OF STARCHES FROM FOXTAIL MILLET

No.	Sample name	Iodine absorption spectra				Gel filtration of debranched materials ^a				
		$A_{\max}$		Type	Blue value (OD at 680 nm)	Fraction 1 (%)	Intermediate fraction (%)	Fraction 2 (%)	Fraction 3 (%)	Fr.3/Fr.2
		(nm)	(OD)							
101	YOUZHI 1	592	0.521	Non-waxy	0.414	20.8	7.8	18.7	52.7	2.8
102	YOUZHI 2	535	0.279	Waxy	0.094	1.3	3.1	18.7	76.8	4.1
103	YOUZHI 3	593	0.533	Non-waxy	0.427	21.0	5.6	17.5	55.9	3.2
104	YOUZHI 4	536	0.349	Waxy	0.130	2.7	3.5	23.3	70.6	3.0
105	JIQU 9	590	0.656	Non-waxy	0.518	24.0	4.4	18.6	52.9	2.8
106	LONGQU 23	595	0.517	Non-waxy	0.416	18.2	4.9	21.7	55.2	2.6
107	LONGQU 25	606	0.524	Non-waxy	0.456	22.2	5.5	17.8	54.5	3.1
108	NINGHUANG 1	590	0.559	Non-waxy	0.434	21.0	5.8	16.6	56.6	3.4
109	SHUQU	598	0.554	Non-waxy	0.458	23.1	4.9	16.0	56.0	3.5
110	LUMIQING	591	0.471	Non-waxy	0.372	17.4	4.8	19.3	59.3	3.1
111	CHANGLIBAIMI	594	0.444	Non-waxy	0.354	18.3	3.5	19.1	59.0	3.1
112	GAOLIANQU	594	0.430	Non-waxy	0.340	22.4	3.9	18.8	54.9	2.9
113	HEISHATAN	587	0.475	Non-waxy	0.364	19.4	2.9	21.2	56.5	2.7

^a The range for fractions 1, 2 and 3, and the intermediate fraction was divided according to the wavelength at maximum absorption ($A_{\max}$) of iodine-carbohydrate complexes as follows: Fraction 1, $A_{\max} \geq 620$ nm; intermediate fraction, $620 > A_{\max} \geq 600$ nm; fraction 2, $600 > A_{\max} \geq 540$ nm; and fraction 3, $A_{\max} < 540$ nm.

Fig. 1. Relationship between the Heat of Gelatinization and Onset Temperature for Gelatinization for Endosperm Starches of Foxtail Millet.

Table II. CHARACTERISTICS OF STARCHES OF FOXTAIL MILLET

No.	Sample name	Temperature for gelatinization			ΔH^a (cal/g)
		To ^a (°C)	Tp (°C)	Tc (°C)	
101	YOUZHI 1	65	72	79	3.5
102	YOUZHI 2	68	75	83	3.7
103	YOUZHI 3	67	74	81	3.4
104	YOUZHI 4	66	74	82	3.8
105	JIQU 9	68	74	81	3.2
106	LONGQU 23	60	66	74	3.1
107	LONGQU 25	60	67	74	2.8
108	NINGHUANG 1	66	73	79	3.3
109	SHUQU	56	64	72	2.1
110	LUMIQING	63	70	78	3.6
111	CHANGLIBAIMI	57	65	75	2.8
112	GAOLIANGQU	68	74	81	3.4
113	HEISHATAN	65	71	77	3.3

^a Onset (To), peak (Tp) and conclusion (Tc) temperatures for gelatinization, and the heat of gelatinization (ΔH) were measured.

higher temperature for gelatinization than the non-waxytype, and a similar tendency has also been observed in other cereals. Lorenz has reported that the To values for two foxtail millet starches were 52 and 55 °C, respectively,⁸⁾ these figures being lower than the results obtained in this study. The difference in the result might have been due to the difference in the analytical methods and/or variety of millet. The heat of gelatinization (ΔH) of the non-waxytype averaged 3.1 cal/g, SHUQU showing the smallest ΔH value (2.1 cal/g) of all. On the other hand, ΔH of the waxytype was 3.7 cal/g or more, greater than the values for the non-waxytype. A similar tendency has also been observed in corn¹²⁾ and rice.¹⁵⁾

Figure 1 shows the relationship between To and ΔH of the foxtail millet starches, a strong correlation being

observed. The coefficient of correlation was 0.805, but this relationship is not necessarily observed in other grains. A similar relationship has been found in corn¹²⁾ and rice,^{15~17)} but not clearly in adlay¹⁴⁾ and sorghum starches.¹³⁾

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