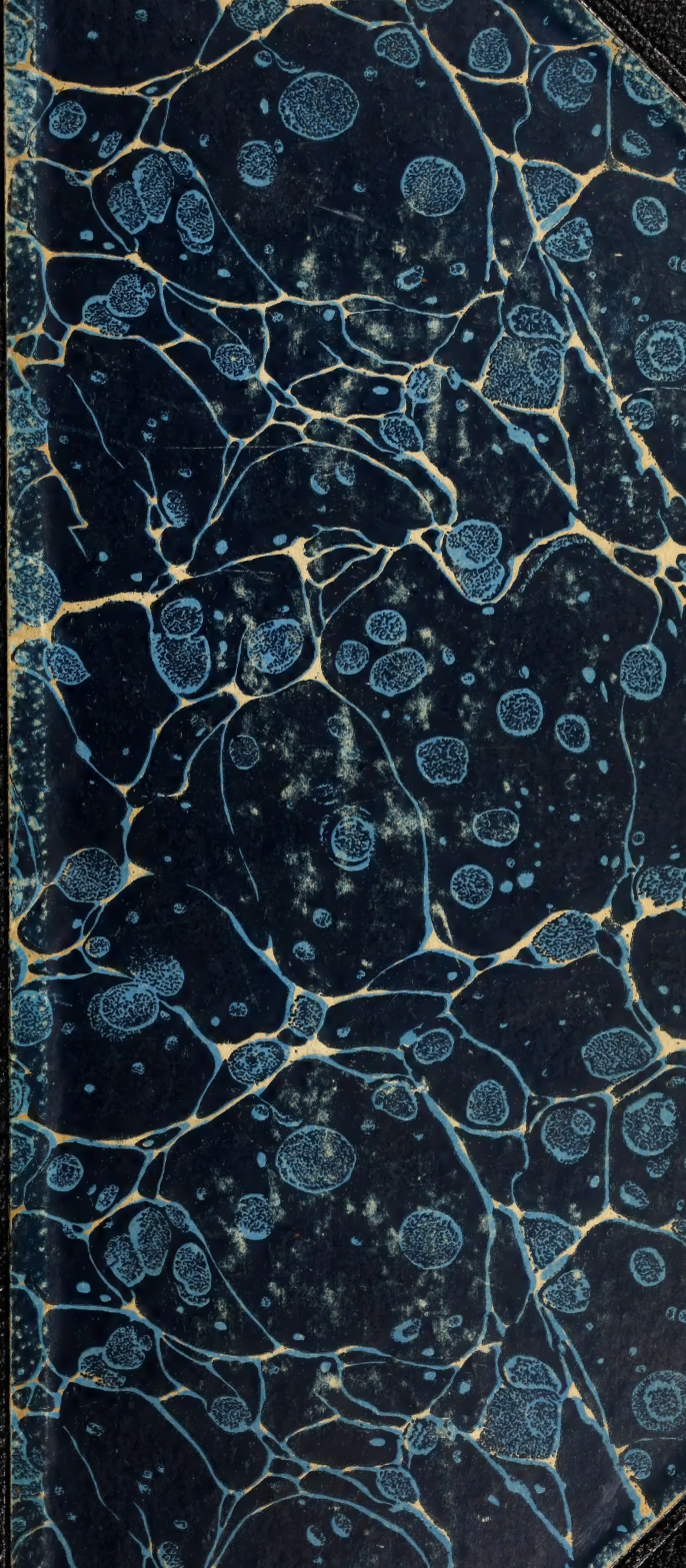

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DEVELOPMENT OF WILT-RESISTANT TOMATOES.

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CONTENTS.

PREVALENCE AND CHARACTERISTICS OF TOMATO WILT.

Tomato wilt (*Fusarium lycopersici*) causes an estimated annual loss of more than 115,000 tons of tomatoes in the Middle Atlantic, Gulf, and lower Mississippi Valley States.[1] As it is prevalent also in the Ohio River Valley, in California, and in parts of Colorado and Utah, it reduces the yield even more than is expressed by these figures. This loss can and should be overcome by the use of wilt-resistance varieties.

Wilt is characterized in its early stage by a wilting of the plant and an upward and inward rolling of the leaves (Pl. I, fig. 1). Later the lower and finally the upper leaves turn yellow and slowly die. When a branch is thus deprived of its foliage it dies back from the tip, turns brown, and shrivels. Some of these final changes and the varied progress of the disease in different branches are shown in

[1] The loss from wilt in the canning crop of tomatoes estimated by the Plant-Disease Survey of the Bureau of Plant Industry from reports of State and Federal pathologists for the year 1918 was 115,000 tons, but this did not cover the whole area infested by wilt nor did it include the loss in the crop grown for trucking and home gardening.

Plate I, figure 2. Not infrequently whole fields of plants wilt in this manner (Pl. II, fig. 1) and finally succumb to the disease.

In cross and longitudinal sections of infected stems (Pl. III) there is a dark-brown discoloration in the woody area between the pith and the bark, but the pith itself is usually normal. The presence and position of this discoloration are important diagnostic characters which help to distinguish the wilt from another similar disease known as southern bacterial blight (bacterial wilt).

Not only the stems and leaves but also the fruits are infected by wilt (Pl. II, fig. 2). By means of the discolored tissues infection can be traced through the fruit stems into the fruit and even to the seed.

Yearly discoveries of wilt where it has never previously been found indicate that it is either continually spreading or is not infrequently present where it has never been reported. Observations and reports show that both of these conditions obtain.

It is probable that wilt will eventually spread over the greater part of the tomato-canning areas if not prevented by the use of resistant varieties. Although the wilt fungus may not thrive so well in the North as it has in the South, the fact that it is continually spreading in some of the more northern States, such as New Jersey, Indiana, and Ohio, and has even been found in Michigan, New York, and Massachusetts, shows that it is seemingly capable of thriving in the more important tomato-canning regions of the United States.

Wilt is carried to some extent by the seed, but not so commonly as the high percentage of fruit infections in wilt-infested fields would seem to indicate. The fungus passes through the fibro-vascular bundles of the fruit to the seed and often invades the cells surrounding the seed coat. Were it not for the removal of these cells through fermentation and washing of the seed in the seed-saving process the infection of plants through the seed would be much more common. The fungus-bearing particles separated from the seed by fermentation frequently adhere to it, however, and thus become a source of infection for the plant and a means of more widespread distribution for the fungus. Infection of plants through the seed would be more common if tomato seed was produced commercially in badly wilt-infested regions.

The most common method of spreading wilt is through infected seedlings. Tomatoes are very generally grown in seed beds and are transplanted to the field when danger of frost is past. Not infrequently the fungus occurs in the seed-bed soil in wilt-infested regions. As such soil is usually rich in organic matter the fungus multiplies rapidly and soon invades the roots of the seedlings. Although this causes a discoloration of the rootlets, the grower, who not infrequently is unfamiliar with plant diseases, usually fails to

recognize it and either plants or sells the seedlings. Wherever such seedlings are used they spread the disease. In the Middle West the practice of using tomato plants grown in Maryland, Delaware, and the Southern States when there is a shortage of locally grown plants is attended with this danger.

Although wilt does not at present cause so much loss as tomato leaf-blight (*Septoria lycopersici*), it is much worse than blight wherever the soil becomes thoroughly infested with the wilt fungus. It therefore threatens the future success of the tomato-canning industry and should by all means be brought under control.

The only means of controlling wilt successfully has been developed in recent years. As the wilt fungus lives in the soil and invades the tomato plant through its roots, it lies beyond the reach of chemical sprays, such as Bordeaux and other mixtures commonly used for the control of fruit and foliage parasites. It multiplies rapidly in the tomato plant, as it has no competition for its food supply, and it becomes thoroughly distributed through the soil with the plowing under of dead vines. If a piece of wilt-infested land be used successively for growing tomatoes it soon becomes so full of the fungus that ordinary varieties of tomatoes can not be grown on it. Rotation of crops forces the wilt fungus to compete with other fungi for its food and therefore reduces it to a minimum, but so far as known does not eradicate it, as it is capable of living long periods, if not indefinitely, on the organic matter in the soil. Treating the soil with chemicals for the control of wilt has not given results of economical value. Large quantities of lime retard its development,[2] but do not otherwise inhibit its activities. The only successful means of controlling wilt is through the development of resistant varieties.

DEVELOPMENT OF RESISTANT VARIETIES.

SELECTION OF MATERIAL.

It is necessary in breeding for wilt resistance to have at least one variety with some resistance to the disease as a basis for selection or crossing. If it possesses only moderate resistance but exhibits it in diverse degree in individual plants, it will serve as a starting point. If it possesses considerable resistance but lacks yield and quality, its resistance can be combined with other desirable qualities by crossing. If, in addition to partial resistance, it is characterized by superior yield and quality of fruit, it will facilitate the work by eliminating crossing and the breaking up of the type.

In searching for suitable material for resistant foundation stock the writer has tested the best canning varieties, the extra large

[2] Edgerton, C. W., and Moreland, C. C. Tomato wilt. La. Agr. Exp. Sta. Bul. 174, 54 p., 19 fig. 1920. Literature cited, p. 54.

fruited varieties, the more distantly related small-fruited varieties, and the varieties recommended in the literature and in seedsmen's catalogues for resistance to tomato diseases. Some of these were tested in 1915 and others in succeeding years.

PREPARATION OF THE BREEDING PLATS.

In order to have satisfactory breeding plats for making the tests, a piece of sandy soil and a piece of clay loam upland on the Arlington Experimental Farm, near Washington, D. C., were thoroughly inoculated with the wilt fungus. This was done by sterilizing chopped straw in a large autoclave, spraying it with spores from a pure culture of the fungus, and after about a month disking it into the surface soil. A good covering of inoculated straw was thus added to the soil for three successive years. Plowing under this straw and the dead infected vines soon thoroughly inoculated the soil with the fungus.

To increase further the opportunity for infection, during the first two years the seed was soaked before planting in a suspension of Fusarium spores and sown in flats containing wilt-infested soil. Infested soil was also used in the flats to which the seedlings were transplanted and in the holes in which they were set in the field; also pure cultures of the fungus were mixed with the soil in the flats and with the soil around the roots of the plants in the field.

As wilted susceptible vines add large quantities of the fungus to the soil while resistant vines do not, the infected vines were cut into small pieces and distributed over the field to help maintain uniform infestation. This seemed desirable, because in greenhouse experiments with tomato wilt the writer found that even when all plants are exposed to infection the percentage of those infected varies with the quantity of inoculum used. Although the fungus was already thoroughly distributed through the soil, its unequal accumulation in certain parts through the plowing under of susceptible vines in one place and of resistant vines in another, if not corrected, would very likely have affected experimental results.

METHOD OF SELECTION.

Selections from two classes of material have been made: (1) Those of apparently resistant plants from wilt-infested fields, and (2) those of resistant strains from these selected plants.

The original selections were made in the worst wilt-infested areas that could be found, and though not always free from wilt they were much freer from it than the plants immediately surrounding them.

The seed from each plant was harvested separately and tested in progeny rows. These progeny rows or strains were graded for yield and quality of fruit and for wilt resistance. Those inferior to the

FIG. 1.—EARLY STAGE OF TOMATO WILT.

FIG. 2.—LATE STAGE OF TOMATO WILT.

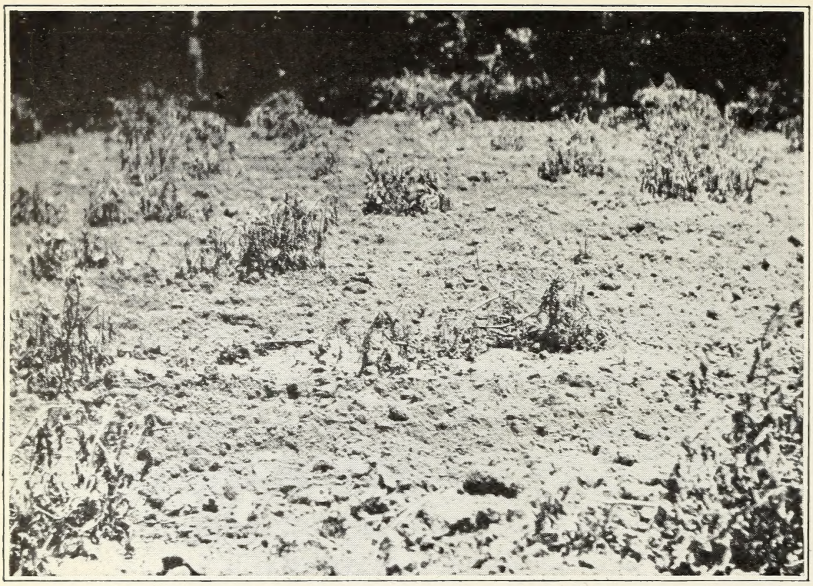


FIG. 1.—FIELD OF WILTED TOMATOES.

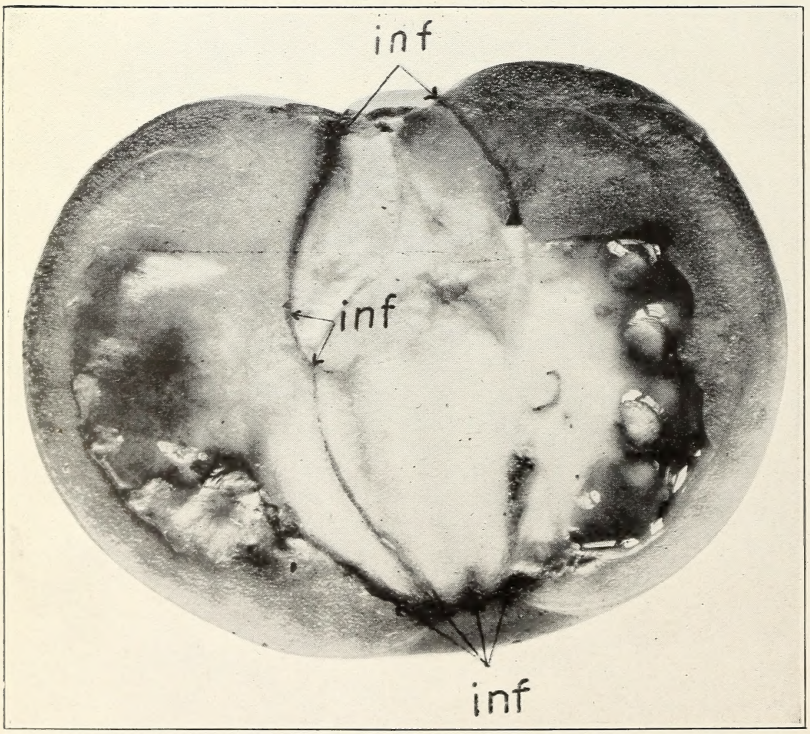
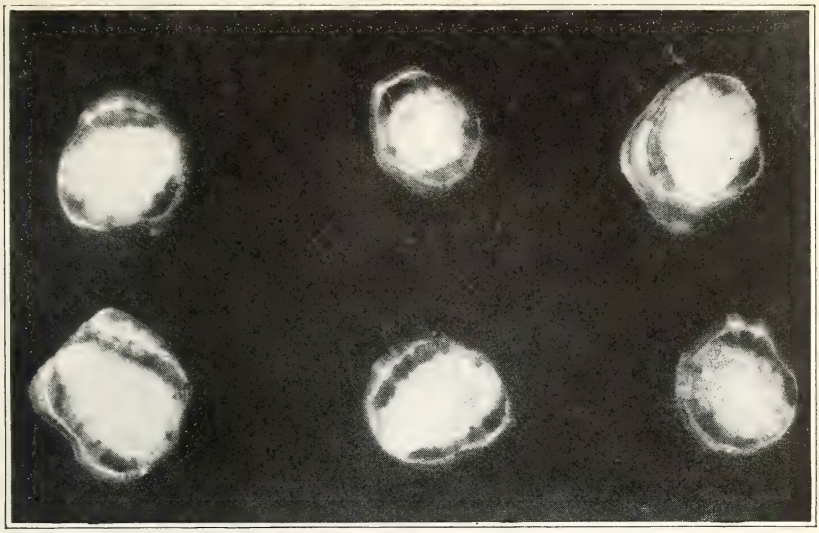
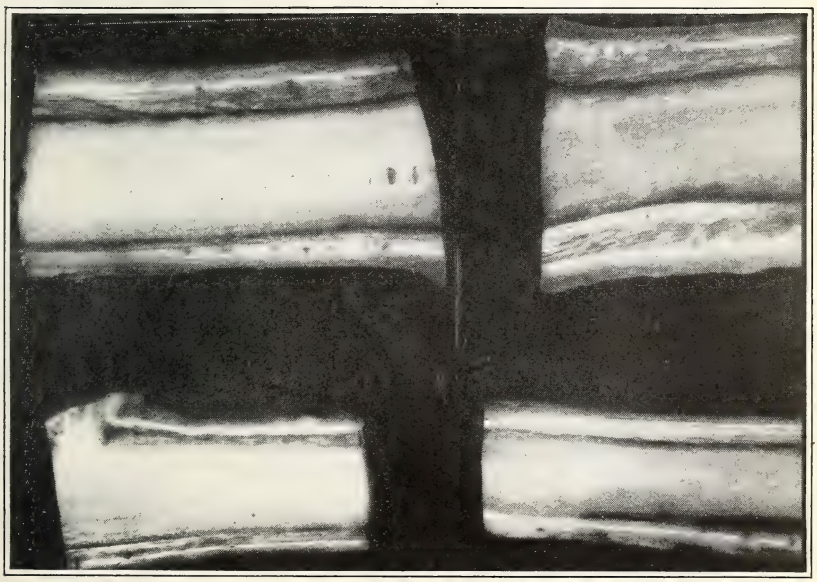


FIG. 2.—WILT-INFECTED TOMATO FRUIT.

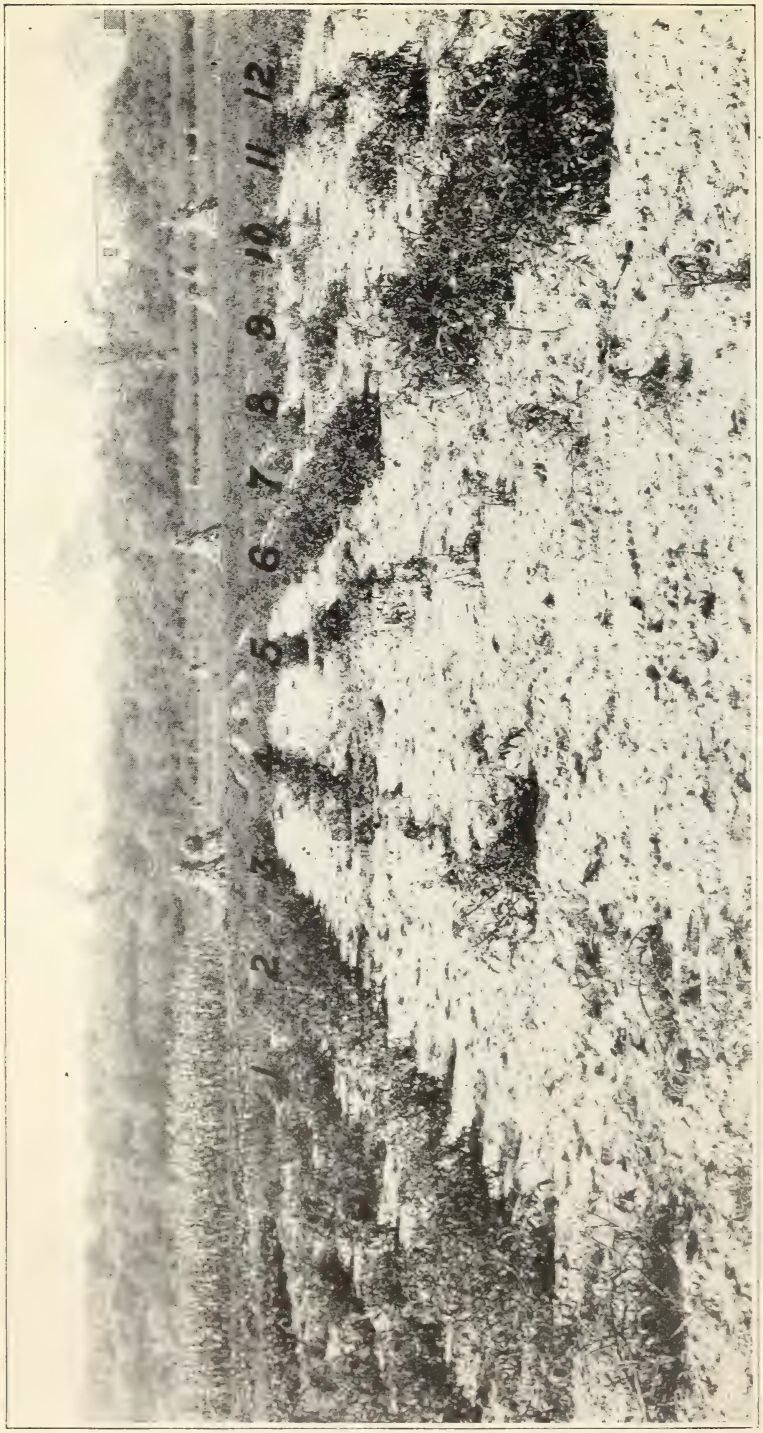
Note the dark-brown discoloration of the vascular tissues marked "inf."





CROSS AND LONGITUDINAL SECTIONS OF WILT-INFECTED TOMATO STEMS.

Note the dark-brown wilt-infected areas between the pith and the bark.



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. I.

Row 1, Norton (selection from Stone); row 2, selection from Greater Baltimore; row 3, Louisiana Wilt Resistant; row 4, Earliana; row 5, Bonny Best; row 6, Duke of York; row 7, Early Detroit; row 8, Ponderosa; row 9, Greater Baltimore.

best commercial varieties in quality of fruit were discarded without regard to other qualities. The most promising strains remaining were tested in subsequent years by repeated plantings on wilt-infested land beside the best commercial varieties, beside the most wilt-resistant varieties, and beside the best strains previously obtained by this method.

As it is difficult to determine accurately the degree of infection in wilted plants, the writer has graded the resistance of strains by a combination of characters correlated with the degree of infection, viz, the percentage of infected plants, the percentage of dead plants, and the yield of fruit.

The percentage of infected plants is correlated with the degree of infection in highly resistant material and is therefore useful in determining resistance when no plants die and when marked fluctuations in yields occur from variations in the environment.

The percentage of dead plants is useful in making selections from very susceptible material in which all or nearly all plants become infected and varying percentages die.

The yield of fruit is inversely correlated with the degree of infection in both resistant and susceptible varieties or strains. It is therefore useful in making selections for wilt resistance, but its exclusive use for this purpose is likely to lead to erroneous conclusions, as yields are often affected by other factors than wilt, and early susceptible varieties, such as Earliana and Texas Bell, partially freed from the effects of the disease because of the low soil temperature in the early part of the season, not infrequently produce a large part of their crop before they are killed by wilt.

Yields in these preliminary tests were not determined from actual weights of fruit but from general appearences; in fact, the differences were great enough to be easily distinguishable without the use of weights.

When the three characters, percentages of infected plants, percentage of dead plants, and yield of fruit, are judiciously used they furnish a fairly effective and rapid means of determining resistance.

VARIETAL RESISTANCE.

The only naturally wilt-resistant varieties of tomatoes having fruit of fair size and quality found by the writer are the Duke of York and the Buckeye State. In type of fruit and vine and in resistance to wilt they appear to be one variety under two names. Livingston's Globe possesses some resistance, enough, in fact, to be of economic importance, but it is not so resistant as the varieties just mentioned. Although the Duke of York and the Buckeye State produce large fruit it is rather hard, especially at the stem end, and has a large

green core. They are suitable varieties for crossing, but not very promising for selection.

A comparison of the resistance of the Duke of York and several selected varieties and commercial varieties may be seen in Plates IV and V. In Plate IV, rows 1, 2, and 3, in the foreground, are varieties that have been selected for resistance to wilt, while row 6 is the Duke of York, a naturally resistant variety. In Plate V, rows 1, 3, and 5 are the Marvel, a selected resistant variety, and rows 2 and 4 are susceptible commercial varieties. The photograph reproduced in Plate V was taken at the end of the season after the crop was harvested. Although the Marvel vines were somewhat defoliated by worms and therefore were less conspicuous than they would otherwise have been, they were still green while the others were dead.

No variety yet tested by the writer has been immune to wilt. The Duke of York, Buckeye State, and several varieties selected for resistance to wilt possess a high degree of resistance, but when grown on heavily infested soil having a temperature of 80° to 85° F. most of the plants show at least a trace of infection in roots or stems.

The comparative resistance of varieties tested by the writer in 1915, 1918, and 1919 are shown in Table 1. As a complete record was not made of the percentages of plants killed in 1916 and 1917, the results for these years are omitted from the table.

Infection was determined by cutting the stems with a knife and noting the color of the tissue between the bark and the pith. Quite thorough cutting was often necessary to find a trace of the disease in plants of the resistant varieties; in fact, some of them were free from it. Whenever the faintest symptom of the disease could be found in the tissues the plant was recorded as infected. Comparisons of the data in Table 1 should be limited to varieties grown in the same field and year. The conditions in different fields and in different years were not similar and therefore did not produce comparable results.

In the variety test for 1915 there was little difference among the varieties in the percentage of plants infected but considerable difference in the percentage of plants killed by wilt. The Louisiana Wilt-Resistant made the best and the Willis variety the poorest record, but in subsequent years the Duke of York and the Buckeye State gave approximately as good results as the Louisiana Wilt-Resistant variety. The Red Majestic and the Enormous made approximately as good records as the Duke of York and the Crimson Cushion for both percentages of plants infected and of plants killed; but the infected plants of the Red Majestic and the Enormous were small, nearly dead, and destitute of fruit, while those of the Duke of York produced about an average crop and those of the Crimson Cushion about a tenth or an eighth of a crop. The degree of infection there-

fore was not fully measured in the Red Majestic and the Enormous by the percentage of dead plants. It was more closely related to the appearance of the crop and quantity of fruit produced. The percentage of dead plants in the other varieties corresponded fairly closely with the degree of infection.

TABLE 1.—*Comparative susceptibility to wilt of different varieties of tomatoes when grown on uniformly wilt-infested soil at the Arlington Experimental Farm, Va., in 1915, 1918, and 1919.*

[I=infected; K=killed.]

Variety.	Comparative susceptibility.													
	Field 1.						Field 2.				Field 3.			
	1915		1918		1919		1918		1919		1918		1919	
	I	K	I	K	I	K	I	K	I	K	I	K	I	K
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Louisiana Wilt-Resistant	87	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Duke of York	92	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Crimson Cushion	92	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Red Majestic	98	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Enormous	84	8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Matchless	100	12	.....	.....	100	63	.....	.....	100	0	.....	.....	.....	.....
Merveille des Marchés	94	16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Perfection	92	24	.....	.....	100	65	.....	.....	100	88	.....	.....	.....	.....
Ponderosa	100	24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Greater Baltimore	100	28	.....	.....	100	72	.....	.....	94	25	68	10	69	44
Texas Bell	98	34	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Trophy	99	35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Tres Hative de Pleine Terre	100	38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Reine des Hative	100	40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Stone	100	44	96	57	91	72	.....	.....	81	44	88	31	.....	.....
Willis	100	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Marvel	.....	.....	2	0	81	0	40	0	.....	.....	6	0	25	0
Columbia	.....	.....	40	0	97	3	.....	.....	.....	.....	.....	.....	.....	.....
Norton	.....	.....	43	0	87	0	42	0	66	0	15	0	19	0
Arlington	.....	.....	53	0	89	0	60	0	67	0	35	0	25	0
Tennessee A 16-2	.....	.....	75	0	.....	.....	.....	.....	.....	.....	60	0	.....	.....
Burbank	.....	.....	100	25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mississippi Girl	.....	.....	100	68	.....	.....	.....	.....	.....	.....	75	0	.....	.....
John Baer	.....	.....	100	94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mansfield Tree	.....	.....	.....	.....	81	0	.....	.....	.....	.....	.....	.....	.....	.....
Louisiana Red	.....	.....	.....	.....	91	0	.....	.....	.....	.....	.....	.....	27	0
Louisiana Pink	.....	.....	.....	.....	97	0	.....	.....	.....	.....	.....	.....	75	0
Livingston's New Globe	.....	.....	.....	.....	94	6	.....	.....	.....	.....	.....	.....	100	0
Livingston's Globe	.....	.....	.....	.....	96	4	.....	.....	100	6	.....	.....	.....	.....
Comet	.....	.....	.....	.....	100	13	.....	.....	100	31	.....	.....	.....	.....
Success	.....	.....	.....	.....	100	0	.....	.....	100	50	.....	.....	.....	.....
Earliana	.....	.....	.....	.....	100	38	.....	.....	.....	.....	100	38	.....	.....
Grand Rapids Forcing	.....	.....	.....	.....	100	63	.....	.....	.....	.....	.....	.....	.....	.....
Carter's Sunrise	.....	.....	.....	.....	100	69	56	0	100	75	.....	.....	.....	.....
Red Currant	.....	.....	.....	.....	.....	.....	69	0	.....	.....	.....	.....	.....	.....
Royal Red	.....	.....	.....	.....	100	56	.....	.....	100	93	.....	.....	88	38
Delaware Beauty	.....	.....	.....	.....	100	81	.....	.....	100	81	.....	.....	89	41
Red Cherry	.....	.....	.....	.....	.....	.....	94	75	.....	.....	.....	.....	.....	.....
Early Jewel	.....	.....	.....	.....	.....	.....	.....	.....	100	88	.....	.....	.....	.....
Red Head	.....	.....	.....	.....	100	94	.....	.....	100	100	.....	.....	94	56
Bonny Best	.....	.....	.....	.....	100	100	.....	.....	.....	.....	94	38	.....	.....

In 1918 and 1919 the Marvel, Columbia, Norton,[3] and Arlington, wilt-resistant varieties developed by the writer, the Louisiana Red and Louisiana Pink, wilt-resistant varieties developed by Edger-

[3] The Norton, as will be explained later, was developed in cooperation with Mr. J. B. S. Norton, of the University of Maryland.

ton, and the Tennessee A 16–2, a wilt-resistant variety developed by Bain and Essary, were almost free from wilt; while the John Baer, Greater Baltimore, Stone, Royal Red, Delaware Beauty, Early Jewel, Red Head, and Bonny Best were nearly destroyed by the wilt. Moreover, the differences were much greater than the figures in Table 1 show.

Livingston's Globe and Livingston's New Globe possess considerable resistance to wilt, but not so much as the more highly developed resistant varieties.

The Mansfield Tree tomato resisted the disease fairly well in the one test made, but produced little fruit. It is by no means certain that it possesses as much resistance as the results of this test indicate. The Success and the Mississippi Girl gave good results in one test, but poor results in another.

From the results of these tests it is not surprising that the Bonny Best, one of the most productive varieties grown in the Middle Atlantic and Middle Western States, dies so rapidly in many places in the South. No different results could be expected from so susceptible a variety. The John Baer, Early Jewel, Royal Red, Delaware Beauty, Red Head, and Willis would probably do no better.

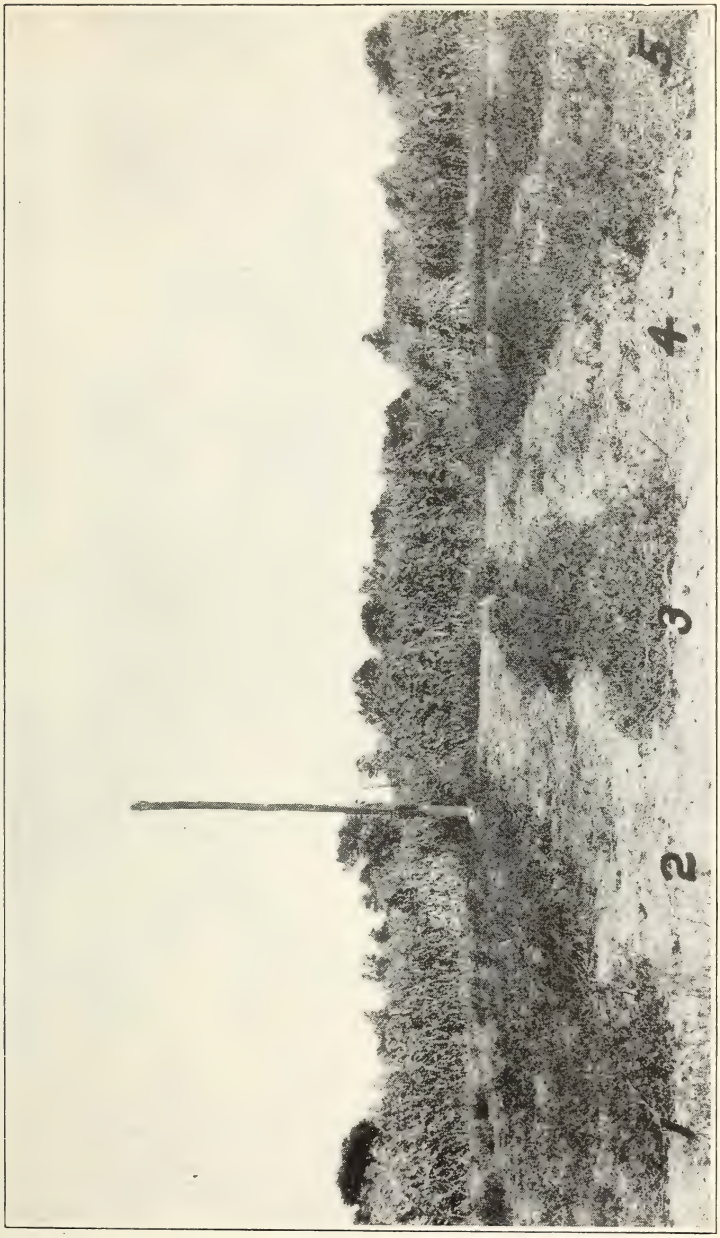
INTRAVARIETAL VARIATION.

Most varieties of tomatoes differ little from one another in the wilt resistance possessed by their individual plants. Very susceptible varieties, such as the Bonny Best, Delaware Beauty, John Baer, and Red Head, usually show about the same variation in intravarietal resistance as the fairly resistant varieties, Livingston's Globe, Duke of York, and Buckeye State. A few varieties, such as Stone, Greater Baltimore, and Merveille des Marchés, possess a much wider range of intravarietal resistance than the average. By selecting and testing a considerable number of plants from these varieties strains can be obtained that transmit a high degree of resistance to their progeny.

BEHAVIOR OF SELECTIONS.

Most plants selected for resistance to wilt transmit to their progeny no more resistance than is possessed by their parent varieties. A few excel in this respect, but their number is very small. Moreover, these few, even when selected from the same variety, differ in the degree of resistance they transmit.

Selections from a variety that transmits about the same degree of resistance to all its individual plants seldom transmit increased resistance. They are therefore probably fluctuations caused by inequalities in soil infestation, drainage, etc. A large number of selections from three such varieties, Livingston's Globe, Buckeye State, and Duke of York, were tested by the writer, but not one surpassed



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. II.

Rows 1, 3, and 5, Marvel; row 2, John Baer; row 4, Stone.

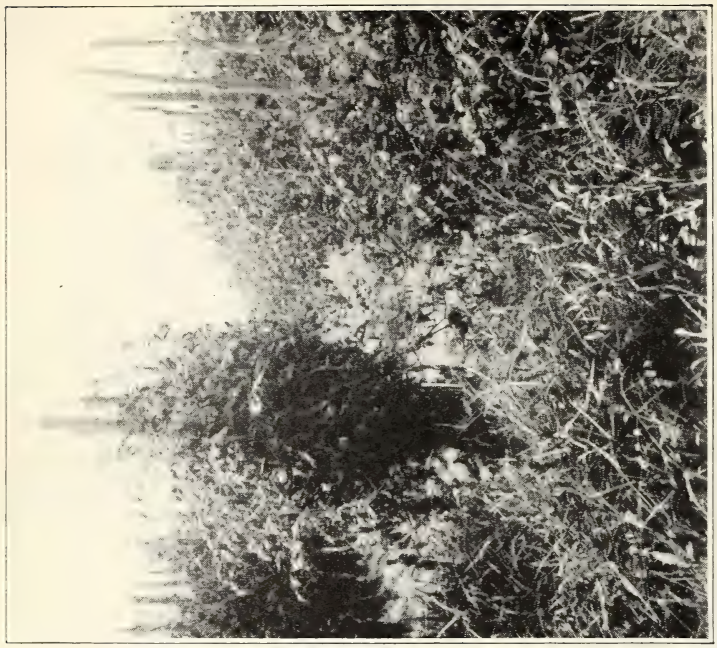


FIG. 2.—Wilt-resistant Norton tomatoes grown in the opposite ends of the rows of Brimmer shown in figure 1.

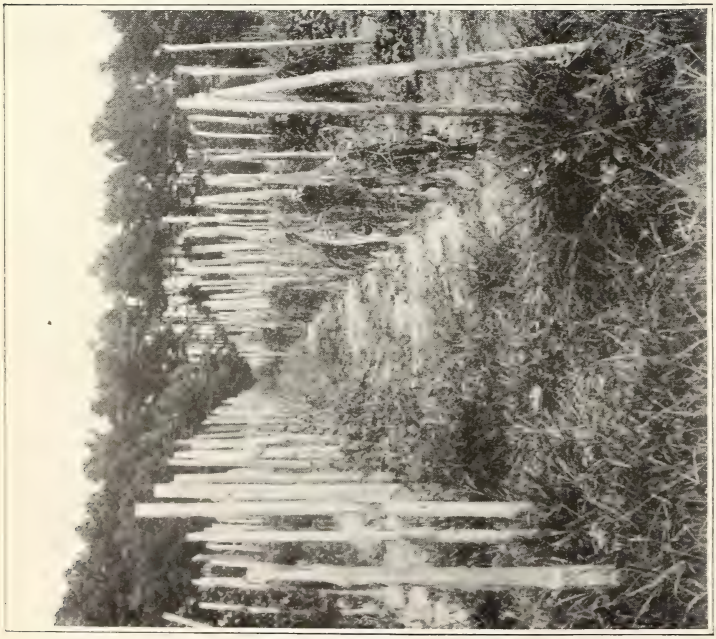
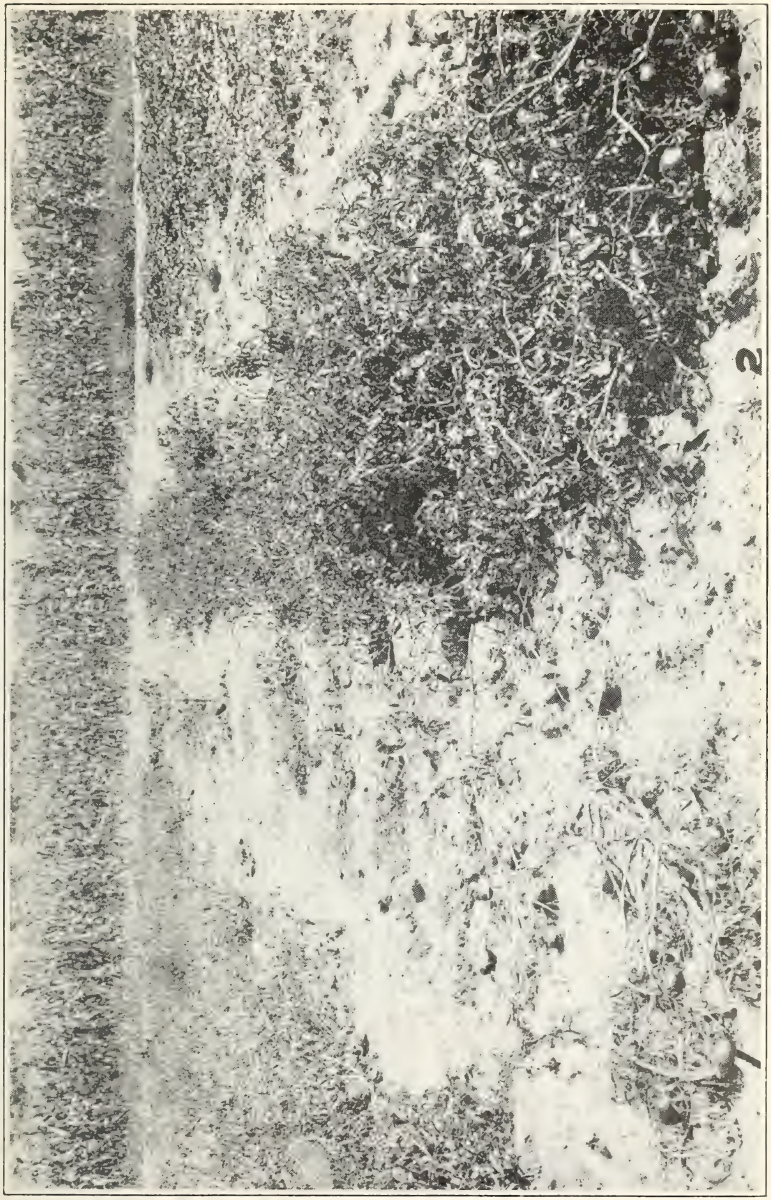


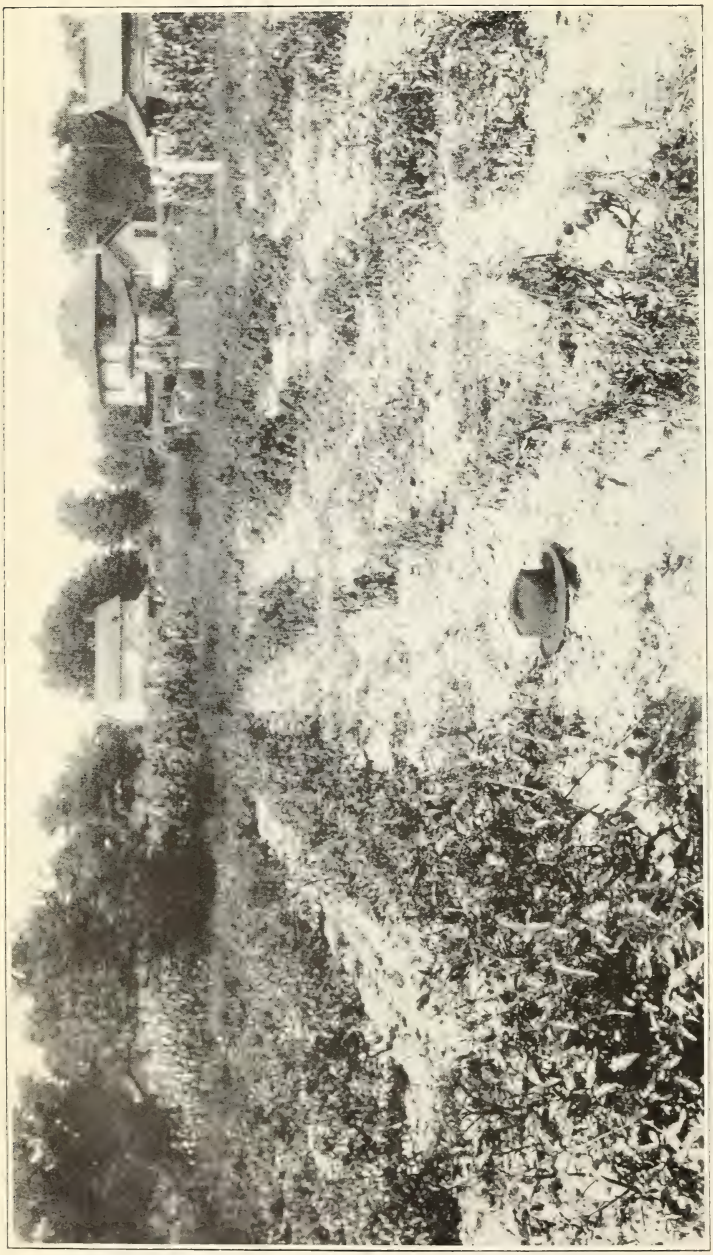
FIG. 1.—Nonresistant Brimmer tomato grown near Richmond, Va.

BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. III.



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. IV.

Row 1, Greater Baltimore; row 2, Arlington (selection from Greater Baltimore).



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. V.

The rows left of the center are of the Norton variety, grown at Brazil, Ind.; those at the right of the center are commercial varieties (one row of each)

its parent variety in degree of resistance transmitted. In another similar case, 30 apparently resistant plants of Earliana and 118 of Bonny Best, the only wilt-free plants found in two fields of 6 acres each, failed to transmit more than average resistance for their respective varieties.

Selections from varieties that transmit resistance to their individual plants somewhat diversely, such as the Stone, Greater Baltimore, and Merveille des Marchés, not infrequently excel their parents in the transmission of wilt resistance.

BEHAVIOR OF RESISTANT VARIETIES.

Although none of the varieties of wilt-resistant tomatoes developed by the writer are immune to wilt, they are highly resistant to it. In repeated tests on heavily wilt-infested soils they have maintained a high degree of resistance. A more important possession, however, is their high yield and the superior quality of their fruit when grown on wilt-infested soil. As they have been selected from the best commercial varieties, primarily for yield and quality of fruit and secondarily for wilt resistance, they possess the high yielding power of the parent varieties in addition to resistance and are therefore equal to them on wilt-free soil and far superior to them on wilt-infested soil. The behavior of two of these varieties is illustrated in Plates VI and VII. Plate VI, figure 1, shows the Brimmer, a very popular variety in the South, while figure 2 is the Norton. They were grown in opposite ends of the same rows near Richmond, Va. The Brimmer was absolutely destroyed by wilt, while the Norton produced an excellent crop of fruit. In Plate VII, row 1 is the Greater Baltimore and row 2 the Arlington, a selection from the Greater Baltimore. Although planted at the same time and given identical cultural conditions, the Greater Baltimore was completely destroyed, while the Arlington was apparently free from wilt and produced a good crop of fruit.

EFFECT OF CONTINUOUS SELECTION.

A tomato plant usually transmits to its immediate offspring as much wilt resistance as can be developed from it by subsequent selection. In a very small percentage of plants tested for wilt resistance by the progeny-row method, increased resistance has been obtained in the second selection, but no higher resistance has resulted from a continuation of this process. As crossing occasionally occurs in the tomato, the hybrid condition resulting from it may account for the exceptions noted.

The effect of continuous selection from two wilt-resistant varieties developed at Washington, D. C., and from one developed in Louisiana are shown in Table 2. The tests were made in rows of 16 plants

each on the wilt-infested breeding plats at the Arlington Experimental Farm. After one to three years of continuous selection the selected strains were planted beside the resistant varieties from which they were selected.

TABLE 2.—*Effect of continuous selection of varieties of tomatoes on the resistance to wilt.*

Variety and year.	Field.	Number of plants in the experiment.		Percentage of plants showing a trace of infection.	
		Variety under test.	Selections from same.	Variety under test.	Selections from same.
Norton:					
1917	3	15	48	33	63
1917	1	16	175	50	39
1918	1	48	32	52	63
1918	2	16	16	19	19
1919	2	16	112	69	66
Marvel:					
1918	1	16	64	19	8
1918	2	48	16	31	34
Louisiana Wilt-Resistant:					
1916	1	48	25	65	76

Continuous selection has apparently made no improvement in the wilt resistance of these strains. Whenever the real differences become small, however, as in the present case, they are obscured by fluctuations caused by environmental factors. Such a factor is soil moisture. On wet spots wilt is much worse than on better drained areas. Moreover, water is probably not the only variable environmental factor that affects the development of wilt. Until the methods of reducing these environmental effects are sufficiently refined to enable the breeder to distinguish real differences from fluctuations it will be impossible to determine whether or not continuous selection leads to further improvement. Under the present methods it does not seem to do so. The writer has found no difference in this respect between tomatoes, which are nearly always self-fertilized, and sugar beets,[4] which are normally cross-fertilized.

DURATION OF RESISTANCE.

Wilt resistance is apparently as permanent as other characters of the tomato. It fluctuates somewhat with changes in soil temperature, soil moisture, and other physiological factors, but on the average is less variable than tomato fruit characters. Its stability is shown by the fact that the varieties developed by the writer have maintained the same degree of resistance under both continued and discontinued selection and have remained relatively constant in all places tried. This is further supported by the fact that varieties

[4] Some recent investigations in sugar-beet breeding. *In* Bot. Gaz., v. 62, no. 6, p. 425–465, 51 figs. 1916.

developed by Edgerton and by Bain and Essary have shown approximately the same resistance at Washington as in Louisiana and Tennessee. The permanence of wilt resistance would therefore seem to depend on the prevention of crossing with susceptible varieties.

RESULTS OF FIELD TESTS.

Field tests[5] of the varieties of tomatoes described in this bulletin have been made on an extensive scale in Maryland, Delaware, Virginia, Georgia, and Alabama and on a smaller scale in 19 other States. In no case[6] have these varieties failed to maintain a high degree of resistance to wilt. Numerous reports from pathologists, horticulturists, canners, truckers, and growers of home gardens show that the yield and quality of fruit have usually been much better than from other varieties. On heavily wilt-infested soils the superiority of the resistant varieties has often been very great; in fact, in many fields in which it has been impossible to grow tomatoes for years on account of wilt these varieties have produced a heavy crop of fruit.

Wilt resistance in these tests has not usually been reported on a percentage basis by tomato growers, as they are not always able to distinguish wilt from blight or other diseases. Moreover, they are interested in general results more than in percentages, and they therefore usually report by means of such general statements as these:

They were beauties and splendid yielders. They surely had a fair chance and proved to be nonwilt. When one-half of our patch was dead, they were green and the ground lay full of nice tomatoes.

Up to date none of the plants of yours have shown any sign of wilt, whereas all other plants of tomatoes I had wilted badly, being entirely destroyed long ago.

Throughout the entire county the tomato crop was a complete failure except the ones that used the wilt-resistant seed.

They were all heavy bearers and none of them wilted.

Your tomatoes were grown in four different parts of a 10-acre field of Stone tomatoes. The fruit and quality were better than the Stone tomatoes.

The Norton gave at least double the yield of the Greater Baltimore.

If we could buy the kind of seed you sent us last spring in sufficient quantities to plant our entire crop, it would double our yield, even if the vines were slightly affected by the wilt.

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[5] Many of these tests were arranged with commercial tomato growers and growers of home gardens by plant pathologists, botanists, and horticulturists of the State agricultural experiment stations and by members of the Office of Extension Work South in the States Relations Service. Much credit should be given to these cooperators, especially to C. E. Temple, Thomas F. Manns, J. M. LeCato, F. D. Fromme, George L. Peltier, G. M. Armstrong, and Ola Powell, who have conducted extensive tests.

[6] One apparent exception to this statement was made by McClintock to the Plant-Disease Survey when he reported: "All so-called resistant strains which we were able to obtain were tested in badly infested soils in 1919 and none proved sufficiently resistant to grow and bear throughout the summer." As these results are so different from those reported by McClintock for Georgia the previous year and by others for several years and from several thousand reports received from various localities in Georgia and other States, the writer is of the opinion that wilt was not the sole cause of these unfavorable results.

The tomatoes you sent us gave fully twice as many fruits per acre as the others; besides, the fruits were of a much better quality.

I had a canning-club girl who planted one-tenth acre in disease-proof seed. She has canned 1,100 quarts of tomatoes, made 1 dozen bottles of catsup, and 3 gallons of green-tomato pickle from her patch. These are the only tomatoes that have been raised on this ground for years; all other plants would grow to be about a foot high, take the wilt, and die.

Although most of the reports received state the results in some such popular way as expressed in the foregoing paragraphs, a few report them in percentages of infected plants. Mr. Lewis Walker, county agent, Waycross, Ga., says:

I had one plat to run 100 per cent resistant and I feel that all the work would have averaged at least 95 per cent resistant. They were placed beside other seed and all wilted to about 60 per cent, leaving yours good.

Dr. G. A. Osner, formerly of the Indiana Agricultural Experiment Station, reported the data included in Table 3 on the test of the Norton variety.

TABLE 3.—*Comparative resistance to wilt of varieties of tomatoes at Lafayette and Brazil, Ind., in 1917.*

Variety.	Locality.	Number of plants.	Percentage of plants dead or badly diseased.
Norton	Lafayette	102	6.8
17 other varieties	do	627	67.0
Norton	Brazil	160	2.0
14 other varieties	do	1,045	55.0

The Norton was much more resistant than the other varieties and produced a better yield and quality of fruit. Although a small percentage of Norton plants was infected by wilt at the end of the season, this was not apparent in August when the writer visited these fields. A view of part of the field at Brazil is shown in Plate VIII. The rows at the left of the center are the Norton; those at the right are commercial varieties. The view shows only a few commercial varieties (one row of each) growing beside the Norton, but there were 14 commercial varieties in this field.

The percentages of wilt-free plants reported by Prof. D. C. Neal, plant pathologist of the Georgia State Board of Entomology, are grouped in Table 4. Included in this test were one of Edgerton's varieties, viz. Louisiana Hybrid (probably Louisiana Red or Louisiana Pink), Stone, and Livingston's Globe.

The resistant varieties, Louisiana Hybrid, Columbia, Marvel, Norton, and Arlington, were superior to Livingston's Globe, a somewhat resistant variety, and much superior to Stone, a typical susceptible variety. Although it is not stated whether the percentages

are based on real or apparent resistance, it is quite likely that they refer to apparent resistance.

TABLE 4.—*Comparative resistance to wilt of several varieties of tomatoes at Thomasville, Ga., in 1919.*

Variety.	Number of plants.	Percentage of wilt-free plants in August.	Variety.	Number of plants.	Percentage of wilt-free plants in August.
Louisiana Hybrid	57	96	Norton	55	90
Columbia	54	94	Livingston's Globe (check)	60	70
Marvel	58	94	Arlington	58	96
Stone (check)	60	46			

The percentages of wilted Norton plants reported for Georgia in 1917 by Mr. J. A. McClintock are summarized in Table 5. As not all of these fields were visited, it is quite likely that some of the injury attributed to wilt may have been due to blight or root-knot.

TABLE 5.—*Comparative resistance to wilt of the Norton and several commercial varieties of tomatoes in Georgia in 1918.*

County.	Number of experimenters.	Size of planting.	Wilt noted.	
			In Norton.	In checks.
			Per cent.	*Per cent.*
Ware	8	One-tenth acre	5	10 to 90
Colquitt	20	do	2 to 5	75 to 100
Thomas			5	100
Glynn	12	One-tenth acre	35	50
Chatham	35	Half acre or less	[a] 20	40 to 75
Dodge	14	One-tenth acre	2	50 to 75
Toombs	10	do	0	25 to 50
Bibb	24	do	Small.	([b])
Walton	12	do	3	85
Coffee	10	One-twentieth acre	3	10 to 30
Brooks	4	About 100 plants per person	0	20

[a] In one instance. [b] More than Norton.

The percentages in Table 5, which probably refer to apparent resistance, agree fairly well with those in Table 4. In some instances, as in Glynn County, it is quite possible that wilt was not always distinguished from blight or root-knot. For Chatham County only one result is reported, and it is a percentage which is very likely much higher than the average for the 35 tests. But even as the results of these tests are reported, they show that the Norton is much more resistant to wilt than the commercial varieties planted beside it.

The results reported by Edgerton for Louisiana in 1920 are summarized in Table 6. They include data on Edgerton's wilt-resistant varieties, Louisiana Red and Louisiana Pink, and also on several commercial varieties. The percentages are arranged in two columns:

(1) Those of plants apparently infected, determined by visual inspection only, and (2) those of plants actually infected, determined by cutting the stems and noting the appearance of the tissues.

TABLE 6.—*Comparative resistance to wilt of several varieties of tomatoes in Louisiana in 1920.*

Variety.	Plants infected.		Variety.	Plants infected.	
	June 25, apparent infection.	July 11, actual infection.		June 25, apparent infection.	July 11, actual infection.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Marvel	6.6	55.7	Earliana	47.6	87.6
Louisiana Red	6.2	62.2	Manyfold	24.5	90.7
Louisiana Pink	6.3	69.3	Early Jewel	58.4	92.7
Norton	5.0	70.0	Stone	78.3	96.1
Columbia	15.0	75.4	June Pink	60.1	96.6
Arlington	13.2	77.7	Bonny Best	80.6	97.2
Livingston's Globe	1.2	77.9			

There is considerable difference between these varieties in percentage of plants apparently infected, but not so much in percentage of plants actually infected. As apparent infection is somewhat closely related to degree of infection, the percentages recorded in the first figure column show the superior resistance of varieties developed for resistance to wilt. However, the resistance of Livingston's Globe was much higher in these tests than the writer has personally observed. In a test of 87 strains of the Globe variety at the Arlington Experimental Farm in 1920 the percentage of apparently infected plants was much higher than for the Marvel, Norton, Arlington, Columbia, or Louisiana Red. The Globe must therefore fluctuate considerably in its resistance to wilt.

The report in Table 7 by Mr. U. G. Swingle, of Columbus, Ohio, gives a fairly good comparison of the behavior of the Marvel variety in wilt-infested soil in a greenhouse as compared with commercial varieties. The Arlington, Columbia, and Norton varieties were used in this test, but only on a small scale, as they are rather large, heavy, and late for forcing.

TABLE 7.—*Comparisons of wilt-resistant and nonresistant varieties of tomatoes in a greenhouse at Columbus, Ohio, in 1919.*[a]

Variety.	Number of plants.	Average yield per plant.	Average returns per plant.	Yield per acre.
		Pounds.		*Tons.*
Resistant varieties, mostly Marvel	1,650	4.76	$1.02	22
Nonresistant varieties, mostly Bonny Best	5,160	3.23	.70	15

[a] Swingle, U. G. Successful greenhouse tomato crop. *In* Market Growers' Jour., v. 25, no. 11, p. 7. 1919.

Table 7 shows the effect of resistance on yield. Because of its wilt resistance, the Marvel was able to produce a much better crop than the Bonny Best. There is probably no more productive tomato than the Bonny Best when grown in an environment free from disease, but like most other tomato varieties it is susceptible to wilt and can not produce a heavy crop on wilt-infested soil; in fact, when the soil is heavily infested by wilt it produces very little fruit. The resistant varieties are so lightly attacked by wilt that they are hardly affected by it.

In regard to their wilt resistance, Swingle says:

> There was a wonderful difference in vitality between the resistant and non-resistant varieties. All the latter were practically dead before the end of the season and consequently did not mature all their fruit. The resistant varieties were all still green on July 25 when pulled up.

In some rows the resistant varieties were planted at the ends; in others in the middle. Although the resistant varieties were still green when pulled up, the others were so dry they could be lighted with a match.

ORIGIN AND DESCRIPTION OF WILT-RESISTANT VARIETIES.

The Marvel is a selection from Merveille des Marchés (Marvel of the Market), a French variety sold by Vilmorin-Andrieux & Co., Paris, France. Before it was named it was distributed for trial as F 59. The Marvel and F 59 are therefore the same variety.

Under favorable conditions the Marvel produces a heavy crop of medium-early smooth red fruit, similar in size, shape, and smoothness to the fruit shown in Plate IX, figure 1. It usually sets a great many fruits and continues to bear heavily long after most early varieties are dead.

It is highly resistant to tomato wilt and possesses a little resistance to tomato leaf-spot (*Septoria lycopersici*).

It is an excellent variety for forcing, for medium-early trucking, and for home gardening. Its wonderful vitality of vine, its relative freedom from diseases, and its superior fruit for use in the fresh state make it an excellent tomato for all-round use.

Variety very productive, medium early, long bearing, highly resistant to tomato wilt (*Fusarium lycopersici*), somewhat resistant to leaf-spot (*Septoria lycopersici*) and to leaf-mold (*Cladosporium fulvum*).

Plant medium large, erect, vigorous; branches many, long, medium stout; internodes long.

Foliage type, standard;[7] leaves large, deeply divided, smooth, dark green, shading the fruit.

Flowers large; fruit cluster small, many, scattered.

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[7] In making comparisons three types of foliage were used, viz, standard, potato leaf, and Dwarf Champion.

Fruit medium large, oblate, bright red, with occasional shallow cracks either encircling or radiating from the stem; stem-end cavity shallow, smooth; blossom-end basin small; stylar scar small, circular; skin thin; vertical section medium long, oval; cross section round, smooth; walls thick, firm, juicy, evenly colored; cells many, small, irregular, well filled; seeds fairly numerous, small; pulp medium thick; core not defined; flavor sprightly acid.

The Arlington[8] and Columbia varieties are selections from the Greater Baltimore. As they are similar in fruit characters, the illustration for the Arlington (Pl. IX, fig. 2) will serve for both varieties.

Like their parent variety, the Arlington and Columbia produce a heavy crop of large, smooth, deep-red fruit, which ripens uniformly; in fact, it is practically free from green tissue around the stem by the time the blossom end is ripe, but it ripens so fast that it can not be held long. Although they are similar in many respects, the Arlington produces a little larger vine than the Columbia and seems to possess a little more resistance to wilt. There is very little difference, however, in their yield.

They are medium-late tomatoes of the canning type and should be tried wherever the Greater Baltimore is used, as they are adapted to the same environmental conditions and produce the same quality of canned fruit.

Variety very productive, late, highly resistant to tomato wilt (*Fusarium lycopersici*), somewhat resistant to leaf-spot (*Septoria lycopersici*).

Plant large, erect, vigorous; branches many, long, stout, internodes long.

Foliage type, standard; leaves large, deeply divided, smooth, yellowish green, shading the fruit.

Flowers large; fruit clusters small, many, scattered.

Fruit large, oblate, dark red, very seldom cracked; stem-end cavity medium deep, ribbed; blossom-end basin small, fairly deep; stylar scar small, irregular; skin medium thick; vertical section short, oval; cross section round, smooth except near stem; walls thick, firm, juicy, evenly colored; cells many, small, irregular, well filled; seeds fairly numerous, medium large; pulp medium thick; core not defined; flavor pleasantly acid.

The Norton is a selection from the Stone, which has been distributed both as F 20 and as Norton by the Office of Cotton, Truck, and Forage Crop Disease Investigations and as Wilt-Resistant Stone by Prof. C. E. Temple in Maryland. The original fruit from which it descended was selected by Mr. J. B. S. Norton, of the University of Maryland, and with several other seed samples was given to the writer for trial in the spring of 1915. The fruit produced by this selection was exceptionally good for the conditions under which it was grown. The plants, though with one exception badly infected, showed some resistance to wilt. One plant contained only a mere trace of infec-

[8] As some of the seed of this variety which was distributed in 1919 and 1920 was found to be impure, having given several different off types of tomatoes, a result, it is believed, of accidental crossing in the seed-production fields, the seed has been withdrawn until it can be fully purified.

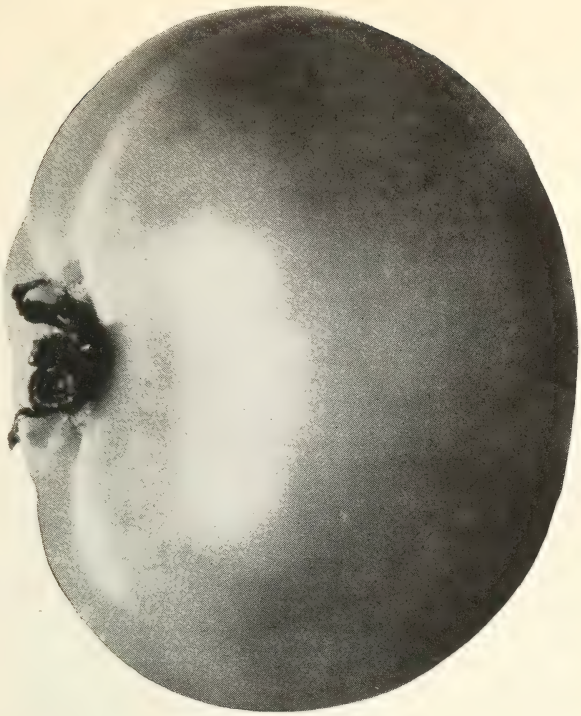


FIG. 2.—Arlington.

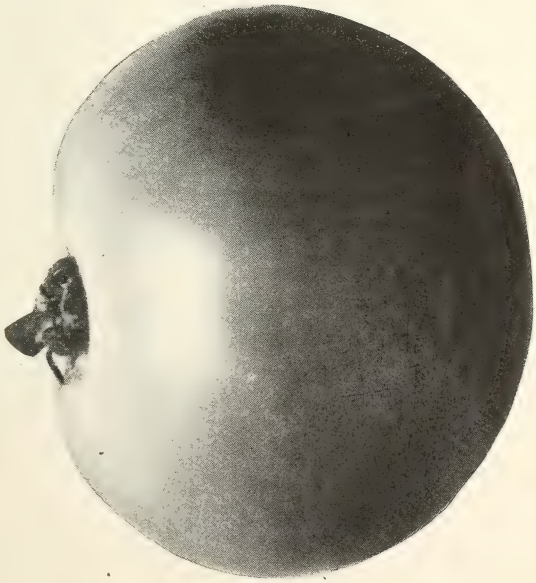
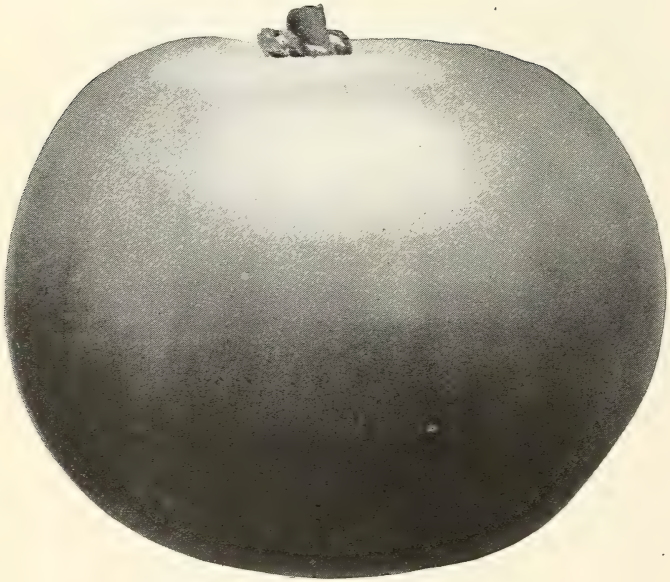


FIG. 1.—Marvel.

NEW VARIETIES OF WILT-RESISTANT TOMATOES. I.

About average natural size.



Norton.

NEW VARIETIES OF WILT-RESISTANT TOMATOES. II.

About average natural size.

tion and produced a heavy crop of fruit. Cuttings were made from this superior plant and transferred to the greenhouse. By repeatedly making cuttings during the winter from this greenhouse material enough seed was obtained by spring to make an acre field test. The results were so good that the entire crop was saved for seed and used for making extensive field trials in 1917. This new strain was equal to the original strain in quality and quantity of fruit and much superior to it in wilt resistance. This is one of the cases in which a second selection gave further improvement, the other cases being selections from Merveille des Marchés.

The Norton produces a heavy yield of large, smooth, solid red fruit (Pl. X), which ripens slowly and therefore ships well. It is similar to the Stone in time of maturity, but usually produces heavier yields and more solid fruit. It is highly resistant to tomato wilt (*Fusarium lycopersici*) and possesses a little resistance to tomato leaf-spot (*Septoria lycopersici*). It has frequently been commended by growers for resistance to drought, but its apparent drought resistance is probably due largely to its resistance to wilt.

It is an excellent tomato for canning, for home gardening, and for late trucking, as it not only produces an excellent crop of fruit, but begins to ripen about midseason and continues to bear heavily until killed by frost.

Variety, very productive, late, highly resistant to tomato wilt (*Fusarium lycopersici*) and somewhat resistant to leaf-spot (*Septoria lycopersici*).

Plant large, erect, vigorous; branches many, long, stout; internodes long.

Foliage type, standard; leaves large, smooth, dark green, deeply divided, shading the fruit.

Flowers large; fruit clusters small, many, scattered.

Fruit large, smooth, oblate, bright red, very solid, comparatively free from cracks; stem-end cavity shallow, smooth to smooth ribbed; blossom-end basin medium small, shallow; stylar scar small, circular to linear; skin thin; vertical section medium long, oval; cross section round to oval, smooth; walls thick, firm, juicy, evenly colored; cells many, small, irregular, well filled; seeds few, medium large; pulp thick; core not defined; flavor pleasantly acid.

SUMMARY.

Tomato wilt (*Fusarium lycopersici*) causes in the United States an annual loss of more than 115,000 tons of tomatoes. By the use of wilt-resistant varieties this loss can be overcome at the mere expense of handling the extra crop.

Three varieties of tomatoes developed by the writer and one developed by Mr. J. B. S. Norton and the writer produce heavy crops of excellent fruit on land so heavily infected by wilt that ordinary tomatoes can not be grown on it. They are selections from the Greater Baltimore, Stone, and Merveille des Marchés (Marvel of the Market), three of the best commercial varieties of tomatoes grown, and possess in addition to wilt resistance all the good qualities of their parent varieties. Moreover, extensive field tests have shown

them to be well adapted to all parts of the United States in which tomato wilt is present.

Very few commercial varieties possess appreciable resistance to wilt. The Duke of York and the Buckeye State, apparently one variety under two names, are highly resistant, but they produce poor fruit. Livingston's Globe is somewhat resistant, but its purple fruit is objectionable to canners and is not in universal favor in other markets. Moreover, it is very susceptible to nail-head rust, a destructive disease prevalent in the South, where this variety is most commonly grown.

Varieties that normally produce a heavy crop of excellent fruit and vary considerably in the degree of wilt resistance possessed by their individual plants afford the best material for the development of superior wilt-resistant varieties by selection. Although such varieties may be very susceptible to wilt, they are nevertheless valuable if they produce occasional resistant plants, as such plants are usually much better material than selections from more resistant varieties that produce a poorer crop of fruit. Most varieties transmit approximately the same degree of wilt resistance to all their plants and consequently offer little opportunity for improvement by selection.

Tomato plants selected for wilt resistance usually transmit to their immediate offspring as much resistance as can be developed from them by subsequent selection. In a few instances increased resistance has been obtained in the second selection, but not in later selections. This may be due either to a limited response of the material to selection or to an obscuration of real differences by fluctuations.

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