

# A SURVEY OF THE RESISTANCE OF SUBSPECIES OF BRASSICA OLERACEA TO YELLOWS (FUSARIUM CONGLUTINANS)<sup>1</sup>

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## INTRODUCTION

The wild cabbage (*Brassica oleracea* L.) is a native of the Old World, where it is found on the sea cliffs of western and southern Europe. From this leafy biennial or its progenitor have been derived presumably the cabbage (*B. oleracea* var. *capitata* L.), kale and collard (*B. oleracea* var. *acephala* DC.), cauliflower and broccoli (*B. oleracea* var. *botrytis* L.), Brussels sprouts (*B. oleracea* var. *gemmifera* DC.), and kohlrabi (*B. oleracea* var. *caulo-rapa* DC.).<sup>2</sup> The organism (*Fusarium conglutinans* Woll.) causing yellows of this group of plants is apparently native to America and so far has not been reported from the Old World. Though first described as a disease of cabbage, it has been found on other forms of *B. oleracea*, and the data presented herewith show that the wild form and nearly all the varieties of the cultivated subspecies tested are more or less susceptible. Two reports of its occurrence on other species of Brassica have been made. According to Melhus,<sup>3</sup> Gilman found it upon the Chinese cabbage (*B. pekinensis* Rupr.) and Gregory reported it upon turnip (*B. rapa* L.).<sup>4</sup> The writers have never found it on the last two species, although they have included them in trials on infested soils where the disease developed abundantly on susceptible forms. The varieties of cabbage and its related forms have been developed largely in Europe out of contact with yellows and where natural or artificial selection for resistance through exposure to the disease could not have occurred.

The successful control of cabbage yellows has been based upon the fact that in every commercial variety so far tested at least a few individuals are highly resistant under field conditions. The selection of highly resistant strains from such individuals of several standard varieties has already been described.<sup>5 6</sup> Although none of

<sup>1</sup> Received for publication July 5, 1928; issued October, 1928. Cooperative investigations between the Office of Vegetable and Forage Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Department of Plant Pathology, University of Wisconsin.

<sup>2</sup> SINSKAJA, E. THE ORIGIN OF THE VARIETIES OF THE CABBAGE TRIBE AND THE BASIS OF THEIR CLASSIFICATION. Trudy Prikl. Bot. i Selekt. (Bul. Appl. Bot. and Plant Breeding) 17 (4): 351-390. 1927. [In Russian.]

<sup>3</sup> MELHUS, I. E., ERWIN, A. T., and VAN HALTERN, F. CABBAGE YELLOWS, CAUSED BY FUSARIUM CONGLUTINANS, IN IOWA. Iowa Agr. Expt. Sta. Bul. 235, p. 186-216, illus. 1926.

<sup>4</sup> GREGORY, C. T. CABBAGE YELLOWS. Purdue Agr. Ext. Bul. 104, 8 p., illus. 1922.

<sup>5</sup> JONES, L. R., and GILMAN, J. C. THE CONTROL OF CABBAGE YELLOWS THROUGH DISEASE RESISTANCE Wis. Agr. Expt. Sta. Research Bul. 38, 70 p., illus. 1915.

<sup>6</sup> WALKER, J. C., MONTEITH, J., Jr., and WELLMAN, F. L. DEVELOPMENT OF THREE MIDSEASON VARIETIES OF CABBAGE RESISTANT TO YELLOWS (FUSARIUM CONGLUTINANS WOLL.). Jour. Agr. Research 35: 785-809, illus. 1927.

the varieties popular in America seems to possess sufficient resistance in itself to be of commercial value for use on yellows-infested soil, no exhaustive study has been made of the degree of natural resistance, especially of varieties used commonly in Europe but seldom in America. The fact that Jones and Gilman<sup>7</sup> found two varieties, the Volga or Stonehead and the Houser, that possessed a marked degree of resistance leads one to expect that other such varieties might be found.

No previous study of the varietal differences in resistance among forms other than cabbage has been made. In connection with the program of selection of yellows-resistant varieties of cabbage it has been a matter of scientific and practical value to give some attention to the relative resistance not only among a larger number of cabbage varieties but also among the varieties of cabbage relatives. This paper is a report of such investigations, which have been under way since 1924.

#### METHODS

The method of testing was similar to that already described in connection with the trials of cabbage strains selected for resistance.<sup>8</sup> The test plot of soil, which is located in eastern Kenosha County, Wis., has become, through repeated cropping with cabbage, as uniformly and thoroughly infested with the yellows organism as possible under natural conditions. The seed was sown upon yellows-free soil about May 15, and the plants were transplanted to the infested soil during the first week of July. They were inspected several times during the season, and each plant that showed any sign of yellows was marked permanently with a bamboo stake. The symptoms of the disease on the cabbage relatives are so similar to those on cabbage that special description here seems unnecessary. As in cabbage, the severity of attack commonly varies among individuals of a given variety. Part of this variation may be due to environmental influences or variation in distribution of the pathogene, and part to hereditary differences, but these points can be settled only by further study. Some plants are killed rapidly; others are decidedly stunted, but not killed; others show very slight injury; and still others show traces of yellows in midseason on lower leaves that soon drop off, but mature with no apparent setbacks. From the practical standpoint one is interested in the total damage done by the disease, which obviously is not always truly represented when only the percentage of total plants showing yellows is given. At the end of the season, therefore, the affected plants were divided into two lots: (1) Those killed or severely injured, and (2) those showing only slight injury or apparently complete recovery.

The number of plants used for the test of a given variety was in some cases less than 25. This number may appear too small to compensate for variations in soil infestation. Larger trials and numerous replications are of course desirable, but time and space did not permit more extensive planting when so many lots were to be tested. Repeated use of the soil in question for similar purposes has given such consistent results that confidence in the reasonable accuracy of the method is sustained. Further weight is given the results by the repetition of many of the trials during two successive seasons.

<sup>7</sup> JONES, L. R., and GILMAN, J. C. Op. cit.

<sup>8</sup> WALKER, J. C., MONTEITH, J., Jr., and WELLMAN, F. L. Op. cit.

## RESULTS

## CULTIVATED CABBAGE

The results secured with cabbage varieties are divided into two groups, those used commonly in the United States and those used chiefly in Europe. In Table 1 is found, first, the behavior of four varieties of cabbage selected for resistance. It will be seen that little severe injury was noted, although a small percentage of each variety showed some evidence of the disease. Second, the results are given of tests with a number of lots of Volga or Stonehead and Houser, the two varieties earlier noted by Jones and Gilman<sup>9</sup> to possess some natural resistance. With the exception of one lot of Houser, all of these are fairly resistant, although less so than the varieties selected for resistance. Third, the reactions of a number of the varieties more commonly used in America are shown. All these, in contrast with the other two groups, are very susceptible and quite obviously of no value for use upon infested soil.

TABLE 1.—Comparative *Fusarium* resistance of a number of cabbage varieties commonly used in the United States, including varieties selected for resistance

Degree of resistance	Variety	1925 trials			1926 trials		
		Total number of plants	Plants dead or severely yellowed	Plants slightly yellowed or recovered	Total number of plants	Plants dead or severely yellowed	Plants slightly yellowed or recovered
Resistant (selected)	Wisconsin Hollander.....	100	1	6	25	0	20
	Wisconsin All Seasons.....	100	1	7	50	0	6
	Wisconsin Brunswick.....	50	0	16	25	0	16
	Maryland Flat Dutch.....	52	0	4	25	0	8
		25	16	36			
Moderately resistant (natural) <sup>a</sup>	Volga.....				24	8	33
					15	0	47
					23	13	13
					24	21	29
	Early Stonehead <sup>b</sup> .....				34	21	41
	Late Stonehead <sup>b</sup> .....						
		25	28	32			
	Houser.....				25	16	24
					24	54	21
					24	17	46
Susceptible	Jersey Wakefield.....	72	65	17			
	Charleston Wakefield.....	246	64	20			
	Copenhagen Market.....	251	78	9	44	73	0
	All Head Early.....	112	54	37	51	61	14
	Succession.....				192	51	27
	All Seasons.....				47	55	23
	Danish Ballhead.....	191	73	23	65	65	12
Haco (red).....	256	79	12	246	58	13	

<sup>a</sup> Samples of each from several sources.

<sup>b</sup> The Stonehead variety is very similar to if not identical with the Volga.

In Table 2 are given the data from trials of a number of varieties seldom used in America but commonly listed by seedsmen in one or another part of the Old World. Most of these varieties came from England and France but two came from Egypt. Most of them differ from the varieties in general use in America and in the north of Europe in that they produce loose rather than compact heads. The 1925 trials showed many of them to be very susceptible, and only those showing distinct resistance were tested again in 1926. They are

<sup>9</sup> JONES, L. R., and GILMAN, J. C. Op. cit.

grouped roughly into three lots. In the first group are those that are very susceptible and fall into a class with the average commercial variety used in America. In the second group are 12 varieties that are moderately resistant. Many of these compare favorably with the Houser and Volga varieties. In the third group are 7 varieties that are rather highly resistant and could be used with commercial success on infested soil. Though all are not quite in a class with the varieties selected for resistance (Table 1), St. Denis and Vaugirard d'Hiver compare very favorably with them. None of these varieties, however, are of the type suitable for culture in America.

The evidence is sufficient to show that there is a wide range of resistance among cabbage varieties that have been developed, so far as is known, out of contact with the yellows organism. If it is true that cultivated cabbage has evolved from the present known wild form without opportunity for natural selection for resistance to *Fusarium conglutinans*, the conditions found are what might be reasonably expected, since, as is shown later in this paper, the wild form is apparently heterozygous for the resistance character. It is perhaps a mere coincidence that those cultivated varieties of cabbage that became popular in American culture were of the very susceptible sorts, while certain others that might have been introduced except for other undesirable features would not have been jeopardized by yellows.

TABLE 2.—Comparative *Fusarium* resistance of a number of cabbage varieties in general use in the Old World but seldom grown in the United States

Degree of resistance	Variety	Source of seed	1925 trials			1926 trials		
			Total number of plants	Plants dead or severely yellowed	Plants slightly yellowed or recovered	Total number of plants	Plants dead or severely yellowed	Plants slightly yellowed or recovered
				Per cent	Per cent		Per cent	Per cent
Very susceptible.	Joanet Hatif	France	24	88	0			
	All Heart	England	24	63	4			
	Offenham	do	25	60	0			
	Express	do	25	52	28			
	Late Drumhead Savoy	do	25	52	20			
	Etamps	France	25	52	12			
	Charentais Tardif	do	24	50	29			
	Blanc d'Hiver	do	24	50	17			
	Milan Cressonier	do	25	48	40			
	Joanet Gros	do	25	48	8			
	Flower of Spring	England	24	42	21			
	Coeur de Boeuf de Jersey	France	25	36	32			
Moderately resistant.	Bacalan Hatif	do	26	35	15	28	29	18
	Dax	do	25	32	20			
	Sultani	Egypt	24	29	21			
	Christmas Drumhead	England	21	29	14	24	0	50
	Auvergne	France	24	25	33			
	Earliest of All	England	25	24	16	15	0	0
	Quintal	France	25	24	20			
	Amchiri	Egypt	23	22	0	20	20	10
	Habas	France	25	16	28	21	5	52
	York	do	25	4	12	21	19	14
	Fumel	do	25	12	12	24	21	29
	Imperial	England	25	8	28	24	8	42
Rather highly resistant.	Coeur de Boeuf Gros	France	25	8	8	12	8	25
	Pisé	do	25	4	28	14	0	7
	Quintal d'Alsace	do	24	4	21	25	0	12
	Bacalan Gros	do	24	4	17	23	0	9
	St. Denis	do	24	4	0	24	8	8
Vaugirard d'Hiver	do	25	0	0	22	5	0	

## WILD CABBAGE

A small quantity of seed of wild cabbage was secured from Sutton & Sons, Reading, England. The first trial was made in 1924 on naturally infested soil. Of the 17 plants grown, 1 showed slight symptoms of yellows. Seed was obtained in the greenhouse the following winter from 3 of the surviving plants, each of which was self-pollinated. The strains thus secured were labeled WC-1s, WC-2s, WC-3s. Results of trials with these lots in 1926 and 1927 are given in Table 3. It is evident that most of these progenies exhibited a fair degree of resistance to yellows and that they were



FIG. 1.—Cabbage and related forms growing on soil thoroughly infested with the yellows organism, Kenosha County, Wis. Photographed September 6, 1927. The bamboo stakes were used to mark each plant as the disease appeared. A, Danish Bailhead cabbage which showed 95 per cent total infection and 68 per cent killed or severely diseased; B, Hartman's Special cauliflower which showed 21 per cent infection but only 6 per cent dead or severely diseased; C, Large White Mammoth broccoli which showed 18 per cent infection, in all cases very slight; D, Improved Danish Brussels sprouts which showed 28 per cent infection, though only 10 per cent were severely affected. See further data in Table 3 and in text

more resistant than the average variety of cultivated cabbage. These data should be compared with those secured from the varieties of cultivated forms.

## RELATIVES OF CULTIVATED CABBAGE

Some preliminary tests were made with cabbage relatives in 1924 and 1925. Only a few varieties were used, and the data collected are not included, since they are confirmed by the more extensive trials of

1926 and 1927. It was noted during the first two seasons that cauliflower, broccoli, and Brussels sprouts were distinctly more resistant than most cabbage varieties, while kohlrabi, collard, and kale, with the exception of Siberian kale, which was highly resistant, showed varying degrees of susceptibility. The trials of 1926 and 1927 gave opportunity for more extensive analyses. A portion of the 1927 trial plot is shown in Figure 1.

TABLE 3.—Comparative *Fusarium* resistance of varieties of the cultivated and the wild forms of *Brassica oleracea*

Common name	Subspecies	Variety or strain	1926 trials			1927 trials		
			Total number of plants	Plants dead or severely yellowed	Plants slightly yellowed or recovered	Total number of plants	Plants dead or severely yellowed	Plants slightly yellowed or recovered
Cabbage	Capitata	{Copenhagen Market <sup>a</sup> .....	44	73	0	149	36	52
		{Hollander <sup>a</sup> .....	65	65	12	104	68	27
		{Wisconsin All Seasons <sup>b</sup> .....	49	0	6	100	0	6
Wild cabbage	Sylvestris	{WC-1s.....	23	0	26	20	25	10
		{WC-2s.....	8	13	0	18	17	17
		{WC-3s.....	25	4	12	60	8	7
Kale	Acephala	{Tall Green Curled.....	21	33	67	73	27	45
		{Dwarf Green Curled.....	25	60	40	46	67	33
		{Excelsior Moss Curled.....	20	25	75	50	36	44
		{Thousand-Headed.....	23	13	26	50	14	2
		{Mosbach Winter.....	17	18	29	50	40	22
		{Siberian.....	24	0	8	75	0	3
Collard	do	{North Carolina Short Stem.....	21	14	24	50	22	10
		{White or Cabbage.....	24	13	42	49	8	6
Kohl-rabi	Caulo-rapa	{True Georgia.....	25	24	20	50	14	10
		{Short Top Early Erfurt.....	17	65	24	50	36	32
		{Early Purple Vienna.....	20	40	50	50	40	16
		{White Vienna.....	24	38	33	35	20	3
		{White Goliath.....	21	33	52	40	15	25
		{Improved Danish.....	23	0	35	49	10	18
Brussels sprouts	Gemmifera	{Paris Market.....	20	0	50	50	2	18
		{Dwarf Improved.....	18	0	28	49	2	10
		{Improved Long Island.....	26	4	27	50	2	2
		{Paris Half Dwarf.....	25	0	40	-----	-----	-----
		{Amager Market.....	19	0	32	-----	-----	-----
		{Hartman's Special.....	21	0	52	50	6	15
Cauliflower	Botrytis	{Vaughan's New Snowball.....	23	30	30	23	4	30
		{Danish Snowball.....	24	50	38	47	15	36
		{Vaughan's Snowball.....	35	11	63	23	0	39
		{Wieboldt's Express.....	23	13	43	47	6	64
		{Extra Early Paris.....	20	5	85	25	4	76
		{Half Early Paris.....	25	12	52	25	24	48
		{Extra Early or Second Erfurt.....	24	33	42	50	8	68
		{Large Early Erfurt.....	25	16	56	23	4	61
		{Le Normand's Short Stem.....	25	12	76	25	4	44
		{Dry Weather.....	22	14	55	25	0	36
Broccoli	do	{Danish Perfection.....	22	23	45	-----	-----	-----
		{Autumn Giant.....	21	0	0	49	2	10
		{Purple Cape.....	23	0	13	26	4	4
		{Large White Mammoth.....	25	12	76	55	0	18
		{Early Large White French White Cape.....	25	0	0	-----	-----	-----

<sup>a</sup> Susceptible.

<sup>b</sup> Resistant.

The results of trials with six varieties of Brussels sprouts are given in Table 3. It should be noted that very few plants were severely affected with yellows, although an appreciable number of each variety showed slight symptoms. The damage was of minor consequence from the commercial standpoint. It is evident that any of these

strains could be grown upon thoroughly infested soil with confidence in their successful evasion of the disease. This subspecies is the most uniformly resistant of any of the groups studied.

Cauliflower varieties were, as a rule, distinctly resistant to yellows, though not generally to such a high degree as Brussels sprouts. It will be seen from the data in Table 3 that in most varieties tested a comparatively large percentage of the plants showed evidence of the disease. The important distinction to be noted is that a large portion of the affected plants were only slightly attacked, and in many cases the actual damage to a variety as a whole was relatively small. (Fig. 1.) But here again, as in cabbage, varieties differ widely in their reactions. It is of interest to note particularly the wide variation among the different strains of Snowball. Undue reliance should not be placed upon a single test for a given variety, for there might exist numerous strains of that form which vary considerably in resistance. As the practical need for resistant strains of cauliflower arises, advantage should be taken of the natural yellows resistance both for its value in meeting needs temporarily and as a basis for further improvement.

Broccoli, which is very closely related to the cauliflower, probably less often encounters yellows, as it is most commonly grown as a winter crop. Curiously, however, all four varieties tested are highly resistant to *Fusarium conglutinans*, and there will probably be little need for their further improvement in this respect.

Many varieties of kale have come into use and are widely grown. Only a few of those most common in America were tested. It was found (Table 3) that the curly-leaved varieties were decidedly susceptible. The smoother leaf types such as Thousand-Headed and Mosbach Winter were on the whole more resistant, and the Siberian was very resistant. The collards are closely related to the smooth-leaved kales and are especially popular in the southern part of the United States. They were susceptible to about the same degree as Thousand-Headed and Mosbach Winter kales. Thus, as in the forms previously considered, there is considerable variation in resistance within this subspecies. The smooth-leaved forms were only moderately damaged on infested soil under conditions favorable for the disease, while curly-leaved varieties were so affected that their commercial value was seriously impaired. In any of the smooth-leaved varieties considered except Siberian there is ample opportunity to develop more highly resistant strains through selection. In the curly-leaved forms the possibility of finding resistant individuals for selection is not so certain, but in spite of the fact that all three of these varieties showed 100 per cent yellows in the 1926 trials, a few plants were resistant in two of the varieties in 1927.

Kohl-rabi appears to be the most generally susceptible subspecies with the exception of cabbage. (Table 3.) All four varieties tested were severely attacked. From their behavior it is evident that they can not be safely used on thoroughly infested soil during the season favorable for the development of yellows. Further search might possibly reveal more naturally resistant strains. On the other hand, it is evident that the way is open for improvement in resistance through selection from any of these commercial varieties by methods already shown to be successful with cabbage.

## DISCUSSION

*Brassica oleracea* is interesting for study of the variation in resistance to *Fusarium conglutinans* among its cultivated subspecies and varieties. Whether or not the present wild form of Europe is the progenitor of our cultivated forms or whether it also has evolved from some common ancestor is problematical. The wild form of cabbage as we now know it, when tested on soil infested with *F. conglutinans*, shows a high degree of resistance, but a study of the progeny of individual plants shows them to be segregating in this character. In fact, of 154 plants tested from three selfed progenies, 33 became diseased, showing a segregation reasonably close to 3 resistant to 1 susceptible. This is in accordance with previous findings in the case of cultivated cabbage, where resistance behaves as a single dominant Mendelian character.<sup>10</sup>

The apparent absence of the *Fusarium* disease in Europe, even in regions climatically favorable for its development, seems to substantiate the belief that the parasite is of American origin. The development of the subspecies of *Brassica oleracea* now known and their further segregation into numerous varieties under cultivation have thus gone on out of contact with this disease. If the yellows organism had been present and active it is not unlikely that natural elimination of susceptible individuals of this species, which normally is cross-pollinated, would by this time have resulted in quite general resistance. On the contrary, the state of affairs that did actually exist would naturally lead to no uniformity in resistance. Chance might result in certain varieties becoming highly resistant and in others becoming very susceptible.

The data that have been presented show this to be the case. The cabbage varieties range from the highly resistant types such as St. Denis and Vaugirard d'Hiver to the very susceptible forms such as Danish Ballhead. In kale the very resistant Siberian stands at one extreme and the susceptible moss-curl types at the other. All Brussels sprouts varieties tested are highly resistant, while all kohlrabi forms examined are very susceptible. Out of this whole series, however, the important fact is revealed that no variety tested, with the possible exception of one of the moss-curl kales, appeared to be homozygous in the susceptible character. Thus since resistant individuals occur the opportunity exists to improve by selection any given variety in this respect, as has been already amply demonstrated with cabbage.

The observations here reported are not intended as a final statement of the comparative behavior of the subspecies and varieties mentioned. Since the tests were made in a single locality, the results must be taken only as an indication of the relative resistance of the varieties used. However, experience with resistant strains of cabbage has led to the conclusion that the tests thus employed give a fair index to behavior to be expected in other localities, granted the general assumption that the rise in the average temperature may be expected to increase the incidence of yellows. Variation with locality in the pathogene leading to selective pathogenicity has not yet come to the attention of the writers, but should be constantly watched for as a possible complicating factor.

<sup>10</sup> WALKER, J. C. STUDIES UPON THE INHERITANCE OF FUSARIUM-RESISTANCE IN CABBAGE. (Abstract) *Phytopathology* 16: 87. 1926.



## SUMMARY

A survey was made of the behavior of wild cabbage and a number of varieties of the cultivated subspecies of *Brassica oleracea* when grown upon soil infested with *Fusarium conglutinans*.

Although most cabbage varieties commonly used in America are very susceptible to yellows, various degrees of resistance were found when a number of European varieties not ordinarily used in America were tested.

The wild cabbage of Europe was highly resistant, but selfed progenies from individual plants showed about one-fourth of the plants diseased.

Brussels sprouts and broccoli varieties, though showing a considerable number of plants slightly affected, were not seriously damaged by yellows.

Cauliflower varieties varied somewhat in reaction, but in general they were damaged to a greater degree than broccoli or Brussels sprouts.

The kale varieties differed widely in susceptibility. The Siberian kale was very resistant, while the curled-leaf types were very susceptible. The smooth-leaf varieties and the collards occupied an intermediate position.

The kohl-rabi varieties were all very susceptible.

Within all of the forms tested a sufficient number of individuals survived to make it possible to improve their resistance through selection.

