PREVALENCE AND DISTRIBUTION OF PHYSIOLOGIC RACES OF LEAF RUST OF WHEAT IN KANSAS, 1940-51

by

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TABLE OF CONTENTS

INTRODUCTION

Disease is one of the most important of many factors limiting the production of wheat in Kansas. Leaf rust, *Puccinia rubigo-vera tritici* (Eriks. and E. Henn.) Carleton, is one of the most abundant and widely distributed diseases, and is the cause of some loss in yield nearly every year. In some years the losses may be quite severe (18), depending mainly upon favorable environment and extensive acreage of susceptible varieties of wheat. The only practicable method of control is breeding for resistance, and this method of control has been used extensively in the control of the disease.

The breeding for resistance is complicated by the occurrence of so many physiologic races of the fungus. The latest revision of the International Register of physiologic races of leaf rust of wheat (15) lists 132 described races. Of these, 46 have been found in Kansas since 1940. However, only a few of these races occur each year in considerable abundance. If a breeding program is to be successful, these races must be known and carefully considered.

Studies on the prevalence and distribution of the physiologic races of leaf rust of wheat in Kansas have been carried on for many years, but until the present time, the data obtained have not been fully analyzed. This work presents the results of the analysis of data compiled during the period 1940 to 1951 inclusive.

The studies discussed herein were divided into two phases,

1. the culturing and physiologic race analysis of a large number of leaf rust collections made in the field in Kansas in 1951, and 2. a complete analysis of all physiologic races isolated from Kansas collections each year during the period 1940 to 1951 inclusive.

REVIEW OF LITERATURE

Leaf rust has long been recognized as a common and widely distributed disease of wheat as pointed out by Carleton (6) in 1898. The disease was then commonly called "orange leaf rust" of wheat. Carleton noted the presence of this disease in Kansas in 1898 and observed that some injury seemed to be caused by the rust in eastern Kansas, but comparatively little injury resulted in the western part of the state.

Several workers in the early 1920's noticed what seemed to be different forms of the disease that had different reactions on different varieties of wheat. The first definite step toward differentiation of these forms came in 1926 when Mains and Jackson (17) described 12 physiologic forms of the fungus as a result of testing 200 varieties of wheat. From the 200 varieties tested with rust collections from all parts of the United States, 31 showed variability in reaction. They chose 7 of these wheat varieties to use as differentials, and later increased the number to 11 varieties, with which they isolated the 12 distinct physiologic forms. Since then work has been done in many parts of the world in the classification of physiologic races. A few years after the original work on physiologic races, Johnston and Mains (11) added 25 new forms of the fungus and these combined with 8 races found by other workers increased the total to 53 physiologic races. The additional races were added as a result of experiments with 8 differential varieties of wheat; four of winter habit and four of spring habit. The other three varieties which had been used by Mains and Jackson were not used because it was shown that they exhibited reactions similar to some of the eight differential varieties retained and therefore were of no particular value in race determination. The varieties of winter habit used by Johnston and Mains were Malakof (C.I. 4898), Mediterranean (C.I. 3332), Hussar (C.I. 4843), and Democrat (C.I. 3384). Those of spring habit were Webster (C.I.3780), Carina (C.I. 3756), Brevit (C.I. 3778) and Loros (C.I. 3779). These varieties have been used since that time and the latest revision of the International Register of physiologic races of leaf rust of wheat (15) lists 132 races of leaf rust identified by the use of these 8 varieties.

Race determination is based on the physiologic raction of the differential wheat varieties to the rust fungus. The reactions based on infection types varying from 0 to 4 were described by Mains and Jackson in 1926 (17) as follows:

> <u>0-Highly resistant</u>- No uredinia formed: small flecks, chlorotic or necrotic areas more or less prevalent.
>
> <u>1-Very resistant</u>- Uredinia few, small, always in small necrotic spots. Also more or less necrotic areas produced without development of uredinia.
>
> <u>2-Moderately resistant</u>- Uredinia fairly abundant, of moderate size, always in necrotic or very chlorotic spots. Necrotic spots seldom without uredinia.

<u>3-Moderately susceptible</u>- Uredinia fairly abundant, or moderate size. No necrosis is produced, but sometimes slight chlorosis immediately surrounding the uredinia.

<u>4-Very susceptible</u>- Uredinia abundant, large. No necrosis or cholorsis immediately surrounding the uredinia. Infected areas sometimes occurring as green islands surrounded in each case by a chlorotic ring.

Another type of reaction occurring on wheat has been described by Stakman and Levine (22). This type encountered first with stem rust is heterogenous in pustule type and has been called the mesothetic or "X-type" reaction. They define it as follows:

> Uredinia very variable, apparently including all types and degrees of infection on the same blade; no mechanical separation possible; on reinoculation small uredinia produce large ones, and vice versa. Infection ill defined.

Some writers have expressed the opinion that most of the 132 physiologic races may be grouped into a relatively few "race-groups", these being groups of races that may duplicate the reactions of others when subjected to certain environmental conditions. One such advocate is Chester (8) who with his work and that of others listed several race-groups that were made up of closely related races. For example, the race-group 5 is made up of physiologic race 5 and physiologic race 52, which can be distinguished only by a reaction on Hussar, a differential variety that may readily vary in susceptibility with changes in environment. Another such example is race-group 9, made up of physiologic races 9, 10, 13, 19, 20, and 31, which can be distinguised as separate races only under certain environmental conditions. It is quite evident that many of the present described physiologic races are duplicates of prior races, but described under different environmental conditions. Newton and Johnson (19) tested the effect of light and temperature on the reaction of varieties used for race determination, and found that Malakof and Democrat become increasingly susceptible with lower temperatures, while Carina, Brevit, and Hussar become increasingly resistant. Webster and Mediterranean did not react consistently in either direction, and Loros showed very little change in reaction due to temperature changes. All of the differential varieties showed a more or less marked tendency to become increasingly resistant with conditions of short day and weak light. In general it appeared that temperatures affected the reactions more than did light. The phases of the rust seemed to develop more rapidly in warmer temperatures than in cooler.

The occurrence of the various physiologic races in Kansas has been studied for many years; however, the first list of the races present in the state was drawn up by Johnston and Mains (11) in 1929. They listed physiologic races 9, 37, 36, 5, 38, 1, 3, 11, 20, and 39 as being present in Kansas in 1928. The list was drawn up as to race prevalence, race 9 being the most prevalent. In 1929, physiologic races 9, 13, 5, 2, 3, 29, 30, 31, 35, 40, 41, and 42 were found in that order. The next report of prevalence in this area of the various races appeared in 1948 and included all the physiologic races found in the Great Plains area from 1938 to 1943 inclusive (14). Physiologic races 1, 2, 5, 6, 9, 10, 11, 13, 15, 19, 20, 28, 31, 37, 40, 44, 64, 84, 103, 105, 112, and 128 were found, and race 9 was the most prevalent.

Loss in yield in Kansas due to leaf rust has been variously estimated. Melchers (18) in 1917 stated that losses in Kansas fields ran as high as 38 percent on some susceptible varieties of wheat. Under these conditions the foliage infection was generally 100 percent in this particular season. He expressed the belief that too little stress was being given to the importance of this rust. Under epiphytotic conditions produced in the greenhouse, Johnston and Miller (13) found that under greenhouse conditions leaf rust reduced the yield of susceptible varieties of wheat from 42.4 percent to 93.8 percent, depending upon the length of infection period and time of infection. Under the same conditions it was found that abundant flecking of resistant varieties resulted in a maximum of 15.2 percent reduction in yield. Caldwell et al. (4), (5) estimated that grain losses ranged from 14.8 percent to 28.4 percent in epiphytotic conditions in the field. These estimates are a bit higher than that of Waldron (23) who estimated the average maximum loss at about 13 percent. However, he noted that two susceptible varieties showed losses of 19 percent and 28 percent due to leaf rust infections. Notwithstanding the extremities of estimates it seems safe to say that in some years the yield is reduced as much as 20 percent.

The loss of yield has been due mainly to two factors, either decrease in the number of kernels or decrease in the kernel weight as shown by Mains (16), Johnston and Miller (13), Caldwell et al. (5), and Waldron (23). Whether the loss is due to decreases in kernel weight or decrease in the number of kernels seems to be determined by the stage of development reached by the plant before the rust becomes severe (20). Mains (16) stated that the correlation of reduction of the number of kernels with the relative time of blossoming is very good, indicating that stage of development of the plant when infected seems to determine the cause of yield losses.

It is also evident that protein content of grain is affected by leaf rust. Caldwell et al. (5), Waldron (23), Peterson, Newton, and Whiteside (20), found that the protein content of grain is lowered considerably by heavy leaf rust infections, and resistant varieties showed a much higher protein content than comparable susceptible varieties when subjected to leaf rust infection. Experiments indicated that environmental conditions determine to a great extent how much protein content of the grain is reduced as a result of leaf rust infection (20).

Losses in yield due to leaf rust even if rather light may be of very important consequence in regions such as Kansas, Oklahoma, Nebraska, etc., where extremely large acreages of wheat are planted, as pointed out by Mains (16). The losses may be affected by time of planting due to the fact that some varieties of wheat require considerable time before exhibiting their maximum maturity resistance (20). Studies along this line were carried on by Johnston and Melchers (12) who observed that several varieties showed increasing resistance if infected later in the growth of the plant. Many varieties which showed susceptibility in the seedling stage exhibited considerable resistance if they remained free from infection until the boot stage or even more so if inoculated in the heading stage. If planting is late, the wheat may fail to develop resistance in time to protect it from severe leaf rust infection.

Johnston and Miller (13) observed that heavy leaf rust infection on susceptible varieties resulted in excessive production of green tillers about the time of maturity of the primary tiller. They also noticed that heading was retarded and the fruiting period was lengthened in susceptible varieties.

The observations on water requirements of infected wheat are rather conflicting. Johnston and Miller (13) reported that the water requirements of susceptible varieties increased 31.7 percent to 104 percent, and resistant varieties showed only very slight increases in water requirement. Weiss (24) on the other hand, stated that under epiphytotic conditions there was but slightly more water used by the plant. Such disagreements point to the necessity of further research on this subject.

Environmental conditions favorable to epiphytotic conditions are generally about the same as those listed by Chester (7) as occurring in Oklahoma during the 1938 epiphytotic in that state. He states that heaviest infections occur under warm, moist conditions of early spring and summer, with a sufficient supply of overwintered inoculum and an extensive acreage of susceptible wheat varieties. With these conditions he estimated the losses due to leaf rust in Oklahoma from 30 percent to 50 percent in 1938.

The presence of so many physiologic races, and the occurrence of new races has been of great interest to plant pathologists. The heterothallic nature of both stem rust and leaf rust suggests the possible role of hybridization in the production of new physiologic races. Craigie (9) proved that new races of the stem rust of wheat (Puccinia graminis tritici) on the barberry arose by hybridization. Mains and Jackson (17) proved the heterothallism of leaf rust (P. rubigo-vera tritici) and it was also studied by Allen (1). The alternate hosts were found to be certain species of Thallictrum; however, the susceptible species are European and do not occur in the Great Plains area and seldom in the United States except in ornamental plantings, and therefore formation of new races cannot be attributed to this cause, as pointed out by Allen (1) and Johnston and Mains (11). If the alternate host is not the means of race variation, then it seems not at all unlikely that leaf rust might have developed an alternate means of variation such as interchange of nuclei in hyphal fusions, or mutation. Both of these require further study before definite conclusions may be made. Brown and Johnson (3) suggest that there may be a possibility that leaf rust might have its alternate stage on certain other species of "ranunculaceous genera". Chester (8) mentions publications from Russia in which the authors state that the alternate host in Eastern Siberia is Isopyrum fumariodes. However, other experiments in other countries have failed to substantiate this view.

The possibility of a mutation causing the appearance of a new race was strongly suggested by the occurrence of an "aberrant" physiologic form of leaf rust isolated by Johnston (10) in 1927. The form occurred on a supposedly resistant wheat variety. It differed from any known physiologic race in spore color, spore size, uredinia size, and length of incubation period. On standard differential varieties the reaction was different from any known physiologic form. The incubation period for this aberrant form was about 7 days longer than for others.

Another possible means of the occurrence of new physiologic races has been suggested by Rodenhiser and Hurd-Karrer (21). They observed fusion of rust hyphae first on nutrient agar and then on host plants of wheat. If these fusions do occur between hyphae of different physiologic races, this may account for the large number of physiologic forms in areas where the aecial stage is rarely, if ever, present. However, Brown and Johnson (3), as a result of their research, mention that the possibility of nuclear exchanges between mycelia of different races in the uredial stage does not seem probable. Further studies along these lines must be undertaken before definite conclusions are reached.

As far as prevalence of the disease is concerned, only the uredial stage is of importance in Kansas. It was noticed as early as 1889 (2) that leaf rust of wheat overwinters in the uredial stage in the tissues of the young wheat plants. Sometimes the uredia are not visibly present, but the mycelial growth remains within the leaves.

One of the earliest suggestions for control and still the most important control of the disease was the growth of resistant wheat varieties. Bolley (2) suggested in 1889 that some varieties showed more resistance than others to leaf rust infection. This method of control has remained the only practical one and is used extensively in control of the disease.

MATERIALS AND METHODS

The collections used in accumulation of data analyzed in this paper were made in various ways throughout the period of research. In general, the methods were of two types. One type, and probably the most important, was the collection of wheat leaves which showed a uredial infection. In most cases these leaves were placed in an envelope, preferably glasine bags, and the leaves drawn out to a flat position. Such samples either were sent immediately to the plant research laboratory at Kansas State College or pressed and dried in a book for two or three days and then sent. In all cases the date and place of collection were included with the collection and where possible the host variety of wheat was named. The collections upon reaching the rust research laboratory were placed in a refrigerator and cooled at approximately 45 degrees F. and allowed to remain there until such a time as they could be tested for physiologic race content.

The other method of collection was used during the winter and early spring periods. In this method, wheat brought into the greenhouse for any purpose was examined for possible infection, and if an infection was noticed, the spores immediately were scraped from the pustule with a moistened spatulate tipped needle and placed in suspension in a drop of water. These spores in suspension then were immediately transferred to a susceptible host variety (usually Cheyenne) in the seedling stage, and this inoculated seedling plant placed in a moist chamber.

All seedling plants used in the determination of physiologic races were grown in small clay flower pots, either the 2 1/2 inch or 3 inch size. In all cases the seedlings used for race differentiation were grown in 2 1/2 inch pots.

The identifications of physiologic races were carried on in the greenhouse from about October or November to the end of April. The principal reason for this limited time is that greenhouse temperatures before and after those times are too high for favorable study. Furthermore, the higher temperatures sometimes cause a wilting of the seedling plants so as to make accurate readings very difficult and often modify infection types, thus giving unreliable results. Collections made after April and before October therefore were allowed to remain in the refrigerator until the following fall. In this type of collection it was found necessary to be positive that all leaves were flattened before storage, because after a few days the leaves become brittle and shatter readily when handled.

Collections of this type were removed from the refrigerator, placed on a clean white sheet of paper so that the upper infected portion of the leaf was exposed. The exposed leaf surface on which the uredial pustules occurred was then carefully scraped with a moistened spatulate-tipped needle, and the needle point immersed in a droplet of distilled water on a glass microscope slide. This allowed the loose spores to distribute themselves freely in the water. Following this one of two steps was employed. If the inoculum was sufficient, it was transferred by the use of the spatulate needle to a set of differential varieties. This method also was used with collections from fresh material if the amount of inoculum was sufficient.

If in either case the amount of inoculum was small, it was transferred either to a half series (2 winter and 2 spring wheat differential varieties), or to a susceptible variety such as Cheyenne upon which the inoculum was increased. In every case the leaves of the seedling were rubbed with moistened finger-tips to remove the waxy coating that is present on the surface. The most favorable size of seedling with which to work was found to be one in which the first secondary leaf was just beginning to emerge. Under normal conditions this is about 7 to 9 days after planting. Only primary leaves were used for inoculations.

Care was exercised to prevent mixtures and cross inoculations in the cultures. After each transfer of a collection, the needle used was flamed to maintain sterile conditions, and the paper on which the leaf was placed for collection of inoculum was discarded. As soon as work on a collection was completed, the hands were thoroughly washed in running water before work was started on the next collection. This removed loose spores and prevented mixtures. All pots of seedlings were labeled so that their identity could easily be distinguished.

Seedlings of the differential varieties and all other plants to be inoculated were started in a separate section of the greenhouse where no rust was grown. They were removed from that section only when needed for inoculation. After inoculation the seedlings were placed in moist chambers, the type of chamber used depending on the area required to adequately contain the number of pots of inoculated plants. If the full sets of differentials were used, moist chambers of heavy galvanized metal about 13-15 inches high and 15 inches in diameter were used. If the half series or only one or two pots of susceptible increase seedlings were inoculated, moist chambers made of 2-gallon crocks were used. In each case, the technique followed was similar to that described by Johnston and Mains (11). Slight modifications were used to facilitate application to this particular work. About an inch of fine sand was placed in the bottom of each moist chamber so that when water was added a high humidity would be maintained throughout the infection period. The sides of the chamber were also moistened in an attempt to maintain the highest humidity possible inside the chamber. It was found that the best results were obtained if the moist chambers were placed under the greenhouse benches behind cloth shades where they were protected from direct sunlight.

After the pots of seedlings were placed in the chambers, the leaves of the plants were moistened with tap water by use of a sprayer. In most cases a two gallon Hudson Junior knapsack sprayer was used. By pumping this up to a rather high pressure a fine mist-like spray which covered the leaves with small droplets of water was obtained. In some cases where only a single pot or a few pots of seedlings were inoculated, a smaller DeVilbiss hand atomizer was used in place of the pressure sprayer. In either case, the plants were sprayed until dew-like droplets formed on the leaf surface. This condition was necessary so that optimum germination of the urediospores could be obtained. It was noticed that the best germination occurred when inoculated seedlings were placed in moist chambers having a free water surface in the bottom.

After the plants were thoroughly moistened, a sheet of ordinary greenhouse glass, approximately 3/8 of an inch in thickness and large enough to cover the top of the moisture chamber, was placed on the top of the chamber so that all edges of the chamber were covered. After covering the chamber the glass and outside of the chamber were usually sprayed to lower the temperatures and produce condensation within the chamber. Under conditions of high temperatures the plants were moistened with the sprayer or atomizer at intervals of about two hours for several hours after they were placed in the moist chambers.

The seedling plants were allowed to remain in the moisture chambers for about 24 hours, after which they were removed and placed on the greenhouse bench. If the material taken from the moist chamber was a half series or an increase on a susceptible variety, from which further isolations were to be made, the pots were kept in isolated compartments to further protect them from outside contamination. Full sets of differential varieties were simply removed from the moist chambers and set on the greenhouse bench next to other inoculated series until uredial formation was complete and they were ready for reading since no further isolations were made from them. This varied with temperature and light conditions from about 10 to 15 days. After this time, uredial infection usually had reached maturity so that inoculated plants could be used to inoculate sets of differential varieties. The differentials had been moistened similarly to the method described previously, and had been arranged so that the leaves were in a position to retain moisture droplets. The infected susceptible variety then was used as a brush and methodically drawn over the leaves of the differential plants. The brushing was used to afford even distribution of spores on all leaf surfaces. The plants in the moist chamber were again atomized and the glass cover placed on the chamber as mentioned before. The differentials were removed after 24 hours and placed on a bench to allow infections to develop.

When the inoculated plants consisted of a half series, readings were made when infections were fully developed after which single pustule isolations were made from each of the four varieties. These were made by using a spatulate tipped needle on which a drop of distilled water was suspended. The moistened needle-tip was placed in contact with an isolated pustule and the spores of that single pustule were drawn up into the drop of water by surface tension. Extreme caution was used to obtain only the spores from one particular pustule as other pustules might be of a different physiologic race. The spores in the drop of water were then transferred to the primary leaves of seedlings of a susceptible variety which had been trimmed of their secondary leaves. Four-inch clay pots were used for these cultures. The seeds in these pots were located at or near the center. There were usually 5 or 6 seedlings per pot. These plants were inoculated by drawing the flat surface of the needle along the flat surface (usually the lower surface, although the upper surface was found to be satisfactory also) of the leaf so that only a thin film of water extended between the needle and the leaf. The suspended spores were deposited on the leaf surface in this manner. The inoculated plants then were placed in moist chambers. It was found that wash tubs were very satisfactory for moist chambers for 4 inch pots when large areas were required. In these moist chambers vermiculite or sand was placed in a layer in the bottom. Over this was placed a hail screen of about 1/4 inch mesh so that the pots would not sink into the material used to retain the moisture. The plants placed in these moist chambers were moistened in the same manner as described earlier.

When single pustule isolations were removed from the moist chamber, a glass lantern globe was placed over the plants in each pot to reduce mixture of cultures. The bottom of the globe was in contact with the soil in the pot. The infections were allowed to develop in these small isolation chambers. After 10 to 12 days the uredia had developed to a stage where the spores could easily be disseminated. At this stage, the single-pustule isolations were used to inoculate full sets of differentials by the brushing method described earlier. After 24 hours the differentials were removed from the chambers and placed on a bench for further observation. All single pustule isolation cultures were kept in case the infection was poor or mixed and the inoculation needed repeating.

After a set of differentials had been allowed to develop pustules, the type of infection on each variety was recorded and the physiologic race content determined by varietal differentiation. Adequate pustule formation for accurate reading usually developed in 10-15 days.

Race determinations were made by using the key supplied in the 3rd revision of the International Register of physiologic races of leaf rust of wheat (15). The physiologic races were keyed by noting the varietal reaction (resistance or susceptibility) of the differential varieties in this order, Malakof, Carina, Brevit, Webster, Loros, Mediterranean, Hussar, and Democrat. A reaction was called susceptible if the readings were of a 3 or 4 type as distinguished by Mains and Jackson (17). The reaction was called resistant if the plants had infection types of 2 or lower. Readings that could not be definitely classed as susceptible or resistant were called intermediate. By classifying each reaction in one or another of these categories, the physiologic race content could be determined. Each set of differentials had a wooden label giving the collection number, the single-pustule isolation from which it was derived, and the date it was inoculated. The readings for each set were recorded in a book and the physiologic race present was recorded. If a culture proved to be a mixture of races, the single pustule isolations were repeated from the stock culture, and the readings repeated. In cases of slight mixtures where the races were easily distinguishable, the reading was recorded along with a notation of "slight mixture".

The accumulation of data thus derived was used in analysis of prevalence and distribution of the physiologic races present in the state of Kansas in 1951.

The second part of the studies discussed herein consisted of summarizing data on the prevalence and distribution of physiologic races of leaf rust in Kansas for the period 1940 to 1951 inclusive. The data had been collected year by year and entered on cards, each card showing the place and date of collection and the variety upon which it was collected wherever possible. These data were combined and summarized by years, geographic location, crop areas, time of collection, etc. The object here was to bring together and summarize data that had been collected over a period of years but which had never been summarized or published in full.

EXPERIMENTAL RESULTS

Studies on the Prevalence and Distribution of Physiologic Races of Leaf Rust in Kansas in 1951

In order to interpret accurately the data accumulated for the past years it seemed imperative that an understanding of the methods of study employed be gained. To achieve this an attempt was made to identify the physiologic races of leaf rust in all collections that were made in Kansas during the 1951 season. There were a much larger number of collections than had been analyzed previously, thus obtaining a more thorough representation of leaf rust in the state than usual. Collections were made from 46 counties throughout the state as shown by Figure 2. The number of collections varied from county to county due to the random collection method used. In general the collections in eastern Kansas were rather limited. The number of collections totaled 90 for the entire state. From the 90 collections made during 1951, 28 races were identified. The occurrence of these races by county in 1951 is shown in Table 1. Although these 28 were identified as separate races, studies showed that many of them were similar to one or another of the few major races. It has been found that in most cases a wheat variety resistant to a major race is also resistant to similar races. This fact has led some workers (8, 19), to consider similar races as race-groups. Further support for race grouping was obtained in greenhouse experiments conducted in 1951. The writer observed that races identified as 10, 13, 19, 20, and 31, respectively, lost their identity under environmental conditions, and when tested later, were recognized only as race 9. Similar observations have been noticed by others, (8, 9). During the same experiments, collections identified as race 52 were later seen to be race 5, this apparent change being due to the difference in the reaction of Hussar, a variety considerably affected by temperature and light conditions.

The concept of race grouping has been followed in this paper, the numbers of the major race-groups being designated by the principle race within the groups.

It was desired to obtain information not only on the prevalence and distribution of physiologic race-groups in the state as a whole, but also in certain parts of the state. Divisions were arbitrarily drawn up, dividing the entire state into 6 more or less equal divisions according to the crop reporting districts used by the federal crop reporting service as shown by the heavy line in Figure 1. Distribution of the four major race-groups within these areas is shown to good advantage in Table 2. Since

Table 1. The occurrence of physiologic races of leaf rust of wheat in Kansas during 1951.

County	Physiologic race and number of times isolated																										
	2	5	6	7	8	9	10	13	15	17	19	20	21	27	28	31	35	42	45	49	52	58	62	77	105	115	126
Barber			1																		3						1
Chautauqua	3	1	3												1												
Coffey	2								1																		
Cowley	1		1																		3						
Douglas	2	5																			1						
Ellis		4					2	2		1	1	7	1					1							2		
Ellsworth												3															
Finney						1			2			1									6				1		
Ford		1									2																
Graham	1							2				3									1						
Gray																1											
Greely						4																					
Harper	2		1												1												
Jewell		3																			2						
Kearney		2				1						2															
Kingman																											3

Table 1. (Continued)

County	Physiologic race and number of times isolated																										
	2	5	6	7	8	9	10	13	15	17	19	20	21	27	28	31	35	42	45	49	52	58	62	77	105	115	126
Labette		4	2												1												5
Lane	1	2				2																					
Leaven-worth		1	3																								
Logan						2			1						1												
McPherson			3																								
Mont-gomery		2	1						1												2						
Neosho		3							1																		
Ness		2				2																					
Norton	1		1		1									1													
Osage																					1						
Osbourne			2												1										1		
Ottawa			2																						1		
Pawnee		4	1						1												3						
Phillips		1	1	1		1			2			3					1				1			1	1		
Republic	1					1		1													2					1	
Rice			5																								

Table 1. (Continued)

County	Physiologic race and number of times isolated																										
	2	5	6	7	8	9	10	13	15	17	19	20	21	27	28	31	35	42	45	49	52	58	62	77	105	115	126
Riley	4	17	8				1		5										2		8	2		1	8		10
Rooks	1						1															1					
Rush	2																				5						
Russell		2	2						1												3			1			
Sedgwick									1												2						3
Sheridan		1				1		1			1																
Sherman		1				1			2			1															
Stafford		2	4				1		1												6		1		1		
Sumner			1									1						1			1						
Thomas		1				3																					
Trego		2									2																
Wabaunsee																									1		1
Wallace		1					1					1								1							
Wichita						1						1												1			

Table 1. (Concluded)

County	Physiologic race and number of times isolated																										
	2	5	6	7	8	9	10	13	15	17	18	20	21	27	28	31	35	42	45	49	52	58	62	77	105	115	126
Wyandotte			1												1										1		
Total number of times isolated	23	62	43	1	1	20	6	6	19	1	6	23	1	1	6	1	1	2	2	1	50	3	1	4	17	1	23
Percentage of total isolates	7.1	19.1	13.3	.3	.3	6.2	1.8	1.8	5.9	.3	1.8	7.1	.3	.3	1.8	.3	.3	.6	.6	.3	15.0	.9	.3	1.2	5.2	.3	7.1

the number of collections from each area varied so much, the computations were made on the basis of percentage of total isolates within each given area. The data shown here indicate that physiologic race-group 5 increased in prevalence from the western areas to the eastern areas, the largest percentage being present in the northeast area. Race-group 9 presents a condition diametrically opposed to race-group 5, that is, race-group 9 is most prevalent in the western areas, diminishing toward the eastern areas. Race-group 9 was not isolated from any of the collections made from the two eastern areas during 1951. The occurrence of race-group 15 in 1951 appeared to be rather well distributed, being slightly more prevalent in the southeast area than in the others. Race-group 126 showed a very pronounced prevalence in the eastern and central areas. Its occurrence in the western areas was very slight. Analysis of the data showed that much of the prevalence of race-group 126 in the central areas occurred bordering, or near the eastern areas, establishing race-group 126 as a prevalent race-group in the eastern part of the state.

Another interesting phase of the work carried on in 1951 was the dominance of different races at different times of the year. For example, race-group 9 showed definite evidence of having very noticeable autumnal occurrence as shown in Table 3. Race-group 126 on the other hand showed just as definite a trend towards spring occurrence. Race-groups 15 and 5 seemed to be rather well established as year round races, though race-group 15 does show a slight degree of autumnal occurrence.

During the 1951 season the occurrence of two minor races was

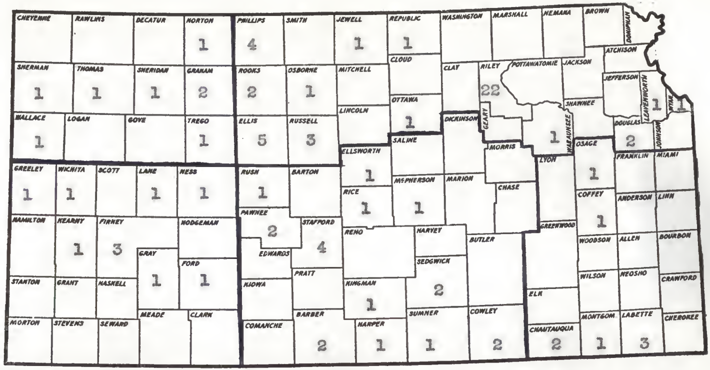

Fig. 1. Map showing the number of collections from each county during 1951. The heavy lines designate divisions of the state into crop areas.

Table 2. The distribution of the four major race-groups within crop areas during the year 1951.

Area	Percentage of isolates of each race-group			
	5	9	15	126
Northwest	27.6	55.0	13.8	2.9
Southwest	37.2	51.5	8.6	3.5
Northcentral	38.1	19.1	10.5	31.4
Southcentral	42.9	7.1	12.9	37.1
Northeast	50.0	0.0	14.3	35.7
Southeast	42.0	0.0	29.0	29.0

especially interesting. Physiologic race 58, which is a very important race in the Ohio Valley and one which could possibly become of considerable importance in Kansas, was very minor in occurrence, being isolated but 3 times in 1951. The other race of interest, 77, was more abundant this year than in the past. Although isolated but 4 times, it could ve a very severe race if it increased sufficiently since nearly all wheat varieties show almost complete susceptibility to this most virulent race.

Studies on Distribution and Prevalence of Physiologic Races of Leaf Rust in Kansas During the Period 1940 to 1951

Data analyzed for the entire 12 year period were obtained by testing 353 collections for their physiologic race content. The collections yielded 1580 single pustule isolations which proved the presence of 46 physiologic races of the leaf rust of wheat in Kansas at some time during the 12-year period. Collections were made from all but 21 of the 105 counties of Kansas as shown in Fig. 2. Though the number of collections varied, more than one collection was generally made during the period from each county. In each case the collection was sent to the plant research laboratory at Manhattan, Kansas, and analyzed for its physiologic race content. The results obtained were filed on cards as a permanent record. Upon analysis of these data certain trends in prevalence and distribution were found to be evident.

Table 3. Prevalence of the 4 major race-groups in fall and spring seasons during 1951.

	Percentage of total isolates for race-group			
Season	5	9	15	126
Fall	39.2	35.1	16.0	6.4
Spring	39.1	7.3	9.8	39.7

The occurrence of the various races from 1940 to 1951 inclusive is shown in Table 4. In addition to those races listed in the table, races 7, 8, 11, 14, 17, 27, 42, 43, 45, 61, 62, 69, 83, 93, 115, and 122 were isolated at some time during the period. They were not included in the table due to the fact that their prevalence did not seem to be important in the state as they were isolated less than twice in the 12 year period.

It was found that of all the races present, only 4 major race-groups were of enough importance to be considered as major races in prevalence and distribution. These 4 race-groups were found to make up 88 percent of the total isolates for the entire period. Race-group 9 was the most abundant followed by 126, 5, and 15 in that order as shown in Figure 3. The prevalence of these 4 major race-groups each year is shown in Figure 4. Race-group 5 as shown was a relatively minor race during the first half of the 12-year period. However, since 1946 it has slowly increased until it has become the most prevalent of the major races in Kansas. Race-group 9 presents a picture of an almost exact opposite in prevalence. It was easily the most dominant race in the first half of the 12-year period, but since 1946 it has diminished gradually to the third most important race in Kansas. The change in prevalence of these two physiologic races is thought to be due to changes in the variety of wheat grown in Kansas. Pawnee wheat, a variety of wheat resistant to race-group 9 and susceptible to race-group 5 was distributed in Kansas in 1944. At the time of the introduction of Pawnee in Kansas race-group 5 was a very minor race in prevalence and distribution. For a few years the acreage of Pawnee was so small that no rapid changes were noticed in the prevalence of the physiologic races. However, when the rapid and great increase in acreage planted to Pawnee wheat took place, race-group 9 slowly faded from prominance as the most prevalent race, and race-group 5 increased in proportions not previously known to Kansas. At present it is estimated that approximately 40 percent of land planted to wheat in Kansas is with Pawnee.

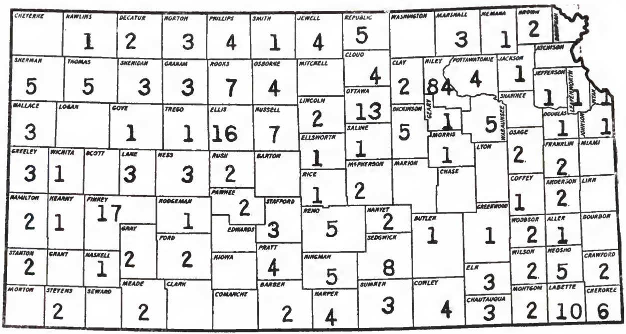

Fig. 2. Number of collections of leaf rust of wheat from various counties in Kansas made during the period 1940-1951 inclusive and analyzed for their physiologic race content.

Table 4. The prevalence of the principal physiologic races of the leaf rust of wheat in Kansas during the period 1940 to 1951 inclusive, expressed as the number of times each race was isolated each year.

Physiologic race no.	Year											
	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951
	Number of times isolated											
2		1					4	3	1	1	1	21
3	4	1				1	4				3	
5	10	2	2		3		28	22	32	61	74	53
6		3	1			1	1	1	13			45
9	30	31	20	20	31	19	35	11	3	35	58	17
10	3	1								1		6
11	1				2							
13	5	2	6	2			2					6
15	8	7	12	3	10	3	6	9	4	9	16	15
19	11	10	13		11	6	6	3	7	7		4
20	3	3	3			3	2		2	8		22
21									1	2	28	1
28	6	2	2					1				5
30							12					
31	4	3	4		2	1		3				1
35	3	1			3	1					4	
37	1	1				1	2	3				
42											2	
44	9	10	8	4	11	8	13	6		1		
45												2

Table 4. (Concluded)

Physiologic race no.	Year											
	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951
	Number of times isolated											
49		6										1
50		1				2	4				4	
52												51
58		2	2			3	1	1	2	2	8	2
61			3									
64	1	11				3						
77							1				1	4
88		12										
93											2	
103	7				1							
105	1	1				6	2	1	33	14	22	10
126		23	8	16	50	24	19	1	27	29	30	21
128			1		4	3	3					

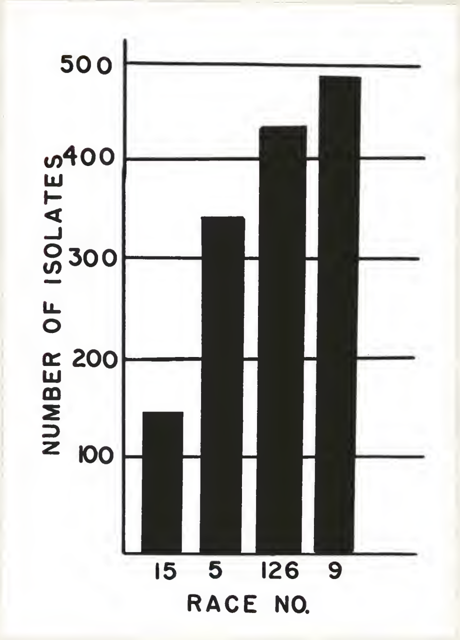

Fig. 3. Total number of isolates for each of the four major physiologic race groups of the leaf rust of wheat made from Kansas collections of leaf rust during the period 1940-51 inclusive.

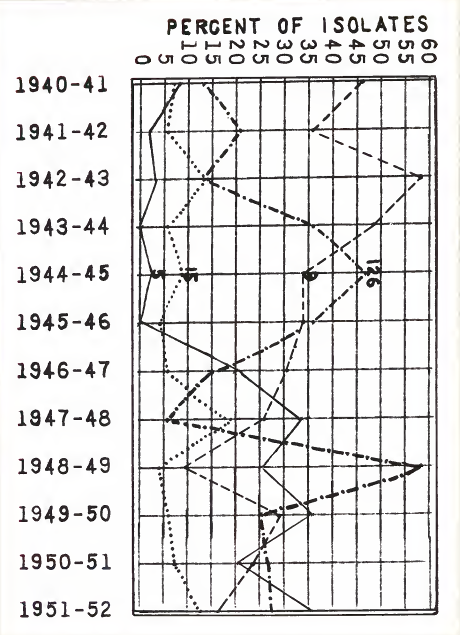

Fig. 4. Percentage of total isolates each year represented by 4 major physiologic race-groups of the leaf rust of wheat isolated from collections made in Kansas during the period 1940-51 inclusive.

Race-group 15 has been more or less stable in its prevalence in Kansas throughout the entire period of investigation. It is probably least important of the 4 major race-groups. Race-group 126 has been very sporadic in its prevalence, being of much importance in some years and of relatively little importance in other years. At the present time it is about the second most important race-group in Kansas.

It was noticed that the major physiologic race-groups seemed to be more prevalent in certain parts of the state than in other parts despite the fact that each race-group occurred to some extent throughout the entire state. Analysis of the data revealed that the race-group 5 was about equally prevalent in all parts of the state, being slightly less prevalent in the northeast area as shown in Table 5. Race-group 9 showed definite evidence of prevalence in the two western areas of the state. This is in keeping with the opinions of other pathologists (14) who found race 9 to be the most prevalent physiologic race in the Great Plains area. Race-group 15 was more or less uniform in prevalence in most of the areas. While occurring less frequently than race-group 5 it appears to be rather widespread. Race-group 126 was found to be clearly more prevalent in the two eastern areas than in other areas, thus establishing itself as nearly a direct opposite to race-group 9 in Kansas.

Another interesting phase of the prevalence of physiologic races in Kansas was the apparent dominance of some of the major race-groups at different times of the year. For example, it was noticed that collections from volunteer of fall-sown wheat apparently

Table 5. Relative prevalence of the four major race-groups of leaf rust of wheat in the six crop areas of Kansas based on percentage of total isolates for each area.

	Race-Group			
Crop area	5	9	15	126
Northeast	10.6	13.6	7.6	68.2
Northcentral	23.3	34.6	8.4	33.6
Northwest	25.0	51.0	17.0	6.8
Southeast	24.3	9.3	17.7	48.8
Southcentral	31.6	28.5	7.0	32.9
Southwest	27.5	56.5	8.7	7.2

contained a high content of race 9, while collections made from plants infected the following spring appeared to contain high percentages of races 5 and 126. The data were analyzed in order to obtain some exact information concerning this point. Collections made before December and after September were designated as fall collections while those made from December throughout the remainder of the growing season were considered as spring collections. Inasmuch as only the 4 major race-groups seemed to be of major importance, other races were not included in the analysis.

The data show that physiologic race-group 5 is about equal in prevalence throughout the year as shown by Table 6. Race-group 9, on the other hand, shows definite trends towards autumnal dominance, being nearly twice as prevalent in fall collections as race-group 5, its closest competitor in the fall. Race-group 15 showed a slight tendency toward fall prevalence but the significance is not too

Table 6. Percentage of total isolates represented by the 4 principal physiologic race-groups in collections of leaf rust made at different seasons of the year in Kansas during the period 1940-52 inclusive.

Season	Percentage of total isolates for Race-Groups 5	9	15	126
Fall	21.8	38.4	10.3	16.7
Spring	22.3	24.8	7.2	32.8

well marked. Race-group 126 shows a very marked dominance in spring collections and is apparently more suited to warmer environmental conditions. The data of the past 3 or 4 years showed more clearly defined spring and fall prevalence than data from the entire period, but the general trends appear to be the same throughout the period of investigation. The better definition shown in the later years of research is thought to be due to the fact that many more collections were examined, thus more clearly showing difference in prevalence and distribution.

DISCUSSION

The analysis of data has shown that many physiologic races of leaf rust of wheat have occurred in Kansas during the period 1940-51 inclusive. However, it is equally evident that of the 46 races found, only about 4 major race-groups occur with annual regularity and in great abundance, these being race-group 9, 126, 5, and 15 in order of prevalence.

Definite trends in prevalence and distribution were noticed in connection with these 4 major race-groups. For example, upon dividing the state into 6 more or less equal divisions, it was found that some of the races were definitely more abundant in some of these areas than in others. Data for the entire period as well as more comprehensive studies during the past year showed physiologic race-group 5 to be about equally prevalent in all parts of the state. Race-group 9 is definitely more prevalent in the western areas of the state. This is in keeping with the findings of other workers (14) who listed race 9 as the dominant race in the Great Plains area which includes western Kansas. Race-group 15 was shown to be about equal in prevalence throughout the state while race-group 126 was shown to be more prevalent in the two eastern areas of the state.

It was further shown that some of the major race-groups were more prevalent in the fall of the year and others more prevalent in the spring. Analysis of data showed that during the period of consideration, races 5 and 15 appeared to be about equally prevalent the year round. On the other hand, races 9 and 126 showed definite seasonal occurrence. Race 9 appeared nearly twice as often in fall collections as in those made in the spring, while race 126 was shown to be about twice as prevalent in spring collections as in fall collections. These findings are more or less in keeping with the opinions of other workers though this particular phase had not been carefully investigated before.

It has been shown that race 5 has exhibited a definite rise in prevalence since about 1945 due to the rapid increase in acreage of Pawnee wheat planted in Kansas, a factor which in the case of race 9 has had an effect quite the opposite. Race 9 was easily the dominant race from 1940 to 1945. However, Pawnee is resistant to race 9 and since its distribution that race has gradually diminished to its present position of about third in importance of the 4 major races. Race 5 at the same time has risen to become the first-ranked physiologic race in Kansas. It was also shown that race 15 and race 126 have been more or less stationary in their prevalence and distribution. Race 15 has remained about the fourth most important race in Kansas from year to year, while race 126 had in some years been the most abundant race and in others had been of very little importance. The sporadic occurrence of race 126 throughout the 12 year period is as yet unexplained. It may be possible that a combination of environmental conditions at some time during the growing season is responsible for these sporadic occurrences; however, a review of weather information over the period showed no correlation of any kind between weather conditions and race prevalence.

Observations of some of the major races in the greenhouse during 1951 seemed to indicate that some of the closely related races may be differentiated only at certain temperature and light levels. It was noticed that collections which were found to contain race 10, 13, 19, and 20 in the early autumn were later identified as race 9. Also, many collections in the early autumn were identified as race 52 but later in the season after having been kept in pure culture for several months were recognized only as race 5. The principal difference between race 5 and race 52 lies in the reaction of the variety Hussar and the fact has been established that Hussar becomes increasingly resistant with lower temperatures and more susceptible with increasing temperatures, Newton and Johnson (19) and Chester (8). Thus since the reaction on Hussar is the only difference between the two races, it seems evident that the temperature factor was probably involved in this case also. Races such as 10, 13, 19, and 20, in like manner, may be distinguished from race 9 only under special temperature and light conditions. Such observations uphold the concept of grouping of similar races into race-groups, and in each case it has been found that a wheat variety resistant to one race within a race-group is also resistant to the other members of that particular group.

On the basis of results shown by the data analyzed, it seems advisable that a successful program of breeding for leaf rust resistance in Kansas should follow these lines: (1) the continued breeding of wheat varieties resistant to the 4 principal race-groups, (2) a more concentrated effort in breeding for resistance to many physiologic races, i.e. broadening the base of resistance, (3) continued breeding for resistance to prevalent stem rust races, including the new 15-B race in combination with leaf rust resistance, and (4) continued breeding for the various agronomic characters in wheat that assure the high quality demanded by wheat growers, processors, and consumers.

SUMMARY

A total of 353 collections of leaf rust of wheat were made in the field in Kansas during the 12-year period, 1940-51 inclusive, and analyzed for their physiologic race content.

Forty-six physiologic races were identified; however, grouping of similar races revealed that only 4 race-groups were dominant in the state every year. Race 9 was the most abundant, followed by 126, 5, and 15, in that order.

It was found that certain of the major race-groups prevalent in the state occurred in some parts of the state more often than in other parts. Race 9 appeared to be definitely more abundant in the western part of the state, and race 126 appeared to be just as definitely abundant in the eastern part of the state.

There were indications that some races were more prevalent during one season of the year than in other seasons. Race 9 was found to be more prevalent during the fall than in the spring, while race 126 was definitely more abundant in the spring than in the fall.

Evidence was obtained that environmental factors affect race expression, several races exhibiting different responses under different light and temperature conditions.

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PREVALENCE AND DISTRIBUTION OF PHYSIOLOGIC RACES OF LEAF RUST OF WHEAT IN KANSAS, 1940-51

by

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B. S., Kansas State Teachers College
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AN ABSTRACT OF A THESIS

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1952

The purpose of this research was twofold. The first part of the research dealt with the analysis of leaf rust of wheat collections made from all parts of the state during 1951, and was done in the greenhouse by the writer. The second part dealt with the analysis of the data accumulated from the period 1940-51 inclusive. The race determination of these data had been made by various workers throughout that period. It was hoped that such an analysis would indicate the prevalence and distribution of the important physiologic races of leaf rust of wheat that occur in Kansas so that definite objectives in breeding for resistance might be reached.

In the first part of the research, collections sent in to the plant research laboratory from all parts of the state were examined for their physiologic race content. The data thus derived were analyzed for indications of prevalence and distribution. In the second part of the research, data which had been accumulated from 1940-51 were examined and prevalence and distribution of physiologic races were noted for each year.

The data showed the presence of at least 46 physiologic races of leaf rust of wheat in Kansas from 1940-51, this number being obtained as a result of 1580 single-pustule isolations from 353 collections. However, it was found that of those present only four of the physiologic races and their close associates were of major importance in Kansas. Each of the four major physiologic races was combined with one or more closely associated races into race-groups, the number of each race-group being that of the dominant race therein. Throughout the twelve-year period race-group 9 was the most prevalent, followed by 126, 5, and 15 in that order.

Certain changes in prevalence were noted in at least two of the race-groups, with race-group 9 decreasing and 5 increasing over the twelve-year period.

Two of the race-groups showed definite distribution tendencies in certain areas of the state, race-group 9 being most prevalent in the western part of the state while 126 was the most prevalent in the eastern part of the state. The same two race-groups showed variations in seasonal prevalence. Race-group 9 was definitely more abundant during the fall while 126 was just as definitely prevalent in the spring.

On the basis of the analysis of the data in this paper, it is recommended that a program of breeding lines of wheat resistant to the four major race-groups found to be the most prevalent in the state be continued.