Potato Breeding in Japan
—Breeding for Resistance to Late Blight—

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The present article mainly deals with one of the recent achievements made in the potato improvement program of Japan. Before proceeding immediately to that subject, however, it will be appropriate to give a briefing of the potato industry in Japan, including a historical review, because so far information on this matter has rarely been introduced to other countries.

Potato production in Japan

The round-about migration of potatoes to Japanese shores is believed to have occurred in around 1600, when they were brought to Kyushu Island by Dutch merchants from Jakarta, present Indonesia. Acceptance of potatoes as food, however, was reluctant and said to be in the beginning of the 19th century.

Although in 1878 the acreage under potato was only 10,000 ha, today it has reached somewhere about 200,000 ha, occupying 2.7 per cent of the whole farmland areas or 5 per cent of that excluding paddy fields in average of 1963-1967.

An astonishing fact is that the nation-wide average yield per ha has almost doubled, from one ton to nearly two tons during the 1940-1967 period. The mean annual potato production (1963-1967) amounts to 3,699,754 tons. Nearly 40 per cent of the total crop is used for table stock including growers' own consumption, 29 per cent for starch, 17 per cent for livestock feed, and 10 per cent for seed according to the five-year average, 1963-1967; most pronounced is a larger use for starch compared to other countries. In a diet of our people today potatoes have become a vital part; the per capita consumption of fresh potatoes is 16.4 kg (average, 1961-1965).

Japan stretches long in a north-south direction and is hilly and mountainous. Therefore, the season adapted for potato growing is extremely different with regions to grow, with latitude and elevation. As seen in Fig. 1 the rate of spring-planted and summer-planted crop changes according to different regions; in the north only spring-planted crop is found, while in the south-west an increase in the rate of summer-planted crop is noticed.

It also shows that nearly half of the crop is produced in Hokkaido Island with cool climate conditions favorable for raising potatoes, located in the northern part of Japan. In Hokkaido the potato is one of the major crops, occupying 8.8 per cent of the farmland areas and 11.6 per cent of that excluding paddy fields (average, 1963-1967).

Hokkaido produces good quality table and seed potatoes, and more than half of the crop is used in starch manufacture, as against the fact that in other regions nearly whole crop produced is used for table stock.

Potato improvement program

In accordance with the situation of potato production mentioned above considerable emphasis is placed on the potato improvement program in Japan. There are three potato breeding stations, activities of which are

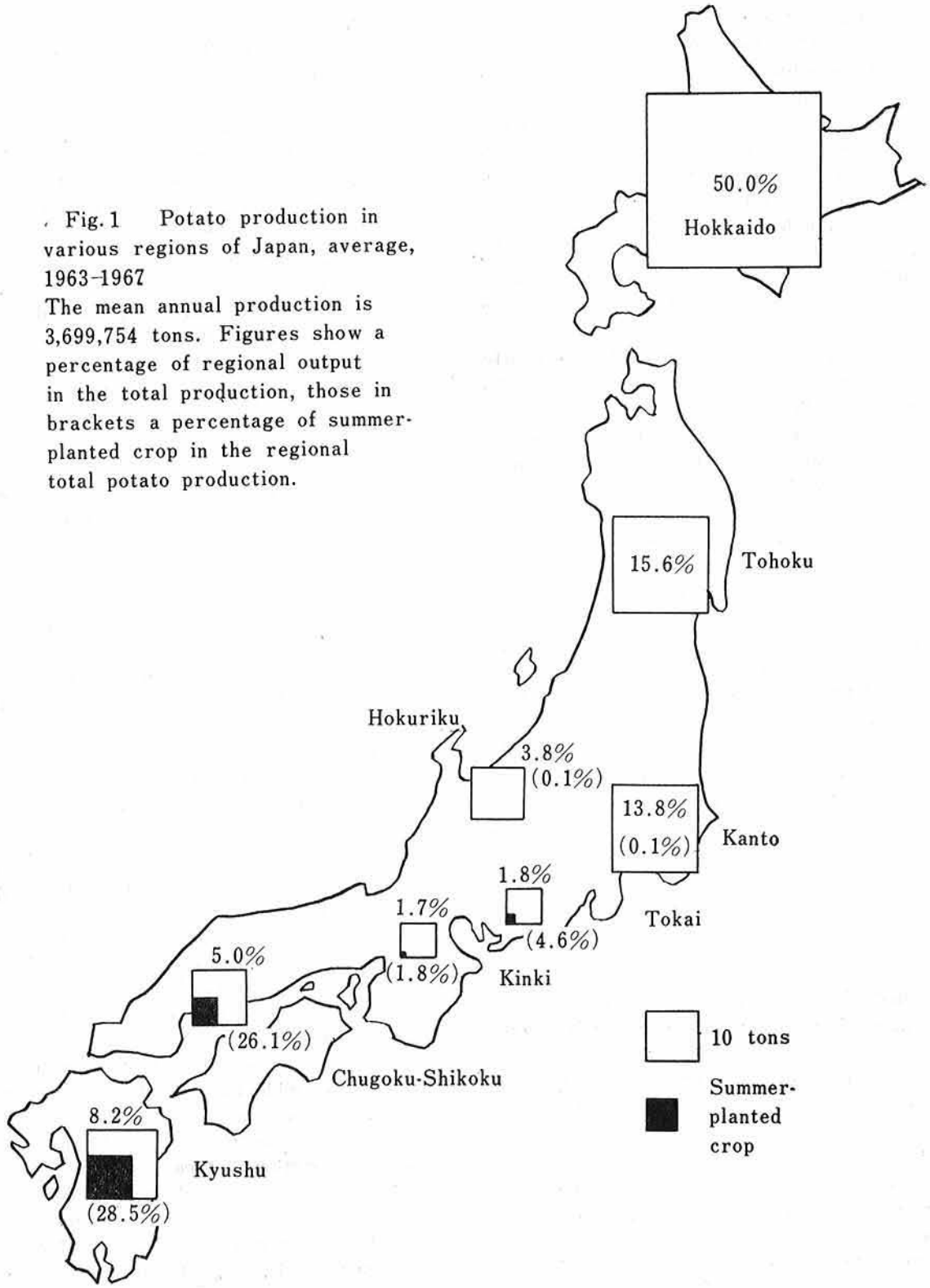

Fig. 1 Potato production in various regions of Japan, average, 1963-1967
The mean annual production is 3,699,754 tons. Figures show a percentage of regional output in the total production, those in brackets a percentage of summer-planted crop in the regional total potato production.

briefed as follows:

1) Potato Breeding Center, Hokkaido National Agricultural Experiment Station, Shimamatsu-Eniwa, Hokkaido.

The center, being the only one national organization for potato research, is practically responsible for a nation-wide potato improvement program. Among its main works are introduction and maintenance of wild species and foreign and domestic varieties, studies on the utilization of wild species, development of dihaploid plants and their evaluation in practical breeding, breeding both starch and table potatoes preferably with early maturity and resistance to late blight, fundamental studies on development of efficient screening techniques, particularly at a young seedling stage, and studies in hybrid field between breeding and cultural method.

2) Section of Potato, Konsen Region Hokkaido Prefectural Agricultural Experiment Station, Nakashibetsu-Nemuro, Hokkaido.

This section is engaged in breeding starch and feed potatoes specially adapted to the north-east part of Hokkaido, induction of mutants by radiation, studies on factors affecting yields and improvement of cultural method.

3) Aino Potato Research Center, Nagasaki Prefectural Agricultural Experiment Station, Aino-Korai-Gun, Nagasaki.

This center is solely engaged in breeding yellow-freshen table potatoes especially adapted for double-cropping areas locating in the south-west of Japan, and further in studies on techniques of pollination and improvement of cultural method.

Breeding potatoes for resistance to late blight (*Phytophthora infestans*)

Because of a considerable amount of rainfall and temperature conditions favorable for blight epidemics, prevailing during the potato growing season, late blight is among the worst diseases of the potato throughout Japan, particularly drastic in Hokkaido, which is the main potato producing region. Accordingly development of blight resistant varieties is one of the major potato breeding objectives in Japan.

Since 1939, when wild species of potatoes were introduced into Japan for the first time, the study on interspecific hybridization has been continuing and will be made more extensively in an attempt to improve domestic varieties. It was in 1952, however, that breeding for blight resistance gained special emphasis in a breeding program in cooperation with plant pathologists.

As was the case in many other countries, introduction of resistance, represented by major genes, R_1, R_2, R_3 and others, into a commercial variety has been made, and as a result several varieties carrying R genes, singly or in combination, were developed and released to growers.

In early years the source of genes for resistance was the seedling 41089-8 carrying R_1R_4, derived from *Solanum demissum* forma *atrocyaneum* after backcrossed once with cultivated variety by Prof. Dr. K. Taguchi. Later, Kennebec, Cherokee and 96-56, all carrying R_1, from the United States, and Scottish varieties such as 2070-ab(31) carrying R_2R_4, 2070-ab(32) carrying R_1R_3, and Pentland Ace carrying R_3, and others from Germany and the Soviet Union were used.

Inoculation of interspecific hybrids with races of the fungus revealed that there was a nearly complete correlation between foliage and tuber resistances, provided that special caution be given to an inspection of the tuber resistance, generally regarded more declined than the foliage.

Furthermore, it was found in leaf-tests that there were differences in the resistance within genes, R_1, R_2, R_3 and R_4; level of resistance is highest in R_3 gene, followed by R_1, R_4 and R_2 in the order. Because of the lack of genuine race 4 at the time of experiment, it was not discernible whether R_2 was weaker than R_4. In the course of experiment the specialization of the fungus seemed more frequent in a direction of races 2 and 4.

Indications are that differences in the resistance of R genes were associated in some way with the frequency of specialization of the fungus; that is, race 1.3 is likely to make

its appearance less often than race 2.4. So far the following 12 races have been identified: races 0, 1, 2, 3, 4, 1.2, 1.3, 1.4, 2.4, 3.4, 1.2.4 and 1.2.3.4, of which races 2, 4, 1.3, 2.4, and 3.4 were lost.

Since the prevalence of specialized races of the late blight fungus had been a menace to potato breeding for resistance represented by R genes, a shift of breeding program to giving potatoes so called field resistance was made in around 1955 in Japan.

Field resistance is considered to be brought about by polygenic factors and regarded as not specific to the particular race of the fungus but almost equally effective to each of the races of the fungus with the least susceptibility.

Consequently it is expected that there will be no drastic change in the field resistance, which takes place quite often in the major-genic resistance through the occurrence of newly specialized races of the fungus.

In breeding potatoes for high level of field resistance, the development of a reliable method of assessing resistance is highly desirable, but there had not been enough works to meet our requirements. Therefore, a number of studies have been carried out both in the field and laboratory in order to know more about the field resistance, using varieties with varying maturities and varying apparent field resistances.

Since an artificial inoculation tends to favour the pathogen, close care must be taken to evaluate field resistance in the laboratory tests. It often happens that an inoculation with unduly heavy sporangial suspension of the fungus erases originally existing varietal differences in the resistance.

The series of studies led to a conclusion that the field resistance as usually recognized in the field under the conditions prevailing in Hokkaido, located in the north of Japan, 41°—45° N. L., had better be called the field resistance in a wide sense, controlled by a number of factors, and that the resistance shown at an early stage of growth might be called the field resistance in a narrow sense, controlled by a fewer factors, which later would be influenced to some extent by age of leaves or of plants.

As commonly accepted, the late varieties are generally more resistant than the early ones. In our breeding program, however, the development of early to medium late varieties carrying high level of field resistance is of special importance. Accordingly emphasis is placed on the study of the nature of field resistance, independent of maturity or age and of the possibility of its introduction into a commercial variety.

At the present time in our breeding program the field resistance in a narrow sense is ascertained by the four following different tests:

1) Field observations of changes in appearance and severity of blight with advancing maturity of potatoes.

Within the varieties normally planted in early May in Hokkaido, discrimination of the narrow-sensed field resistance is difficult because late blight generally appears in about middle July, several days after or right at the onset of flowering, when changes in maturity among varieties are taking place.

In the late plantings, a month or so later than the normal, however, blight appears later and spreads more slowly in some particular varieties than the others. From this result it is suggested that when potatoes are exposed to infection by the late blight fungus at an earlier stage of growth differences in the narrow-sensed field resistance within varieties can be more easily detected.

2) Sprout tests.

Inoculation of detached sprouts grown in the dark with a weak sporangial suspension of the fungus revealed that the resistance owing to R genes was easily recognized and that upon inoculation with a compatible race of the fungus marked differences in susceptibility were seen within varieties. The latter fact seems to be a valuable aid in identifying the narrow-sensed field resistance.

Among three measurements made on the inoculated sprouts, the number of disease lesions, size of a single disease lesion and degree of sporulation, the latter two seem to

be of use, indicating a relatively high correspondence with foliage blight in the field.

3) Field trails at the Toluca Valley, Mexico.

In Mexico, the native habitat of *S. demissum* and some other wild *Solanum* species, highly specialized races of the late blight fungus are prevalent and there are so many races, some of which have not yet been known in Japan, that varieties survived blight screening given them in Mexico would subsist longer with lasting stable resistance in Japan.

Besides the problem of races of the fungus affecting resistance, it may be reasonable to think that such conditions in Mexico as shorter day length and comparatively earlier occurrence and heavier attack of late blight than in Hokkaido do not afford to show differences in resistance resulted from late maturity, which are clear under conditions in Hokkaido.

This fact may be interpreted that under conditions in the Valley of Toluca the narrow-sensed field resistance is likely to be exhibited. In cooperation with Dr. John S. Niederhauser of the Rockefeller Foundation, blight resistance of our seedlings were tested in Toluca for the past three years, 1966-1968, and this cooperative work continues hereafter. The result obtained is quite interesting; a high percentage of seedlings that have been extremely resistant in Hokkaido are found very susceptible, possibly because of the prevalence of more specialized races of the fungus and the concealment of apparent resistance owing to late maturity (Table 1).

4) Young seedling tests.

Thorough examination of the data obtained from the above mentioned tests indicates that some of the seedling varieties derived from *S. demissum* possess the narrow-sensed field resistance (Table 1). The pedigree of these seedling varieties follows:

60096-16, 60096-30, 60096-50 — [Rishiri — (41089-8...*S. demissum* × T²), Norin No. 1] × Hochprozentige

T...*S. tuberosum*

Seeds from crosses between field resistant varieties and common cultivated varieties, or from selfing of the concerned varieties are sown in a nursery box, capable of raising

Table 1. Evaluation of the narrow-sensed field resistance to late blight in potatoes

Variety	R gene	Field trial	Late planting	Sprout test	Field trial Mexico	Conclusive rating	Percent. resistants in progeny
Irish Cobbler	r	s	s	s	s	s	—
Ojiro	r	s	s	s	s	s	1.5
Norin No. 1	r	R′-s	s	s	s	s	—
Hochprozentige	r	R′	s	s	—	s	4.5
41089-8	R_1R_4	R	—	R′	R	R	21.9
Rishiri	R_1	R	R	R	R	R	26.5
Hokkai No. 16	R_1	R′	R	R	R′	R′	—
60096-16	R_1	R	R	R	R	R	31.1
60096-17	R_1	R′	R′	R′-s	R′-s	R′-s	13.2
60096-24	R_1	s	s	s	s	s	3.1
60096-30	R_1	R	R	R	R	R	23.7
60096-43	R_1	R′	s	s	s	s	1.1
60096-46	R_1	R′	R′	s	s	s	—
60096-50	R_1	R′	R	R′	R′	R′	—
60096-56	R_1	R′	s	s	s	s	4.6
Hokkai No. 42	r	R′	s	s	s	s	—
Hokkai No. 45	r	R′	s	s	s	s	—

Notes: R: resistant, R′: intermediate, r: susceptible

500 seedlings. When they reach 5-6 leaf stage of development a sporangial suspension of an appropriate race of the fungus is sprayed on them, allowed to stay overnight in a moist chamber at 18-20°C. Four to six days after inoculation various types of disease lesions become visible: 0, no lesions; 1, arrested necrotic lesions; 2, slow-spreading and non-sporulating lesions; 3, spreading and sporulating lesions, finally killing seedlings.

The result of inoculation clearly shows (Table 2) that the varieties, supposed to possess the narrow-sensed field resistance, such as 41089-8, Rishiri, 60096-16 and 60096-30 brought fourth a significantly larger number of resisters in their progenies from crosses or selfing, while other varieties gave a fewer number of resisters, most of which might be a result of escaping infection.

Table 2. Segregation of resistants in progenies of crosses and selfing of varieties carrying various level of field resistance upon inoculation with the late blight fungus

Cross	Number of seedlings inoculated	Number of resistants	Percentage of resistants (%)
Ojiro, selfing	129	5	3.9
Hochprozentige, selfing	111	10	9.0
41089- selfing	107	41	38.4
Rishiri, selfing	170	72	42.3
Shima No. 483, selfing	129	45	34.9
60096-16. selfing	118	55	46.6
60096-17, selfing	101	16	15.8
60096-56, selfing	92	14	15.2
Rishiri×Ojiro	135	28	20.8
41089-8×Ojiro	151	32	21.2
60096-16×Ojiro	173	44	25.4
529-1×60096-16	161	32	19.7
Benimaru×Shima No. 483	182	28	15.8
Irish Cobbler×Shima No. 483	134	15	11.2
Shima No. 483×Ojiro	150	11	7.3
Benimaru×Elenita	168	25	14.9
Hokkai No. 24×Elenita	130	15	11.5
Shima No. 477×Elenita	119	15	12.6

The routine of breeding potatoes for late blight resistance at the moment will be described below, though several modifications may exist.

1) Seedling should have as many major genes for resistance as possible; the presence of major genes can be noticed relatively easily by inoculating leaves, tubers and sprouts, whatever they may be, with an appropriate race of the fungus. In the years following the field resistance is evaluated of the selected seedlings by some of the methods described above.

2) In an attempt to breed particularly for high level of field resistance, on the other hand, young seedling progeny from crosses of varieties carrying heritable field resistance are inoculated with a compatible race and seedlings survived screening are transplanted in the open field. Constitution of major genes for resistance of the selections is investigated as soon as possible thereafter.

Whether which routine to take depends on the nature of parents used and breeding program. It is insisted that insofar as the late blight control is concerned, the major-genic resistance is still, if not almighty, effective in some of the years and in some of the regions, although an incorporation of high level of field resistance in a commercial variety is of greatest importance particularly in such a place as Hokkaido where frequent specialization of the fungus occurs, and accordingly that the best varieties should have both types of resistance. In order to reach this goal sooner, further search for higher level of resistance in a number of wild species is also being carried on in full swing.

It is expected that in the future issue will appear articles dealing with achievements other than the above-mentioned, such as screening techniques of early potatoes, good table potatoes and starch or feeding potatoes, which may be of interest to potato researchers in foreign countries.

References

1) Hokkaido National Agricultural Experiment Station.: The Historical Review of Agricultural Techniques in Hokkaido, 1967.
2) Kawakami, K.: The Potato. Yokendo Publish. Co., Tokyo, 1957.
3) Niederhauser, J. S.: Late Blight in Mexico and Its Implications. Phytopath. 44 (8): 406-408, 1954.
4) Taguchi, K.: Studies on the Breeding of Potato by Hybridization. Bull. Tohoku National Agricultural Experiment Station, No. 12, 1957.
5) Takase, N.: Studies in Breeding Potatoes for Resistance to *Phytophthora Infestans* With Special Reference to Laboratory Assessment of Resistance. Hokkaido National Agricultural Experiment Station Report No. 71, 1968.