UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1046

Contribution from the Bureau of Plant Industry, WM. A. TAYLOR, Chief, in cooperation with the Kansas Agricultural Experiment Station

Washington, D. C. ▼ May, 1922

RUST RESISTANCE IN WINTER-WHEAT VARIETIES

By

LEO E. MELCHERS, Plant Pathologist, and JOHN H. PARKER, in Charge of Crop Improvement, Kansas Agricultural Experiment Station; Agents, Office of Cereal Investigations

CONTENTS

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RUST RESISTANCE IN WINTER-WHEAT VARIETIES.[1]

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CONTENTS.

SCOPE OF THE INVESTIGATION.

A project to determine the rust resistance of existing varieties of winter wheats and to breed new varieties for rust resistance was begun in 1911 at the Kansas Agricultural Experiment Station, in cooperation with the Office of Cereal Investigations of the United States Department of Agriculture. The first two years were devoted to preparatory work, when no infection of stem rust was produced. The writers [2] took charge of the work in 1913, and the data given herein are those obtained since that time.

The investigation outlined in 1913 had two major purposes: (1) To study the rust resistance of about 130 varieties and strains of winter and spring wheats, particularly to the stem rust, *Puccinia graminis tritici* Erikss. and Henn.,[3] in the field and in the greenhouse; and (2) to study the inheritance of rust resistance in wheat and to produce hybrids adapted to commercial use.

[1] Paper No. 183 of the Department of Botany and Plant Pathology and No. 136 of the Department of Agronomy, Kansas Agricultural Experiment Station.

[2] The writers wish to acknowledge their indebtedness to Mr. Victor H. Florell and Mr. M. N. Levine, of the Office of Cereal Investigations, who assisted in the greenhouse studies and in other phases of the investigation.

[3] *Puccinia graminis tritici*, as used in this bulletin, has reference to those strains of stem rust used in the experiments in 1915, 1916, and 1917. In 1915 a strain was used to which Kanred, P1066, and P1068 were only partially resistant, while in 1916 and 1917 strains were used to which these varieties were very resistant. The strains used in 1916 and 1917 may have been one or more of the several strains which at present are known not to cause normal infection of these varieties.

Climatic conditions at Manhattan, Kans., are generally unfavorable for the development and spread of the stem rust of wheat; the development of a suitable technique for the production of severe epidemics in the rust nursery was therefore an essential part of these investigations.

Special attention was given to those varieties which are most promising agronomically.

If a variety of hard red winter wheat could be found which was resistant to stem rust and suitable for Kansas conditions, breeding for rust resistance would be much simpler than if it becomes necessary to cross with varieties of the durum or emmer groups.

Hayes, Parker, and Kurtzweil (*13*)[4] recently have found that "there is an indication of linkage of durum or emmer characters and rust resistance, since the production of rust-resistant durums or emmers in the F_2 and F_3 generations is comparatively easy and the production of resistant common wheats much more difficult." Moreover, the only known rust-resistant varieties of the emmer or durum groups are spring forms, a fact which complicates the task of obtaining a rust-resistant winter wheat from such a cross. Winter hardiness, high yield, and good milling quality also are essential for the success of any variety of wheat in Kansas, which increased the complexity and difficulty of the problem. To obtain accurate information as to the resistance of existing varieties of winter wheat was, therefore, the first important step.

REVIEW OF THE LITERATURE.

Differences in the resistance of wheat varieties to rust were known to exist as early as 1841, when Henslow (*15*) observed that some wheats were injured less by rust than others. La Cour (*23*) and Little (*26*) made similar observations. Bolley (*3*) noted that hardy and stiff-stemmed varieties with smooth, fibrous leaves seem to resist rust for a longer time. Anderson (*1*) observed that hard, flinty wheats are more resistant than others, believing that this might be due to a larger proportion of silica in the plant. Cobb and Farrer (*35*) and Farrer (*35*) found that wheat varieties resist leaf rusts and stem rusts in different degrees. Hitchcock and Carleton (*16*) state that hard varieties of wheat suffer least from rust in Kansas and early varieties are likely to mature before being seriously injured. Henning (*14*) and Eriksson and Henning (*11*) found that certain wheat varieties resisted different kinds of cereal rusts.

It has long been known that some of the emmers (*Triticum dicoccum*) and certain varieties of durum wheat (*Triticum durum*) show marked resistance to stem rust. Carleton and Chamberlain (*9*) and Carleton (*8*) called attention to this in connection with the com-

[4] The serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

mercial value of the durums. Carleton (*8*), in discussing the stem-rust epidemic on wheat in 1904, observed that no wheat varieties, with the exception of einkorn and some of the durums, spelts, and emmers, showed marked resistance under all conditions. He stated further, that during ordinary seasons when stem rust may be quite prevalent the hard-kerneled Russian winter wheats are considerably more resistant to rust than other varieties ordinarily grown.

Bolley (*4*, *5*), Biffen (*2*), and Nilsson-Ehle (*33*) were among the first to conduct wheat-breeding experiments with the definite object of obtaining rust-resistant varieties. No definite plan or method of study, however, was described until Johnson (*20*) explained the methods used for producing an artificial rust epidemic in Minnesota and furnished a working basis for the studies which have been made since in this country in breeding cereals for rust resistance. These methods are further described by Freeman and Johnson (*12*). They state that certain varieties, such as Extra Squarehead in Sweden, American Club in England, and Rerrarf and Ward's Prolific in Australia, have been shown to be resistant to rust. They add, however, that some of these varieties can not be said to be universally rust resistant, as their behavior in different countries to different biologic forms of rust is variable.

Field experiments have verified early observations that some of the durums and emmers are much more resistant than the common spring-wheat varieties. Stakman (*37*) found this to be true in both field and greenhouse experiments. Melchers and Parker (*29*, *31*) recently have called attention to the resistance of three winter-wheat varieties to stem rust and leaf rust. Waldron and Clark (*42*) have described a variety of common wheat named Kota and stated that it was resistant to the strain or strains of stem rust prevalent at Fargo, N. Dak., Brookings, S. Dak., and St. Paul, Minn., in 1918. These authors state that "this resistance is decidedly greater than that possessed by the common spring wheats and second only to the more resistant durum wheats." Clark, Martin, and Smith (*10*) speak of the rust behavior of varieties of durum and common wheat grown during the seasons of 1914 to 1919 at several field stations in the northern Great Plains. They state that none of the varieties of common wheat grown is really rust resistant, but early-maturing varieties have ripened before the rust has developed extensively and are sometimes rust escaping. Most varieties of durum wheats are more or less rust resistant, as compared with common wheats. Acme, Monad, and D–5 are known to be especially rust resistant. In years of heavy rust infection these varieties have produced the highest yields. When grown under comparable conditions in these and other experiments, the D–5 variety shows the greatest resistance of all varieties to stem rust.

NURSERY EXPERIMENTS.

METHODS AND MATERIALS.

Because of the infrequent occurrence of natural epidemics of stem rust under Kansas conditions,[5] it was necessary to study varietal resistance in a rust nursery (Pl. I, figures 1 and 2), following the general plan suggested by Johnson (*20*). This rust nursery was located near Manhattan, Kans., on land which is low and slopes slightly toward the south and west. Along the south side of the nursery is a hedge of common barberry bushes (Pl. I, fig. 2). A large drainage ditch on the south side carried off the surplus water. Because of the likelihood of frequent heavy rains during the crop season, the rust nursery was sown in slightly elevated plats, separated by depressed alleys, which received the surplus water and carried it into the main ditch. The rust nursery has been sown in various ways. At first a plat 1 rod square was used for each variety, but it was found impossible to produce severe epidemics of stem rust on large areas under Kansas conditions. The plats, therefore, were reduced to a single rod row and in 1915 to 5-foot nursery rows spaced 10 inches apart. The seeds are sown 3 inches apart in the row. A small hand plow was used for opening a furrow and a seeding board with notches at regular intervals served to obtain uniformity in spacing the seed.

The spring varieties generally were sown during the last week in March or the first week in April in rows close to the winter-wheat rust nursery.

The rust used in these experiments up to and including 1917 was obtained from the Minnesota Agricultural Experiment Station. In 1914, 1915, and 1916 the urediniospores came from greenhouse cultures of *Puccinia graminis tritici*, but in the fall of 1917 cultures were used from rusted wheat plants obtained in the field. These were found later to be a new strain of stem rust (*30*). The stock cultures of rust which were used in these field experiments were cultured on Improved Turkey (Kansas No. 2382), a variety which has been found in these experiments to be very susceptible to stem rust. When the leaves produced uredinia which were sporulating abundantly they were used in one of two ways: (1) The leaves were clipped from the plants, placed in a few quarts of water, the urediniospores removed, and the liquid used as a spray on the wheat plants in the rust nursery, or (2) the potted wheat plants bearing uredinia were used as centers of infection in the nursery.

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[5] The only natural epidemic known to the writers occurred in 1904. In 1915 and 1916 stem rust was very prevalent in many fields in Kansas and in some instances there was an appreciable loss. In 1919 stem rust was uniformly present in eastern and central Kansas, and although it was difficult to estimate the actual injury caused by stem rust it was one of several factors which reduced the yield and quality of wheat.

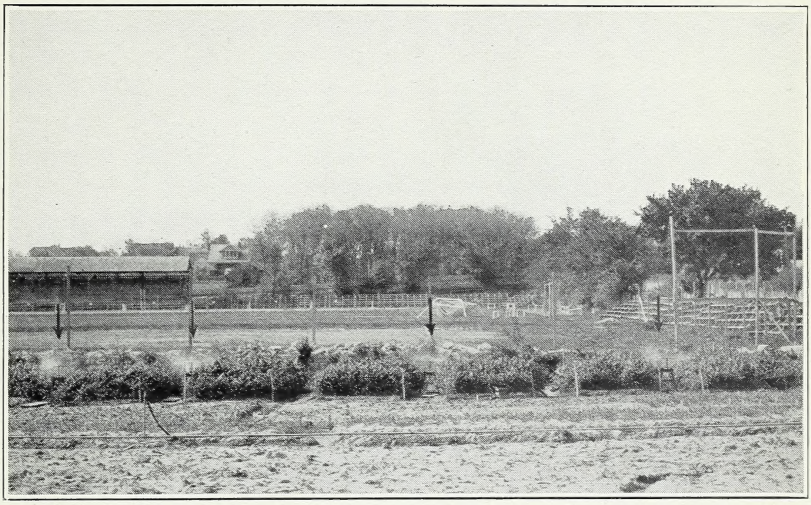


FIG. 1.—GENERAL VIEW OF THE WHEAT-RUST NURSERY.

The investigation of the comparative rust resistance of varieties of wheat at the Kansas Agricultural Experiment Station was conducted here. The arrows indicate the location of rotary sprayers.

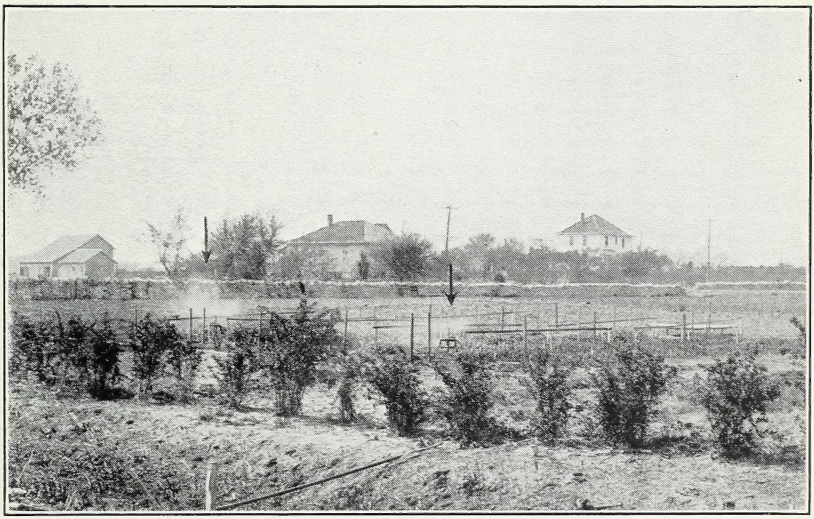


FIG. 2.—ROW OF BARBERRY BUSHES ADJACENT TO THE WHEAT-RUST NURSERY.

Each arrow indicates the location of a rotary sprayer.

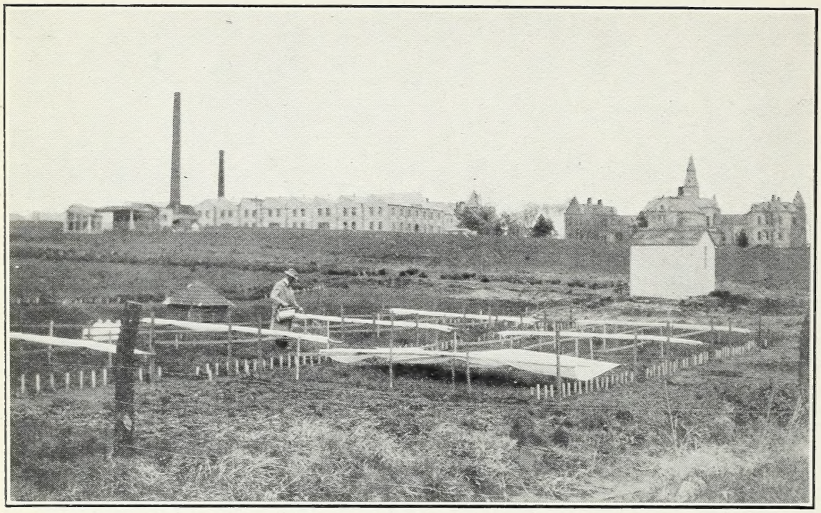


FIG. 1.—REMOVABLE CANVAS COVERS USED IN THE WHEAT-RUST NURSERY TO RETAIN MOISTURE.

A urediniospore sprayer is shown in operation.

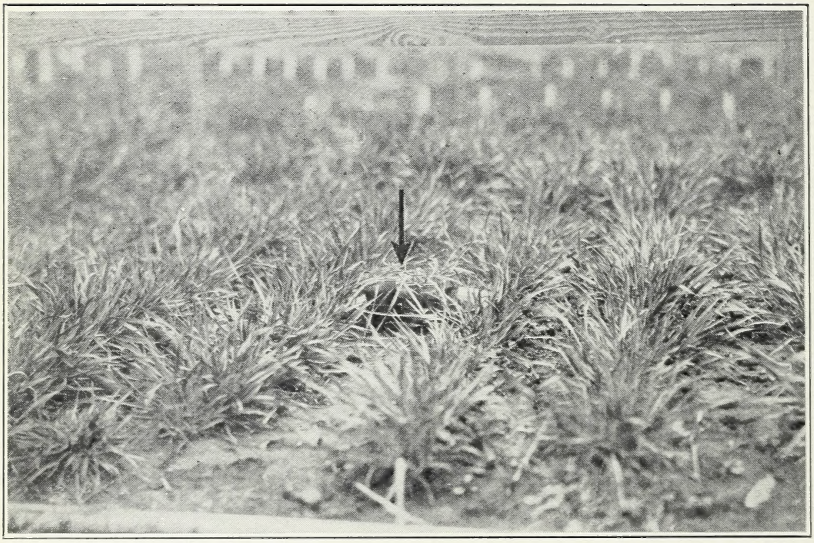


FIG. 2.—POT CONTAINING RUSTED SEEDLINGS FROM THE GREENHOUSE.

Used in establishing infection centers in the wheat-rust nursery.

When sprays of urediniospore decoction were used in the study at Manhattan, Kas., a small knapsack pressure sprayer was employed. All sprays were applied in the evening; if possible during periods of moist, cloudy weather. The plants were first sprayed with water and then with the urediniospore spray. Sprays of urediniospores were found to be unreliable, however, because of the hot dry winds which frequently occur in Kansas during the late spring and early summer. In order partially to overcome this difficulty, removable canvas covers were placed over a wooden framework which was built over the plats. These covers were used the day following the urediniospore sprays and aided materially in retaining moisture. They were easily handled by one man, being unrolled from a long strip of wood and drawn over the nursery plats, to be fastened at the corners as shown in Plate II, figure 1.

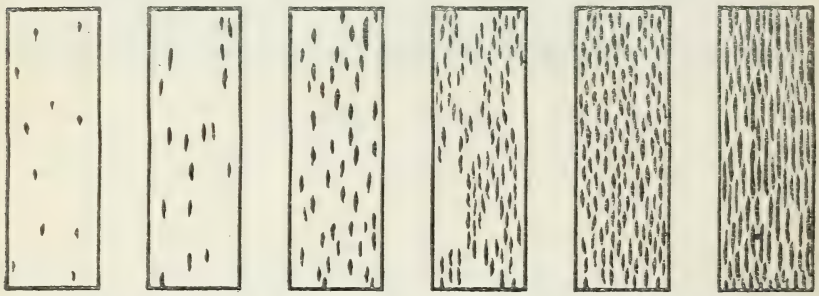
Several attempts have been made to inoculate plants in the rust nursery in the fall. Not only was it difficult to obtain satisfactory infection, but it was of doubtful value in view of the fact that it is questionable whether stem rust lives over winter in Kansas to any great extent (*17*).

On account of the unsatisfactory results obtained with the urediniospore sprays, the infection-center method of obtaining an epidemic was tried. This method is somewhat similar to inoculating plants in the field, but it is much simpler and more certain to give satisfactory results. The inoculated seedlings are carried from the greenhouse to the plats, where they spread the infection. Numerous infection centers were located in each plat, so as to provide ample spore material (Pl. II, fig. 2).

Most of the rust cultures for these experiments were grown on seedlings in 2½-inch flowerpots, two seedlings in each pot. Frequently 4-inch pots were used, as they held more seedlings and did not dry out so rapidly. It was found that if small galvanized-iron pans were placed between the rows of wheat in the rust nursery early in the spring and filled with pots of inoculated seedlings, a most successful center of infection could be established. (Pl. II, fig. 2). The pans were kept filled with water at all times.

As soon as the seedlings died or the rusted leaves no longer produced urediniospores, the pots were replaced with a new set. In this manner the wheat plats were continually exposed to rust infection. It recently has been found that if plants in the heading stage are inoculated in the greenhouse and used in place of seedlings for the centers of infection, their usefulness in the field continues longer than that of seedling plants; hence, they are much more satisfactory. It was found also that wherever the centers of infection were located the rust obtained a start and spread rapidly from the centers to all adjacent plants.

In 1914 only two urediniospore sprays were applied, one on April 19 and the other on May 23. Neither of these sprays was followed by any noticeable rust infection. Canvas covers were not used. In 1915 urediniospore sprays were given on April 20, 21, 27, and 29, and on May 7, 10, 20, 22, and 31. Inoculated seedlings were transplanted into the soil in vacant rows, which were left for that purpose, this being the first attempt to use the infection-center method. Canvas covers were used and a severe epidemic was caused, as shown by the data on rust infection. In 1916 urediniospore sprays were given on April 6, 13, 14, 20, 25, 26, and 29, and on May 1, 4, 16, 19, and 27. Canvas covers were used. In addition to these sprays the infection-center method was employed. A severe epidemic resulted. In 1917 sprays of urediniospores were given on May 23 and 29, and on June 6. A few hand inoculations in the field were made in the spring, but the efforts were mostly directed toward establishing in-



A, 5 per cent. B, 10 per cent. C, 25 per cent. D, 40 per cent. E, 65 per cent. F, 100 per cent.

FIG. 1.—Scale for estimating rust, illustrating six degrees of rustiness used in estimating the percentage of stem-rust infection. The shaded spots represent rust, and the figures represent approximately the rust percentages computed on the basis of the maximum of surfaces covered by rust as shown in the 100 per cent figure (F). Figure F in the diagram represents 37 per cent of actual rust-covered surface and is arbitrarily selected as 100 per cent. The other percentages are in terms of figure F.

fection centers. It was evident from the results obtained that the latter method was sufficiently dependable to warrant the discontinuance of urediniospore sprays.

The common barberry (*Berberis vulgaris* L.; see Pl. I, fig. 2), planted south of the rust nursery plats, furnished some æcial infection in 1915, 1916, and 1917. Straw, bearing telia of stem rust, was placed around each shrub in the fall, so as to provide the necessary teliospore material to infect the barberry leaves in the spring.

The final field notes were taken during the latter part of June or early in July, at the time the nursery was harvested. These included the percentage of stem rust, estimated in accordance with the scale shown in figure 1 and used by the Office of Cereal Investigations of the Bureau of Plant Industry, United States Department of Agriculture. Notes on the type of head, plumpness of grain, and other characters also were recorded.

The varieties grown in the rust nursery included the commonly grown hard red winter wheats of the Crimean group, such as Turkey and Kharkof, and the varieties of soft red winter wheat grown in eastern Kansas and other soft red winter-wheat districts. Some of the varieties were obtained from the Office of Cereal Investigations of the Bureau of Plant Industry and others from the agricultural experiment stations of other States. The strains grown under a pedigree number, and so designated in Table 1, represent pure-line selections made by Prof. H. F. Roberts, formerly of the department of botany, Kansas Agricultural Experiment Station. These strains were turned over to the department of agronomy in 1910, and seed was obtained from that department when the study of wheat varieties for rust resistance was begun. Not all the varieties have been grown throughout the period of experiment, because some of them were found to be of little or no agronomic value. Some were shown to be extremely susceptible to stem rust, and others were eliminated because of complete winter killing. A small number of spring-wheat varieties were grown, to obtain comparative data on rust infection.

BREEDING PLAT.

Certain varieties of spring and winter wheats were grown in a breeding plat each year to serve as material for crossing. The winter-wheat varieties were sown in the fall at the time the varieties were sown in the rust nursery. Considerable space was left between the rows of winter wheat, to allow for seeding spring wheats for crossing. Occasionally a few of the spring varieties bloomed at the same time as the winter wheats, thereby simplifying the work of making the crosses. Generally, however, it was necessary to sow such spring varieties in the greenhouse about the first of February. These were transplanted to the breeding nursery in April and May, thus providing some of the spring-wheat plants, which were in flower at the same time as the winter varieties.

Crosses have been made between Kanred (Kansas No. 2401), Kansas No. 2414, and Kansas No. 2415,[6] three closely related winter-wheat varieties which are resistant to leaf rust (*31*) and to certain strains of stem rust (*29*, *30*); also between Marquis, Haynes Bluestem, and Preston, varieties of spring wheat which are susceptible to stem rust. The F_1, F_2, and F_3 generations have been grown to maturity, and data on the inheritance of resistance to stem rust (*Puccinia graminins tritici*) have been obtained. These results, however, are not presented in this bulletin.

[6] These varieties have been known as P762, P1068, and P1066, respectively. They have recently been given Cereal Investigations numbers as follows: C. I. 5146, C. I. 5879, and C. I. 5880, respectively.

RESULTS OF THE NURSERY EXPERIMENTS.

The percentage of stem rust found on the varieties grown in 1915, 1916, and 1917 and the 3-year average for all varieties grown in all three seasons are shown in Table 1. Notes on the quality of grain also are given for the years 1916 and 1917.

The varieties are arranged according to type and are grouped as to the characters, winter or spring, awned or awnless, glabrous or pubescent glumes, and soft or semihard to hard kernel. All of the winter-wheat varieties with the exception of Binkel Club are common wheats (*Triticum vulgare*). The spring grains include varieties of common wheat, as well as durum wheat (*T. durum*), emmer (*T. dicoccum*), and einkorn (*T. monococcum*).

The "Identification numbers" include the "Pedigree number," as used by Prof. H. F. Roberts; the "Kansas number," which is an accession number assigned by the department of agronomy; and the C. I. number, used by the Office of Cereal Investigations of the Bureau of Plant Industry.

TABLE 1.—*Stem-rust infection of wheat varieties after artificial inoculation in the nursery at Manhattan, Kans., in the years 1915, 1916, and 1917, together with data on kernel quality in 1916 and 1917.*

[KEY TO SYMBOLS.—*Identification numbers* (columns 1 and 3): C. I.=Cereal Investigations, H=hybrid, K=Kansas, P=pedigree. *Rust infection* (columns 5 to 7): T=trace, Wk=winterkilled. *Quality of kernels* (columns 9 and 10): E=excellent, F=fair, F−=poor to fair, F+=a grade better than fair, F±=variable quality (some poor to fair, some fair to good), G=good, G−=a grade poorer than good, G+=a grade better than good, G±=variable quality (some fair to good, some good to excellent), P=poor, Vp=very poor.]

Group 1.—AWNED, GLUMES GLABROUS, KERNEL SEMIHARD TO HARD.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection (per cent).				Quality of kernels.	
				1915	1916	1917	3-year average.	1916	1917
1	2	3	4	5	6	7	8	9	10
WINTER VARIETIES.									
Common wheats:				*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
P647	2356	.....	Japan	40	55	Wk	.....	F+	.....
P651	2357	.....	Russian	25	68	Wk	.....	F+	.....
P675	2368	.....	Red Winter Java	25	70	Wk	.....	F±	.....
P678	2370	.....	do	50	75−	Wk	.....	F	.....
P693	2376	1665	.....	50	60	88	66	F+	F−
P706	2382	5592	Improved Turkey.	50	57+	58	55	P	P
P707	2383	.....	Red Winter Java	45	47	Wk	.....	G±	.....
P711	2385	.....	.....	25	52	95	57.3	G±	F−
P712	2386	.....	.....	40	32	80	50.6	G	F−
P717	2388	1437	Crimean	25	45	95−	55	F+	G
P721	2390	.....	.....	40	30	T to 40	35	G	G
P722	2391	.....	.....	35+	42	95	57.3	G−	F−
P732	2398	.....	.....	40+	65	98	67.6	F	F
P733	2399	.....	.....	45	60	Wk	.....	F−	.....
P736	.....	.....	.....	65	48	90+	67.6	G	P
P737	.....	.....	.....	65	54	65	61.3	F−	F−
P742	2434	1538	Ulta	65+	42	78	61.6	F−	P
P744	.....	.....	.....	40	38	95	57.6	P	F
P745	2433	1539	Torgova	35	45+	90	56.6	F−	F
P746	.....	.....	.....	25	35	97	52.6	F	P
P750	2411	1543	Beloglina	25+	47	85	52	F−	P

TABLE 1.—*Stem-rust infection of wheat varieties after artificial inoculation in the nursery at Manhattan, Kans., in the years 1915, 1916, and 1917, together with data on kernel quality in 1916 and 1917*—Continued.

Group 1.—AWNED, GLUMES GLABROUS, KERNEL SEMIHARD TO HARD—Continued.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection (per cent).				Quality of kernels.	
				1915	1916	1917	3-year average.	1916	1917
1	2	3	4	5	6	7	8	9	10
WINTER VARIETIES—continued.									
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		
Common wheats—Con.									
P751	2427	1543	Beloglina	25	35	60	40	P	F
P752				40	40	Wk		F−	
P753				50	60	88	60	F−	G−
P754				35+	40+	95	56.6	F−	P
P755				30+	65+	68	54.3	F−	P
P757				30+	67	50	49	F−	P
P758	2419	1544	Beloglina	35	65+	95	65	P	F
P759				20−	40	70	43.3	P	P
P762	2401	5146	Kanred	40 to 70	10	10	25.0	G	E
P771	2436		Power Fife × Jonathan.	40	45	85	56.6	F+	F
P772				45	50+	95	63.3	F	G
P773				55−	55−	97	69	F−	G−
P774	2418		Power Fife × Jonathan.		60+	80+		G−	G+
P877				60	65	70	65	F−	F
P882				60	48	90	66.0	P	G
P889	2409	6217	Turkey	20+	40	50	36.6	P	G
P935	2404		Bucanera		42	70+		G	F+
P951	2417		Scottish Rank	40	45+	88	57.6	F−	P
P967				60+	62	90	70.6	P	G
P973				45+	65−	90	66.6	F−	F
P1000	2435		Hickling	55+	85−	75	71.6	F+	P
P1003				35	82	Wk		G	
P1008	2428		Victoria	60+	82+	78	73.3	G	F
P1013				30	75	50	51.6	F−	F−
P1036	2412	2479	Romanella	35−	77	Wk			
P1038	2422	2478	Fern or April	25	85+	85	65	F	F−
P1066	2415	5879		45	5±	15	18.3	G+	G
P1068	2414	5880		40+	5±	5 to 25	20	G+	G
P1078	2416	1543	Beloglina	25−	50+	85	53.3	F−	F−
P1080				60−	60+	78	66	F−	F
P1111				30	78	Wk		G−	
P1119				45	45	Wk		G−	
P1128				40	65+	85	63.3	F−	F
P1131				40+	70+	97	69	F	F
P1134	2420	1436	Crimean	30	85+	85	66.6	F−	P
P1161	2410	1787		65	40	Wk		G+	
K34		5147	Nebraska No. 28		60	Wk		F−	
K570		1558	Turkey		45	95		F+	P
K2048		5797	Alberta Red			88			F
K2101		6213	Red Winter			70+			F
K2123		6214	Defiance Hard Winter.			Wk			
P2141	2413	6474		30−	60−	95+	61.6	G−	F−
K35		1442	Kharkof		60+	88		F−	F

Group 2.—AWNED, GLUMES GLABROUS, KERNEL SOFT.

WINTER VARIETIES.									
Common wheats:									
P638	2358		Binkel Club		68	Wk		F	
P668	2365		Michigan Bronze		90+	70		G	P
K51		1981	Dietz Longberry		90−	Wk		P	
C. I. 1945			Lancaster		88	Wk		F−	
K36		2008	Mammoth Red		95	Wk		F−	
C. I. 1973			New Amber Longberry.		85	Wk		P	
K47		2980	Stoner		90−	Wk		F	

TABLE 1.—*Stem-rust infection of wheat varieties after artificial inoculation in the nursery at Manhattan, Kans., in the years 1915, 1916, and 1917, together with data on kernel quality in 1916 and 1917*—Continued.

Group 3.—AWNED, GLUMES PUBESCENT, KERNEL SOFT.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection (per cent).				Quality of kernels.	
				1915	1916	1917	3-year average.	1916	1917
1	2	3	4	5	6	7	8	9	10
WINTER VARIETIES.									
Common wheats:				*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
P724	2392	.....	.....	40+	50	68	52.6	F+	F
P1071	.....	.....	.....	20+	45	Wk	.....	F+	.....
P1082	.....	1571	Turkey	25	50	65	46.6	F+	P
K49	.....	3277	Virginia	.....	85+	95+	.....	P	P
(?)	.....	.....	Velvet Chaff	.....	65	Wk	.....	G−	.....

Group 4.—AWNLESS, GLUMES GLABROUS, KERNEL SOFT.

WINTER VARIETIES.									
Common wheats:									
P718	2389	.....	.....	30	40	95+	55	G	G−
P739	.....	.....	.....	80+	40−	60	60	F	F
P740	2441	1535	Berdiansk	.....	65	70	.....	F−	P
P741	.....	.....	.....	85	40−	95	73.3	P	P
P748	.....	.....	.....	40−	65+	85+	63.3	F+	G−
P765	2402	.....	.....	.....	65+	90+	.....	F−	F+
P871	.....	.....	.....	40−	60+	80	60	F−	F+
P970	2403	.....	.....	.....	65	90	.....	F−	F
P980	2405	.....	North Allerton	40+	68	75	61	P	F−
P1064	2440	6218	Zimmerman	30+	60+	70	53.3	F	F
P1092	2406	6216	Currell	25+	75	90	63.3	G−	P
K39	.....	1733	Dawson Golden Chaff.	.....	75+	Wk	.....	F	.....
K38	.....	1744	Early Genesee Giant.	.....	77	Wk	.....	Vp	.....
K42	.....	1915	Purple straw	.....	60	Wk	.....	F−	.....
K40	.....	1923	Fultz	.....	67	Wk	.....	F+	.....
K52	.....	1969	Michigan Amber	.....	80	Wk	.....	P	.....
C. I. 1979	.....	.....	Poole	.....	85	Wk	.....	F−	.....
K48	.....	1980	Fultzo-Mediterranean.	.....	90+	Wk	.....	P	.....
K46	.....	2997	Kofod	.....	65	Wk	.....	F	.....
C. I. 3326	.....	.....	Currell	.....	95−	Wk	.....	P	.....

Group 5.—AWNLESS, GLUMES PUBESCENT.

WINTER VARIETIES.									
Common wheats:									
P1073	2408	.....	Jones × Red Fife	.....	95	Wk	.....	P−	.....
K44	.....	1933	Jones Winter Fife.	.....	90	Wk	.....	P	.....
K50	.....	.....	Mealy	.....	85	Wk	.....	P	.....

Group 6.—AWNED, GLUMES GLABROUS (TRITICUM VULGARE, T. DURUM, AND HYBRIDS).

SPRING VARIETIES.									
Common wheats:									
C. I. 2958	.....	.....	Preston (Minn. No. 188).	35	40	85	53	.....	P
H. 3×111	.....	4783	Iumillo × Preston.	25	40	80	48	.....	P
H. 4×942.10	.....	4788	Kubanka × Preston.	.....	.....	68	.....	G−	F−
H. 6×2223	.....	4789	Kubanka × Bluestem.	.....	.....	60	.....	G	F−

TABLE 1.—*Stem-rust infection of wheat varieties after artificial inoculation in the nursery at Manhattan, Kans., in the years 1915, 1916, and 1917, together with data on kernel quality in 1916 and 1917*—Continued.

Group 7.—AWNED, GLUMES PUBESCENT.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection (per cent).				Quality of kernels.	
				1915	1916	1917	3-year average.	1916	1917
1	2	3	4	5	6	7	8	9	10
SPRING VARIETIES.									
Common wheats:				*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
C. I. 2442	.....	.....	Black Persian	5—	10	10 to 40	13	.....	G

Group 8.—AWNLESS, GLUMES GLABROUS.

SPRING VARIETIES.									
Common wheats:									
C. I. 1517	.....	.....	Ghirka Spring	35+	50	98	61	.....	F—
C. I. 3641	.....	.....	Marquis	25	65	95	61	.....	G—
C. I. 2873	.....	.....	Glyndon Fife (Minn. No. 163).	25	45	85	51	.....	P

Group 9.—AWNLESS, GLUMES PUBESCENT.

SPRING VARIETIES.									
Common wheats:									
C. I. 2874	.....	.....	Haynes Bluestem (Minn. No. 169).	35+	40	90	55	.....	P

Group 10.—AWNED, GLUMES GLABROUS.

Durum wheats:									
H. 3×122A12	.....	.....	Iumillo × Preston.	.....	.....	5—	.....	.....	G—
C. I. 1493	.....	.....	Arnautka	.....	55	75	.....	.....	F
C. I. 1494	.....	.....	do	(a)	.....	.....	.....	.....	.....
C. I. 1443	.....	.....	Gharnovka	.....	.....	40	.....	.....	G—
C. I. 1513	.....	.....	Beloturka	.....	.....	.....	.....	.....	G
C. I. 1736	.....	.....	Iumillo	25	60	5—	30	.....	G
C. I. 2094	.....	.....	Kubanka	5—	b 25	10	13	.....	G
C. I. 3320	.....	.....	Monad	.....	.....	5—	.....	.....	G—
C. I. 3320	.....	.....	Monad Selection	.....	.....	5—	.....	.....	G—
C. I. 3322	.....	.....	Pentad (D-5)	.....	.....	T	.....	.....	G
C. I. 5284	.....	.....	Acme	.....	.....	30	.....	.....	G

Group 11.—AWNED, GLUMES GLABROUS, WHITE.

Emmer and Einkorn:									
C. I. 1522	.....	.....	White Spring Emmer.	.....	.....	.....	.....	.....	.....
C. I. 1524	.....	.....	do	(c)	5	T	.....	.....	.....
C. I. 4781	.....	.....	do	.....	T	5	.....	.....	.....
C. I. 1526	.....	.....	Yaroslav emmer	T	.....	.....	.....	.....	.....
C. I. 4013	.....	.....	Khapli emmer	(d)	T	T	.....	.....	.....
C. I. 2433	.....	.....	Common einkorn	T	8	T to 35	.....	.....	.....

a Heavy on base; on upper culms, trace.
b On necks.
c Fairly heavy at base; on culms, trace.
d Heavy on necks; on culms, trace.

The names are those which appear in the records of the Kansas Agricultural Experiment Station. Most of the varieties in the bearded, glabrous-glumed, hard red-kerneled group are very similar to the well-known Turkey and Kharkof varieties.

Nearly all the winter-wheat varieties proved to be very susceptible to stem rust (Pl. III). Three of the pedigreed strains, however, were found to be remarkably resistant. These were Kanred and two unnamed varieties, P1066 and P1068. These three pure-line selections differ morphologically from Turkey and Kharkof in the greater length of the short awn or beak found at the tip of the outer or empty glume. The average length of the beak in these three varieties is considerably greater than in the case of Turkey, Crimean, and Kharkof.[7] The variety P762 (Kansas No. 2401) was named Kanred (from Kansas Red) and distributed to farmers in 1914. The other two resistant strains, P1066 and P1068, are very similar to Kanred; in fact, the three strains seem to be morphologically identical. They appear to differ slightly in certain agronomic characters, such as yield, winter hardiness, and grain quality. The experimental data which are available indicate that each of these other two selections is equal to Kanred in yield and other agronomic qualities, although they have not been grown as long in plats at the agronomy farm and have not been compared at the branch experiment stations or in cooperative experiments with farmers.

These three strains did not attract any particular attention in 1915, as they seemed as heavily rusted (40 to 70 per cent) as many of the other varieties, but in 1916 and 1917 very different results were obtained.[8] They were almost free from stem rust (Pl. IV). The estimated infections of rust on these three varieties in 1916 were 10, 5, and 5 per cent respectively, and in 1917 they were 10, 15, and 5 to 25 per cent, respectively, compared to the maximum figures of 95 to 98 per cent on other varieties in the same seasons.

The only other variety of winter wheat which gave any evidence of resistance was Kansas No. 2390. The infection of stem rust on plants of this variety was estimated at 40 per cent in 1915, at 30 per cent in 1916, and as "Trace to 40 per cent" in 1917. This variety was much less heavily rusted than many other varieties in 1916 and 1917, but it does not appear to be nearly as resistant as Kanred, P1066, and P1068.

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[7] This distinguishing character was first called to the attention of the writers by Carleton R. Ball and J. Allen Clark, of the Office of Cereal Investigations.

[8] In the light of present knowledge of the existence of several biologic strains of stem rust, with different infection capabilities, the results in 1915 are easily explained as being due to the presence in the rust nursery of one or more strains of stem rust which were able to attack these varieties.

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TYPICAL INFECTION OF STEM RUST OF TURKEY WHEAT.

This represents the susceptible strain of this variety used as a check in the wheat-rust nursery in 1916.

A TYPICAL PLANT OF KANRED WHEAT FROM THE RUST NURSERY IN 1916.

Note the very slight rust infection. The other pure lines (P 1066 and P 1068) presented a similar appearance.

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TYPICAL RUST INFECTION OF TWO VARIETIES OF WHEAT IN 1916.

A, Mealy, a susceptible variety of soft red winter wheat; *B*, Ghirka Spring wheat, also very susceptible.

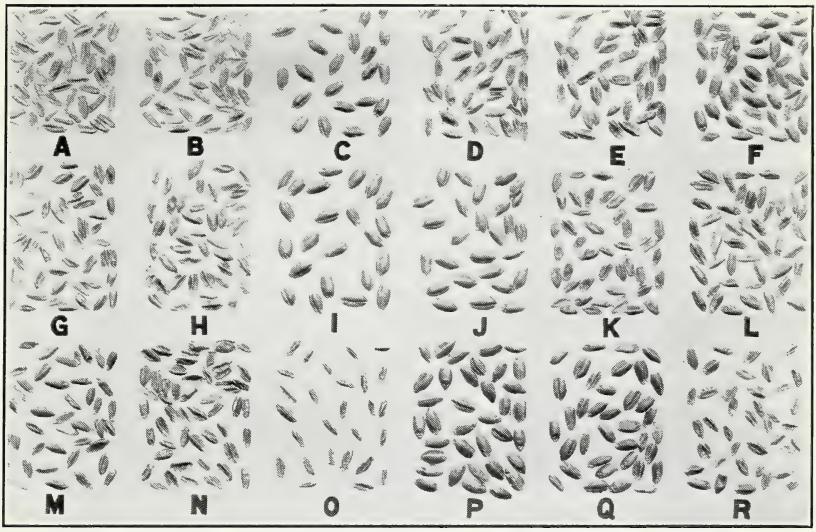


FIG. 1.—KERNELS OF SUSCEPTIBLE AND RESISTANT WHEAT VARIETIES IN 1916.

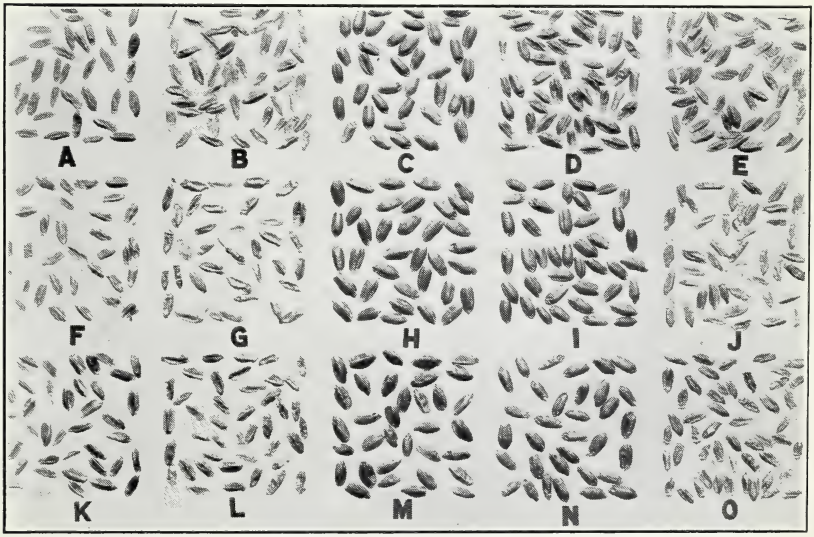
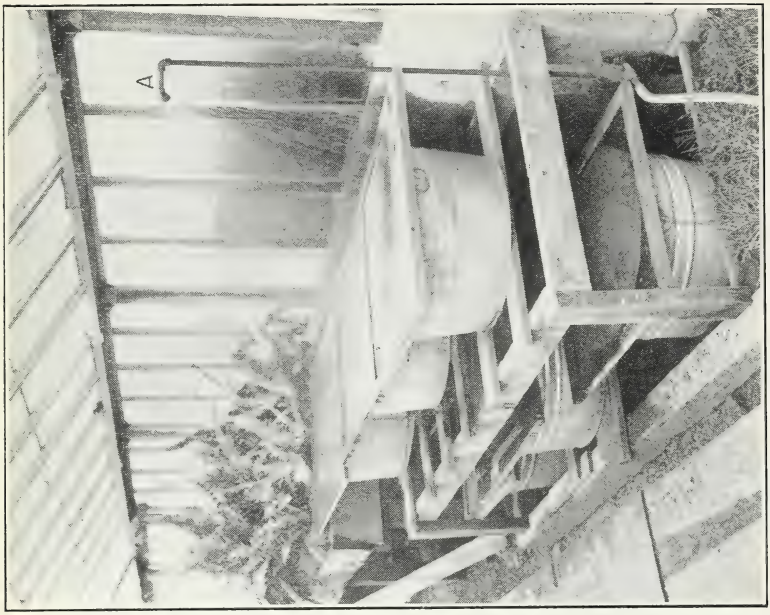


FIG. 2.—KERNELS OF SUSCEPTIBLE AND RESISTANT WHEAT VARIETIES IN 1917.



MOIST CHAMBER USED FOR INOCULATED SEEDLINGS IN THE GREENHOUSE.

A fine spray of water at *A* is used to lower the temperature.

All varieties of soft red winter wheat were found to be susceptible to stem rust. Plate V, *A* shows a typical plant of Mealy, a very susceptible variety.

Several of the varieties of spring wheat showed evidence of being resistant. Other varieties, such as Ghirka Spring (Pl. V, *B*), were found to be very susceptible. Black Persian was the only variety of common spring wheat which showed marked signs of resistance.

Among the durum wheats, Beloturka (C. I. No. 1513), Iumillo (C. I. No. 1736), Kubanka (C. I. No. 2094), Monad (C. I. No. 3320), and D–5 (C. I. No. 3322) all proved rather resistant to stem rust. A hybrid between Iumillo and Preston (No. 3 × 122A12) also was very resistant. This hybrid resembles the durum parent in type of head.

All of the strains of emmer gave some evidence of being resistant, as did the one strain of einkorn. Khapli emmer (C. I. No. 4013), although slightly rusted, never showed the large linear uredinia which develop on susceptible varieties.

Usually a rather close relationship is shown between the extent of stem rust recorded and the quality of grain produced by a given variety. The grain of certain varieties, however, sometimes is severely injured by a medium quantity of rust, while other varieties with a higher percentage of rust infection will produce heavier grain.

Kanred, P1066, and P1068 were all low in quantity of rust in 1916 and 1917, and all produced good heavy plump kernels. Factors other than rust infection, of course, influence grain quality, but it was very evident in 1916 and 1917 that the three rust-resistant varieties produced better grain than the similar but more severely rusted varieties grown in near-by rows.

Typical kernels of resistant and susceptible varieties produced in the wheat-rust nursery in 1916 and 1917 are shown in Plate VI. Table 2 presents data showing the percentage of rust infection on the varieties of which kernels are shown in Plate VI. The letters in the first column of the table correspond with those of figures 1 and 2 of the plate.

TABLE 2.—*Stem-rust infection on susceptible and resistant varieties of wheat grown in the rust nursery at Manhattan, Kans., in 1916 and 1917.*

1916.

Identification.				
Pl. VI, fig. 1.	Pedigree or other number.	Name.	Class.	Rust infection.
				Per cent.
A	P758		Hard red winter	65
B	P759		do	40
C	P762	Kanred	do	10
D	P771		do	45
E	P772		do	50
F	P773		do	55
G	P1038		do	85
H	P1064		do	60
I	P1066		do	5
J	P1068		do	5
K	P1071		do	45
L	P1078		do	50
M	P1036		do	77
N	Check	Turkey	do	45
O	C. I. 1517	Ghirka	Hard red spring	50
P	C. I. 3322	D-5	Red durum	
Q	P721		Hard red winter	30
R		Mealy	Soft red winter	85

1917.

A	P758		Hard red winter	95
B	P759		do	70
C	P762	Kanred	do	Trace.
D	P765		do	90
E	P877		do	70
F	P1038		do	85
G	P1064		do	70
H	P1066		do	5
I	P1068		do	5
J	P1078		do	85
K	Kans. 2048	Alberta Red	do	88
L	Minn. 169	Haynes Bluestem	Hard red spring	85
M	C. I. 2094	Kubanka	Durum	10
N	P721		Hard red winter	40
O	C. I. 3277		Soft red winter	95

GREENHOUSE EXPERIMENTS.

To check the nursery results similar experiments under controlled conditions were conducted in the greenhouse.

INOCULATION METHODS.

Nearly all the varieties, both winter and spring, which were used in the field were inoculated in the seedling and heading stages in the greenhouse. Careful records of the inoculated plants of each variety have been kept and their behavior compared with the behavior of the same variety in the field. The number of plants which can be grown under greenhouse conditions is more or less limited, and for this reason conclusions from such experiments should always be drawn with caution.

INOCULATION OF SEEDLINGS.

In inoculating seedlings the first leaf was inoculated and all others were trimmed off. The uredinial material came from stock cultures grown on Improved Turkey (Kansas No. 2382), or some other sus-

sceptible variety. The inoculation method used was described by Melchers (*28*) and was a modification of the method proposed and used by Kellerman (*22*) and Carleton (*7*) in their studies of cereal and other rusts. This is a satisfactory method where the supply of rust is limited, as there is little chance for loss of spores. The spore supply was collected in a Petri dish and applied to the seedlings by means of a flattened or a rounded needle. The leaves to be inoculated were first thoroughly dampened by stroking them several times between the fingers previously moistened in water. Tap water was used with satisfactory results, although Melhus and Durrell (*32*) have shown that tap water may have a toxic effect on the germination of certain kinds of rust spores.

In the studies in the greenhouse the seedlings were grown in 2½-inch pots, illustrated in figure 2. Fifteen pots, each containing 2 seedlings, or 30 seedlings in all, constituted one series of each variety.

FIG. 2.—Seedlings grown to determine rust resistance of wheat varieties under greenhouse conditions. Pots 1 and 2 contain seedlings of a susceptible variety used as a check; Nos. 3 to 6 contain seedlings of P1068. Each of the two seedlings in each pot is trimmed to a single leaf blade which is inoculated.

In most cases it was not necessary to inoculate more than one series of plants, but if the results were at all doubtful a second series was inoculated. Hundreds of inoculations were made on seedlings of Kanred, P1066, and P1068. Two to four seedlings of Improved Turkey (Kansas No. 2382) were used as checks for each series.

After inoculation, the seedlings were kept in damp chambers for 48 hours, after which they were removed and placed on the greenhouse bench. Bell jars were first used, but these proved impracticable. An inexpensive and effective damp chamber, shown in Plate VII, was devised. It consisted of a galvanized-iron washtub with a pane of glass for a cover.[9]

About one-quarter of an inch of water was placed in the bottom of each chamber, to keep the air saturated. The chambers were kept in the shade, so as to maintain a temperature of 50° to 70° F. In warm weather, a spray of water was directed upon the damp chambers to reduce the temperatures. Difficulty was experienced during

[9] Cylinders made of galvanized iron (without permanent top or bottom), with a diameter of 15 inches and a height of 12 inches, have been used more recently. A removable piece of glass is used for a top. If these cylinders stand on damp sand, sufficient moisture is supplied to keep the chamber saturated, and the potted seedlings do not stand in water. Damp chambers of this type have proved very satisfactory.

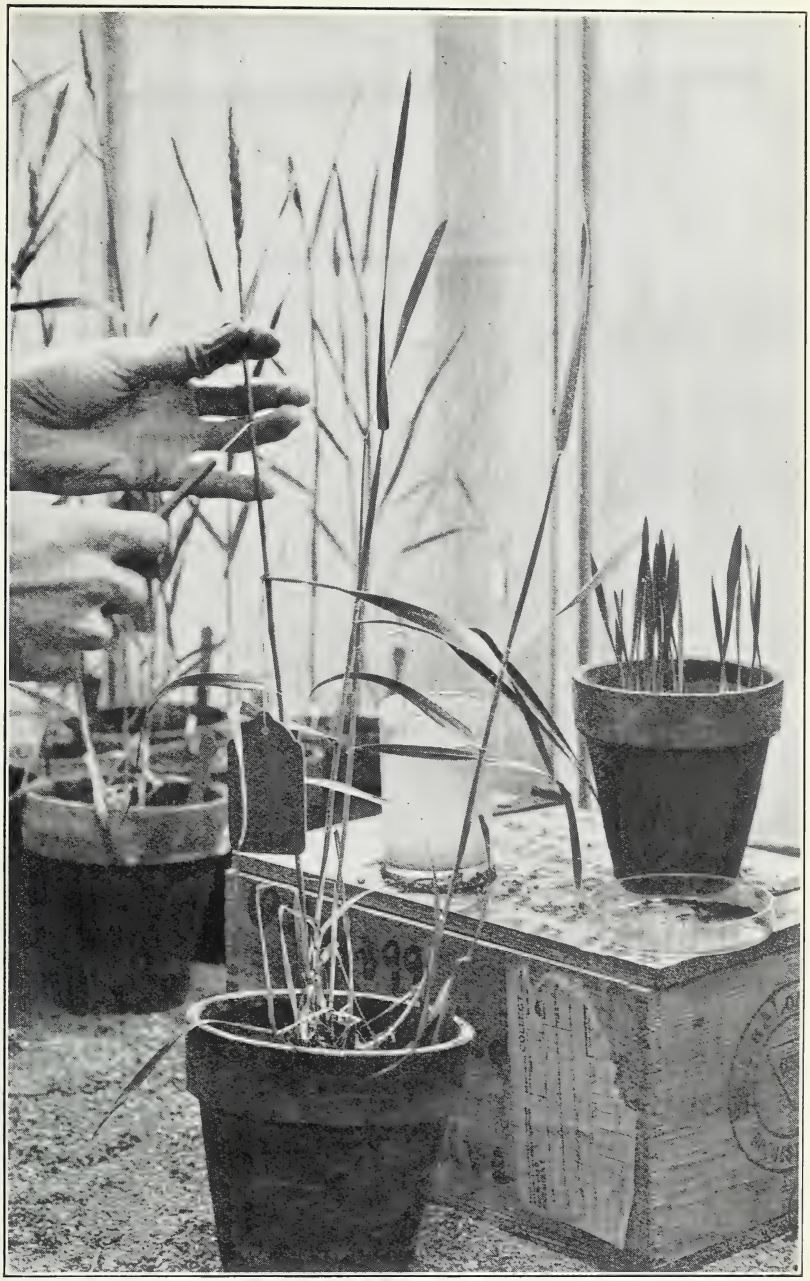
the first year in carrying the cultures through the summer, on account of the prolonged periods of temperatures ranging from 100° to 110° F. It was found that sprays of water directed upon the chamber not only cooled the air in the greenhouse but in addition kept the temperature in the damp chambers within a few degrees of that of the water itself. By such means a difference of 11° C. between the temperature inside and that outside the chambers was obtained, as shown by some of the readings at different dates during July and August.

Johnson (*21*) found that the maximum temperature at which urediniospores of *Puccinia graminis* would germinate in a normal manner was about 88° F., though the experiments of the writers have shown that temperatures of 80° to 95° F. do not prevent normal infection. However, temperatures of 65° to 70° F. are believed to be the most favorable for inoculations with stem rust. These methods have been satisfactory in every respect; 100 per cent of infection always was obtained on plants of susceptible varieties, including checks, and it is believed the notes on resistance or susceptibility are as dependable as can be obtained under greenhouse conditions. The methods described, however, might not give as satisfactory results with other cereal rusts.

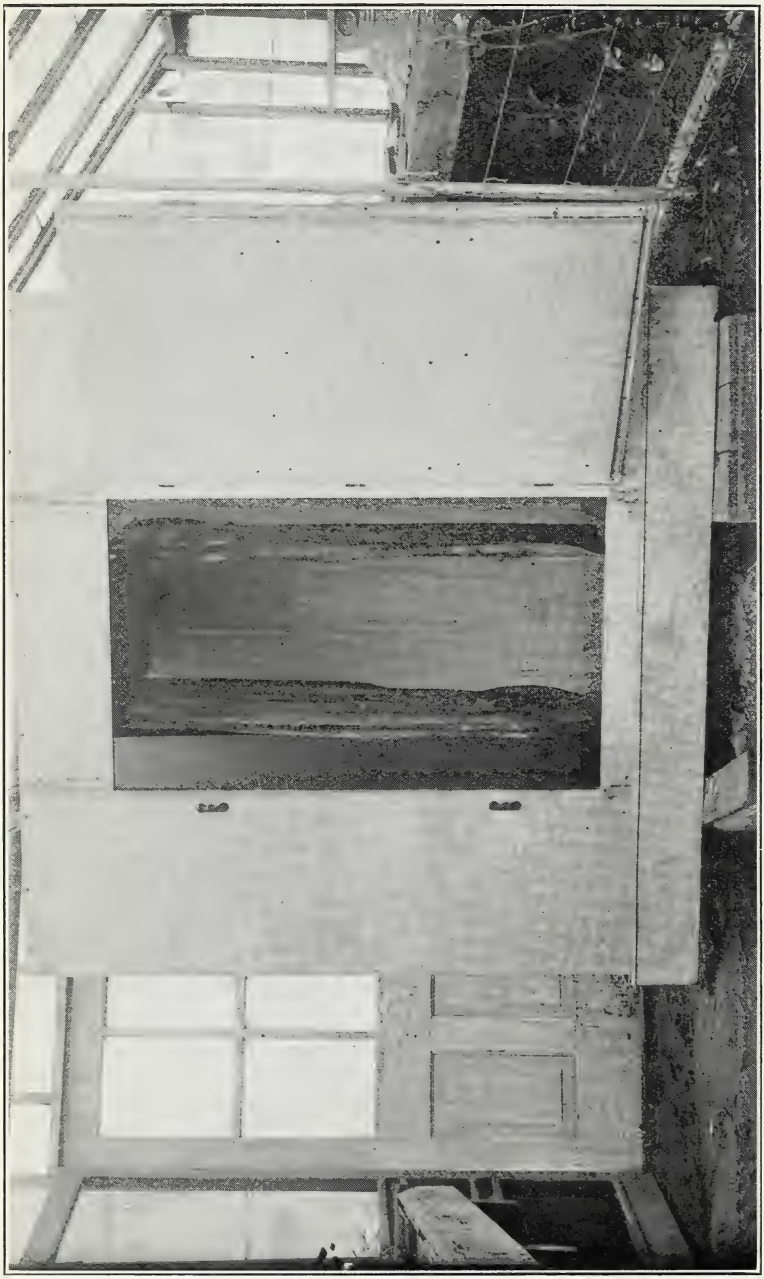
INOCULATION IN THE HEADING STAGE.

One plant of each variety which was grown in the rust nursery was allowed to develop to the heading stage in the greenhouse. One seed was sown in each pot in October. It has been found that by maintaining the proper temperature, either spring or winter wheat can be matured and normal seed developed in the greenhouse. Hutcheson and Quantz (*18*) have shown that temperatures from 55° to 70° F. are best suited to this purpose. In the experiments of the writers, where plants were grown to the heading stage, a night temperature of about 50° F. was maintained, but not infrequently the night temperature during the early stages of growth fell as low as 35° or 40° F. The temperature was kept below 75° F. during the daytime whenever possible.

The plants were inoculated as soon as the heads were well out of the boot and the neck or peduncle exposed, as illustrated in Plate VIII. Two to six culms of each variety were inoculated with stem rust. In the case of Kanred, P1066, and P1068 the inoculations included a much larger number of plants. In some cases the culms of these three varieties were reinoculated a number of times, so as to expose them to infection as often as possible and at different periods of development. The uppermost leaf blade and the sheath of each culm of all varieties grown were thoroughly inoculated, as were the necks, glumes, and awns. These plants were then placed for a period of 48 to 72 hours in a specially constructed galvanized-iron damp chamber, similar to the one described by Parker (*34*). This damp chamber is of sufficient

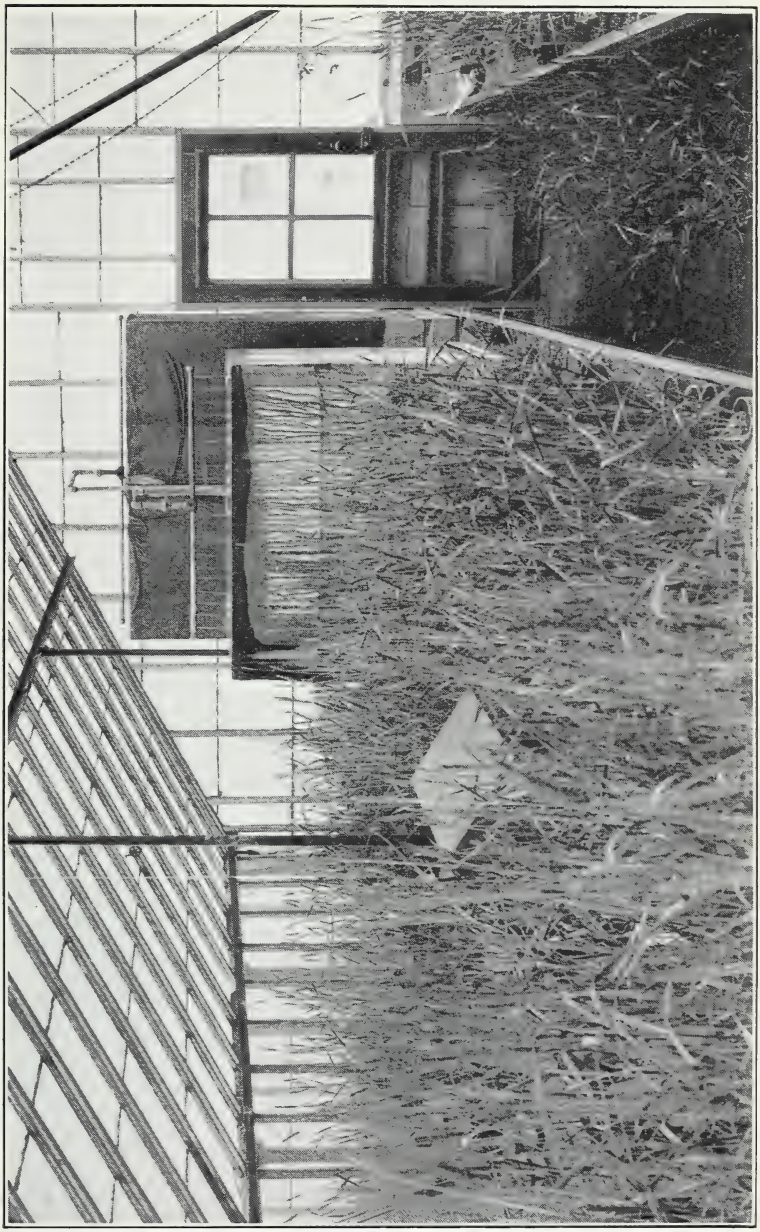


METHOD OF INOCULATING WHEAT PLANTS AT THE TIME OF HEADING AND SEEDLINGS AT THE INOCULATING STAGE.



LARGE SHEET-METAL MOIST CHAMBER USED FOR WHEAT PLANTS INOCULATED AT HEADING TIME.

The pan of water and wick maintain a high degree of humidity.



LARGE WATER-COOLED MOIST CHAMBERS USED FOR PLANTS INOCULATED AT HEADING TIME.

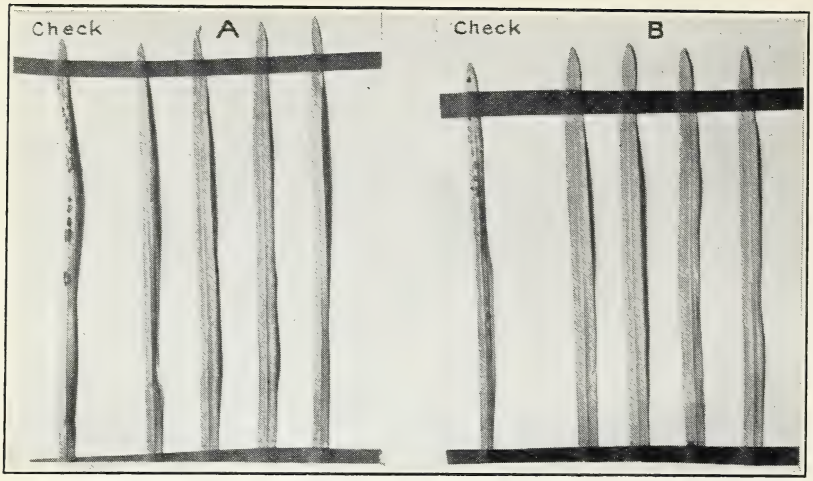


FIG. 1.—RUST RESISTANCE OF TWO VARIETIES OF WINTER WHEAT IN 1918.

Seedling leaves of P1066 (*A*) and Kanred (*B*), both inoculated on April 22 and photographed on May 11. Compared with the rusted leaves of the susceptible check (shown at the left of each group) these leaves are seen to be entirely free from flecks and uredinia.

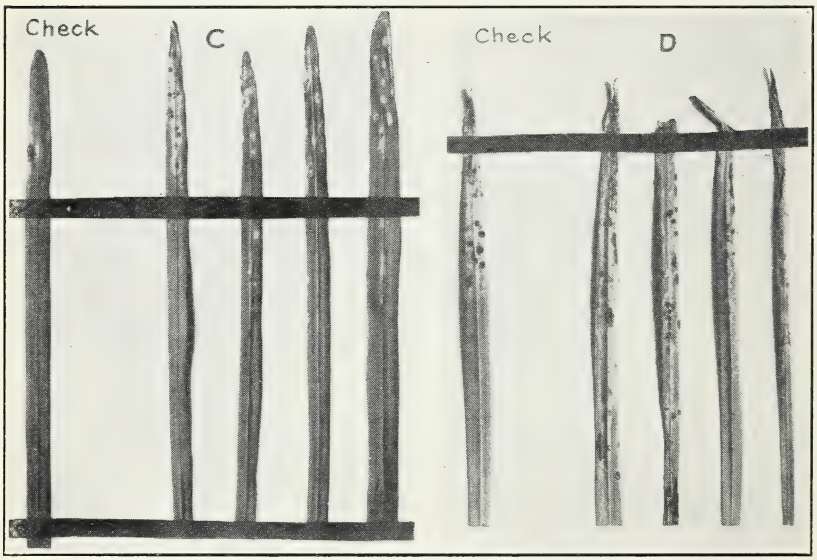


FIG. 2.—RUST SUSCEPTIBILITY OF TWO VARIETIES OF SPRING WHEAT IN 1917.

Seedling leaves: *C*, Arnautka (C. I. 1493), inoculated on March 29 and photographed on April 19; *D*, hybrid 3 × 122A12, showing normal uredinia in this stage, inoculated on April 4 and photographed on April 27. Although known to be resistant to some strains of stem rust in the field, these two varieties show visible signs of infection when inoculated with the same strain of rust used with *A* and *B* (fig. 1, above).

COMPARATIVE RUST RESISTANCE OF SOME WINTER AND SPRING VARIETIES OF WHEAT.

size to accommodate about 72 plants. About half an inch of water was kept in the bottom of the chamber and a pan of water was suspended from the top. A cloth wick was placed over this pan and was allowed to hang down on two sides, as shown in Plate IX. This helped to keep the air saturated. A glass top allowed sufficient light to enter the moist chamber, so that the plants did not become etiolated during the incubation period. On warm days a stream of water was allowed to flow over the top, as illustrated in Plate X. This helped to maintain a cool temperature within the chamber. Cloths were hung over the outside walls to help distribute the water evenly. An overflow pipe in the pan at the bottom of the chamber carried away the surplus water. The inoculated plants were placed on inverted empty flowerpots, to avoid setting them in water.

RESULTS OF THE GREENHOUSE EXPERIMENTS.

The results obtained from greenhouse inoculations are shown in Table 3. Very heavy infection always was obtained on the checks and the susceptible varieties, but in the case of Kanred, P1066, and P1068 no uredinia appeared. Some of the spring-wheat varieties also showed only slight to moderate infection. The peduncles, glumes, and awns of all susceptible varieties were just as readily infected at heading time as were the seedlings. In the case of the three resistant varieties, if any portion of the head becomes infected it is the awn. No signs of infection, however, could be noticed on plants of the three resistant varieties with the exception of a few indefinite flecks on the culms. A plant of Improved Turkey was included with each set of varieties and on being inoculated was placed in the damp chamber and maintained under the same conditions. These checks always became heavily infected. It is evident that favorable conditions for infection were present, as uredinia were produced on plants of Khapli emmer (C. I. No. 4013), Kubanka durum (C. I. No. 2094), and other varieties of emmer and durum wheat which are known to be resistant to stem rust.

The "type of infection," is shown in the table by symbols (explained below) indicating the relative resistance or susceptibility. The results of inoculations in the seedling and heading stages should be regarded as a corollary to the field results, however. It is hardly safe to draw final conclusions on the comparative resistance of varieties from experiments in the seedling stage alone, as the conditions under which the inoculations must be made are certain to vary and frequently may cause a different interpretation of the results. This is especially true where only a few seedlings are inoculated. A variety inoculated with a given strain of stem rust may show a somewhat different type of infection when inoculated at another time, even though the check which is run with every series may show a normal infection.

TABLE 3.—*Results of inoculating wheat varieties with stem rust in the greenhouse at the Kansas Agricultural Experiment Station at Manhattan, Kans., in the winter of 1916–17.*

[Key to identification numbers (columns 1 and 3): C. I.=Cereal Investigations, H=hybrid, K=Kansas P=pedigree.]

Group 1.—AWNED, GLUMES GLABROUS, KERNEL SEMIHARD TO HARD.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection. Seedlings. Number inoculated.	Seedlings. Number infected.	Headed plants. Number inoculated.	Headed plants. Number infected.	Type of infection.[a] Seedlings.	Type of infection.[a] Headed plants.	Remarks.
WINTER VARIETIES.										
Common wheats:—Continued.										
P373				30	30	3	3	S	S	
P647	2356		Japan	30	13	6	6	S	S	Purple color.[b]
				30	29			S		
P651	2357		Russian	30	28			S	S	
				30	30			S		Do.
P675	2368		Red Winter Java	30	28	3	3	S	S	
P678	2370		do	30	22	3	3	S	S	
P693	2376	1665		30	23	3	3	S	S	
				30	30			S		
P706	2382	5592	Improved Turkey.	30	30	9	9	S	S	
P707	2383		Red Winter Java	30	30	3	0	S		Plant died.
P711	2385			30	29	6	6	S	S	
P712	2386			30	30	3	3	S	S	
P717	2388	1437	Crimean	30	27	3	3	S	S	
P721	2390			30	29	6	6	S	S	
P722	2391			30	28	3	3	S	S	
P732	2398			30	30	3	3	S	S	
P733	2399			30	30	3	3	S	S	Purple color.
P736				30	30	4	4	S	S	
P742	2434	1538	Ulta	30	30	3	3	S	S	
P744				30	26	5	5	S	S	
P745	2433	1539	Torgova	30	30	3	3	S	S	
P746				30	30	3	3	S	S	
P750	2411	1543	Beloglina	30	30	6	6	S	S	
P751	2427	1543	do	30	30	3	3	S	S	
				8	8			S		
P752				30	30	3	3	S	S	
P753				30	16	3	3	S	S	
				30	30			S		
P754				30	30	3	3	S	S	
P755				30	24	6	6	S	S	Do.
P757				30	28	6	6	S	S	
P758	2419	1544	Beloglina	6	6	3	3	S	S	
				28	21			S		
P759				30	30	3	3	S	S	
P762	2401	5146	Kanred	[c]242	0	[d]6	0	R	R	
P771	2436		Power Fife × Jonathan.	30	24	3	3	S	S	
				30	30			S		
P772				30	30	3	3	S	S	
P773				30	30	3	3	S	S	
P774	2418		Power Fife × Jonathan.	30	30	6	6	S	S	
P877				30	27	3	3	S	S	Purple color.
P882				30	30	3	3	S	S	
P889	2409	6217	Turkey	28	22	3	3	S	S	
				8	8			S		
P935	2404		Bucanera	30	30	3	3	S	S	
P951	2417		Scottish Rank	30	7	3	3	S	S	
				30	30			S		
P967				30	30	6	6	S	S	
P973				30	28	3	3	S	S	
				30	28			S		
				30	30			S		

[a] The symbols indicate the type of infection, as explained on page 22.

[b] Under certain conditions some varieties produced a purple color surrounding the uredinia; where this was pronounced it is indicated in the table.

[c] Since the completion of this work about 200 additional seedlings have been inoculated, with the same results.

[d] Since these inoculations were made, many additional culms have been inoculated, with the same results.

TABLE 3.—*Results of inoculating wheat varieties with stem rust in the greenhouse at the Kansas Agricultural Experiment Station at Manhattan, Kans., in the winter of 1916–17*—Continued.

Group 1.—AWNED, GLUMES GLABROUS, KERNEL SEMIHARD TO HARD—Continued.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection. Seedlings. Number inoculated.	Stem-rust infection. Seedlings. Number infected.	Stem-rust infection. Headed plants. Number inoculated.	Stem-rust infection. Headed plants. Number infected.	Type of infection. Seedlings.	Type of infection. Headed plants.	Remarks.
WINTER VARIETIES—continued.										
Common wheats—Continued.										
P1000	2435	.....	Hickling	30	30	3	3	S	S	
P1003	.....	.....	.....	30	28	3	3	S	S	
P1008	2428	.....	Victoria	30	30	3	3	S	S	
P1013	.....	.....	.....	30	29	3	3	S	S	
P1036	2412	2479	Romanella	30	27	3	3	S	S	
P1038	2422	2478	Fern or April	30	30	3	3	S	S	
P1066	2415	5879	.....	c242	0	d6	0	R	R	
P1068	2414	5880	.....	c212	0	d6	0	R	R	
P1078	2416	1543	Beloglina	30	29	6	6	S	S	
P1080	.....	.....	.....	30	30	.....	.....	S	.....	Plant died.
P1111	.....	.....	.....	30	27	3	3	S	S	Purple color.
P1119	.....	.....	.....	30	30	3	3	S	S	Do.
P1128	.....	.....	.....	30	30	3	3	S	S	
P1131	.....	.....	.....	30	28	3	2	S	S	
P1134	2420	1436	Crimean	30	29	3	3	S	S	
P1161	2410	1787	.....	30	30	3	3	S	S	
K34	.....	5147	Nebraska No. 28	30	29	3	3	S	S	
K570	.....	1558	Turkey	30	30	4	4	S	S	
K2048	.....	5797	Alberta Red	30	30	3	3	S	S	
K2101	.....	6213	Red Winter	30	30	3	3	S	S	
K2123	.....	6214	Defiance Hard Winter.	30	30	3	3	S	S	
K2413	.....	6474	.....	30	30	3	3	S	S	
C. I. 1442	.....	.....	Kharkof	30	30	3	3	S	S	
(?)	.....	.....	Rieti	30	28	3	3	S	S	

Group 2.—AWNED, GLUMES GLABROUS, KERNEL SOFT.

WINTER VARIETIES.										
Common wheats:										
P638	2353	.....	Binkel Club	30	13	3	3	S	S	Purple color.
				30	30	.....	.....	S	.....	
P668	2365	.....	Michigan Bronze	30	30	3	3	S	S	Do.
K51	.....	1981	Dietz Longberry	30	29	3	3	S	S	Do.
C. I. 1945	.....	.....	Lancaster	37	34	3	3	S	S	
K36	.....	2008	Mammoth Red	30	30	3	3	S	S	Do.
C. I. 1973	.....	.....	New Amber Longberry.	30	30	3	3	S	S	
K47	.....	2980	Stoner	30	30	3	3	S	S	Do.

Group 3.—AWNED, GLUMES PUBESCENT, KERNEL SOFT.

WINTER VARIETIES.										
Common wheats:										
P724	2392	.....	.....	30	29	3	3	S	S	
P1071	.....	.....	.....	30	30	3	3	S	S	
K49	.....	3277	Virginia	27	27	3	3	S	S	
(?)	.....	.....	Velvet Chaff	30	30	3	3	S	S	(e)

c Since the completion of this work about 200 additional seedlings have been inoculated, with the same results.

d Since these inoculations were made, many additional culms have been inoculated, with the same results.

e Prominent flecks preceding uredinia.

TABLE 3.—*Results of inoculating wheat varieties with stem rust in the greenhouse at the Kansas Agricultural Experiment Station at Manhattan, Kans., in the winter of 1916–17*—Continued.

Group 4.—AWNLESS, GLUMES GLABROUS, KERNEL SOFT.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection. Seedlings. Number inoculated.	Seedlings. Number infected.	Headed plants. Number inoculated.	Headed plants. Number infected.	Type of infection. Seedlings.	Type of infection. Headed plants.	Remarks.
WINTER VARIETIES.										
Common wheats:										
P718	2389			30	30	3	3	S	S	
P739				30	30	3	3	S	S	Purple color.
P740	2441	1535	Berdiansk	30	29	3	3	S	S	Do.
P741				30	28	3	3	S	S	
P748				30	30	3	3	S	S	
P765	2402			30	30	3	3	S	S	
P871				30	28	3	3	S	S	
P970	2403			30	30	6	6	S	S	Do.
P980	2405		North Allerton	[f]30 30	17 30	3	3	S S	S -----	
P1064	2440	6218	Zimmerman	30	30	3	3	S	S	
P1092	2406	6216	Currell	30	30	3	3	S	S	Do.
K39		1733	Damson Golden Chaff.	30	22	3	3	S	S	
K38		1744	Early Genesee Giant.	30	30	6	6	S	S	Do.
K42		1915	Purple Straw	30	28	3	3	S	S	Do.
K40		1923	Fultz	90	90	3	3	S	S	Do.
K52		1969	Michigan Amber	37	36	3	3	S	S	Do.
C. I. 1979			Poole	30	30	3	3	S	S	
K48		1980	Fultzo-Mediterranean.	30	28	3	3	S	S	Do.
K46		2997	Kofod	8	8	1	0	S	?	
(?)		3326	Currell	30	30	1	1	S	S	

Group 5.—AWNLESS, GLUMES PUBESCENT.

WINTER VARIETIES.										
Common wheats:										
P1073	2408		Jones × Red Fife	30	30	3	3	S	S	
K44		1933	Jones Winter Fife.	30	25	2	2	S	S	
K50			Mealy	30	30	3	3	S	S	

Group 6.—AWNED, GLUMES PUBESCENT (TRITICUM VULGARE, T. DURUM, AND HYBRIDS).

SPRING VARIETIES.										
Common wheats:										
C. I. 2958			Preston (Minn. 188).	30	30	3	3	S	S	
H3 × 111		4783	Iumillo × Preston.	30	30	3	3	S	S	Purple color.
H4 × 942.10		4788	Kubanka × Preston.	60	49	3	3	S	S	Do.
H5 × 223		4789	Kubanka × Bluestem.	30	30	3	3	S	S	Do.

Group 7.—AWNED, GLUMES PUBESCENT.

SPRING VARIETY.										
Common wheat:										
C. I. 2442			Black Persian	30	30	2	2	R_3	R_3	(*f*)

f Uredinia numerous, very small.

TABLE 3.—*Results of inoculating wheat varieties with stem rust in the greenhouses at the Kansas Agricultural Experiment Station at Manhattan, Kans., in the winter of 1916–17*—Continued.

Group 8.—AWNLESS, GLUMES GLABROUS.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Stem-rust infection. Seedlings. Number inoculated.	Seedlings. Number infected.	Headed plants. Number inoculated.	Headed plants. Number infected.	Type of infection. Seedlings.	Type of infection. Headed plants.	Remarks.
SPRING VARIETY.										
Common wheats:										
C. I. 1517	.....	.....	Ghirka Spring	30	27	3	3	S	S	Purple color.
C. I. 3641	.....	.....	Marquis	30	30	3	3	S	S	
C. I. 2873	.....	.....	Glyndon Fife (Minn. No. 163).	30	30	3	3	S	S	

Group 9.—AWNLESS, GLUMES PUBESCENT.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Seedlings. Number inoculated.	Seedlings. Number infected.	Headed plants. Number inoculated.	Headed plants. Number infected.	Type of infection. Seedlings.	Type of infection. Headed plants.	Remarks.
SPRING VARIETIES.										
Common wheat:										
C. I. 2874	.....	.....	Haynes Bluestem (Minn. 169).	30	30	3	3	S	S	

Group 10.—AWNED, GLUMES GLABROUS.

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Seedlings. Number inoculated.	Seedlings. Number infected.	Headed plants. Number inoculated.	Headed plants. Number infected.	Type of infection. Seedlings.	Type of infection. Headed plants.	Remarks.
Durum wheats:										
H3×122A12	.....	.....	Iumillo×Preston	30	29	2	2	R_4toS	R_5	
C. I. 1493	.....	.....	Arnautka	59	49	....	....	R_2toR_4	.....	(*g*).
C. I. 1443	.....	.....	Gharnovka	30	30	....	....	R_3toR_4	.....	(*h*).
C. I. 1513	.....	.....	Beloturka	30	0	....	....	R_1toR_2	.....	(*i*).
C. I. 2094	.....	.....	Kubanka	29	21	6	6	R_2toR_4	R_2	
C. I. 3320	.....	.....	Monad	30	30	....	....	R_5	.....	
				30	30	....	....	R_5	.....	
C. I. 3322	.....	.....	D-5	60	60	....	....	R_4	.....	(*j*).
C. I. 5284	.....	.....	Acme	30	30	3	3	R_5toS	R_5toS	
C. I. 2228	.....	.....	Saragolla	29	29	....	....	R_5toS	.....	

Group 11.—AWNED, GLUMES GLABROUS (WHITE).

Season, class, and identification number.	Kansas No.	C. I. No.	Varietal name.	Seedlings. Number inoculated.	Seedlings. Number infected.	Headed plants. Number inoculated.	Headed plants. Number infected.	Type of infection. Seedlings.	Type of infection. Headed plants.	Remarks.
Emmer and Einkorn:										
C. I. 1524	.....	.....	White Spring emmer.	30	17	3	3	R_2	R_5	(*k*).
C. I. 4781	.....	.....	.....do	30	30	3	3	R_2toR_4	R_1	(*l*).
C. I. 1526	.....	.....	Yaroslav emmer.	30	22	3	2	R_3	R_1	
C. I. 4013	.....	.....	Khapli emmer	30	30	10	10	R_3	R_3	(*m*).
C. I. 3109	.....	.....	"Wild wheat" (*T. hermonis*).	16	16	....	....	S	.....	
C. I. 2433	.....	.....	Common einkorn	30	30	....	....	S	.....	
C. I. 2973	.....	.....	.....do	30	30	....	....	S	.....	

g Uredinia uniformly small.
h Yellowish areas surround uredinia.
i No uredinia; extremely resistant.
j Prominent yellowish areas surround uredinia.
k Heavy infection on mature plant.
l Yellow areas pronounced in some cases.
m Uredinia small; resistant.

All the varieties of winter wheat used can be placed in one of two classes: (1) Those which fail to show visible signs of uredinia and (2) those entirely susceptible. Those of the first group are designated by the symbol R, and those of the second group by S. Among the spring varieties there were different types of infection, these being represented by the symbols R_1 to R_5 and by S. Following is a description of the types of rust infection designated by the symbols:

EXPLANATION OF SYMBOLS USED.

R=Extremely resistant.

R_1=No uredinia produced. Occasionally very small indefinite flecks, dead areas, or yellowish blotches occur. Signs of hypersensitiveness may be present.

R_2=Very rarely the occurrence of minute uredinia (0.1 to 0.5 mm.); presence of flecks, dead areas, or blotches.

R_3=Numerous minute to small uredinia (0.2 to 0.75 mm.); presence or absence of yellowish "islands" surrounding uredinia, or the occurrence of numerous yellow blotched areas surrounding or adjoining uredinia.

R_4=Uredinia numerous, variable in size and number (0.2 to 0.4 mm.); flecked or blotched, yellow areas present; yellow areas adjoining uredinia.

R_5=Uredinia apparently quite normal in size and shape, but presence of yellowish green areas surrounding or adjoining some uredinia indicative of slight resistance.

S=Showing ordinary susceptibility; uredinia large, normal, vigorous.

The inoculations of Kanred, P1066, and P1068 both in the seedling and in the heading stage produced consistent results, indicating extreme resistance.

The hard and soft wheat varieties did not differ strikingly in susceptibility, except in the case of Kanred, P1066, and P1068. The other hard red winter wheats apparently were as susceptible as the soft red winter wheats, although Leach (*24*) found a "decided correlation between the hardness and softness of wheat varieties and their relative susceptibility to *Puccinia graminis tritici-compacti*."

A greater variation occurred among the varieties of durum spring wheat. Beloturka (C. I. No. 1513) seemed to behave very much like the three resistant winter-wheat varieties, in that no uredinia were formed. In more recent work, however, in which the same strain of rust was used, Beloturka (C. I. No. 1513) occasionally has shown a few very small uredinia. Some of the durum varieties showed more or less uniformly the same type of infection (R_2 or R_4) as in the case of Kubanka (C. I. No. 2094), Arnautka (C. I. No. 1493), D–5 (C. I. No. 3322), and Gharnovka (C. I. No. 1443). A Poulard wheat (C. I. No. 4384) manifested a high degree of resistance. Among the emmers there was more or less similarity in the type of infection. The type of infection fluctuated in both of these groups, showing that various factors may affect the infection results. Two White Spring emmers (C. I. Nos. 1524 and 4781) showed the R_2 and R_4 types of infection, while another White Spring emmer (C. I. No.

1526) and Khapli emmer (C. I. No. 4013) seemed to show more consistently the type designated as R_3. Khapli emmer (C. I. No. 4013) is the only variety of spring wheat so far studied that under all conditions seemed to exhibit a high degree of resistance in the field and in the greenhouse. Even this variety, however, may be classed at times as R_2 instead of R_3. The seedlings of the so-called wild wheat of Palestine, *Triticum hermonis* Cook (C. I. No. 3109), really a form of emmer, all proved to be susceptible.

The purple color mentioned under "Remarks" occurred in some varieties and surrounded the uredinia. It does not appear consistently in any one variety. Environmental conditions seem to affect its production.

COMPARISON OF NURSERY AND GREENHOUSE RESULTS.

In general, the results of the greenhouse inoculations were similar to those produced under field conditions in the rust nursery. All of the winter-wheat varieties were found to be susceptible except Kanred, P1066, and P1068. Kansas No. 2390, which appeared to be partially resistant in the rust nursery, gave no evidence of being resistant in the greenhouse.

In the nursery, results on rust behavior usually are obtained on varieties in the heading stage, but in the greenhouse the seedling stage is most commonly used. Determining the resistance of varieties as seedlings is the most convenient method, particularly when a number of distinct biologic strains of rust are being used. It perhaps is the most severe test that can be given a variety and should always serve as a check on nursery results. The results thus obtained, however, scarcely can be considered as the sole criteria of the actual field resistance or susceptibility of a variety; in fact, plants showing certain effects when inoculated in the seedling stage in the greenhouse may respond very differently to the same rust when they are subjected to it in the heading stage under field conditions. No definite statements as to the cause of these differences can be made at this time. The same factors causing resistance or susceptibility may operate in all stages of growth, but the reaction of the host and parasite at various stages of development may be different.

It is possible that time of maturity may have an important influence on the extent of the rust on a given variety, but if the rust is epidemic before the plants reach the heading stage there can be no doubt as to the plants having been exposed to infection. The differences perhaps are due to complex factors in the developmental stages in a variety, which may cause a different response to rust infection. To whatever cause these differences in behavior in the seedling and heading stages may be due, the behavior of any variety

under field conditions is of first importance from the agronomic and plant-breeding viewpoint. The growing of wheat varieties in the rust nursery places them under conditions at least as severe as those to which a commercial field is subjected in a natural epidemic. Field tests must finally determine the value of any variety.

EVIDENCE OF SPECIFIC RUST RESISTANCE.

In the studies made of the resistant varieties, Kanred, P1066, and P1068, it was noted that their reaction to rust infection was entirely different from anything that had been observed in any other variety. Such varieties as Khapli emmer (C. I. No. 4013), White Spring emmers (C. I. Nos. 1524 and 1526 and Minnesota No. 1165), and the resistant durums Kubanka (C. I. No. 2094) and Arnautka (C. I. No. 1493) are known to show resistance in the seedling stage in the greenhouse as well as under field conditions. Their resistance in the seedling stage is shown by the formation of relatively small uredinia, surrounded by yellow or yellowish white areas, the occurrence of minute brown or yellowish dead areas, the presence of yellowish islands, or other characters generally regarded as indicative of resistance or hypersensitiveness. This evidence of resistance is illustrated in Plate XI. All the spring-wheat varieties which the writers have studied and which are classed as highly resistant show such reactions to rust infection, and almost always very distinct uredinia, though frequently small, are formed in inoculated seedlings of these varieties.

Kanred, P1066, and P1068 are unique in their behavior toward *Puccinia graminis tritici*, as hundreds of seedlings and of culms in the heading stage have been inoculated with this strain of rust and not a single uredinium ever has been observed. The entirely rust-free and unflecked inoculated leaves of Kanred and P1066 are illustrated in Plate XI, fig. 1, *A* and *B*. These varieties may be said to be immune[10] from this particular stem rust, if it be assumed that the controlled conditions provided in the greenhouse are as favorable and that exposure to infection is as severe as under natural field conditions, and that seedling inoculations are as severe a test as can be given to a variety. They are certainly more strikingly resistant to *Puccinia graminis tritici* than any other varieties of common wheat (*Triticum vulgare*) which have been studied by the writers.

Because of this specific behavior these varieties have been used as differential hosts in separating certain biologic strains of stem rust of wheat. The inoculation studies with these varieties have been carried over a long period, including every month in the year,

[10] The word "immune" is here used to mean freedom from any macroscopic evidence of rust infection or to designate the inability of the rust fungus to sporulate.

under various temperature conditions and at various stages of development of the plant. The work has been done by different persons at different agricultural experiment stations and always with the same results. The only visible evidence of infection in the seedling stage has been the occasional appearance of very indefinite, scarcely visible, whitish flecks, generally less than 0.1 millimeter in diameter. These indefinite flecks are not similar to the areas or flecks occurring on the seedlings of the resistant emmers and durums (Pl. XI, fig. 2, *C*) and are very much less conspicuous. In this respect these three varieties of winter wheat are distinct in their behavior.

The behavior of Kanred, P1066, and P1068 in the nursery and field is not greatly different from that in the greenhouse. Table 1 shows that these varieties had very low percentages of stem-rust infection, varying in 1916 and 1917 from a trace to 10 per cent. In 1915 the percentages recorded were higher. In view of present knowledge of the existence of several distinct biologic strains of wheat-stem rusts (*38, 39, 40, 41*), this rather heavy infection very probably was due to the use of one or more biologic strains of stem rust similar to, if not identical with, the one recently described by the writers (*30*).

When mature culms of the three resistant varieties were inoculated in the greenhouse with cultures of *Puccinia graminis tritici*, a response on the part of the host to the rust infection was only occasionally visible. Slightly yellowish or brownish white minute dead areas were sometimes vaguely visible, indicating that infection had occurred but that the organism had ceased to develop.

The results reported in this bulletin establish the fact that Kanred and two other very similar pure lines of hard red winter wheat are resistant to certain biologic strains of black stem rust.

More recent studies (*25, 30, 41*) have shown that these varieties are not resistant to all the known strains of stem rust. Extensive field observations made in 1919 and 1920 have indicated, however, that Kanred is much less severely injured by most of the stem-rust strains occurring in Kansas than are Turkey and Kharkof, the other varieties commonly grown. Reports from Wisconsin, Alabama, Nebraska, New York, Illinois, Missouri, Iowa, California, and New South Wales (Australia) indicate that these three varieties have shown resistance to stem rust, while the Minnesota and the South Dakota agricultural experiment stations report them rather severely rusted, although in South Dakota Kanred showed less rust than Turkey. Because of the existence of distinct strains of stem rust it is probable that the behavior of these varieties will vary in different seasons and in various sections of the country.

RESISTANCE TO LEAF RUST.

Observations (*31*) made at Manhattan, Kans., during the 5-year period from 1915 to 1919, inclusive, and field notes recorded in all sections of the State in 1919, 1920, and 1921 show that these three pure lines of Crimean wheat are remarkably resistant also to leaf rust (*Puccinia triticina*) as it occurs in Kansas. Mains and Jackson (*27*) also have found these three varieties to be very resistant to leaf rust under field conditions and where the plants were approaching the heading stage. According to these workers, however, seedlings of these varieties do not prove to be resistant to leaf rust when inoculated and maintained under greenhouse conditions.

The resistance to leaf rust has been manifested also in experimental field sowings made in the States of Alabama, California, Missouri, North Carolina, North Dakota, Oregon, South Dakota, Tennessee, Texas, Virginia, and Wisconsin, and also in New South Wales, Australia. Present knowledge of the leaf-rust problem and the records from a wide range of sowings subjected to severe epidemics of leaf rust indicate rather definitely that Kanred, P1066, and P1068 will maintain this high degree of resistance under a wide range of conditions. It should not be supposed, however, that the resistance of these varieties to leaf rust will be absolute under all conditions or in the presence of all the biologic strains of leaf rust which may exist.

AGRONOMIC VALUE OF KANRED WHEAT.

Kanred wheat presents a unique combination of desirable agronomic characters, a fact which is of even greater significance than its resistance to rusts. Jardine (*19*) described the origin and history of Kanred wheat and called attention to its higher yield, earliness, and cold resistance.

Call and Salmon (*6*) state that "at Manhattan, the average production of Kanred has been 4.5 bushels per acre more than Turkey and 4.7 bushels more than Kharkof." It has outyielded these varieties in every season but one and in that season (1914) practically equaled the others. Salmon (*36*) presents further experimental data on the superiority of Kanred and gives statements regarding the value of Kanred from a large number of farmers who have grown the new variety.

It is estimated that at least 1,500,000 acres were sown to Kanred wheat in Kansas in the fall of 1920, and it is expected that within a few years this variety will occupy a large percentage of the hard winter-wheat acreage of Kansas. If the area sown to Kanred should reach 7,000,000 acres and the yield should be increased 3 bushels per acre, with wheat selling at $1 per bushel, other factors remaining unchanged, the annual value added to the Kansas wheat

crop as a result of the production of Kanred wheat would be $21,000,000. A statement of the agronomic value of this variety will be found in Circular 194 of the United States Department of Agriculture.

Although the problem of breeding wheat for resistance to stem rust has been greatly complicated by recent discoveries of a number of distinct biologic strains of rust which are present in the several grain-growing regions, Kanred wheat in the future probably will prove of great value as a parental variety in crosses, for it certainly contains factors for resistance to some strains of leaf rust and stem rust. There is good evidence that these factors are transmitted in wheat hybrids in the same general way as the factors for other characters. Kanred wheat is being used by the Tennessee Agricultural Experiment Station as the rust-resistant parent in a series of crosses with adapted varieties of soft red winter wheat, in the hope of producing varieties of soft red winter wheat resistant to leaf rust and otherwise equal to the best varieties now being grown, which are often severely damaged by leaf rust. Kanred also has been used at the Kansas and Minnesota Agricultural Experiment Stations as a parent in a large number of crosses. It is too early to make any predictions as to the value of any of these hybrids, although several of them appear promising.

SUMMARY.

(1) Field experiments to determine the resistance to black stem rust (*Puccinia graminis tritici*) of about 100 varieties and strains of winter wheat, many of them pure-line selections, and of a few varieties of spring wheat, were conducted in a rust nursery at Manhattan, Kans., in 1915, 1916, and 1917. Greenhouse experiments were conducted during the winter of 1916–17, using the same varieties. Special methods were developed for producing rust epidemics under the prevailing climatic conditions of Kansas.

(2) In the rust nursery severe epidemics were produced each season, and the percentage of rust infection probably represented the maximum rust attack which the varieties would encounter under field conditions.

(3) All the winter-wheat varieties grown were found to be susceptible to stem rust except Kanred and two very similar pure-line selections, P1066 and P1068. These three varieties were found to be resistant. Another pure-line strain, Kansas No. 2390, gave evidence of being partially resistant.

(4) Plumpness of kernels usually is reduced by severe rust attack. The three resistant varieties produced grain of good quality in 1916 and 1917, when other varieties grown under the same conditions but much more severely rusted produced very badly shrunken kernels.

(5) Several varieties of spring wheat proved rust resistant under the conditions of these experiments, though the Black Persian was the only spring-wheat variety of the common or bread-wheat group (*Triticum vulgare*) which was found to be resistant. Of the varieties of durum or macaroni wheat (*Triticum durum*), Beloturka (C. I. No. 1513), Iumillo (C. I. No. 1736), Kubanka (C. I. No. 2094), Monad (D-1), and Pentad (D-5) showed definite signs of resistance to stem rust. A hybrid of Iumillo × Preston, resembling the durum parent, also was found to be rust resistant. All of the strains of emmer and einkorn grown gave some evidence of resistance.

(6) In the greenhouse experiments the plants were studied for rust resistance at two stages of growth, viz, as seedlings and at the time of heading. The results were very similar to those in the field experiments. All the winter-wheat varieties were susceptible except three—Kanred, P1066, and P1068. Kansas No. 2390, which appeared to be somewhat resistant in the field, showed no evidence of resistance at either stage of growth in the greenhouse. Most of the spring-wheat varieties which the field experiments had shown to be resistant also gave more or less evidence of resistance under greenhouse conditions. This was not true, however, of einkorn.

(7) Although the results obtained in the field and those in the greenhouse agree fairly well, final conclusions as to rust resistance of a variety should not be drawn from greenhouse tests alone. The combined evidence from nursery experiments and inoculations of seedlings and of plants in the heading stage under greenhouse conditions is much more likely to agree with actual field trials, which must always be the final test of the practical value of any variety.

(8) The behavior of the rust parasite on the inoculated plants of the three resistant varieties—Kanred, P1066, and P1068—seems to be different from that in other varieties described as resistant. In most other varieties prominent flecks are nearly always present in 8 to 12 days after inoculation, and most frequently small uredinia are produced. In these three varieties, however, flecks are very rarely visible, and in no instance have even the most minute uredinia been observed.

(9) Reports from Alabama, California, Illinois, Iowa, Missouri, Nebraska, New York, Wisconsin, and New South Wales indicate that these three varieties are resistant to stem rust; but Minnesota and South Dakota report them rather severely attacked by stem rust. The occurrence of distinct strains of stem rust complicates the problem of predicting what their behavior may be during different seasons. Present knowledge of the distribution of stem-rust strains and whether they occur each season in definite regions is so limited that the resistance or susceptibility of these wheats in any region may differ from season to season.

(10) The very light infection of leaf rust in sowings made in Alabama, Arkansas, California, Missouri, North Carolina, North Dakota, Oregon, South Dakota, Tennessee, Texas, Virginia, and Wisconsin, and in New South Wales has proved that these three varieties are extremely resistant to leaf rust also. Present knowledge of the leaf-rust problem indicates rather definitely that these varieties will maintain this high degree of resistance under a wide range of conditions.

(11) Kanred, one of the three rust-resistant pure lines, has an unusual combination of desirable characters. In Kansas it yields from 3 to 5 bushels more per acre than either Turkey or Kharkof, the varieties commonly grown. It ripens a little earlier, thus escaping some of the damage from drought and hot winds during the ripening period. Kanred also seems to be more winter hardy in Kansas than other varieties and survives the severe winters with less loss from winterkilling. In milling and baking quality it apparently is equal to Turkey and Kharkof, varieties of hard red winter wheat which have established a world-wide reputation for quality.

(12) Experiments and the experience of large numbers of farmers have shown that Kanred is adapted to other sections of the hard winter-wheat area, and it is now rapidly being introduced and widely grown in Oklahoma, Texas, Nebraska, eastern Colorado, and some other States.

(13) Kanred wheat is believed to have considerable potential value also as a parental variety to be used by plant breeders in combining its rust resistance and other valuable characters with those of the varieties of other classes of wheat adapted to the several wheat-growing districts.

LITERATURE CITED.

(1) Anderson, H. C. L.
1890. Rust in wheat. Experiments and their objects. *In* Agr. Gaz. N. S. Wales, v. 1, pt. 1, p. 81–90, illus.

(2) Biffen, R. H.
1907. Studies in the inheritance of disease resistance. *In* Jour. Agr. Sci., v. 2, pt. 2, p. 109–128.

(3) Bolley, H. L.
1889. Wheat rust. Ind. Agr. Exp. Sta. Bul. 26, 19 p., 9 fig.

(4) 1905. Experiments and studies upon wheat. *In* No. Dak. Agr. Exp. Sta. 15th Ann. Rpt. 1904, p. 34–54, 1–5 fig. (on pl.).

(5) 1909. Some results and observations noted in breeding cereals in a specially prepared disease garden. *In* Amer. Breeders' Assoc. Rpt., v. 5 (1908), p. 177–182.

(6) Call, L. E., and Salmon, S. C.
1918. Growing wheat in Kansas. Kans. Agr. Exp. Sta. Bul. 219, 51 p., 11 fig.

(7) Carleton, Mark Alfred.
1903. Culture methods with Uredineæ. *In* Jour. Appl. Micros. and Lab. Methods, v. 6, no. 1, p. 2109–2114.

(8) 1905. Lessons from the grain-rust epidemic of 1904. U. S. Dept. Agr., Farmers' Bul. 219, 24 p., 6 fig.

(9) ——— and Chamberlain, Joseph S.
1904. The commercial status of durum wheat. U. S. Dept. Agr., Bur. Plant Indus. Bul. 70, 70 p., 1 fig., 5 pl.

(10) Clark. J. Allen, Martin, John H., and Smith, Ralph W.
1920. Varietal experiments with spring wheat on the northern Great Plains. U. S. Dept. Agr. Bul. 878, 48 p., 2 fig., 3 pl. Publications on cereals in the Great Plains area, p. 48.

(11) Eriksson, Jakob, and Henning, Ernst.
1896. Die Getreideroste. Ihre Geschichte und Natur sowie Massregeln gegen dieselben. vii, 463 p., 5 fig., 13 col. pl., 1 col. tab. Stockholm. Litteraturverzeichnis, p. 446–457.

(12) Freeman, E. M., and Johnson, Edward C.
1911. The rusts of grains in the United States. U. S. Dept. Agr., Bur. Plant Indus. Bul. 216, 87 p., 2 fig., 1 pl. Bibliography, p. 79–82.

(13) Hayes, H. K., Parker, John H., and Kurtzweil, Carl.
1920. Genetics of rust resistance in crosses of varieties of Triticum vulgare with varieties of T. durum and T. dicoccum. *In* Jour. Agr. Research, v. 19, no. 11, p. 523–542, pl. 97–102. Literature cited, p. 541–542.

(14) Henning, Ernst.
1894. Några ord om olika predisposition för rost å säd. *In* K. Landtbr. Akad. Handl. och Tidskr., årg. 33, p. 205–217.

(15) Henslow, J. S.
1841. Report on the diseases of wheat. *In* Jour. Roy. Agr. Soc. England, v. 2, p. 1–25.

(16) HITCHCOCK, A. S., and CARLETON, M. A.
1893. Preliminary report on rusts of grain. Kans. Agr. Exp. Sta. Bul. 38, 14 p., 3 pl.

(17) 1894. Second report on rusts of grain. Kans. Agr. Exp. Sta. Bul. 46, 9 p.

(18) HUTCHESON, T. B., and QUANTZ, K. E.
1917. The effect of greenhouse temperatures on the growth of small grains. *In* Jour. Amer. Soc. Agron., v. 9, no. 1, p. 17–21, 1 fig., 2 pl.

(19) JARDINE, W. M.
1917. A new wheat for Kansas. *In* Jour. Amer. Soc. Agron., v. 9, no. 6, p. 257–266.

(20) JOHNSON, EDWARD C.
1911. Methods in breeding cereals for rust resistance. *In* Proc. Amer. Soc. Agron., v. 2 (1910), p. 76–80.

(21) 1912. Cardinal temperatures for the germination of uredospores of cereal rusts. (Abstract.) *In* Phytopathology, v. 2, no. 1. p. 47.

(22) KELLERMAN, W. A.
1903. Uredineous infection experiments in 1902. *In* Jour. Mycol., v. 9, no. 65, p. 6–13.

(23) LA COUR, J. C.
1863. Sygdommene i kornet og midlerne derimod. *In* Tidsskr. Landøkon., Raekke 3, Bd. 11, p. 249–264.

(24) LEACH, JULIAN G.
1919. The parasitism of Puccinia graminis tritici Erikss. and Henn. and Puccinia graminis tritici-compacti Stak. and Piem. *In* Phytopathology, v. 9, no. 2, p. 59–88, pl. 4–6.

(25) LEVINE, M. N., and STAKMAN, E. C.
1918. A third biologic form of Puccinia graminis on wheat. *In* Jour. Agr. Research, v. 13, no. 12, p. 651–654.

(26) LITTLE, W. C.
1883. Report on wheat-mildew. Jour. Roy. Agr. Soc. England, ser. 2, v. 19, p. 634–691.

(27) MAINS, E. B., and JACKSON, H. S.
1921. Two strains of Puccinia triticina on wheat in the United States. (Abstract.) *In* Phytopathology, v. 11, no. 1, p. 40.

(28) MELCHERS, LEO E.
1915. A way of obtaining an abundance of large uredinia from artificial culture. *In* Phytopathology, v. 5, no. 4, p. 236–237.

(29) ——— and PARKER, JOHN H.
1918. Three varieties of hard red winter wheat resistant to stem rust. (Abstract.) *In* Phytopathology, v. 8, no. 2, p. 79.

(30) 1918. Another strain of Puccinia graminis. Kans. Agr. Exp. Sta. Circ. 68, 4 p.

(31) 1920. Three winter wheat varieties resistant to leaf rust in Kansas. *In* Phytopathology. v. 10, no. 3, p. 164–171, 3 fig. Literature cited, p. 171.

(32) MELHUS, I. E., and DURRELL, L. W.
1919. Studies on the crown rust of oats. Iowa Agr. Exp. Sta. Research Bul. 49, p. 115–144, 6 fig. Bibliography, p. 143–144.

(33) NILSSON-EHLE, H.
1911. Kreuzungsuntersuchungen an Hafer und Weizen. II. *In* Lunds Univ. Årsskr., n. f., afd. 2, bd. 7, nr. 6, 84 p. Literaturverzeichnis zu der Einleitung, p. 20.

(34) PARKER, JOHN H.
1918. Greenhouse experiments on the rust resistance of oat varieties. U. S. Dept. Agr. Bul. 629, 16 p., 2 fig., 3 pl. Literature cited, p. 16.

(35) RUST IN WHEAT CONFERENCE.
1891–92. Report of the proceedings, 2d–3d session, 1891–92. Sydney (N. S. Wales), Adelaide (S. Australia).

(36) SALMON, S. C.
1919. Establishing Kanred wheat in Kansas. Kans. Agr. Exp. Sta. Circ. 74, 16 p., 7 fig.

(37) STAKMAN, E. C.
1914. A study in cereal rusts. Physiological races. Minn. Agr. Exp. Sta. Bul. 138, 56 p., 9 pl. Bibliography, p. 50–54.

(38) ——— and HOERNER, G. R.
1918. The occurrence of Puccinia graminis tritici-compacti in the southern United States. *In* Phytopathology, v. 8, no. 4, p. 141–149, 2 fig.

(39) ——— LEVINE, M. N., and LEACH, J. G.
1919. New biologic forms of Puccinia graminis. [Preliminary paper.] *In* Jour. Agr. Research, v. 16, no. 3, p. 103–105.

(40) ——— and PIEMEISEL, F. J.
1917. Biologic forms of Puccinia graminis on cereals and grasses. *In* Jour Agr. Research, v. 10, no. 9, p. 429–496, pl. 53–59.

(41) UNITED STATES DEPARTMENT OF AGRICULTURE.
1920. Kanred wheat epoch-making for Kansas ... *In* U. S. Dept. Agr. Weekly News Letter, v. 8, no. 6, p. 6.

(42) WALDRON, L. R., and CLARK, J. A.
1919. Kota, a rust-resisting variety of common spring wheat. *In* Jour. Amer. Soc. Agron., v. 11, no. 5, p. 187–195, pl. 7.

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