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Ohio M-R 9 and Ohio M-R 12: Two New Tomato Varieties Resistant to Five Ohio Strains of TMV

LEONARD J. ALEXANDER and GENE L. OAKES[1]

SUMMARY

Two new greenhouse tomato varieties, Ohio M-R 9 and Ohio M-R 12, are described. These new varieties are resistant to all five Ohio strains of the tobacco mosaic virus (TMV) and are adapted to Ohio glasshouse culture. The vine types and fruit characteristics are of the Livingston Globe type. These varieties differ in two significant aspects from the standard varieties now grown, Ohio W-R 25 and Ohio W-R 29. They are highly resistant or possibly immune to TMV but unfortunately are moderately susceptible to blotchy ripening. The yielding ability and fruit quality of the new varieties are equal or superior to the standard varieties. Other aspects of the varieties are described in detail.

INTRODUCTION

This publication describes and gives the pedigrees of two new tomato varieties which are resistant or immune to tobacco mosaic virus (TMV). Introduction of the two new tomato varieties Ohio M-R 9 and Ohio M-R 12 marks the first commercially acceptable method of controlling the TMV disease of tomato. A project was started in 1946 to control TMV when the directors of the Ohio Greenhouse Vegetable Growers Association came to the Ohio Agricultural Research and Development Center (then the Ohio Agricultural Experiment Station) and stated that they badly needed a control for the TMV disease of greenhouse tomatoes. They further offered to support the project financially.

First it was shown that the virus lived in the soil for periods up to 3 or 4 months, that it was seedborne, that it lived in debris from old crops, and that certain weeds outside of the greenhouse served as reservoirs of inoculum. Workers were found to be the principal source of infection; i.e., they carried the virus on their hands and clothes from the old to the new crop (2, 3, 15). Broadbent (13) reviewed the literature on the epidemiology of tomato mosaic and therefore no effort is made here to comprehensively review the literature.

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A sanitary program for control of the disease was devised which, if strictly adhered to, would control the disease. However, on a commercial basis, sanitary measures were only partially successful because greenhouse operators found that it was almost impossible to convince laborers of the importance of the sanitary procedures. The lack of success with the sanitary program stimulated the initiation of a project to breed for TMV resistance.

Yield studies conducted in Ohio by Alexander (1, 2, 3, 4, 5), Heuberger and Moyer (21) in Delaware, Jones and Burnett (25) at Washington State, and Selman (37) and Broadbent (14) in England all tended to support the hypothesis that infection by TMV could cause losses in yield of as much as 25 percent. However, the amount of loss varied from season to season. Alexander (1, 2, 3) showed that the loss also varied with the stage of development at which the plants became infected, with the younger the plants at the time of infection the greater the loss. Undoubtedly the average loss to commercial greenhouse growers from TMV infection is less than 25 percent. Probably 12 to 15 percent is a reasonable estimate.

No resistance to TMV had been found in varieties of the domestic species (11). Thus, when attempts were made to breed for resistance, it was necessary to look to the wild tomato species. The chromosome number in all six known species of the tomato is 2N=24. However, the species are divided into two distinct groups, red and green fruited. The three red-fruited species, *Lycopersicon esculentum, L. pimpinellifolium,* and *L. cheesmanii* all intercross readily (35). In fact, Rick considers that the latter should not be considered a distinct species but a variant of *L. esculentum* and probably *L. pimpinellifolium.*

The green-fruited species can be crossed with varieties of the domestic species only with difficulty. *L. hirsutum* can be crossed directly but the number of seed produced from each cross generally is reduced. *L. peruvianum* usually can only be crossed successfully by the embryo culture method (6, 38). Paddock and Alexander (data unpublished) showed that in interspecific crosses, including *L. peruvianum,* the endosperm fails to develop beyond the 8 to 10 cell division and thus there is no food for the developing embryo.

The first attempt to breed for TMV resistance was made by using an accession of the wild species, *Lycopersicon hirsutum,* P. I. 126445, which had been found to be resistant (19, 20). Crosses of this species with commercial varieties were obtained and the F_1, F_2, and backcross populations were grown. In a 3-year period, it is estimated that more than 35,000 hybrid plants were grown in efforts to obtain plants resistant to

TMV and having the appearance of a domestic plant, but without success.

Others making crosses with accessions of *L. hirsutum* succeeded and it is probable that the resistant material of Walter (39) originated from this species. However, this type of resistance subsequently was shown by Holmes (22, 23), Walter (39), and others to be of a type which escapes infection. Today this type of resistance is not used extensively in tomato breeding programs.

The second attempt to breed for resistance was made by using resistant breeding lines supplied by the late J. M. Walter of the Florida Gulf Coast Experiment Station. Walter's TMV resistant material appeared at first to be an excellent source of TMV resistance, but in the F_3 generation all plants became susceptible. Subsequently, McRitchie (28, 29, 30) described different pathogenic strains of TMV which possessed varying potentials for infection.

Another attempt was made to breed for TMV resistance by using a plant of an accession of *Lycopersicon peruvianum,* P. I. 126832, as the resistant parent. After several crosses to good commercial type plants, all breeding material became susceptible. McRitchie (29, 30) and McRitchie and Alexander (31) then described four pathogenic strains of the virus.

A fourth attempt to breed for resistance to TMV was initiated by using a selfed selection of P. I. 128650-6Y-IV-1-12-22 of *Lycopersicon peruvianum* as the resistant parent. This selection was resistant to four of the five Ohio strains of the virus (30, 32). Later, when the fifth strain of the virus appeared, it was possible to select for resistance to it in segregating progenies (10, 16, 17, 18).

The work of Cirulli and Alexander described the gene Tm-2^a. Thus, the existence of three genes for TMV resistance was established, two of which may be allelic. Pelham (33) reviewed the literature on genes for TMV resistance and therefore no attempt will be made here to review that aspect of the literature.

Alexander (7, 8) described the transfer of the gene Tm-2^a from *L. peruvianum* to varieties of the domestic species. Since then, continued progress has been made in the improvement of the breeding lines to the point where they produce equally with good commercial tomato varieties and are resistant to all five known Ohio strains of TMV.

PARENTS AND PEDIGREES OF NEW VARIETIES

Since the gene for TMV resistance was found in a selfed accession of P. I. 128650 of the wild species, *Lycopersicon peruvianum,* one parent of the initial cross was a plant of this species. The other parent was a plant of a greenhouse breeding line which was not introduced as a variety. The embryo culture method was used to effect the first cross and the backcross. Two selfs were made and then an outcross was made to Ohio W-R Jubilee. Following this outcross, the F_1 was crossed to Ohio W-R 7, followed by four backcrosses to Ohio W-R 7. After the last backcross to Ohio W-R 7, the material was selfed once and then outcrossed to W-R 41, a greenhouse breeding line. Following the last cross, the material was either selfed or bulk selected for nine generations. It was then named Ohio M-R 9.

Ohio M-R 12 has the same pedigree, except that after six selfs from the outcross to W-R 41, another outcross was made to Ohio W-R 29. Following the last cross, four selfs were made and the resulting progeny was named Ohio M-R 12. The diagrammatic outlines of the pedigrees are shown in Figure 1.

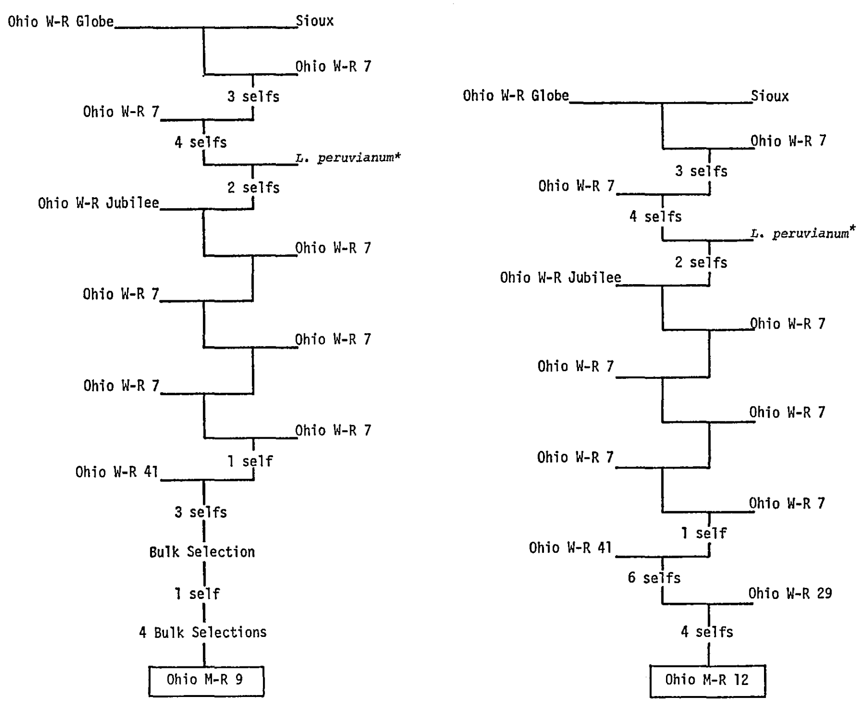

FIG. 1.—Pedigrees of Ohio M-R 9 (left) and Ohio M-R 12 (right). Note that for Ohio M-R 9, eight backcrosses or outcrosses were made to good type; for Ohio M-R 12, nine backcrosses or outcrosses were made to good type.

Since the gene Tm-2[a] for resistance to all five strains of TMV is dominant, the plants could be assayed after each cross or outcross to a good type susceptible parent and the resistant plants, even though heterozygous for resistance, could be used for additional crosses. In this manner it was possible to largely reconstitute the good parent in a relatively short period. The backcrossing method also served the important purpose of preserving the good genes of the commercial parents.

At the time the series of crosses was made to produce Ohio M-R 9 and Ohio M-R 12, Ohio W-R 7 was the most widely grown greenhouse variety. Since then, Ohio W-R 25 and Ohio W-R 29 (9) have largely replaced Ohio W-R 7. If the two latter varieties had been available at the time the early crosses were being made, perhaps better tomato varieties could have been introduced.

These varieties were test grown by commercial growers with the designations 2409 and 712, which were plot number descriptions. For simplicity, the varieties were named Ohio M-R 9 and Ohio M-R 12, respectively.

GENERAL CHARACTERISTICS OF THE NEW VARIETIES

Both of the new varieties Ohio M-R 9 and Ohio M-R 12 are of the Livingston Globe type and closely resemble Ohio W-R 25 and Ohio W-R 29.

Fruit Shape: The shape of the fruit of both Ohio M-R 9 and Ohio M-R 12 under average growing conditions can best be described as smooth and globose (Fig. 2). Under some environmental conditions, such as short days with low intensity and short duration of light, the fruit, especially with high nitrogen fertilization and high water applications, may be somewhat rough with a slight tendency to flatness.

Internal and External Fruit Color: Under most conditions when fully ripe, the internal fruit color of both varieties is a medium to dark red and has a minimum of white vascular tissue (Fig. 3). In fact, the internal color could be described as excellent. The fruit ripens to an excellent external red color. Because the outer skin is colorless, the fruits are free of the yellow cast of most outdoor tomatoes. The fruits have the uniform ripening gene and thus do not have dark green shoulders.

Firmness: Vigorous efforts were made to select fruits for firmness. As a result, the fruits of both varieties equal or exceed any of the Livingston Globe type varieties. This characteristic can be expected to give the fruit good shipping qualities.

Likewise, the carpel walls of the fruit are thick and meaty. During the dark weather of late 1969, several growers noted that the size, shape, color, and firmness of these varieties were much superior to TMV-susceptible varieties.

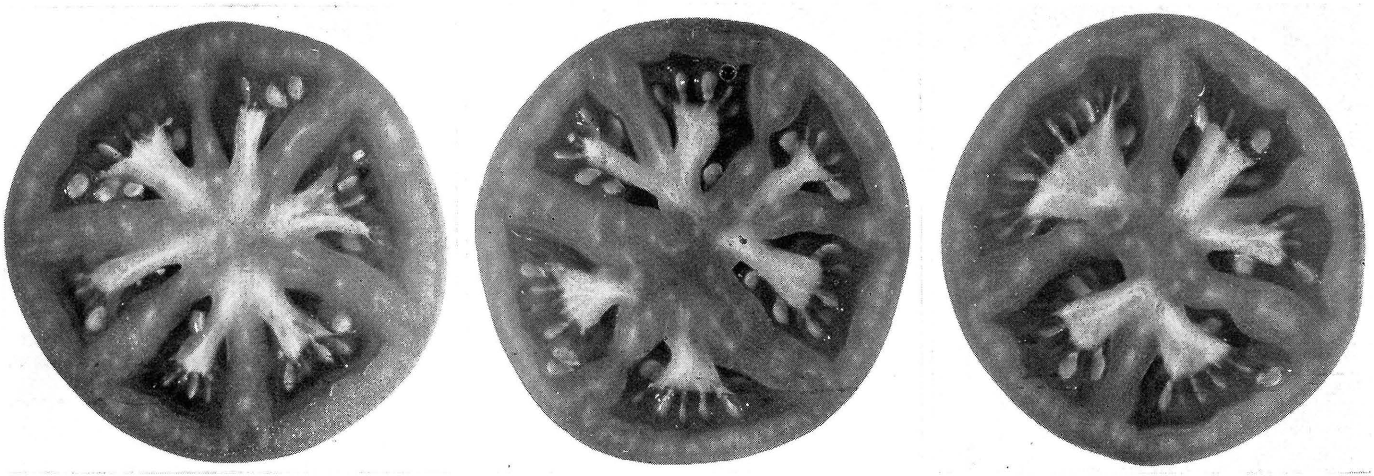

FIG. 2.—Cross sections of Ohio M-R 9 (left), Ohio M-R 12 (center), and Ohio W-R 25 (right).

FIG. 3.—Whole fruits of Ohio M-R 9 (upper), Ohio M-R 12 (center), and Ohio W-R 25 (lower).

Smoothness: Fruits of both varieties are smooth and probably exceed most other greenhouse varieties in this respect. However, they produce a few large, rough fruits. These occur more frequently on early clusters of the spring crop.

Plant Vigor: Plants of both Ohio M-R 9 and Ohio M-R 12 grow more vigorously than those of Ohio W-R 25 and as vigorous as Ohio W-R 29, or possibly slightly more so. The vigorous growth is especially evident when the plants are several feet tall. However, there is a possibility that the apparently more vigorous growth is due to the fact that varieties susceptible to TMV are seriously handicapped by the disease, particularly when fruiting heavily. There is not much, if any, difference in vigor between the two varieties Ohio M-R 9 and Ohio M-R 12.

Temperature and Water Requirements: Temperature requirements for the two new varieties are similar to the older pink greenhouse varieties. Likewise, so far as known, the water requirements of the two varieties do not differ from that of other varieties.

However, it should be emphasized that every variety, although largely the same as an older variety due to backcrossing, has its own temperature, water, and fertilizer requirements. The observing plantsman soon detects these differences and modifies his management practices to meet the different requirements. Thus, it can be expected that there will need to be some changes in growing practices in order to reach the maximum productivity from each new variety.

Fruit Setting Potential: Thus far, no difference has been noted between the fruit setting potential of the new varieties Ohio M-R 9 and Ohio M-R 12 and the presently grown varieties Ohio W-R 25 and Ohio W-R 29.

Maturity: Maturity of the two varieties is similar to that of other established commercial greenhouse varieties, although some growers have reported that Ohio M-R 12 is a few days earlier.

COMPARATIVE YIELD DATA

Yield data from the Ohio Agricultural Research and Development Center greenhouses are given in Table 1. Yield and grading data from seven commercial greenhouses are included in Table 2. Final evaluation will have to await large-scale trials by commercial growers and their acceptance of the varieties.

The data in Table 1 show the comparative yields for Ohio M-R 12 for the spring crops of 1967 and 1968. The data are from single row plots in the OARDC greenhouses. In the spring of 1967, yields of all test varieties were high; Ohio W-R 29 yielded the highest and Ohio M-R 12 slightly less. In the spring of 1968, yields were somewhat lower than 1967 and Ohio M-R 12 had the highest. In the fall crops of 1966 and

TABLE 1.—Comparative Yields of Ohio M-R 12 and Three Commercial Varieties.*

Varieties	Spring Crops		Fall Crops		
	1967	1968	1966	1967	1968
	8-lb. Baskets per Acre				
Ohio M-R 12	20,061	17,530	10,934	9,185	10,258
Ohio W-R 7	16,438	16,280	———	11,529	7,763
Ohio W-R 25	18,354	15,090	14,874	11,913	9,210
Ohio W-R 29	20,432	15,400	12,247	10,937	8,986

*OARDC Plant Pathology Greenhouses.

1967, Ohio M-R 12 had lower yields than the test varieties, but in 1968 it was the highest yielding.

The comparative yield data submitted by seven commercial growers for Ohio M-R 12 are shown in Table 2. Generally, the data were obtained from adjacent single row plots without replication. Unfortunately, the same check variety was not used by all growers. Four times out of seven, plants of Ohio M-R 12 produced more total weight of fruit than the controls.

Data in Table 3 were collected by two greenhouse growers in northern Ohio in the fall of 1969 for Ohio M-R 9. In the case of grower A, Ohio M-R 9 produced 15 percent more than the check variety Hybrid-O. Grower B had two tests. In test A, Ohio M-R 9 and Ohio M-R 12 produced higher yields than the check variety Hybrid-O by 21.8 and 30.9 percent, respectively. In the second test, Ohio M-R 12 exceeded the yields of the two check varieties, Hybrid-O and Ohio W-R 25, by 25.7 and 20.3 percent, respectively.

Fruit Weight: Fruit size, as measured by fruit weight, of Ohio M-R 12 appears to be larger than Ohio W-R 25 but slightly smaller than Ohio

TABLE 2.—Comparative Yields of Ohio M-R 12 in Commercial Greenhouses, Spring Crop 1969.

Grower	Ohio M-R 12	Controls
	Pounds per Plant	
A	13.9	13.3 (Ohio Hybrid-0)
B	11.4	10.2 (Ohio W-R 7)
C	12.3	11.9 (Ohio W-R 25)
D	14.1	11.5 (Ohio W-R 25)
E	11.4	16.5 (Ohio W-R 25)
F	16.9	17.5 (Ohio W-R 25)
G	13.7	15.0 (Ohio W-R 25)

TABLE 3.—Comparative Yield Data from Two Growers in Northern Ohio for Ohio M-R 9, Ohio M-R 12 and Two Commercial Varieties. Yield Row Tests, Fall Crop 1969.

			Grower B			
	Grower A		Test A		Test B	
Variety	8-lb. Baskets per Acre	Percent Increase or Decrease	8-lb. Baskets per Acre	Percent Increase or Decrease	8-lb. Baskets per Acre	Percent Increase or Decrease
Ohio M-R 9	7168	+15.0	5837	+21.8	——	
Ohio M-R 12	——		6272	+30.9	6185	+a 25.7 +b 20.3
Hybrid-0	6230		4791		4922	
Ohio W-R 25	——		——		5140	

TABLE 4.—Comparative Fruit Weight in Ounces of Ohio M-R 12 and Three Commercial Varieties.*

Varieties	Spring Crops 1967	Spring Crops 1968	Average	Fall Crops 1966	Fall Crops 1967	Fall Crops 1968	Average
Ohio M-R 12	5.2	5.4	5.3	4.9	4.6	3.8	4.4
Ohio W-R 7	5.1	5.2	5.2	—	4.7	3.8	4.3
Ohio W-R 25	4.7	4.8	4.8	4.3	4.6	3.8	4.2
Ohio W-R 29	5.7	5.5	5.6	4.3	5.7	4.2	4.7

*OARDC Plant Pathology Greenhouses.

W-R 29 for the spring crops of 1967 and 1968 and the fall crops of 1966, 1967, and 1968 at Wooster (Table 4). Observations indicated that the fruit size of Ohio M-R 9 is comparable to Ohio M-R 12.

Grading Data: One grower kept grading data for the spring and fall crops of 1969 for Ohio M-R 12 (Table 5). In both crops, Ohio M-R 12 produced more select fruit and slightly less off-grades. The percentage of fruit in the intermediate grades varied. A higher percentage of select or first grade tends to increase profits, although at times a premium is paid for tomatoes in the large grade.

It has been noted that fruits of TMV-resistant varieties produced during the hot months of June and July and dark months of November and December tend to be firmer, better colored, and larger than the fruits of the TMV-susceptible varieties Ohio W-R 25 and Ohio W-R 29. If these observations can be substantiated, the value of using TMV-resistant varieties should be increased.

TABLE 5.—Comparative Percentage Grading Data by Weight for Ohio W-R 25 and Ohio M-R 12, Spring and Fall Crops 1969.*

Variety	Grade: Select	Large	Select Small	B-grade	Off-grade
		Spring Crop			
Ohio W-R 25	69.2	8.6	13.5	6.7	2.0
Ohio M-R 12	74.7	5.8	10.0	9.0	0.5
	+5.5	—2.8	—3.5	+2.3	—1.5
		Fall Crop			
Ohio W-R 25	58.0	4.2	20.0	14.2	3.6
Ohio M-R 12	60.8	3.2	16.8	16.2	3.0
	+2.8	—1.0	—3.2	+2.0	—0.6

*Data supplied by courtesy of a commercial tomato grower.

RESISTANCE TO OTHER DISEASES

Since the domestic parent of the interspecific cross, *Lycopersicon esculentum* x *L. peruvianum* (128650-6Y-IV-1-12-22), was a greenhouse variety and, except for the first outcross, there were six backcrosses and one outcross to greenhouse varieties, it is to be expected that the new TMV-resistant varieties should have all of the good genes possessed by established greenhouse varieties. As far as known, this is true except for blotchy ripening resistance and the tendency for horizontal growth. The new varieties are resistant to Race I of the Fusarium wilt pathogen, *Fusarium oxysporum* f. *lycopersici;* to fruit cracking; and to fruit pox. They are tolerant to high manganese soil content and the fruits are relatively free of white vascular tissue.

CHARACTERISTICS APPARENTLY ASSOCIATED WITH TMV RESISTANCE

It was not surprising to find that undesirable plant characteristics appeared to be associated with TMV resistance because the resistant parent was a selection of P. I. 128650, *Lycopersicon peruvianum.* If such characteristics are closely associated or linked, they then would be on chromosome 9 because the dominant gene $Tm\text{-}2^a$ for resistance to the five Ohio strains of TMV has been found to be on one arm of chromosome 9 (27, 36). The associated characteristics are: 1) a tendency for excessive succulence, 2) hairless stems, 3) small fruit, 4) poor fruit set, 5) horizontal growth, and 6) susceptibility to blotchy ripening.

By rigorous selection, it has been possible to largely eliminate the first four characteristics. Despite careful selection, the tendency for horizontal growth and susceptibility to blotchy ripening still persist. Fortunately, even though both characteristics are present in both varieties, their severity has been greatly reduced. If plants are regularly trimmed and trained to a single stem each week, the tendency for horizontal growth is scarcely noticeable and causes very little inconvenience. However, if the plants are neglected, the characteristic is troublesome.

Both varieties are moderately susceptible to blotchy ripening but very little blotchy ripening has been observed in either variety in the breeding plots at Wooster. However, the disease has been observed in commercial plantings. The percentage of infected fruit from entire crops has been low, perhaps not exceeding 1 or 2 percent. It has been higher on certain picking dates, infecting in some cases perhaps 10 percent of the fruit.

DISCUSSION

The introduction of the two new TMV-resistant varieties Ohio M-R 9 and Ohio M-R 12 does not end the TMV-resistant breeding program. It is still necessary and efforts are underway to combine blotchy ripening resistance with resistance to TMV. It has been established that there is a close association between TMV resistance and blotchy ripening susceptibility. Definitive data are not at hand to establish that this association is a linkage but it appears logical to make that hypothesis. If this hypothesis can be confirmed, it will be established that a main gene for blotchy ripening susceptibility is on chromosome 9.

Little is known concerning the inheritance of blotchy ripening. However, Jones (24) and Jones and Alexander (25) showed that resistance to the disease is heritable. Ohio W-R 25 and Ohio W-R 29 are known to be resistant to the disease (9). Several recently introduced Florida tomato varieties are also resistant to the disease. Since there appear to be varying degrees of susceptibility to blotchy ripening, it would also appear logical to think that there is one main gene and one or more minor genes which govern resistance and susceptibility to the disease. However, one cannot overlook the possibility that the inheritance to the disease is multigenic.

Although the two new varieties are moderately susceptible to blotchy ripening, it is possible to grow them at a reasonably rapid rate, but not excessively succulent, and avoid the disease. Growth rate and succulence are thought to be largely controlled by water and nitrogen applications. Observational evidence and some experimental work (12, 40) also indicate that high potassium nutrition helps to prevent the disease.

It has been observed that it is easier to control TMV where the spring tomato crop follows a fall lettuce crop. A logical explanation for the absence of TMV infection following a lettuce crop is that there is not a source of TMV inoculum either in the soil or debris around the greenhouse. Likewise, it has been observed that growing a fall crop of TMV-resistant tomatoes has the same effect as growing lettuce or some other non-host of the virus.

It was observed in the fall tomato crop of 1969, where rather large areas of the new varieties were grown, that the fruit were larger, firmer, and better colored than nearby TMV-susceptible varieties. If this observation can be firmly established, the production of good quality fruit in winter months alone will justify growing the new varieties.

The yield data are not comprehensive and it will be necessary for growers themselves to determine whether there is a favorable increase in yield from the new varieties. In considering yielding ability, it is necessary to remember that Ohio W-R 25 in northern Ohio greenhouses and Ohio W-R 29 in southern Ohio greenhouses are the two best varieties. Obviously, yields and fruit quality are reduced by TMV infection. The degree of reduction appears to be influenced by the age at which infection occurs, amount of sunlight, and prevailing temperatures. Since these two commercial varieties or breeding lines closely related to them were used in the crossing and backcrossing program, it is logical to expect the new varieties to yield approximately the same as Ohio W-R 25 or Ohio W-R 29 when grown under ideal conditions.

It is difficult to make accurate yield comparisons because all varieties have their own optimum growing conditions. However, when testing new varieties, the plants are usually grown under conditions which favor one variety and that is almost universally the old standard variety. Thus, it is necessary to have large blocks of a new variety in commercial greenhouses where the plants will be grown under environmental conditions especially favorable to them. From all indications, both observational and determinative, it can be concluded that the new varieties will yield well.

To minimize the danger of saving seed from plants which may have a tendency for necrosis, seed should only be used from sources where there is little danger of necrotic plants occurring.

It should be emphasized that neither of these varieties can be used as resistant TMV parents to produce an F_1 hybrid, even though the gene Tm-2^a is dominant. This is due to the fact that it has been shown that F_1 generation plants with the Tm-2^a gene become necrotic at high temperatures when infected with four of the five Ohio strains of the virus. On the other hand, Pelham (34) has shown that F_1 hybrid varieties which contain all three genes for TMV resistance (Tm, Tm-2, and Tm-2^a) do not become necrotic when infected with TMV. Pelham's observations have been partially confirmed here (data not included) in that his F_1 hybrids remained healthy following inoculation with Ohio Strain V, which produces severe necrosis.

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The State Is the Campus for Agricultural Research and Development

Ohio's major soil types and climatic conditions are represented at the Research Center's 11 locations. Thus, Center scientists can make field tests under conditions similar to those encountered by Ohio farmers.

Research is conducted by 13 departments on more than 6200 acres at Center headquarters in Wooster, nine branches, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres
Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres
Jackson Branch, Jackson, Jackson County: 344 acres
Mahoning County Farm, Canfield: 275 acres
Muck Crops Branch, Willard, Huron County: 15 acres
North Central Branch, Vickery, Erie County: 335 acres
Northwestern Branch, Hoytville, Wood County: 247 acres
Southeastern Branch, Carpenter, Meigs County: 330 acres
Southern Branch, Ripley, Brown County: 275 acres
Western Branch, South Charleston, Clark County: 428 acres