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REVIEW

Studies on the Breeding for Improving Starch Properties in Sweet Potato

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Abstract

To develop new uses for sweet potato starch, we studied about breeding for improving starch properties in sweet potato. The amylose content of the germplasm collections of sweet potato ranged from 11.2 to 15.3%. There were varietal and geographical differences in the amylose content of sweet potato. Analysis of the varietal and annual variations in starch properties suggested that selection for pasting temperature, setback and amylose content can be effective. The variations of amylose content in sweet potato and its related diploid wild species could be increased by crossing and mutagenesis, and variants with a low/high amylose content could be selected. Furthermore, a new sweet potato cultivar “Quick Sweet” was developed, featuring low gelatinization temperatures and altered starch fine structure. Gelatinization temperatures and pasting temperatures of Quick Sweet starch were approximately 20ºC lower than those of ordinary sweet potato cultivars. The chain-length distribution of amylopectin showed that Quick Sweet starch had a higher proportion of short chains (DP6-11) than the ordinary cultivars. Starch retrogradation, evaluated by leaked water percentage and hardness of starch gels after cold storage, indicated that Quick Sweet starch had excellent cold storage stability.

Discipline: Plant breeding
Additional key words: amylose content, chain-length distribution, gelatinization temperature, pasting temperature, retrogradation

Introduction

Sweet potato (*Ipomoea batatas* Lam.) is one of the most important starch-producing crops in the world. Asia and Africa account for 95% of the world's sweet potato production[17]. Sweet potato can be used in various ways, as direct food, processing food, industrial starch and feed. In Japan, sweet potato is mainly used as direct food (50% of the total consumption) and the rest is used as starch (20%), processing food (10%), and alcohol (10%). However, the use of sweet potato starch in Japan is comparatively limited. Most of the sweet potato starch produced in Japan is used for the production of sugar syrup or glucose, and the rest is used for foodstuffs such as starch noodles and gelatinized cakes, but the consump-

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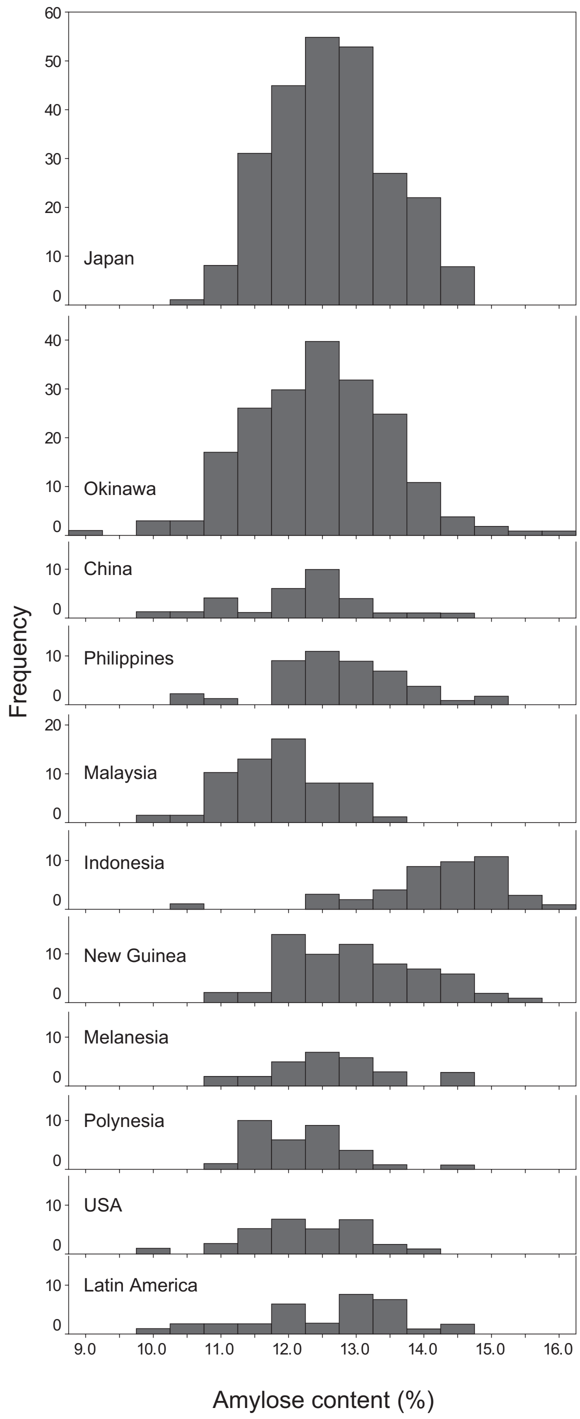


Fig. 1. Amylose content (%) in crude starch of 812 sweet potato germplasm accessions from different areas

Number of lines tested: Japan (250); Okinawa Prefecture, Japan (196); China (30); Philippines (46); Malaysia (59); Indonesia (44); USA (30); Latin America (33);

New Guinea including Irian Jaya and Papua New Guinea (64);

Melanesia including Solomon Islands, Vanuatu, New Caledonia and Fiji (28);

Polynesia including Tonga, Western Samoa, Cook Islands, New Zealand, Society Islands, Marquesas Islands, and Hawaii (32).

tion as sugar syrup is decreasing because of the competition with cheaper imported corn starch. Therefore, in order to support and spread the demand for sweet potato starch, it is necessary to develop varieties with new starch properties.

The utility of sweet potato starch is primarily determined by its physicochemical properties, which are affected by amylose content, molecular starch structure, starch granule shape and size, etc. The gelatinization and retrogradation play important roles in starch applications. Pasting properties also influence the quality of food processing materials and industrial products. Sweet potato starch with slower retrogradation is suitable for confectioneries like gelatinized cakes, and starch with faster retrogradation is suitable for starch noodles. The improving of retrogradation is expected to spread the application of sweet potato starch to such foodstuffs. A number of studies on the distinctive properties of sweet potato starch were undertaken in the last two decades[12,16]. So far sweet potato cultivars with high starch content have been developed in Japan. However, there were only a few studies on the breeding of varieties for starch properties[10,11].

In this paper, the amylose content and starch pasting properties in the storage roots and the thickening roots were investigated using the germplasm collections of sweet potato and its related diploid wild species (*Ipomoea trifida* (H.B.K.) Don.), to analyze the varietal and annual variations. Enlarging the variations of amylose content through crossing and mutagenic treatments were attempted, and the screening of variants and the analysis of starch properties in variants were conducted. Further, a new sweet potato cultivar was developed with interesting starch properties, e.g. much lower gelatinization temperature and much slower retrogradation than those of ordinary sweet potato cultivars.

Evaluation of amylose content in germplasm collections

To analyze the varietal differences in amylose content of sweet potato and diploid *Ipomoea trifida*, 812 accessions[3] of sweet potato and 58 accessions[5] of *I. trifida* introduced from various countries or areas were used. The amylose content was determined by the simplified iodo-starch reaction and the starch content was also examined. The amylose content in the crude starch of 812 accessions of sweet potato ranged from 8.9 to 16.1% (Fig. 1). Accessions from Okinawa Prefecture in Japan showed the widest variation in the amylose content, and the frequency of the lines with low amylose content was the highest. Indonesian accessions showed the highest frequency of lines with a high amylose content. Then, 22 cultivars and lines with different levels of amylose content were selected and further investigated in both 1991 and 1992. The starch content of these cultivars and lines ranged from 9.3 to 28.8% and the amylose content ranged between 11.2 and 15.3%. A line "Oki88-29" with the lowest amylose content was selected from Okinawan accessions, and a line "Bis397-1" with the highest amylose content was selected from Indonesian accessions. These lines are considered to be useful for breeding sweet potato cultivars with various amylose contents. Also the range of amylose content in 58 accessions of *I. trifida* was 11.1–16.5%, as wide as that of the 812 accessions of sweet potato. These results indicated that there were varietal and geographical differences in amylose content in sweet potato, and the lines with low/high amylose content could be selected.

Varietal difference and annual variations in the physicochemical properties of sweet potato starch

Twenty cultivars and lines, including Japanese breeding lines, local cultivars from Okinawa Prefecture, and introductions from Indonesia and Papua New Guinea were grown in 1996–1998 to analyze the varietal and annual variations in the physicochemical properties of sweet potato starch[4,5]. Eating quality of steamed roots and dehydrated steamed roots were also investigated in 1998[5]. The pasting properties showed wide ranges of variation among cultivars and lines, and the amylose content by the blue value method[15] ranged between 13.4 and 17.6%. Analysis of variance showed that the varietal differences were significant at the 0.1% level for the pasting properties, amylose content and starch content (Table 1). The estimated heritability values of the pasting temperature, setback, amylose content and starch content were relatively higher than those of the other characters. The positive correlations of these four characters between the years were significant at the 0.1% level and the annual variation in these characters was relatively small. These results suggest that the selection for the pasting temperature, setback, amylose content, and starch content is relatively effective and it is possible to breed for the improvement in the starch pasting properties of sweet potato. The amylose content showed significant positive correlations with the peak viscosity temperature ($r = 0.482$, $P < 0.05$) and the setback ($r = 0.622$, $P < 0.01$). The eating quality of steamed roots showed significant positive correlation with the starch content ($r = 0.575$, $P < 0.01$). The eating quality of dehydrated steamed roots showed significant negative correlations with the peak viscosity ($r = -0.562$, $P < 0.01$) and the breakdown ($r = -0.463$, $P < 0.05$), as well as a significant positive correlation with the amylose content ($r = 0.445$, $P < 0.05$). These results suggest that the amylose content influences the pasting properties, and the amylose content and pasting properties influence the eating quality of processed foods from the storage roots.

Enlarging the variations of amylose content through crossing and mutagenic treatments, and analysis of *Wx* protein

The enlargement of the variations in amylose content through crossing and mutagenic treatments in sweet potato, and through mutagenic treatment in diploid *I. trifida* was attempted[5]. The distributions of amylose content in progenies from the crossing between parents with low amylose content and between parents with high amylose content were examined. In these crosses, transgressive segregants with lower (13.1%) and higher (19.2%)

Table 1. Analysis of variance and estimation of heritability for pasting properties, amylose content and starch content of sweet potato cultivated in 3 years

Sources of variance	Degree of freedom	Mean squares (MS)						
		Pasting temperature	Peak viscosity temperature	Peak viscosity	Breakdown	Setback	Amylose content	Starch content
Year (y)	2	4.255**	138.899**	387.217***	73.017***	156.817*	9.004***	3.688
Line (v)	19	10.323***	149.356***	98.010***	46.543***	413.526***	3.526***	78.301***
Error (e)	38	0.464	20.617	18.146	7.806	36.203	0.112	3.645
Heritability[a)]		0.83	0.62	0.42	0.54	0.75	0.67	0.87

*, **, ***: Significant at 5, 1 and 0.1%, respectively.
Expectation equation: $MSy = \sigma^2e + 20\sigma^2y$, $MSv = \sigma^2e + 3\sigma^2v$, $MSe = \sigma^2e$
a): $h^2 = \sigma^2v/(\sigma^2y + \sigma^2v + \sigma^2e)$

Table 2. Amylose content (%) in crude starch of F_1 progenies from cross between sweet potato lines

Cross combination	Parents					F_1 progenies			
	Mother[a)]	Father[b)]	Average[c)]	Minimum	Maximum	No. of plant	Average	Minimum	Maximum
Oki89-69×Oki88-77	15.5	15.0	15.3	14.4	16.1	27	15.0	13.0	17.0
Oki88-29×Oki88-77	13.7	15.0	14.4	13.5	15.6	6	15.0	13.6	16.2
Bis20-1×Tokyokintoki	17.6	18.2	17.9	16.7	19.3	28	18.3	16.4	20.1
Bis379-1×Tokyokintoki	18.1	18.2	18.2	17.5	19.3	111	18.3	15.3	20.7

a): Average of 10 plants of mother. b): Average of 10 plants of father. c): Average of 20 plants of mother and father.

amylose content than those of parents were selected (Table 2). The variations of amylose content in sweet potato were enlarged by the crossing.

The distributions of amylose content in progenies of the selfing in the self-compatible sweet potato line, Kankei 25 (amylose content 14.6%), irradiated by gamma-rays were examined. The range of variation in the mutagenic treatment was slightly wider than that of the control. A variant with a low amylose content, 13.2%, was selected, but the irradiation effect was not recognized clearly.

The distributions of amylose content in progenies obtained by open-pollination between brothers and sisters of diploid *I. trifida* irradiated by gamma-rays were examined. The ranges of variations in the mutagenic treatments were 7.2–9.0% wider than that of the control. Variants with a high amylose content (23.1%) and with a low amylose content (11.6%) were selected, and it was considered that the variations of amylose content in *I. trifida* could be enlarged by this mutagenic treatment. The starch properties of interspecific hybrids between sweet potato and diploid *I. trifida* were also examined. The amylose content and pasting properties of the interspecific hybrids were similar to those of the parents, or intermediate between those of the parents.

These results indicate that it is possible to enlarge the variations of amylose content through crossing and mutagenic treatment in sweet potato and *I. trifida,* and the variants with a low/high amylose content could be selected.

The amylose content and the amount of *Wx* protein (granule-bound starch synthase which is responsible for amylose synthesis) were analyzed in sweet potato, diploid *I. trifida* and the interspecific hybrids[6]. The amount of *Wx* protein showed significant positive correlation with the amylose content (Fig. 2). This suggests that in sweet potato a decrease in amylose content is caused by a decrease in the amount of *Wx* protein, and the *Wx* protein controls the amylose content through the change in the protein levels.

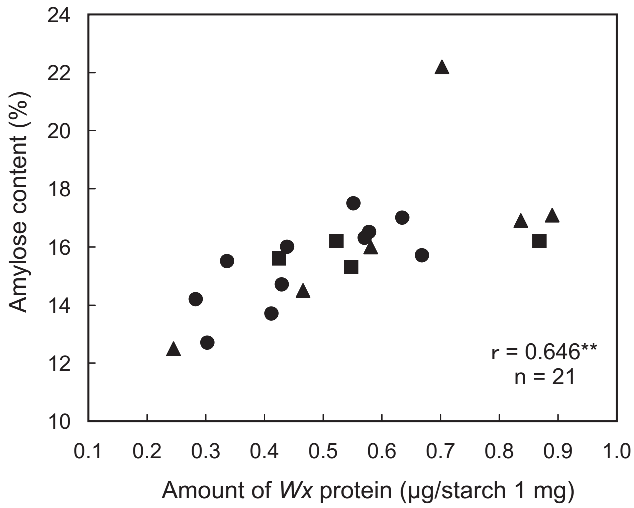
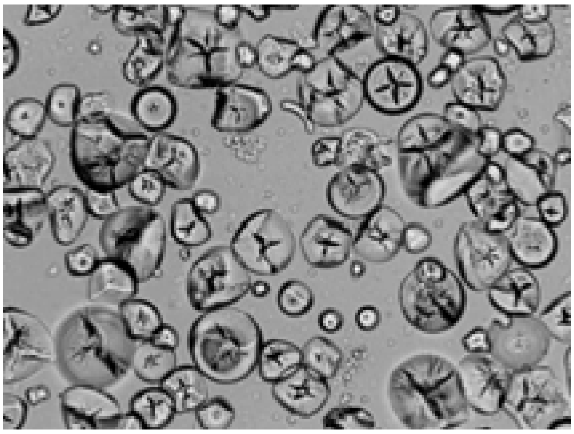


Fig. 2. Relationship between the amount of *Wx* protein and amylose content in sweet potato, *Ipomoea trifida* and interspecific hybrids

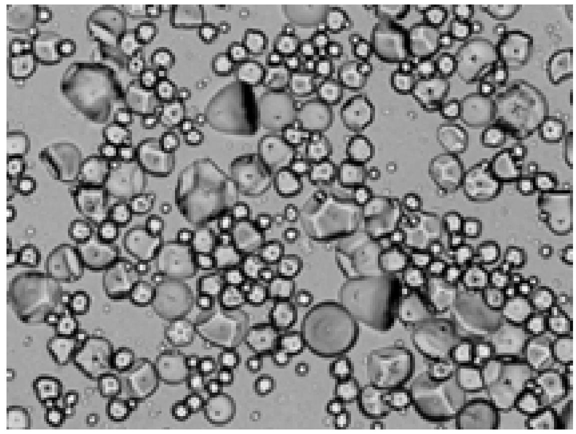
● : Sweet potato, ▲ : *Ipomoea trifida*,
■ : Interspecific hybrids.

A new cultivar "Quick Sweet (Kanto 116)" having low gelatinization temperatures, slow retrogradation and altered starch structure

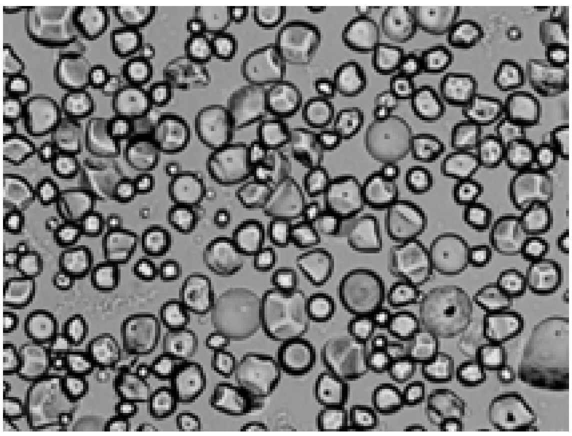
A new cultivar, "Quick Sweet (Kanto 116)", with a low pasting temperature was developed and its starch properties were investigated[7]. The starch content, amylose content and appearance of tuberous roots of Quick Sweet were similar to those of ordinary Japanese cultivars. The starch granules from Quick Sweet showed an abnormal morphology characterized by cracking in the granules (Fig. 3). The pasting temperatures of Quick Sweet starch by the Rapid Visco Analyser were 51.4–52.6ºC, approximately 20ºC lower than those of ordinary cultivars (Fig. 4). Onset, peak, and conclusion temperature of gelatinization, and gelatinization enthalpy by the differential scanning calorimeter of Quick Sweet starch were 39.0ºC, 46.9ºC, 64.8ºC, and 8.8 J/g, respectively,



Quick Sweet (Kanto116)



Koganesengan



Beniazuma

Fig. 3. Light micrographs of starch granules from Quick Sweet (Kanto 116) and ordinary cultivars (×400)

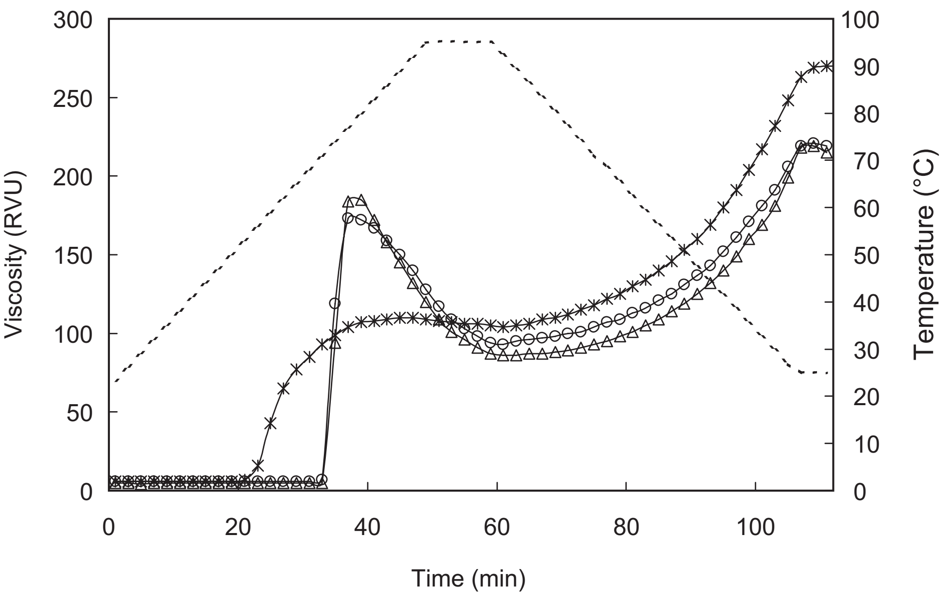


Fig. 4. Pasting profiles of starches from Quick Sweet (Kanto 116) and ordinary cultivars
Starch concentration 7%.
⚹ : Quick Sweet (Kanto 116), ○: Koganesengan, △: Beniazuma, ---: Temperature.

and much lower than those of starches in ordinary cultivars (Table 3). The chain length distribution of the amylopectin molecules by high-performance anion-exchange chromatography showed that Quick Sweet starch had a higher proportion of short chains (DP 6-11) and a lower proportion of chains between DP 12–28 than starches in ordinary cultivars (Fig. 5). Starch retrogradation, evaluated by leaked water percentage and hardness of starch gels after refrigerated-storage, showed that Quick Sweet starch retrograded much slower than starches in ordinary cultivars and exhibited excellent cold storage stability[9] (Table 3). Previous studies of Noda et al.[13] and Ishiguro et al.[1] suggest that the low gelatinization temperature and slow retrogradation of Quick Sweet starch are due to an increase in short outer chains of amylopectin. Quick Sweet starch with slow retrogradation is expected to be used as an ingredient in confectioneries like gelatinized cakes, and as a stabilizer in food products. To our knowledge, this is the first discovery of a sweet potato variant having very low gelatinization temperatures, very slow retrogradation and altered starch structure.

Further, cooking properties of Quick Sweet storage roots were investigated[8]. When ordinary sweet potato cultivars are cooked by microwave oven, their tastes are not so sweet (brix values of Beniazuma were around 5%). However, Quick Sweet was sweet enough (brix values were 6.5%) even after microwave cooking. Also, when the storage roots were steamed, brix values of Quick Sweet increased more rapidly than those of ordinary cultivars (Fig. 6). The sweetness of sweet potato is derived from maltose which is formed from gelatinized starch by β-amylase during cooking[14]. It is likely that the changes in cooking properties of Quick Sweet are derived from the low gelatinization temperatures of its starch. Also, these results indicate that sweet potato having starch with low gelatinization temperatures may be effective for economizing on fuel or heat energy for cooking.

Quick Sweet was officially registered as a new cultivar, "Sweetpotato Norin 57", in 2002 by the Ministry of Agriculture, Forestry and Fisheries of Japan[8]. Also, we

Table 3. Gelatinization and retrogradation properties of starches from Quick Sweet (Kanto116) and Japanese ordinary cultivars

Cultivars	DSC gelatinization properties				Retrogradation ratios ($\Delta Hr/\Delta H$)[a)]				Leaked water (%)[b)]		Hardness (N)[b)]		
	T_O (ºC)	T_P (ºC)	T_C (ºC)	ΔH (J/g)	1 week	2 weeks	5 weeks	65 weeks	2 weeks	14 weeks	2 h	2 weeks	14 weeks
Quick Sweet	39.0	46.9	64.8	8.8	0.17	0.33	0.39	0.80	0.0	0.2	0.38	0.39	0.49
Koganesengan	59.9	67.3	82.2	12.4	0.61	0.68	0.72	0.78	2.3	19.4	0.29	0.90	1.98
Beniazuma	63.1	68.1	82.7	12.9	0.59	0.66	0.71	0.84	–	–	–	–	–

T_O: Onset temperature, T_P: Peak temperature, T_C: Conclusion temperature.
a): Ratios of re-gelatinization enthalpy (ΔHr) after storage at 5ºC for 1 week, 2 weeks, 5 weeks, and 65 weeks to the gelatinization enthalpy (ΔH) at the first run.
b): Leaked water percentage and hardness of 8% starch gels were estimated after storage at 5ºC for 2 h, 2 weeks, and 14 weeks.

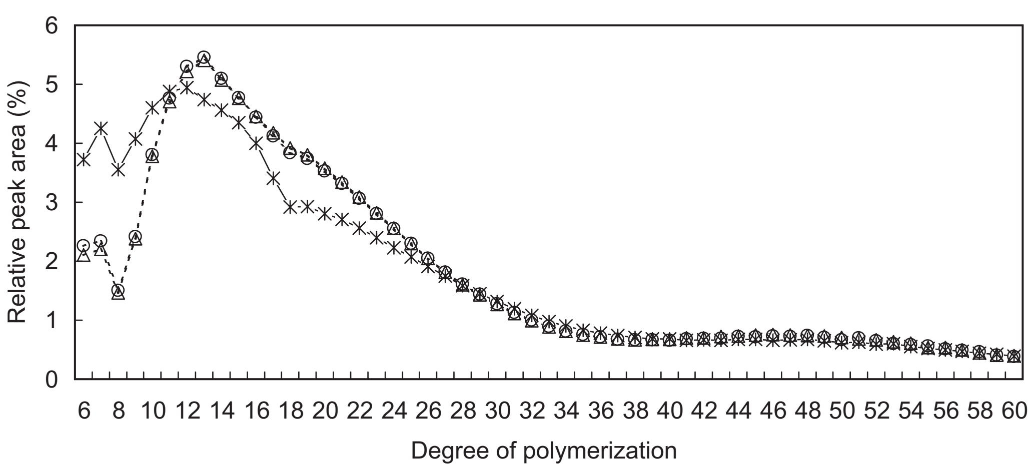


Fig. 5. Chain-length distributions of starches form Quick Sweet (Kanto 116) and ordinary cultivars
⚹: Quick Sweet (Kanto 116), ○: Koganesengan, △: Beniazuma.

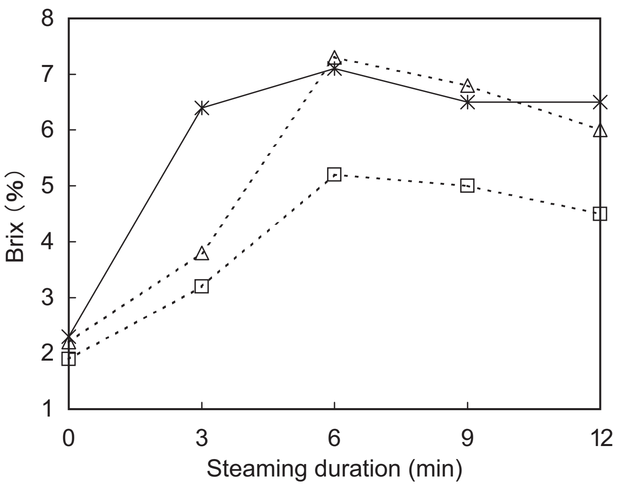


Fig. 6. Changes in brix values of storage roots of Quick Sweet (Kanto 116) and ordinary cultivars during steaming
⚹: Quick Sweet (Kanto 116), △: Beniazuma,
□: Kokei 14.

are developing some new breeding lines with interesting starch properties, e.g. low pasting temperature and slow retrogradation, by using Quick Sweet as breeding material[9]. Quick Sweet is expected to develop new applications for sweet potato starch, and to be a useful breeding material for improving sweet potato starch properties. Further studies on the inheritance and starch biosynthetic enzymes of Quick Sweet could contribute to improve the starch properties of sweet potato.

Conclusion

In these studies, we provided the basic information to breed for the improvement of starch properties in sweet potato, and produced a new cultivar and breeding materials with distinctive amylose content and pasting properties. These results are useful to develop sweet potato cultivars with various starch properties. The stability of starch gels during cold storage or freeze-thaw cycling enhances its potential use in food processing. One of the future targets is production of sweet potato starch having both much short outer chains of amylopectin (Quick Sweet type) and lack of amylose. This starch is expected to show excellent cold storage and freeze-thaw stability[2]. Also, the production of fuel ethanol or biodegradable plastic from the fermentation of biomass is expected as a growing industry in a continuously developing society. The starch with low gelatinization temperature requires less energy input for the gelatinization step that begins the conversion of starch into ethanol or plastic. The sweet potato having high starch yield and low gelatinization temperature of starch may be effective for reducing these production costs. We hope that these improvements in starch properties are useful for providing consumers with superior starch products and spreading the demand for sweet potato starch.

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