Problems in Breeding Disease-Resistant Vegetables in Japan

—Cruciferae Vegetables—

By MASAKAZU ASHIZAWA

Plant Breeding Division, Vegetable and Ornamental Crops Research Station

Major vegetables of the family *Cruciferae* are listed in Table 1. They constitute 30.1% of the total area cropped to vegetables (641,600 ha in 1975), with radish (Daikon), Chinese cabbage, and cabbage ranking first, second and third respectively in cropped area. In addition to the vegetables shown in Table 1, Wasabi (*Eutrema wasabi* Maxim) also belongs to the family *Cruciferae* and it is one of the important vegetables, although the cultivated area is small. Salt green group and Indian and Chinese mustard group (*Brassica juncea* Czer) include many local varieties and their cultivated area exceeds 20,000 ha, with different varieties specific to different regions.

Major diseases of Cruciferae vegetables

Major diseases are listed in Table 1. Extent of damage caused by the disease varies with cropping seasons. For example, bacterial soft rot of cabbage causes almost no damage in the summer-sown cultivation, and a little damage in the autumn-sown, early summer-harvesting cultivation, whereas it causes serious damage in the spring-sown cultivation (particularly when sown in early summer in lower land). Also, sclerotinia rot causes some damage in the summer-sown, spring-harvesting cultivation for fresh vegetable, but it causes destructive damage in seed-production cultivation.

Major diseases causing great damages to Cruciferae vegetables in general are mosaic (except cabbage), bacterial soft rot (particularly with radish and Chinese cabbage), yellows (radish and cabbage) and clubroot (particularly with cabbage and Chinese cabbage). In the present paper, current progress and related problems in breeding for resistance to these diseases will be described.

1) Mosaic diseases

Among TuMV, CMV and a few other viruses attacking Cruciferae vegetables, the most serious damage is caused by TuMV, which is sometimes combined with CMV[6]. Crops which suffer seriously from the mosaic disease are radish, turnip, Chinese cabbage, salt green group, Indian and Chinese mustard group, etc., but in Japan cabbage is not damaged practically although it is infected.

With radish, breeding for resistance to mosaic was attempted after the War, and at about 1955 new resistant varieties such as "Azuma", "Ohkura" and "Takakura" etc. were developed from the "Nerima" group (Tsumari, and Risoh). After that, resistant varieties were also developed from the "Miyashige" group and "Shogo-in" group. They were developed by means of repeated selection for resistant individuals (or strains in advanced generations) under natural infection, not adopting new breeding techniques.

At about the same time, virus-resistant varieties of Chinese cabbage were developed

Table 1. Major Cruciferae vegetables and major diseases attacking them

Latin name of vegetables	Common name of vegetables	Cropped area (1975)	Common names and Latin names of diseases										
			Mosaic TuMV, CMV	Bacterial leaf spot *Pseudomonas maculicola* (MC. CULL.) STEV.	Black rot *Xantomonas campestris* (PAM.) DOW.	Bacterial soft rot *Erwinia aroideae* (TOWN.) HOLL.	Downy mildew *Peronospora brassicae* CAUMANN.	Yellows *Fusarium oxysporum* SCHLE.	Sclerotonia rot *Sclerotonia sclerotiorom* (LIB.) BARY	Alternaria leaf spot *Alternalia japonica* YOSHII	Clubroot *Plasmodiophora brassicae* WORONIN	White spot *Cercosporella brassicae* (FAU. et ROUM.) HOHN.
Raphanus sativus L.	—radish	74,400 ha	◎	○	○	◎	○	◎	○	○	△	
Brassica oleracea L. var. *capitata* L.	—cabbage	41,700	△	○	◎	○	○	◎	○	○	◎	
var. *botrytis* L.	—cauliflower	3,590										
var. *italica* PLE.	—broccoli											
Brassica campestris L. ssp. *pekinensis* RUPR.	Chinese cabbage	42,900	◎	○	○	◎	○		○	○	◎	○
ssp. *cambestris* L.	—salt green	22,700* (including Indian and Chinese mustard) 7,710										
ssp. *chinensis* L.												
ssp. *narinora* BAIL.												
ssp. *japonica* SIEB.												
ssp. *rapa* L.	turnip											
Brassica iuncea CZER.	—Indian and Chinese mustard		◎	○	○	◎	○		○	○	◎	

△ : Disease occurs but damage is not significant.
○ : Damage occurs.
◎ : Serious damage occurs.
□ : Resistant varieties released.
⬚ : Breeding of resistant varieties initiated.
* : 1970 statistics.

from medium to late varieties (mainly from Chih-fuh group), and soon after from early varieties (F_1 hybrids). A variety, "Hiratsuka No. 1" developed for the resistance to bacterial soft rot, was found to be resistant to mosaic too. This variety is now being used widely as a breeding material. The mosaic disease of Chinese cabbage shows two types of symptom: mosaic or ring spot mosaic. It is not known yet whether it is due to characteristic of varieties or that of virus.

2) Bacterial soft rot

This disease is mainly caused by *Erwinia aroideae* (Town) Holl, although a few cases by *E. carotovora* (Jones) Holl. They attack all kinds of Cruciferae vegetables, particularly causing serious damage to radish and Chinese cabbage. In autumn sowing, the earlier the sowing the more is the infection, and the damage is reduced markedly with later sowing (the similar trend is found with mosaic diseases). Differences in pathogenicity exist among different cultures of *E. aroideae*, but no race differentiation was recognized[9].

With the purpose of developing Chinese cabbage varieties resistant to bacterial soft rot, "Hiratsuka No. 1" was bred by producing an inter-specific hybrid between the synthetic napus (CO) and Chinese cabbage (Matsushima New No. 2) and then backcrossing it to Chinese cabbage for three times[8]. This variety is late-maturing, but is widely used as a breeding material for bacterial soft rot resistance. Most of the medium-late F_1 hybrids currently grown are developed by utilizing this variety in the breeding process. From this variety, early-maturing breeding materials have also been developed. As stated above, "Hiratsuka No. 1" is also resistant to mosaic.

3) Yellows

Damage by yellows is serious with radish and cabbage, but the disease hardly occurs with Chinese cabbage and turnip. Pathogenic organism is *Fusarium oxysporum* Schle. f. *conglutanus* Wr. The fusarium attacking cabbage is regarded as race 1, and that attacking radish as race 2. The race 1 attacks many Cruciferae vegetables, but its pathogenicity to radish is lower than that of race 2, whereas race 2 attacks radish, Indian and Chinese mustard group, but it attacks cabbage to a small extent only under high temperature conditions.

(1) Yellows of radish

Since it was found in U.S.A. in 1934, resistant varieties like Red Prince, White Prince and White Spike, etc. have been developed. In Japan, the disease was first found in Wakayama Prefecture in 1955, and its occurrence has been reported in many places. In recent years, serious damage occurs in summer-radish producing areas in highland. Although pathological studies have been made since its first occurrence, the study from the view point of breeding and varieties was very few.

Only recently, the search for resistant varieties and development of method of screening at an early growth stage are being undertaken in the Vegetable and Ornamental Crops Research Station. As to the resistant varieties, it is found that representative varieties and variety groups in Japan show a wide variation in the resistance, suggesting a possibility of developing resistant varieties by the selection of individuals within a variety. There are many resistant varieties in the "Minowase group", and among native varieties "Kotabe" is recognized to be most resistant[3] (Table 2).

As to the screening method, it has been established that:

a) Any method of inoculation, i.e., the immersion of roots, mixture with soil, and injection to soil, can be used according to the purpose of testing.

b) Concentration of inoculum to be applied is 10^{6-7}/cc.

c) Either hill soil, sand, or perlite can be used as the culture media in the test.

d) Soil temperature at 20–24°C is appropriate[4,5].

Table 2. Varietal resistance of radish to yellows (1975)

Name of varieties	Rating of* disease severity	percent diseased plant
		%
Red Prince	4.6	4.6
White Prince	9.7	9.7
Otabe	12.1	64.3
Motohashikei Taibyosei Minowase	17.4	48.4
Scarlet Knight	20.0	24.0
China Rose	29.7	79.3
Shirokubi Shirimaru Kyo	30.8	60.0
Harumaki Minowase	35.8	65.4
Minowase-daikon Shin No. 2	47.6	79.3
Saxa Bright Scarlet Round	48.2	75.0
Natsusen Taibyo Minowase	51.6	83.9
Bansei Sakurazima	56.1	87.9
Kono Minowase	61.7	96.7
Suikomi Chyunaga Ninengo	63.7	88.9
Taibyo Kuroba Minowase	70.9	96.8
Nagaoka F_1 Harumaki Minowase	72.8	100.0
Aokubi Miyashige Maruziri	75.9	93.1
Kiba Riso	82.8	100.0

* 0 (no disease) ~ 100 (seriously diseased).

For the assessment of disease severity it is better to examine the extent of browning of vascular bundles by cutting roots. However, the cutting of roots makes it difficult to assess the quality of roots, the radish product, and therefore the development of new method to assess the resistance as well as root quality in parallel is the future task.

(2) Yellows of cabbage

The disease was discovered in U.S.A. in late 19th century. In Japan, it was first found in 1952 in Aichi Prefecture. In the late half of 1960, the damage by this disease became severe in many places, particularly it became the most important disease in areas where early varieties were sown in spring and early summer and in summer.

Resistant varieties were first developed in U.S.A. and it was made clear that there are two types of resistance: type A (resistant at any condition and genetically single gene dominant) and type B (resistant at relatively low soil temperature: below 24°C, and genetically polygenic). In Japan, the screening for resistant varieties was initiated in the later half of 1960s when the damage became remarkable, and some of the native varieties were found to have the resistance to be regarded as type B, but type A was not recognized. From that time, commercial seed companies have made the breeding work using type A varieties introduced from U.S.A. and since 1970 a number of resistant varieties (F_1) were released successively. As these F_1 hybrids have defects in quality and keeping quality, further improvement is desired.

To increase the efficiency of breeding type A varieties, a method of screening at an early growth stage was deviced[7]. In the screening test,

a) Soil temperature exerts the greatest influence, so that it is better to keep soil temperature at about 27°C, after seedlings of 20–30 days of age are inoculated,

b) Injection of inoculum to furrows (the ditches-inoculation method) is effective in treating large number of plants at one time,

c) Assessment be made when the disease occurred in most plants of the susceptible control variety, and

d) Races which attack type A resistant varieties are not observed in Japan.

4) Clubroot

Clubroot caused by *Plasmodiophora brassicae* WOR. attacks almost all Cruciferae vegetables. Because of its distinct race differentiation, it is necessary to know the race specific to each region for breeding resistant varieties. There are many methods to identify races. By the use of the Williams method, it is presumed that the major race distributed in Japan is the race 2, together with other 2 or 3 races[2].

As to the varietal resistance of cabbage (Table 3), it was found that there is a wide variation from resistant to susceptible varieties, and that some of the kale are almost free from clubroot. From these varieties,

Table 3. Varietal resistance of Crusiferae vegetables to clubroot (1970～1973)

Chromosome number	Name of Vegetables	Name of varieties	Rating of* disease severity	Percent of diseased plant	Chromosome number	Name of Vegetables	Name of varieties	Rating of* disease severity	Percent of diseased plant
				%					%
9	White cabbage	Aichi Daibansei	2.6	62.1	10	Salt green	Mie Zairai	4.0	100.0
							Sensuzi	4.0	99.4
		Toyoda Wase	3.8	52.8			Kyo Mizuna		
		Masago Sanki	3.9	85.0			Seppaku	4.0	100.0
		Bindsaksener 72754	0.1	1.0		Turnip	Nagaoka F_1 Taibyo Hikari	4.0	100.0
		Bömelwaldkohr 72755	0.5	1.0			Kanamachi	4.0	99.3
						Chinese cabbage	Seiho	4.0	100.0
	Red cabbage	Mammoth Red Rock	2.6	69.4			Keijo	4.0	100.0
		Red Acre	3.8	87.0			Nagaoka F_1 Osho	4.0	100.0
	Savoy cabbage	Winter Price	2.4	64.0			Musashi F_1 Toyotama	4.0	100.0
	Kale	K-86	3.1	51.7			Sekine F_1 Minori 80 nichi	4.0	100.0
		K-278	0.8	31.7					
		K-61	2.0	42.3	18	Indian and Chinese mustard	Ha Karashina	4.0	100.0
		K-269	0	0			Ki karashina	4.0	100.0
	Kohlrabi	Kinmon Wase	2.3	97.0			Katsuona	4.0	100.0
		Pekin Kyukei	4.0	62.7			Miike Aka Chirimen	4.0	100.0
	Sprouting broccori	Nagaoka F_1 Wase Komochi	2.3	69.0	19	Rape	Miyagi Bansei	4.0	100.0
		Nagaoka F_1 Chyusei Komochi	3.7	87.0			Yokkaichi Kurodane	4.0	98.4
	Cauliflower	Nagaoka F_1 Snow Crown	3.3	77.0		Rutabaga	Wilhemsburger	0.2	14.0
							Winte Fleshed Neckless	1.2	39.0
		Nozaki Bansei	2.6	65.0					
		Chyogokuwase 40-nichi	1.3	58.0			Majestick No. 1	2.9	89.0
		Early March	2.2	69.0			Nemuro	3.5	87.0

* 0 (no disease) ～ 4.0 (seriously diseased).

many resistant varieties have been developed. Among Japanese varieties, "Aichi-daibansei" is most resistant.

Varietal resistance of Japanese varieties of Chinese cabbage, turnip and salt green showed a variation from medium to susceptible varieties, not including resistant ones. Relatively resistant varieties of Chinese cabbage were found among the Kato-type group which is not usually cropped in Japan. As it is reported that there are resistant varieties among European turnip, they have to be introduced and examined urgently.

No resistant varieties are found with Indian and Chinese mustard group. Rutabaga shows a wide variation from resistant to susceptible varieties[1,11], just like that of cabbage. No resistant varieties are found with rape in Japan. As the genetic composition of Japanese varieties of rape is very simple, it is necessary to re-examine the varietal resistance including European varieties.

Method of screening at an early growth stage has been studied recently in the Vegetable and Ornamental Crops Research Station.

a) Method of inoculation by inserting infested soil blocks is most promising.

b) Concentration of inoculum at 10^{4-7}/g dry soil is enough, but in the screening for highly resistant varieties the concentration of 10^{6-7}/g dry soil is better.

c) The condition of inoculation requires slightly acidic pH of the media, soil temperature above 20°C, and sufficient soil moisture which enables normal growth of plants[10,12].

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