Breeding for Disease Resistance of Vegetable Crops in Japan
—*Solanaceae*—

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Tomato (*Lycopersicon esculentum*), eggplant (*Solanum melongena*) and sweet pepper (*Capsicum annum*) are the three most important vegetables of the *Solanaceae* in Japan. Although their acreage and production are not large compared with leaf- or root-vegetables such as Chinese cabbage and radish their economic value is great because of the high price of their poducts. In the past twenty years production of vegetables under plastic or glass has progressively increased, especially of fruit-vegetables in the *Cucurbitaceae* and *Solanaceae*. The size of glass- or plastic-houses has also increased and the high investment necessary for heating, irrigation, ventilation and steam sterilization has forced growers to produce vegetables with higher economic value including the above-mentioned solanaceous crops. Successive cropping of the same vegetable year after year has resulted in an increase of disease and pests, whereas their control by means of fungicides or pesticides has become increasingly difficult because consideration of their hazard to human life had led to severe legal regulation of their use. The importance of genetic control has thus increased, and much effort has been put into the breeding of disease-resistant varieties.

Tomato

In 1976 Japanese seed growers listed 139 varieties as resistant to disease(s). These include 132 resistant to Fusarium wilt, 57 to leaf mold, 47 to root-knot nematode and 33 to TMV (tobacco mosaic virus). The total for these four diseases is 269 and there is a score of 31 for other diseases. The grand total of 300 is more than twice the number of listed varieties and indicates that, on average, each variety possesses resistance to more than two diseases. Table 1 shows the

Table 1. Number of tomato varieties with resistance to Tobacco Mosaic Virus, leaf mold, Fusarium wilt and root-knot nematode

Resistance	Disease[1)]		Number of varieties
Single	TMV		0
	C		5
	F		49
	M		0
		Total	54
Double	TMV. C		1
	TMV. F		8
	TMV. M		0
	C. F		19
	C. M		1
	F. M		22
		Total	51
Triple	TMV. C. F		10
	TMV. C. M		0
	TMV. F. M		5
	C. F. M		10
		Total	25
Quadruple	TMV. C. F. M		9
		Grand Total	139

1) TMV : Tobacco Mosaic Virus
C : leaf mold
F : Fusarium wilt
M : root-knot nematode

distribution of resistance in these varieties. Of the 54 varieties with single disease resistance 49 are resistant to Fusarium wilt and five to leaf mold. No varieties have resistance to TMV or root-knot nematode alone. This is due to the history of breeding rather than to the relative importance of the individual disease. Six lines Okitsu No. 1–No. 6 were released from the Okitsu Branch Station of the former Horticultural Research Station (in this review the station is called Okitsu Station for the sake of simplicity) in 1960[10]. They were the first Fusarium-resistant lines in Japan and have been widely used as parents of hybrid varieties. The six Okitsu lines only have resistance to Fusarium wilt so all hybrids bred from them have this single resistance.

A similar situation developed in the early stage of breeding for resistance to leaf mold. Okitsu No. 7 and No. 8 were released in 1964[9] as the first leaf-mold resistant lines in Japan, and because they only have this resistance hybrid varieties obtained from them also have single resistance. Later, in 1971[7] and 1972[3], four lines Okitsu No. 9, 10, 11 and 12 were released which had combined resistance to leaf mold and Fusarium wilt.

In contrast to these two diseases, the first lines resistant to root-knot nematode (NFR-1, 2 and 3 released from the Tokyo Agricultural Experiment Station in 1965[4]) also have resistance to Fusarium wilt. All hybrid varieties derived from them have the double resistance, e.g. Azuma (Tokyo Agr. Exp. Sta., 1970). Similarly the first TMV resistant line B-3-4-2-2-2 bred at the Kikyogahara Substation of the Nagano Agricultural Experiment Station (in this review simply called the Kikyogahara Station) also carry resistance to Fusarium wilt so all the hybrids made from it or its derivatives have the combined resistance. These include Raiden, Tukama and others from the Kikyogahara Station and Wakashio from the Chiba Agricultural Experiment Station[5]. TMV resistant varieties newly introduced from the United States such as Ohio MR-9 and MR-12 have also been used extensively as parents of hybrid varieties, and since they have a multiple disease resistance the derived hybrids are also resistant to the same diseases.

Thus, as parental lines with combined resistance became available, hybrid varieties with combined resistance were produced. Furthermore, by crossing two lines with combined resistance, the number of diseases controlled could be increased. At present several hybrid varieties possess resistance to six diseases though they still have yield and quality defects. These must be resolved by further breeding because the use of resistant varieties will be essential for tomato growing in the future.

One difficulty usually encountered when breeding tomatoes for Japan is that the desired characters in tomato fruit for fresh use are rather different from those in most foreign countries. The skin color must be colorless to give pink fruit rather than yellow as in red-fruited varieties. The fruit must be of the greenback type (green color remains around the calyx) rather than uniform ripening. It seems that these requirements are mainly due to the conservatism of the wholesale market rather than the consumers. The consequence is that resistant varieties introduced from abroad can not be used as received; they must be modified to the Japanese style.

1) TMV (Tobacco Mosaic Virus)

In 1973 five resistant varieties with the gene Tm-1 including Raiden and Tukama were released from the Kikyogahara Station[6]. However, as early as 1974 these varieties were reported to be infected with TMV in several major tomato-producing areas like Shizuoka and Chiba which suggested the occurrence of a new strain. The use of other resistance genes, Tm-2 and Tm-2^2, became necessary. At present about one quarter the TMB resistant varieties have Tm-2 or Tm-2^2. The gene Tm-2^2 was introduced to Japanese varieties mainly from American varieties like Ohio MR-9 and MR-12, and it now appears to be carried by between five and ten of the Japanese varieties recently

released. The use of Tm-2 has been rather limited so far because of its tight linkage with nv. The three lines 'IRB 301–30, 31 and 32' bred by the author from interspecific hybridization between *Lycopersicon peruvianum* P.I. 126944 and the cultivated tomato[11] possess Tm-2 without linkage to nv. Although Tm-2 and Tm-2^2 confer much higher resistance than Tm-1, they tend to cause necrosis of the growing point, stem or fruit especially in heterozygous plants grown at high temperature. In order to avoid this, future TMV resistant varieties will have to be homozygous for Tm-2 or Tm-2^2 or possess gene Tm-1 as well. Several seed growers and the Kikyogahara Station have already bred such resistant varieties.

2) Bacterial canker (Corynebacterium michiganense)

'Okitsu Sozai 1' was selected from an interspecific hybrid between *L. hirsutum* and *L. esculentum*, and released to tomato breeders including private seed growers as a breeding stock for bacteria canker resistance (Kuriyama and other 1974[21]). The line is still segregating for horticultural traits such as fruit-size and -color, and needs to be improved further. The mode of inheritance of the resistance is not clear but it seems to be complex.

3) Bacterial wilt (Pseudomonas solanacearum)

No resistant cultivar is available with satisfactory marketing quality, so grafting to resistant root-stocks is carried out for heavily infested soils. 'BF Okitsu 101', a resistant line used as a root-stock, was originally introduced from the North Carolina State University as 'NC 1953-64N' and was subsequently selected for Fusarium wilt (race 1) resistance (Kotani and others, 1970). #7998 introduced from the University of Hawaii in 1975 has shown higher resistance than 'BF Okitsu 101' and is now being tested as a root-stock.

4) Brown root rot (Pyrenochaeta lycopersici)

This disease was identified quite recently: it has increased as tomato growing under glass or plastic has been extended to the cooler season. Grafting culture using a resistant root-stock 'KNVF' is popular. 'KNVF' is a hybrid between *L. esculentum* and *L. hirsutum* var. *glabratum*, the seeds being imported from the Netherlands and the United Kingdom. 'Shinko Ichigo' released from the Takii Seed Company is considered to be a hybrid with similar parentage.

5) Fusarium wilt (Fusarium oxysporum f. lycopersici)

At present more than 130 varieties are available with resistance to race 1. Sugahara and Suzuki (1966[8]) found race 2 (they termed it race J-2) in Fukuoka region, but it has never caused serious damage to tomato crops in Japan. Yamamoto and other (1974[13]) found a new soil-borne disease and identified the casual agent as *Fusarium oxysporum* f. *lycopersici* from its morphology and pathogenicity. They termed it race J-3 because varieties resistant to races 1 and 2 were susceptible to this race. However the symptoms are quite different from those caused by J-1 and J-2. J-3 causes root- and crown-rot but not much browning of vascular bundles of the stem while J-1 or J-2 cause heavy browning of the vascular bundles but not root rot. The favorable temperatures are also different. J-3 is more severe in cooler seasons, J-1 and J-2 in warmer seasons. Thus J-3 can be seen as the cause of a new disease rather than as a new physiological race. The disease is commonly called root-rot wilt in Japan. Komada found resistant plants in *L. peruvianum* P.I. 126944 which had been successfully hybridized after chronic gamma irradiation with *L. esculentum* by the author[11]. 'IRB 301–30 and 31' selected from these hybrids have been shown to possess resistance to root-rot disease which is increasing in Ohio, U.S.A. and Canadian greenhouse soils (Dr. James D. Farley, personal communication). Further

back-crosses are being made to Japanese varieties in order to improve the resistant cultivars.

6) Late blight (Phytophthora infestans)

The Kikyogahara and Okitsu Stations have long been concerned with late-blight resistance. Both stations have used the resistant line 'West Virginia 700', and 'WV 36' was also used at Okitsu.

7) Leaf mold (Cladosporium fulvum)

Among 57 resistant varieties (almost all are hybrids) available in Japan, at least 13 have been bred using Okitsu lines (No. 7–No. 12[3),9)]) as a direct or indirect parent. The Okitsu lines derive their resistance from Improved Bay State. At least four varieties owe their resistance to STEP 390. The source of resistance in other varieties is not known because they were mostly bred by private seed growers. However, most of them seem to owe their resistance to American varieties or lines including Improved Bay State, Waltham Moldproof Forcing and STEP 390.

Recently those varieties with gene(s) from Improved Bay State have frequently been reported to suffer from leaf mold in several major tomato-producing areas. Kishi and Abiko[1)] confirmed the differentiation of new races. The author has been conducting a back-cross breeding programme using the interspecific hybrid previously mentioned, and has obtained several breeding lines which have not yet been released. The lines are resistant not only to Japanese races but also to races 1.2.3, 4, 1.2.4. and 2.3.4 as tested at the Institute for Horticultural Plant Breeding, the Netherlands (Ir. I.W. Boukema, personal communication, 1973). The lines are being backcrossed to Japanese varieties.

8) Leaf spot (Stemphylium lycopersici)

Fifteen varieties are reported to be resistant to leaf spot. They are resistant also to Fusarium wilt and several other diseases. American varieties resistant to leaf-spot and Fusarium wilt, including Anahu, Manalucie, Florida MH-1, Tropic and Walter, were often used as a breeding stock in Japan. Although they were used mainly for Fusarium wilt resistance, it has been shown that the gene Sm which confers resistances to leaf spot is tightly linked with the gene I for Fusarium resistance. Sm seems to have been introduced to Japanese varieties together with Fusarium-wilt resistance.

9) Verticillium wilt (Verticillium albo-atrum)

The disease was found in 1972 in Tokyo and several other districts, and the Tokyo Agricultural Experiment Station started breeding work immediately. It has recently bred several NFVR lines with combined resistance to root-knot nematode, Fusarium wilt and Verticillium wilt, using Tropi-red and Loran Blood as sources of resistance.

10) Root-knot nematode (Meloidogyne incognita var. acrita)

NFR-1, 2 and 3 derived the resistance gene Mi from Anahu, and were used as parents of hybrid varieties including Azuma and Raiden. Many other resistant varieties have been released mainly by seed growers. Their source of resistance is not clear but it seems that there are some differences in resistance between the varieties. The varieties currently available are resistant to *M. incognita* var. *acrita* but not to *M. hapla*. A population of *M. incognita* var. *acrita* was reported from Chiba which infected a variety with the Anahu-type resistance, and a breeding source with high and stable resistance is being sought.

Eggplant

Bacterial wilt, Fusarium wilt and Verticillium wilt are the major soil-borne diseases in Japan.

1) Bacterial wilt (Pseudomonas solanacearum)

'Okitsu No. 1' was released in 1973 from the Okitsu Station after long term selection

of progenies of the cross between the resistant parent Taiwan Naga and a Japanese variety Nakate Shinkuro. The resistance seems to be governed by a polygenic system and it is very difficult to breed a variety which combines high resistance and good agronomic characters. Although Okitsu No. 1 was released as a commercial variety its fruit quality is not good enough to be widely accepted, but it is used as a root stock.

2) Verticillium wilt (Verticillium alboatrum)

Many lines were introduced from the Regional Plant Introduction Station, Georgia, USA, and tested for resistance to Verticillium wilt at our research station in 1975. Although they were all reputed to be resistant, they showed no clear resistance in our trials, and it is strongly suspected that the race in Japan is different from that in the United States.

Taibyo VF Nasu released as a resistant root-stock from the Takii Seed Company (1974) is thought to be an interspecific hybrid and has fairly good resistance.

3) Fusarium wilt (Fusarium oxysporum f. melongenae)

Solanum integrifolium and *S. gilo* have been used widely and for many years as a resistant root-stock. Kurogane No. 1 (Kochi Horticultural Experiment Station 1970) is an interspecific hybrid between *S. integrifolium* and *S. melongena* (Taiwan Naga) and has satisfactory resistance. 'Taibyo VF Nasu' is resistant to this disease as well as to Verticillium wilt.

Sweet Pepper

Almost no breeding work has been conducted for disease resistance in sweet pepper. A line No. 10 introduced from Argentina showed good resistance to Phytophthora blight (*Phytophthora capsici*) and a breeding programme using this material is now being conducted at the Kikyogahara Station.

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