ESTABLISHING A STABLE POTATO PRODUCTION SYSTEM IN JAPAN AND DEVELOPING NEW VARIETIES WITH SPECIFIC END-USE CHARACTERISTICS

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ABSTRACT

Potatoes were introduced in Japan at the beginning of the 17th century, but cultivation began in Hokkaido at the end of the 19th century. Hokkaido accounts for more than 70 percent of the nation's potato production, and potatoes grown in Hokkaido are used for fresh market sale, processing, starch production, and various other purposes. The average nationwide yield per hectare is 33 tons, but yield in Hokkaido surpasses 41 tons, the highest level of productivity in the world. This is due to the establishment of the multiplication system for successful seed potatoes and sound seed potato quarantine system, the progress of cultivation management techniques, and cheap material supply. With regard to cultivation of varieties, utilization characteristics and quality were improved in accordance with end use. For potatoes grown for fresh consumption, primarily shipped to the market, texture and the degree of disintegration and discoloration were improved. Enhancement of the processing quality and processing yield was attempted for potatoes grown as materials for potato chips and other processed foods. In addition, colored varieties such as red- and purple-fleshed potatoes were cultivated in an effort to develop new market demands. Aside from improving utilization characteristics for consumption and processing, developing well-balanced groups of varieties to ensure stable production by breeding potatoes resistant to pests and diseases was also aimed at.

Keywords: stable potato production system, Japan, specific end-use characteristics, potato cyst nematode, potato scab, degree of disintegration, discoloration

INTRODUCTION

It is believed that potatoes were first brought by a Dutchman from Java (Jakarta) in Indonesia to Nagasaki in Kyushu (southen island) at the beginning of the 17th century. However, cultivation of potatoes became widespread at the end of the 19th century when the Meiji Government promoted Western-style agriculture in Hokkaido, particularly in the cool mountainous areas in Honshu (mainland). Potatoes became an important food for settlers in the early days of Hokkaido's development. During World War I in Europe, starch was exported as an international commodity. To accommodate demand, cultivation of potatoes for starch production rapidly increased, and this share of the cultivation area remained significant.

Potatoes grown in Hokkaido are used for all purposes: consumed fresh or used in starch production, as a raw material for processed foods such as potato chips, and as seed potatoes grown to take advantage of the cool area. On the other hand, in warm areas in Honshu and further south, potatoes are generally cultivated for fresh consumption and shipped primarily between April and July, the off-crop season in Hokkaido. Potatoes for fresh consumption are grown all over Japan. Although potatoes for processing purposes are produced in some areas of Kyushu and

Honshu, those grown for starch materials are not produced outside Hokkaido (Mori 2001).

STATE OF DOMESTIC PRODUCTION

The nationwide potato yield per hectare in 2002 was 33 tons. However, yield in Hokkaido surpassed 41 tons, the highest productivity level in the world. The cultivation area and production volume in Japan are approximately 92,000 ha and 3.07 million tons, of which Hokkaido accounts for 63 percent and 76 percent, respectively. In terms of cultivation area, Hokkaido is followed by Nagasaki and Kagoshima Prefectures in Kyushu, each representing 5 percent of the total, where harvesting is carried out during the off-crop season in Hokkaido, mainly shipping to fresh market from spring to early summer. On examination of past developments, the cultivation area was reduced by half from approximately 200,000 ha in 1960 to about 90,000 ha in 2002. However, gross production has remained unchanged at approximately 3 million tons. This was due to an increase in yield from 18 tons/ha (1960) to 33 tons/ha (2002) (Fig. 1).

The primary reasons for improved productivity are the establishment of the multiplication system for disease-free seed potatoes in 1947 and the sound seed potato quarantine system in 1953. The secondary factors are the availability of cheap chemical fertilizers and agricultural chemicals and the progress of cultivation management techniques on proper fertilizer application and pest and disease control. Another factor is the cultivation of highly productive varieties with pest and disease resistance that accommodates changes in demand.

SUCCESSFUL SEED POTATO PRODUCTION SYSTEM

Since potatoes are vegetative propagation-type crops, they are commonly cultivated using seed potatoes. This method is advantageous in that development and end products are uniform and initial growth can be secured even in an unfavorable environment. There is, however, a high risk of spreading pests and diseases such as viruses and nematodes via seed potatoes. The drawback is that since the multiplication ratio of one cultivation is low (a maximum of approximately 20 times), the multiplication of seed potatoes requires many years. Therefore, the National Center for Seeds and Seedlings, Independent Administrative Institution produces foundation seeds and the Plant Protection Station of the Ministry of Agriculture, Forestry and Fisheries inspects seed potatoes in conformity with the Plant Protection Law to breed and produce high-quality material (Fig. 2). Furthermore, the percentage of seed and seedling expenses is high since 200 kg or more of seed potatoes per hectare are necessary for

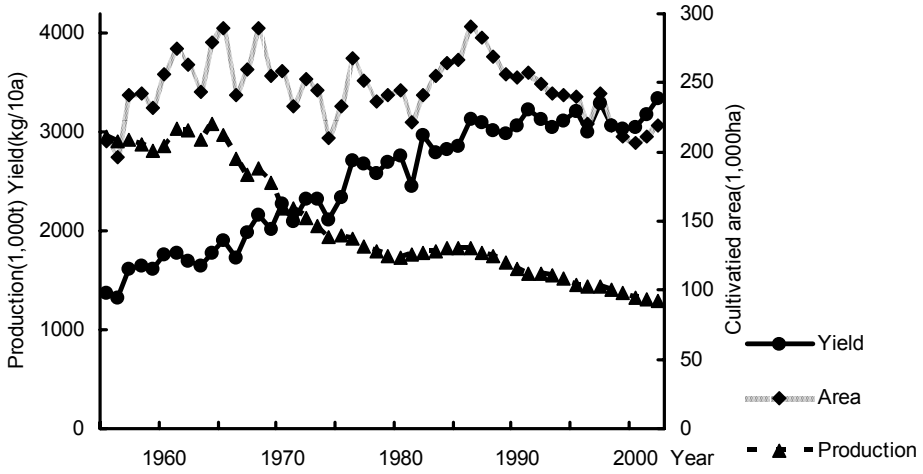

Fig. 1. Cultivated area, domestic production, and unit yield of potato in Japan

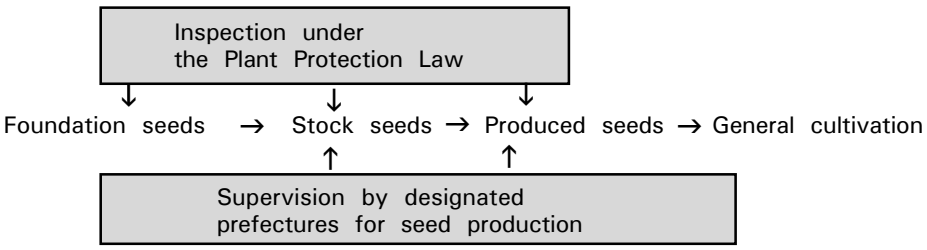

Fig. 2. Flow of successful seed production of potato

ordinary cultivation, and the distribution of seed potatoes requires capital investment in storage and transportation systems and in advanced management technology.

Seed potato production systems such as this have been put in place in many advanced nations, although under different conditions depending on the country. In Japan, seven foundation potato seed farms were established in 1947. Even if foundation seed farms distribute sound, disease-free foundation seeds, seed potatoes lose their value if contaminated with viral diseases in the course of multiplication to stock seed and seed production fields.

Under these circumstances, seed potato quarantine was launched in 1951 in accordance with the Plant Protection Law. This obliges the national government to guarantee the nature (soundness) of seed potatoes, leading to the completion of the present system.

DOMESTIC CONSUMPTION TRENDS

Japan's per capita annual consumption of potatoes was more than 17 kg until around 1960. The figure rapidly decreased as the potato's role as a staple food disappeared, and it reached a record low of 12.9 kg in 1974. Following this, consumption started to increase again and has hovered around 17-18 kg since 1990. The resurgence of consumption is due to the change in consumption pattern from purchasing raw potatoes and cooking them at home to purchasing processed products, eliminating cooking at home. The increased production of potatoes for processed food since 1975 has been remarkable: consumption of potato chips increased tenfold over a decade until 1985 and has since stabilized. Although consumption of frozen fried potatoes increased in conjunction with the development of hamburger chains, products imported from the United States, for example, accounted for the majority of frozen fried potatoes due to cheap, stable supplies. Since 1990, consumption of frozen croquettes and packaged salads has increased, resulting in increased demand for potatoes for commercial use such as primary processing products, including peeled and pre-cut potatoes. These were primarily consumed by the food service industry such as fast-food restaurants and the takeout side dish industry (delicatessen) such as convenience stores. The consumption (including import) of processed foods, mostly nonexistent in 1960, exceeded about 1.3 million tons in 1997 and has since plateaued (Fig. 3).

BREEDING NEW VARIETIES

Although enhancing pest and disease resistance and yield properties of potatoes is the common goal, improving characteristics and quality according to end use is the challenge to be addressed. Potatoes for fresh consumption, which center on market shipment, are required to suit different types of preparation such as boiling and mashing, which depend on texture, degree of disintegration, among other characteristics. They must look good and appeal to consumer taste. Potatoes used for processed food materials are inextricably linked with the profitability of corporate management, and efficiency is important. It is desirable that potato chips do not brown during deep-frying and that product yield is high. For frozen fried potatoes, the dry matter distribution inside potato tubers must be even. The potatoes must be large-sized in

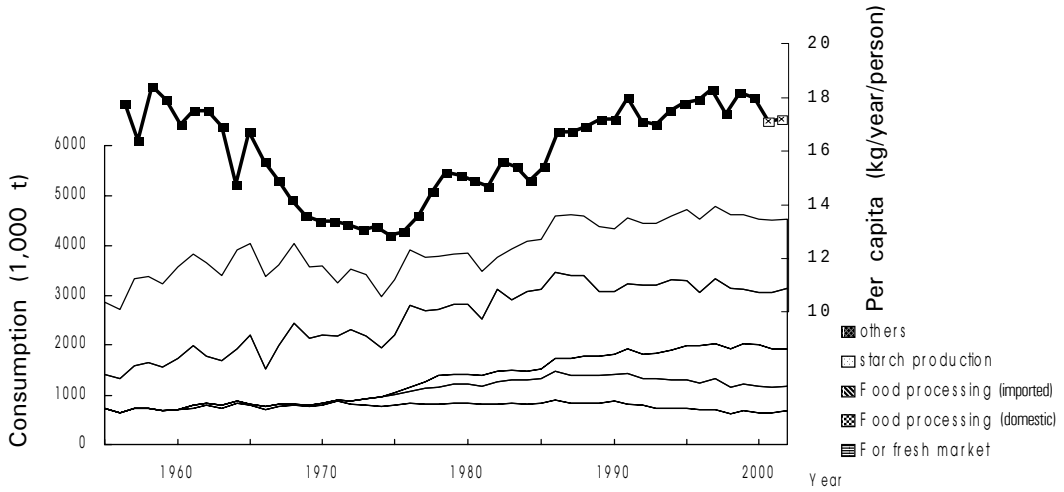

Fig. 3. Consumption of potatoes for various uses and personal consumption in Japan

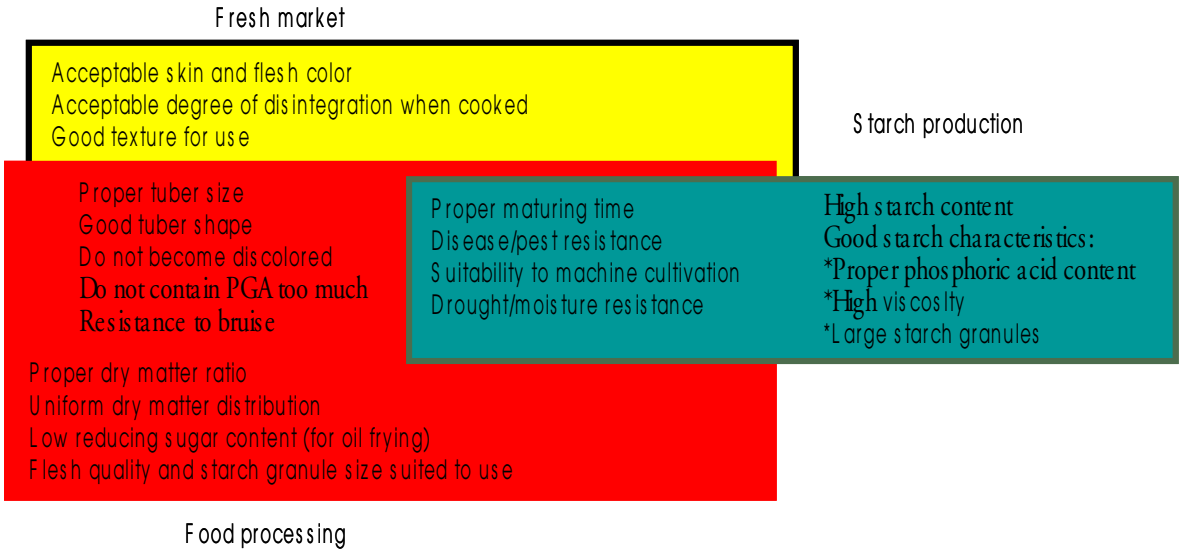

Fig. 4. Objectives of potato breeding in Japan

addition to being suitable for deep frying. Potatoes used in starch production require unique starch quality characteristics in addition to high yield (Fig. 4).

Introduction of pest and disease resistance

In 1972, the potato cyst nematode (*Globodera rostochiensis*) was confirmed for the first time in the Shiribeshi region of Hokkaido. The contaminated area has continued to increase and now exceeds 9,000 ha. The cyst (egg capsule) of the nematode is highly persistent and maintains activity in the soil under natural conditions for more than a decade. Since the nematode adheres to and moves with potatoes and the soil, it is designated as a harmful nematode in international plant quarantine. Beginning with 'Tunika,' which was introduced in 1981 from the former East Germany, numerous nematode-resistant varieties have been bred, with "Tunika," "R392-50" (by introducing hybrid seeds from the United States and performing selection), and others as mother plants (Table 1) (Mori and Umemura 1992).

Table 1. Potato cyst namatode-resistant varieties in Japan

Year	Fresh market	Processing	Starch
1980	Kita-akari Ezo-akari		Tunika Toyo-akari
1990	Toyo-akari Beni-akari Sayaka Hanashibetsu Fugenmaru Star Queen	Musamaru Atlantic Yankee Chipper	Astarte Sakurafubuki Early starch Prevarent
2000	Tokachikogane Haruakari Aiyutaka Star Ruby Kitamurasaki	Kitahime	Natsufubuki

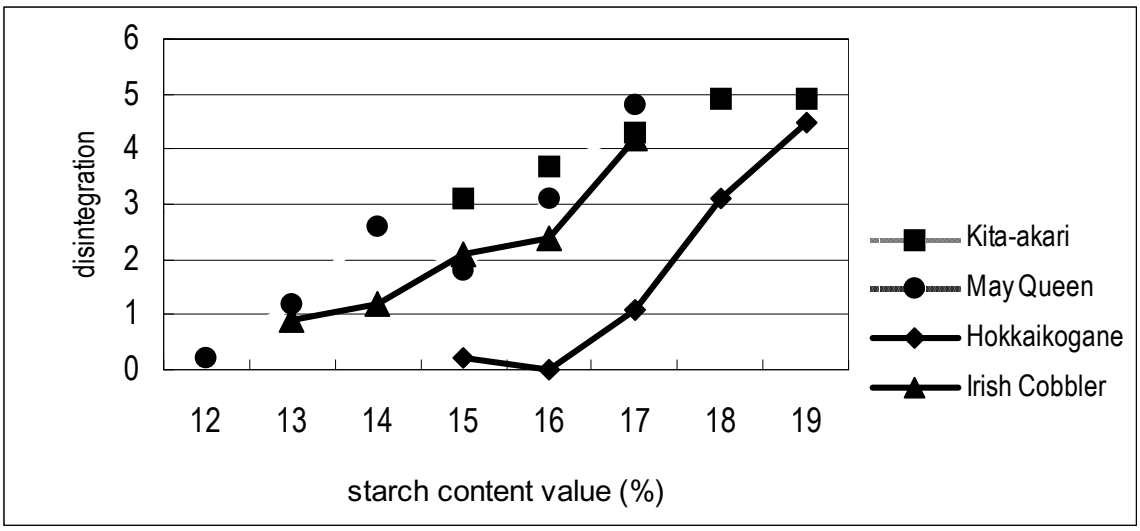

Fig. 5. Relationship between starch content and degree of disintegration after cooking

Potato scab, caused by *Streptomyces* sp. Actinomycetes, is an uncontrollable disease transmitted from soil and seed potatoes. It creates crater-like lesions on potatoes and drastically reduces market value by compromising the outer appearance. Bred in 2000, "Yukirasha" is a variety with sufficient resistance to suffer few lesions under conditions that may result in scab outbreak in "Irish Cobbler" variety (Kobayashi *et al.* 2002).

Degrees of disintegration during boiling

For potatoes grown for fresh consumption, varieties suitable for different recipes that require boiling and mashing are used depending on texture, degree of disintegration, etc. Since disintegration increases as the potato starch volume rises, starch value is used as the index for predicting the degree of disintegration.

Nevertheless, the degree of disintegration is different among varieties even if starch value is identical. One example is when the starch value surpasses 14 percent, disintegration of "May Queen" begins. Disintegration does not occur in "Hokkaikogane" (bred in 1981) even if the starch value has reached 16% (Fig. 5). As for "Irish Cobbler," the higher the starch value, the more the potato disintegrates. 'Kita-akari' disintegrates and becomes mealy irrespective of the starch value.

Varieties prone to disintegration have large cell sizes and intercellular spaces. The structure of these varieties causes cells to separate mostly when internal pressure is applied owing to the gelation and swelling of starch caused by heating. In these instances, starch particles do not break out of cells and every cell is pulled apart by making cells swell. This condition is referred to as disintegration.

On the contrary, varieties resistant to disintegration feature small cell sizes and a small number of starch particles per cell. Intercellular spaces of these varieties are approximately one-seventh of the size of those in varieties that disintegrate easily. Furthermore, cells outside the vascular cylinder have starch with small particle sizes, and the modalities of tissue cells make disintegration from surface layers difficult. The quantities of calcium and galacturonic acid contained in cell walls also affect disintegration: the higher the content of these ingredients, the more resistant potatoes will be to disintegration because of the increase of intermolecular cross-linking power of pectic substances, which cause intercellular adhesion (Matsuura-Endo *et al.* 2002).

Varieties with no discoloration

Peeling potatoes and leaving them to stand in contact with air causes discoloration (black postpeeling discoloration). However, varieties such as "Touya" (bred in 1991), designed for early shipment, and "Sayaka" (bred in 1995) have less black postpeeling discoloration than "Irish Cobbler" and do not discolor to a great extent when left to cool after boiling (postcooking discoloration). These characteristics are appropriate for commercial demands that require cooking at food plants and central kitchens. Attracting attention are "Kita-akari" (bred in 1987), yellow-fleshed, farinose, and tasty; "Sayaka" (bred in 1995), which can be cut and peeled efficiently owing to its large size and shallow eyes; and other new high-quality varieties (Mori 1994) (Table 2).

Table 2. Characteristics of major potato varieties in Japan

Variety	Characteristics in appearance	Starch value(%)	Flesh color	Notes and uses
Irish Cobbler	round, deep eyes	14 to 16	white	easy to disintegrate, fresh market
May Queen	comma shaped	12 to 14	white	waxy firm flesh, fresh market
Dejima	flat round, large	11 to 13	yellow	fresh market, for warm area
Nishiyutaka	flat round	10 to 12	yellow	fresh market, for wam area
Kita-akari	flat round, red eyes	15 to 17	yellow	easy to disintegrate, fresh market
Touya	round, shallow eyes	12 to 14	yellow	smooth flesh, fresh market
Beniakari	flat ovate, red skin	18 to 20	white	extremely mealy flesh, coroquette
Sayaka	ovate, shallow eyes	13 to 15	white	waxy firm flesh, low discloration, salad
Norin no. 1	flat round	15 to 17	white	chips, fresh market
Waseshiro	flat ovate	14 to 16	white	early bulking, ships, fresh market
Toyoshiro	flat ovate	15 to 17	white	roughly mealy flesh, chips
Hokkaikogane	long ellipsoidal	16 to 18	yellow	waxy firm flesh, fry, fresh market
Kitahime	flat round	15 to 17	white	low reducing sugars content, chips
Benimaru	flat ovate, red skin	15 to 17	white	starch, low phosphoric acid content
Konafubuki	flat ovate, large	20 to 22	white	starch, hight phosphoric acid content
Inca-no-mezam	ovate, small	16 to 18	orange yellow	smooth flesh, nuts flavor
Inca red	ellipse, red skin	10 to 12	red	anthocyanin (pelanin), firm flesh
Inca purple	ovate, purple skin	18 to 20	purple	anthocyanin (petanin), mealy flesh

Black postpeeling discoloration, an enzymatic reaction, occurs when phenols (e.g., tyrosine, catechin, and chlorogenic acid) in cells change to quinone by polyphenol oxidase and then become black melanin pigment through oxidation polymerization. The non-enzymatic change of postcooking discoloration occurs when phenol (mainly chlorogenic acid) and iron contained in tubers are combined into iron-diphenol during cooking. Potatoes then turn black because of oxidization during postcooking cooling. In both types of discoloration, phenol is involved in discoloration. As they are positively correlated, it is possible to breed varieties that do not discolor a great deal by screening whether they are raw or cooked (Table 2).

Varieties for processed food and product colors

The demand for potato chips began in 1975. In response to the growing demand, "Toyoshiro" was bred in 1976. It now accounts for approximately 80 percent of potatoes grown for processing into potato chips. "Waseshiro" (bred in 1974) is used as the material for early shipment in July and August. Although "Hokkaikogane" was bred for processing into French fries, its success has diminished because of competition with imported frozen products (Table 2).

Although cold storage can reduce wastage of potatoes, temperatures lower than 10°C cause products to brown. Low temperature decreases and increases the sugar levels (fructose and glucose) in potatoes, triggering the Maillard reaction during potato chip processing that leads to browning referred to as melanoidin. The sugar fluctuation at low-temperature storage is related to the acid invertase activity. Most varieties such as "Toyoshiro" belong to the reducing and increasing sugar-type (Fig. 6). The low sugar level-type, which allows low-temperature storage, includes "Snowden" (introduced in 1999 in the United States) and "Kitahime" (bred in 2001 in Hokuren). However, these varieties have problems with cultivation, and improving their agronomic characteristics is in progress (Matsuura-Endo *et al.* 2004).

Colorful potatoes

Although the flesh of ordinarily cultivated varieties ranges in color from white to lemon yellow, cultivated species of old types (e.g., *S. phureja*, *S. tuberosum* ssp. *andigena*) exist in places of origin like in the Andes in South America. These areas grow orange-yellow potatoes that contain the carotenoid pigment, and red and purple potatoes with the anthocyanin pigment. With these serving as the genetic resource, "Inca-no-mezame," the orange-yellow-fleshed diploid, red-fleshed "Inca red," and purple-fleshed "Inca purple" were bred in 1997 (Table 2) (Mori 2003).

The main pigments of red-fleshed and purple-fleshed potatoes are pelanin and petanin, respectively. These pigments have physiologic functionality like other anthocyanin pigments. Evaluation of antioxidative properties indicated that these properties were comparable with those of synthetic antioxidants among food additives (BHA and BHT) (Ishii *et al.* 1996). Furthermore, functionalities unique to potatoes such as the anti-influenza virus activity of a potato anthocyanin pigment (Hayashi *et al.* 2003) and the apotosis inductor extracted from potato, potato foodstuff containing the inductor, and its processed product were confirmed and patent applications have been submitted.

TOWARD THE FUTURE

Varieties that are distinctive and stand out in one area and those that can be distinguished at a glance lead the way to new trends and make our dietary life more affluent. Without versatility, however, it is impossible to cultivate potatoes in a large land area. Highly adaptable varieties have a wide scope of end uses. Good-quality products are sorted and shipped to markets and off-specification products are used for croquettes, salads, mashed potato, and ultimately, starch. These varieties are extremely capable of shipping adjustment and their profit recovery rates on the whole are high. In Japan, "Irish Cobbler" has fulfilled this role and its corresponding variety in the United States is "Russet Burbank."

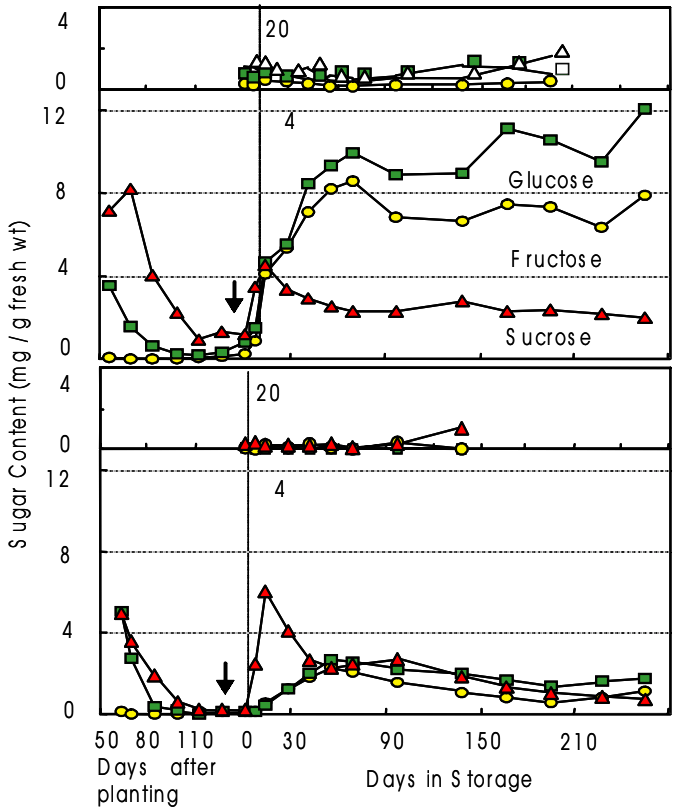

Fig. 6. Changes in sugar contents of potato tubers during the growing season and storage period

There are varieties whose yields are high in normal years but significantly decline in lean years with climate changes such as low temperatures and high humidity, high temperatures and drought. On the other hand, varieties whose yields are relatively stable regardless of meteorological conditions also exist. Furthermore, there are varieties whose yields do not decrease to a large extent even if levels of fertilizer application and pest and disease control are low. Developing highly stable varieties is one of the important objectives from the viewpoint of recent global warming, intensifying meteorological fluctuations, and environmental load reduction.

Pressure against agricultural trade liberalization during World Trade Organization (WTO) negotiations has continued to increase. Promoting domestic potatoes to compete with imported ones requires satisfying the demands for high-quality potatoes for commercial and food processing uses well as supporting consumption by meeting the demands of consumers and manufacturers by enhancing the stability from both the production and supply perspectives. To this end, we are striving to develop well-balanced varieties with expanded versatility and stability while improving specificity and satisfactory end-use characteristics.

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