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Varietal Differences in Storage Root Quality and Physiological Factors in Sweetpotato

Yasuhiro TAKAHATA
Department of Crop Breeding, Kyushu National Agricultural Experiment Station
(Nishigoshi, Kumamoto, 861-11 Japan)

Abstract
Varietal differences in the contents of free sugars, catrotenoids, and free and hydrolyzed amino acids in sweetpotatps were investigated. Based on cluster analysis of the free sugar composition of steamed roots, the lines were classified into 3 groups. Among the 53 entries, 47 lines were classified into group 1 that was characterized by relatively small amounts of fructose and glucose, moderate amounts of sucrose and large amounts of maltose in steamed roots. It was demonstrated that there were 2 breeding lines lacking β-amylase (group 2) and 3 lines with a high hexose content (group 3). Some of the lines with a high hexose content showed a high acid invertase acitivity. The relationship of the maltose content between 2 years was as phenotypically stable as that of the dry matter content. Heat stability of β-amylase and starch gelatinization degree during heating were the major factors controlling the varietal differences in the maltose content. The carotenoid composition of 22 orange flesh lines did not differ among the lines and β-carotene predominated. Retinol equivalents of major cultivars were almost equivalent to the maximum value of carrot cultivars. The largest variability in aspartic acid content among the lines was due to the variability in the free asparagine content.

Discipline: Food / Plant breeding
Additional key words: acid invertase, amino acid, β-amylase, β-carotene, free sugars

Introduction

Eating quality, processing suitability, and nutritional value of sweetpotato (*Ipomoea batatas* (L.) Lam.) roots are largely affected by their chemical composition. Many researchers have analyzed the composition of free sugars, carotenoids, and amino acids of sweetpotato storage roots in a limited number of cultivars. However, the factors controlling the varietal differences in these compounds have not been elucidated. The author investigated the varietal differences of these compounds in sweetpotato storage roots by HPLC. The physiological factors controlling varietal differences in the free sugar composition were also studied.

Varietal differences in chemical composition

1) Free sugars

Free sugar composition of the storage roots of sweetpotato lines was investigated in 1989 and 1990[10]. Based on cluster analysis of the free sugar composition of steamed roots in 1990, the lines were classified into 3 groups. Analysis of the data in 1989 gave similar results. However, since the duration of the storage period from harvest to sampling for the analysis was shorter in 1990 than in 1989, the free sugar composition of representative lines recorded only in 1990 will be shown in this review (Table 1). The differences in the free sugar composition were also found to be identical when the plants were grown in 2 different locations[11]. Among the 53 entries, 47 lines including all the leading cultivars in Japan like Koganesengan, Beniazuma and Kokei 14 were classified into group 1. The free sugar composition of this group was characterized by relatively small amounts of fructose and glucose, moderate amounts of sucrose and large amounts of maltose in steamed roots. It is interesting to note that both cultivars for table consumption (Beniazuma, Kokei 14, etc.) and those for starch production (Koganesengan, Shiroyutaka, etc.) exhibited a similar free sugar composition. These findings can be ascribed to the following reasons: 1) the parental lines for starch production are presumably the same as those for

Table 1. Dry matter content and free sugar composition of steamed and raw roots of sweetpotato lines in 1990

Line	Steamed roots					Raw roots			
	D.M.[a]	Fru	Glc	Suc	Mal	D.M.[a]	Fru	Glc	Suc
Group 1									
Koganesengan	37.9	3.45	3.46	24.9	117.8	38.0	0.69	0.40	16.5
Beniazuma	38.4	1.57	1.70	24.0	119.6	38.6	0.96	0.42	17.3
Shiroyutaka	37.2	0.32	0.99	28.8	110.4	37.5	1.24	0.23	18.7
Beniotome	39.5	1.16	2.61	30.1	131.4	38.3	1.02	0.16	18.2
Kokei 14	39.8	3.21	3.97	19.1	107.4	38.9	0.84	0.64	15.0
Beniaka	38.0	1.16	0.60	29.9	106.2	35.6	0.32	0.19	14.7
Group 2									
Satsumahikari	38.6	4.19	3.48	21.0	N.D.[b]	35.8	2.57	1.74	17.0
Kyushu 89	41.3	2.49	2.78	25.1	N.D.	38.9	1.40	0.23	13.9
Chugoku 37	41.3	3.35	3.91	16.8	N.D.	35.2	2.86	2.15	13.7
Group 3									
Murasakibaru 2	29.4	17.56	18.05	9.3	83.7	28.3	6.38	6.30	9.6
Tokai 5	28.9	13.04	12.16	8.9	65.7	26.5	10.57	8.88	9.1
Georgia Jet	19.2	14.42	15.04	30.9	41.5	17.8	6.09	8.50	31.2

a): D.M.; Dry matter content (%). b): N.D.; Not detected.
Each value is a mean of 3 roots. HPLC injection was performed for 3 roots each.
Free sugar contents are expressed as mg/g on a fresh weight basis.

table use which displayed a relatively narrow range of genetic diversity, and 2) cultivars bred in Japan had not been selected for free sugar contents.

In 3 lines belonging to group 2, no maltose was detected even in the steamed roots. The low content of reducing sugars is considered to be a suitable character for the processing of fried products and sweetpotato granule production because larger amounts of reducing sugars may enhance browning in the frying process and increase the viscosity that prevents granule formation[1]. Satsumahikari registered in 1987 as a cultivar for food processing was characterized by a low β-amylase activity[6]. In the current study, two breeding lines with the same characters as those of Satsumahikari were identified. Especially, Kyushu 89 with a white skin was characterized by a higher dry matter content and a lower content of reducing sugars (fructose, glucose) than Satsumahikari. Kyushu 89 is considered to be a breeding material suitable for food processing.

The other 3 lines in group 3 showed relatively high fructose and glucose contents. For the processing of sweetpotato for frozen or chilled products, these lines are likely to be useful for breeding sweetpotato cultivars with an improved taste. The value of the correlation coefficient of the maltose content between the 2 years that was 0.835 (except for the low maltose genotypes), was close to that of the dry matter content (Fig. 1 A and B). On the other hand, the correlation coefficient of the sucrose content was 0.649 (Fig. 1 C). The maltose content is as phenotypically stable as the dry matter content. It was also demonstrated that the varietal differences in the maltose content in group 1 were significant.

2) Carotenoids[12]

The carotenoid composition of the sweetpotato storage roots did not differ among the lines and β-carotene predominated. β-Carotene contents of 22 lines with orange flesh ranged from 1.1 to 26.6 (mg/100 g, fresh weight basis, Table 2). On the other hand, the carotenoid composition of carrots was found to be a mixture of α-, β- and γ-carotene and varied among the lines. β-Carotene accounted for 44–79% of the total carotene found in carrot cultivars[4]. The predominant carotenoid of tomato fruits was lycopene, and the carotenoid composition also varied widely among the cultivars[5,7,16]. In this study, although the levels of β-carotene ranged widely among the lines, the carotenoid detected in the storage roots consisted almost exclusively of β-carotene. The stability of the carotenoid composition with only β-carotene throughout all the orange flesh lines is noteworthy. In contrast, no carotenoids were detected in cultivars such as Koganesengan and Beniazuma with a yellowish-white flesh.

β-Carotene is a superior carotenoid with an important biological function as pro-vitamin A. In the

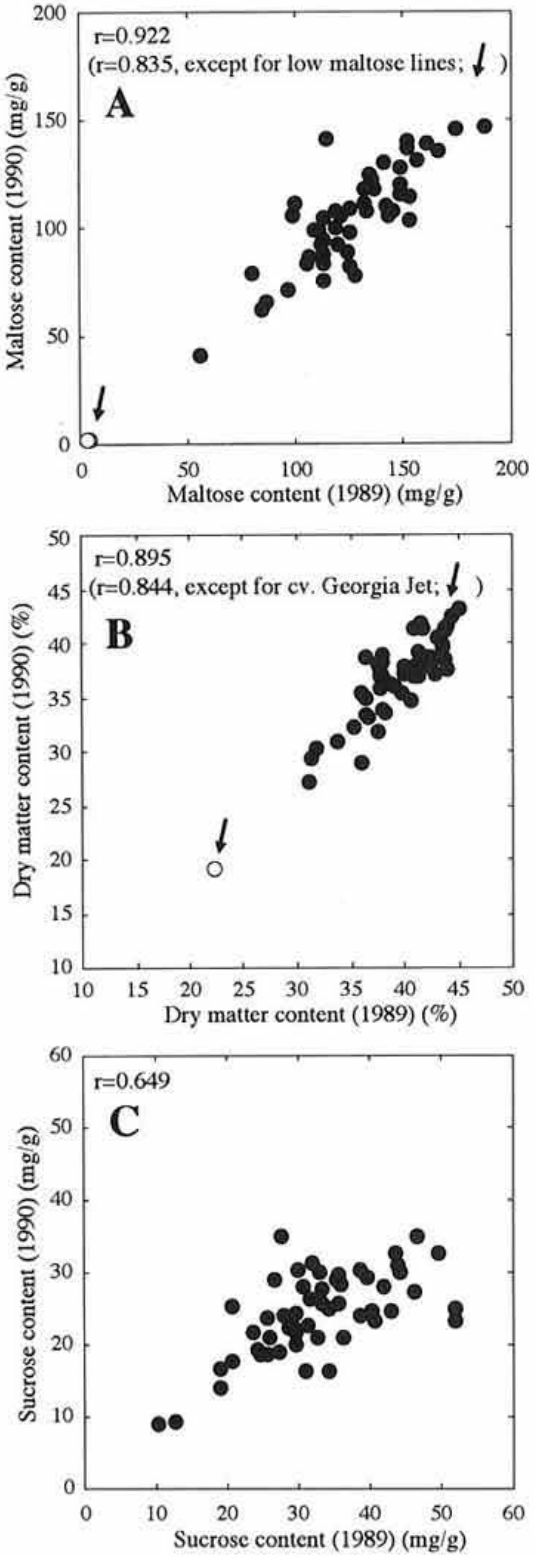

Fig. 1. Scattergrams of maltose content (A), dry matter content (B), and sucrose content (C) in steamed roots between 1989 and 1990

Table 2. β-Carotene content of 25 sweetpotato lines

Line	Source	β-Carotene content[a)]
SPV-61	U.S.A.	26.6 (1.8)
Resisto	U.S.A.	20.3 (1.5)
UC 700	Venezuela	18.9 (1.0)
L-2-116	U.S.A.	18.6 (2.0)
L-4-89	U.S.A.	18.6 (4.6)
Benihayato	Japan	18.2 (4.9)
Santo Amaro	Brazil	15.5 (1.4)
Caromex	U.S.A.	14.9 (1.6)
Red Jewel	U.S.A.	13.8 (0.2)
Benihayato (mutant)	Japan	11.7 (0.5)
Heart Gold	U.S.A.	9.9 (0.2)
SPV-67	U.S.A.	9.8[b)]
AIP-587	Papua New Guinea	9.8 (1.5)
AIP-326	Papua New Guinea	8.1 (3.2)
F 411	Indonesia	7.8 (0.2)
Kyukei 114	Japan	7.5 (1.1)
Unit 1 Porto Rico	U.S.A.	6.9 (0.1)
Georgia Jet	U.S.A.	6.9 (0.2)
W-36	U.S.A.	5.6 (2.3)
Okinawa 100 (mutant)	Japan	2.3 (1.2)
SPV-43	U.S.A.	1.3 (0.2)
PI 208886	U.S.A.	1.1 (0.6)
Koganesengan	Japan	N.D.[c)]
Beniazuma	Japan	N.D.
Beniotome	Japan	N.D.

a): mg/100 g (range), fresh weight basis. b): No replication. c): Not detected (<0.005 mg/100 g).
Each value is a mean of 2 roots. HPLC injection was performed for 2 roots each.

carrot lines, the retinol equivalents (RE) ranged from 1.2-2.3 (mg/100 g)[4]. On the other hand, RE (0.167 × β-carotene content) of sweetpotato lines in this study ranged from 0.2-4.4, and the average RE of major cultivars (cv. Resisto, Benihayato, Santo Amaro, Caromex and Red Jewel) was 2.7, a value equivalent to the maximum value recorded in carrot cultivars. Furthermore, β-carotene contained in foods has been reported to be an anti-oxidant[3] and an anti-carcinogenic compound[8]. Therefore, some sweetpotato cultivars which contain a larger amount of β-carotene are considered to be superior to other crops that contain other types of carotenes. In addition, since the cultivation of sweetpotatoes is easy, they contribute significantly to human health in terms of this function.

3) Amino acids

Free and hydrolyzed amino acid composition of whole root flour of sweetpotato lines that included lines lacking β-amylase was investigated in 1990 and 1991[14]. The composition of hydrolyzed amino acids

was similar among the lines and their profile was almost the same as that previously reported[2,15], although the aspartic acid contents mostly varied among the lines (Table 3). The far right column shows the mean and coefficient of variance (CV) of 8 lines. The CV of the aspartic acid content was

Table 3. Amino acid contents of 8 sweetpotato lines in 1990 and 1991

Amino acid	Kogane-sengan	Tsuru-sengan	Beni-hayato	Shiro-yutaka	Satsuma-hikari	Kyushu 89	Beni-otome	Kokei 14	Mean	CV[a)]
1990										
Alanine	281	273	286	246	273	297	258	274	274	6.0
Arginine	282	278	289	252	243	280	224	260	264	8.9
Aspartic acid	998	1762	1226	1026	1521	1014	1025	1167	1217	24.0
Glutamic acid	619	556	617	550	582	679	501	671	597	10.7
Glycine	263	254	266	248	234	272	247	248	254	5.0
Histidine	142	140	167	139	149	140	139	173	149	9.5
Proline	218	217	226	302	205	320	310	211	251	20.6
Serine	325	332	325	269	293	364	270	294	309	11.1
Threonine	295	305	303	265	273	343	265	303	294	9.2
Valine	388	437	415	353	363	437	357	363	389	9.6
Isoleucine	268	265	273	238	253	300	245	253	262	7.7
Leucine	392	365	400	330	352	396	343	374	369	7.3
Lysine	316	296	320	275	269	316	265	303	295	7.9
Total sulfur	191	216	229	185	163	189	220	200	199	11.3
Total aroma	547	589	585	612	543	593	574	498	568	6.6
1991										
Alanine	255	267	258	250	251	239	263	270	257	4.1
Arginine	218	264	278	262	243	236	262	228	249	8.6
Aspartic acid	853	884	804	997	1241	653	1351	1444	1028	28.7
Glutamic acid	576	473	465	569	488	437	548	620	522	12.9
Glycine	233	256	262	255	249	262	253	250	253	3.8
Histidine	183	159	160	160	152	140	146	169	159	8.8
Proline	209	229	298	271	336	324	238	195	263	20.9
Serine	286	307	266	284	274	276	298	291	285	4.9
Threonine	268	288	260	278	273	258	288	295	276	5.1
Valine	353	378	353	363	357	353	372	366	362	2.7
Isoleucine	248	250	255	250	253	243	260	270	253	3.5
Leucine	365	365	370	356	352	321	378	422	366	8.0
Lysine	286	252	292	323	252	258	289	275	278	9.1
Total sulfur										
Total aroma	547	578	536	585	547	536	589	581	562	4.2

a): CV: Coefficient of variance.
Each value was calculated as mg of amino acid/g of N.
Total sulfur amino acid contents in 1991 were not determined.

Table 4. Free amino acid contents of 8 sweetpotato lines in 1990 and 1991

Amino acid	Koganesengan	Tsurusengan	Benihayato	Shiroyutaka	Satsumahikari	Kyushu 89	Beniotome	Kokei 14
1990								
Asparagine	5.5	29.8	9.9	4.4	25.8	7.4	10.5	15.1
Aspartic acid	3.4	3.9	5.2	3.1	2.5	3.3	2.8	4.6
Glutamic acid	2.9	3.3	4.9	4.8	3.4	3.6	2.2	4.4
1991								
Asparagine	4.6	3.9	6.2	12.1	32.0	5.0	25.0	28.0
Aspartic acid	4.0	3.9	5.0	5.5	4.8	2.3	4.3	6.7
Glutamic acid	3.6	0.8	2.6	7.8	2.8	3.5	6.3	6.5

Each value was calculated as μmol/g on a dry weight basis.

largest among the amino acids, suggesting that there is more variability in aspartic acid than in other amino acids. Furthermore, the profile of the varietal difference in aspartic acid content was different between the 2 years, i.e. the contents of Tsurusengan and Satsumahikari were high in the first year, whereas those of Satsumahikari, Beniotome and Kokei 14 were high in the second year. The CV of the proline content was second largest in both years; mainly due to the low sensitivity of *o*-phthalaldehyde-proline in the determination. The contents of the other amino acids of whole flour of each line were almost similar because the CV of each amino acid was relatively small.

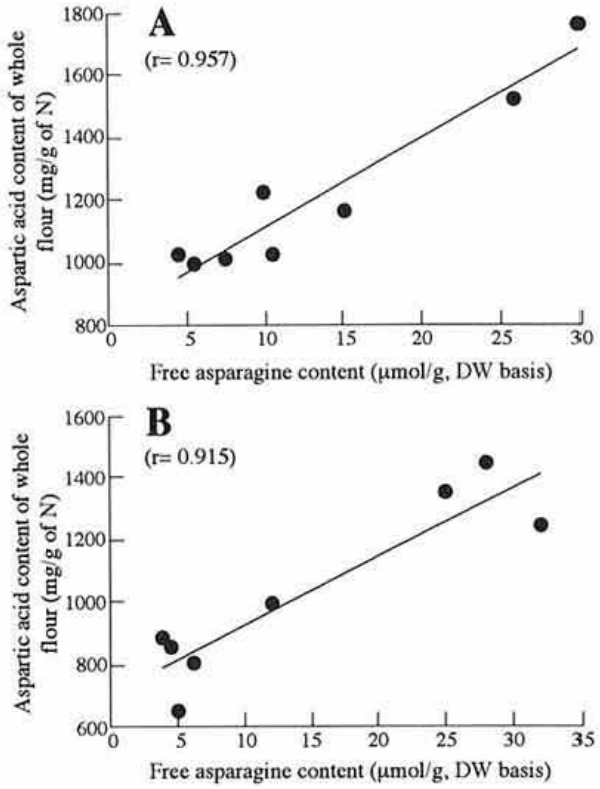

Fig. 2. Scattergrams of free asparagine content and hydrolyzed aspartic acid content in 1990 (A), and in 1991 (B)

Table 4 shows the free amino acid content of each line. Asparagine, aspartic acid and glutamic acid were predominant, and the contents of other amino acids were similar and less than 2 μmol/g (dry weight basis; data are not shown) in all the lines. The most predominant free amino acid was always asparagine in every line. However, the profile of varietal difference was considerably modified between 1990 and 1991, i.e. the contents of Tsurusengan and Satsumahikari were high in 1990 whereas those of Satsumahikari, Beniotome and Kokei 14 were high in 1991. Interestingly, this varietal difference was almost the same as that of hydrolyzed aspartic acid content. Fig. 2 shows the scattergrams of the free asparagine content and hydrolyzed aspartic acid content in both years. The correlation coefficients were 0.957 in 1990 and 0.915 in 1991. The largest variability in the aspartic acid content among the lines in the hydrolyzed amino acid analysis was associated with the variability in the free asparagine content.

Physiological factors controlling varietal differences in free sugar composition

1) Effect of β-amylase stability and starch gelatinization during heating on varietal differences in maltose content

As mentioned above, the varietal difference in the maltose content in group 1 was significant and phenotypically stable. Picha[9] reported that the ranking of the maltose concentration among cultivars paralleled that of alcohol insoluble solids that were positively correlated with the dry matter content. However, among the lines in group 1, the correlation coefficients of maltose content and dry matter

Table 5. Varietal differences in maltose content in steamed sweetpotato roots over several years

Type of line	Line	1992		1990		1989	
		D.M.	Mal	D.M.	Mal	D.M.	Mal
High maltose lines	Kyushu 91	36.8^{ab}	145.1^{a}	37.0^{a}	146.9^{a}	42.5^{ab}	188.2^{a}
	Kyushu 104	37.9^{ab}	153.7^{a}	39.7^{b}	146.1^{a}	43.7^{a}	174.1^{a}
Moderate maltose lines	Shiroyutaka	36.3^{ab}	119.7^{b}	37.5^{a}	110.4^{b}	40.1^{c}	142.0^{b}
	Koganesengan	38.2^{a}	133.3^{c}	38.0^{ab}	117.8^{b}	41.7^{abc}	131.9^{b}
Low maltose lines	Naeshirazu	34.5^{b}	91.7^{d}	39.2^{ab}	61.8^{c}	40.1^{bc}	85.1^{c}
	Shirosatsuma	37.0^{ab}	97.6^{e}	38.6^{ab}	92.7^{d}	43.9^{a}	112.7^{d}

Each value is the average of at least 3 replications.
Numbers in the same column with different letters are statistically different ($P<0.05$).

content in 1989 and 1990 were 0.355 and 0.228, respectively (data not shown). Thus, the dry matter content was not always the major factor controlling the maltose content. Table 5 shows representative lines of group 1 with high, moderate, and low contents of maltose. Although the dry matter contents were similar, there was a significant varietal difference in the maltose contents in the production over several years.

To identify the factors affecting the varietal differences in maltose contents, the changes in β-amylase activity and gelatinization of starch during heating were studied using the lines listed in Table 5[13]. During the heat treatment, β-amylase activity decreased with the increase in temperature in all the lines (Fig. 3). The most striking characteristic was the difference between the high maltose lines and the others at 78 and 82°C. One of the high maltose lines, Kyushu 91, retained a β-amylase activity of 510 (54%, compared to the activity of raw roots) at 78°C and of 150 (16%) at 82°C. Another high maltose line, Kyushu 104, showed almost the same tendency. However, the lines with a moderate content of maltose, Shiroyutaka and Koganesengan, retained activities of only 86 and 44 (8 and 6%) at 78°C, respectively, and the activity was markedly reduced at 82°C. The lowest maltose line, Naeshirazu, completely lost its β-amylase activity even at 78°C. In another low maltose line, Shirosatsuma, the activity of 24 (3%) was lower at 78°C than in the lines with a moderate content and was lost at 82°C. All the lines lost their β-amylase activities at 86 and 90°C.

Starch gelatinization of the high maltose lines occurred at a lower temperature than that of other lines (Table 6). Some starch granules of Kyushu 91 began to gelatinize even at 70°C, and more than half of them gelatinized at 74°C. Another high maltose line, Kyushu 104, exhibited similar starch gelatinization properties. However, the starch granules of the lines with low and moderate contents of maltose gelatinized above 70°C. These results indicate that the heat stability of β-amylase and starch gelatinization properties play important roles in the production of maltose during the heating of sweetpotatoes.

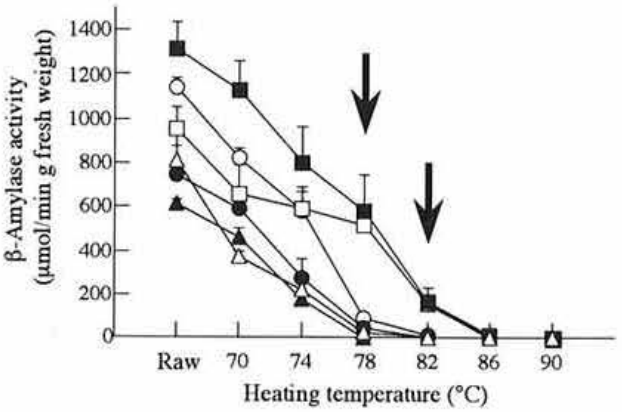

Fig. 3. Change in β-amylase activity during heating
(□) Kyushu 91; (■) Kyushu 104; (○) Shiroyutaka; (●) Koganesengan; (▲) Naeshirazu; (△) Shirosatsuma.
Each value is the mean of 3 replications. Results are reported as μmol of reducing sugar (as maltose) produced/min/g of fresh weight. Vertical bars indicate standard deviation. Arrows indicate the most striking feature with major differences between high maltose lines and the others. For details, see reference 13).

2) Effect of acid invertase activity on varietal differences in hexose content

Some sweetpotato lines showed relatively high fructose and glucose contents as described in the previous chapter. No studies have been carried out on the varietal differences related to the hexose

Table 6. Change in starch gelatinization degree of 6 sweetpotato lines during heating

Type of line	Line	Gelatinization degree[a)]			
		Raw	70°C	74°C	78°C
High maltose lines	Kyushu 91	<1	29±15	58±10	80<
	Kyushu 104	<1	31±14	62±4	80<
Moderate maltose lines	Shiroyutaka	<1	<1	<1	38±3
	Koganesengan	<1	<1	24±6	61±4
Low maltose line	Naeshirazu	<1	<1	<1	32±7
	Shirosatsuma	<1	<1	7±5	38±8

a): Percentage of starch granules which lost their birefringence.
Each value is expressed as a mean of 3 replications (±SD).

Table 7. Dry matter content, free sugar composition and invertase activity in roots of sweetpotato lines

Line	D.M.[a]	Free sugar content (mg/g, fresh)			Invertase activity	
		Fru	Glc	Suc	Acid[c]	Neutral[d]
Group 1						
Shiroyutaka	36.4 ± 0.4	N.D.[b]	N.D.	14.2 ± 2.7	0.54 ± 0.16	4.04 ± 0.31
Naeshirazu	32.9 ± 0.9	0.36 ± 0.21	0.45 ± 0.37	26.4 ± 4.5	0.04 ± 0.03	4.27 ± 1.03
Group 3						
Murasakibaru 2	21.3 ± 1.4	13.9 ± 2.0	10.7 ± 2.1	7.3 ± 0.4	4.66 ± 1.08	4.74 ± 0.49
Tokai 5	21.3 ± 0.2	13.8 ± 0.9	7.4 ± 0.6	6.2 ± 0.5	8.51 ± 1.28	7.13 ± 0.58

a): D.M.; Dry matter content (%). b): N.D.; Not detected.
c): Assayed in Na-acetate buffer (100 mM, pH 4.8), μmol glucose/g h^{-1}.
d): Assayed in Hepes-NaOH buffer (100 mM, pH 7.4), μmol glucose/g h^{-1}.
Each value is a mean of 3 roots ± SD.

metabolism in sweetpotato. To analyze the factors affecting the varietal differences in hexose contents, the acid and neutral invertase activities were preliminarily assayed using representative lines in groups 1 and 3 (Table 7). The activities of acid invertase in Murasakibaru 2 and Tokai 5, high hexose lines, were significantly higher than those in Shiroyutaka and Naeshirazu, which showed very low activities of acid invertase and contained a negligible amount of hexose. In contrast, the activities of neutral invertase were similar among the lines. These results suggest that acid invertase plays an important role in varietal differences in the hexose concentration of sweetpotato roots. Details of these experiments will be reported elsewhere.

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