MONOSOMIC ANALYSIS OF STEM RUST REACTION IN KENYA FARMER WHEAT

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Introduction

Kenya Farmer (Kenya 338 A. C. 2 E. 2), a Kenya variety from the cross (Button's×73. D. 21. 1. (L))×(Robin^3×Gaza) has been proved to be one of the best sources of resistance to many races of stem rust, *Puccinia graminis tritici* Eriks and Henn. A knowledge of the mode of inheritance of the reaction of Kenya Farmer to stem rust races, and information as to which chromosomes carry the factors for resistance would be helpful in future breeding programs.

In this study, the cross of normal Chinese Spring×Kenya Farmer and crosses of the 21 Chinese Spring monosomics×Kenya Farmer have been used to analyse the resistance of Kenya Farmer to race 38 of stem rust.

Materials and Methods

The parental varieties ueed in this study were Kenya Farmer and Chinese Spring, both of which are common vulgare types of spring wheat. Kenya Farmer (C. I. 12888) is early maturing, of medium height, with short, straight awns and white grains. It is resistant both in the seedling and adult stages to most of the races of stem rust in North America. Chinese Spring is later in maturity than Kenya Farmer, of medium height, with very short recurved awns and red kernels. The Chinese Spring monosomic stocks used in this study were obtained originally from Dr. E. R. Sears, University of Missouri, and monosomic plants had been grown and identified at the Minnesota Agricultural Experimental Station.

Crosses between Kenya Farmer and normal Chinese Spring and between Kenya Farmer and each of 21 different Chinese Spring monosomic lines were made in the greenhouse during 1954 and 1955. The F_1 plants from monosomic crosses were grown for production of F_2 caryopsis in the greenhouse during the fall of 1954 and the spring of 1955. The Chinese Spring plants to be used

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as monosomic maternal parents and the F_1 plant from monosomic crosses were checked cytologically to determine chromosome number. All F_1 plants were subsequently examined morphologically to detect possible cases of self-pollination. Two disomic plants from F_1 progenies of Kenya Farmer×Chinese Spring monosomics were selected and 100 seeds from each were planted in the spring of 1955 for the production of F_3 seeds. The resulting F_3 lines provided the material for the conventional genetic study of the mode of inheritance of stem rust reaction in crosses between normal Chinese Spring and Kenya Farmer.

Seedling reaction studies

The inoculum of stem rust race 38 for the seedling reaction studies was obtained from the Department of Plant Pathology, University of Minnesota.

The seedling tests which were run in the greenhouse in March, 1956, included the two parental varieties, normal F_1 and F_2 hybrids, F_3 lines, and F_2 progenies from monosomic F_1 plants for each of the 21 chromosomes. The four differential varieties, Marquis, Vernal, Khapli, and Little Club, were also included in the tests.

The F_2 progenies derived from the monosomic F_1 plants were planted in narrow wooden boxes each holding two rows of 25–28 seeds per row. To insure comparable results and eliminate bias, the materials were sown in four replications in a random arrangement, with the exception of mono-II and mono-III, of which there were not sufficient seeds available. Each replicate consisted of one row of each of the Chinese Spring×Kenya Farmer monosomic F_2 progenies and a single row of each of the two parental varieties. With four replications, most of the monosomic F_2 lines were represented by at least 100 plants.

Additional materials were sown in 4-inch clay pots. Each pot was planted with 25–28 seeds. The materials planted in pots included 97 seeds of normal Chinese Spring, 101 seeds of Kenya Farmer, 44 seeds of the F_1 hybrid, 135 F_2 seeds derived from two disomic F_1 hybrids, and 28 seeds of each of 103 F_3 lines.

The seedlings were first tested with stem rust race 15B. After the infection type from the inoculation to race 15B had been recorded on a single plant basis, each seedling was cut back just above the second leaf and all leaf blades were removed. The plants were then washed and moved to another greenhouse section for the test with race 38. After the new leaves had developed to a length of 2–4 inches, inoculations were made by brushing infected seedlings onto the plants to be infected. The seedlings that had not developed new leaves at the time of inoculation were marked as escapes.

The rust were conducted in greenhouse having automatically controlled ventilators. The room temperature during the test to race 38 was set at 70°F. Throughout the tests the daily temperature was fairly constant, although it rose occasionally 5–10° above the maximum setting on the thermostat during sunny afternoon. During both of the tests supplemental artificial light was used to lengthen the days about six hours in an attempt to improve development of the rust.

The notes on infection type were taken 11–13 days after inoculation, using the classification system described by Stakman, Levine, and Loegering (1944). Individual plant reactions were recorded for all the material. A decision as to which types were similar to the reactions of the resistant parent was made at the time the notes were taken.

Classification of awn characters and kernel color

Notes on the awn characters were taken on individual F_2 plants of the cross Chinese Spring×Kenya Farmer. The awn types were classified seven grades according to the length and shape of awns and the distribution of awns on the spike.

Kernel color was classified as white, as in the Kenya Farmer parent, or red, as in the Chinese Spring parent. The data were taken from the F_3 seeds produced on individual F_2 plants.

Experimental Results

All the material tested was inoculated first with races 15B, then the leaves were cut off and the new growth was inoculated with race 38. Parents, F_1, F_2, F_3 lines and the F_2's from the monosomic crosses were grown at the same time.

Seedling reactions to stem rust race 38

The seedling reactions of the parents, F_1, and F_2, based on the notes taken on individual plants, are summarized in Table 1. All plants of the Chinese Spring parents were highly susceptible to race 38, while all plants of the Kenya Farmer parent were highly resistant. Plants with infections in the 0, 0;, 1, 2, and $3^=$ classes were considered as resistant, and those with 3^-, 3 and 4 type pustules as susceptible since the Kenya Farmer parent rather consistently gave 0, 0;, and 1 reactions in this test. Most of the F_1 seedling had type 1 pustules, although a few had 0; and $3^=$ reactions. These results indicate that resistance was dominant. In F_2 there was a continuous range of variation from resistance to susceptibility and the classification of intermediate infection types was often rather difficult. The most frequent classes were 0; and 1, indicating the dominance of resistance. The frequencies of plants in the more susceptible classes decrease progressively, and there were no plants as susceptible as the most susceptible ones of the Chinese Spring parent. This latter point will be referred to again when the monosomic F_2 data are presented.

The plants in the F_3 lines were classified individually as to their reaction. Of the 99 F_3 lines from which adequate data were obtained, 27 had only resistant plants, 64 were segregating for resistance, and 8 contained only susceptible plants. The F_2 results suggest a one-factor segregation but the F_3 results indicate more factors were segregating.

Table 1. Summary of seedling reactions of the parental varieties, F_1 and F_2 of normal Chinese Spring×Kenya Farmer, tested with stem rust race 38.

Parents and progenies	Pustule type and classifications as to rust reaction									Total
	Resistant			Moderately resistant	Moderately susceptible	Susceptible				
	0	0;	1	3=	3−	3	3+	4−	4	
Chinese Spring							17	72	10	99
Kenya Farmer		81	32							113
F_1		3	35	2						40
F_2	3	44	26	19	17	9	4			122

A tabulation of the 21 monosomic lines, with the data classified into resistant, moderately resistant, moderately susceptible, and susceptible classes, is given in Table 2. Included also are the P values for the Chi-square tests for goodness of fit between the normal F_2 and each of the monosomic F_2 lines. For six of the lines, there were statistically significant deviations from the distribution of the normal F_2 progeny. The deviations were in two directions. The normal F_2 had 75.4 percent of resistant plants. The monosomic F_2's that fit the normal F_2 segregation had same percent of resistant plants. The line for chromosome X had 91.9 percent of resistant plants, while four of the other five lines, those chromosomes V, VII, XII, and XXI, had percentages that ranged from 57.1 to 67.4 percent. These results suggest that there are many genes for resistance to race 38 segregating in this cross.

The significant positive and negative deviations from the normal F_2 suggest two different kinds of gene action for resistance vs. susceptibility in the monosomic tests. If normal action of a monosomic carrying a factor for resistance is assumed, a higher percentage of resistant plants is expected. A low percentage of resistant plants would be expected if a gene for resistance shows an hemizygous effect, i.e. if the gene is not expressed in single dose, as in a plant monosomic for the particular chromosome on which the gene is located.

The F_2 derived from the F_1 monosomic for chromosome I had about the same percentage of resistant plants as did the normal F_2, but the distribution of plants in the four classes was different. It seems probable that this chromosome does not carry a major factor. Since only the F_2 line from the monosomic X cross gave a significant excess of resistant plants over that expected on the basis of the normal F_2, and since this percentage of resistant plants approximates the theoretically expected, the resistant gene or genes may logically be assigned to this chromosome. There is little basis for assigning other genes to any specific chromosome of V, VII, XXI and possibly XII. No attempt has been made to formulate a hypothesis by utilizing as many factors as the monosomic results appear to indicate. More information is needed before attempting to set up a more complete explanation.

Table 2. Summary of the seedling reactions to race 38 grouped into four classes as to disease resistance. The P values from the X^2 test for goodness of fit of each F_2 monosomic line to the normal F_2 are included

Monosomic lines	Seeds planted	Number of plants classified					Percent of resistant plants†	P value
		Resistant	Moderately resistant	Moderately susceptible	Susceptible	Total		
mono- I	98	64	5	8	14	91	75.8	0.01–0.02*
II	8	4	2	2	2	3	75.0	
III	106	52	11	11	13	87	72.4	0.5–0.7
IV	95	57	11	5	9	82	82.9	0.1–0.2
V	108	52	12	14	21	99	64.7	0.001–0.01**
VI	112	53	15	6	14	88	77.3	0.1–0.2
VII	112	47	19	11	21	98	67.4	0.001–0.01**
VIII	113	57	13	18	13	101	69.3	0.5–0.7
IX	107	59	13	8	11	91	79.1	0.3–0.5
X	112	76	16	4	5	101	91.1	0.001–0.01**
XI	112	54	13	13	18	98	68.4	0.05–0.1
XII	34	10	6	5	7	28	57.1	0.02–0.05*
XIII	106	68	13	7	11	99	81.8	0.05–0.1
XIV	112	57	22	12	9	100	79.0	0.1–0.2
XV	112	54	16	21	12	103	68.0	0.05–0.1
XVI	112	64	9	12	9	94	77.7	0.3–0.5
XVII	90	51	14	11	13	89	73.0	0.5–0.7
XVIII	112	60	17	15	12	104	74.0	0.95–0.98
XIX	110	46	22	14	15	97	70.1	0.05–0.1
XX	112	74	16	9	7	106	84.9	0.1–0.2
XXI	112	56	10	13	21	100	66.0	0.01–0.02*
Normal F_2		73	19	17	13	122	75.4	
Selected monosomic F_2 lines §		810	207	163	168	1,348	75.4	

* significantly P value
** highly significantly P value
† included the moderately resistant class
§ monosomic F_2's that fit the normal F_2 segregations

Tests for association between characters

The association between the seedling reaction to stem rust races 38 and

15B, and between disease reactions, grain color and the length of awn in the cross of normal Chinese Spring×Kenya Farmer were studied by using the Chi-square test for independence. The data on awn length were obtained on F_2 plants. The other data were recorded from F_3 progenies. The summary of the tests is presented in Table 3. The probability values were all above 0.05, indicating no association between any of these characters.

Table 3. Chi-square tests for independence of inheritance of the characters in the cross Kenya Farmer and Chinese Spring.

Characters compared	N	D. F.	P value
F_3 seedling reaction to stem rust races 38 and 15B	97	4	0.3–0.5
F_3 seedling reaction to stem rust race 38 and F_3 grain color	97	2	0.8–0.9
F_3 seedling reaction to stem rust race 38 and F_2 length of awn	97	4	0.1–0.2
F_3 grain color and F_2 length of awn	105	2	0.8–0.9

Discussion

In this study, an attempt was made to determine the mode of inheritance and the location of factors for stem rust resistance to race 38 in the crosses of normal Chinese Spring×Kenya Farmer and of the Chinese monosomics×Kenya Farmer.

The results obtained in the present study are not in agreement with these reported by previous workers. Ayad (1948), in crosses of Hindi 62 with Gisa 139 and Hindi Immune, Hindi 62 being susceptible and the other parents highly resistant to race 38, found Gisa 139 have two genes for resistance while Hindi Immune have only one. Athwal and Watson (1954) using Kenya 744 and Kenya 117A as resistant varieties in crosses with the susceptible varieties Federation 107 and Chinese White 1806, assumed that Kenya 774 and Kenya 117A had two dominant genes for resistance to race 38. Plessers (1953), working the material of Lee×Chinese Spring, reported that the seedling reaction to race 38 could be explained by four factors. The source of resistance was Timstein, one of the parents of the variety Lee. Aslam (1956), who studied the seedling reaction to race 38 in F_3 progenies of the cross of Kenya Farmer×Kenya 58, the former resistant and the later moderately resistant to race 38, postulated three different genes for resistance each with an additive effect. The investigations of these workers are not comparable to the present study, since different resistant or susceptible varieties were used.

The present study seems to indicate that many factors are segregating and are not explained on a simple hypothesis. It is possible to relate the recent work with isogenic lines carrying single substituted gene for stem rust. Knott (1959) reported that Kenya Farmer carries five genes, Sr_7, Sr_9, Sr_{10}, Sr_{11} and Sr_{12}, conditioning resistance to stem rust. Green *et al* (1960) tested isogenic lines for resistance to race 38, using varieties known to possess a particular gene which was transferred to the lines of variety Marquis. They reported that isogenic lines carrying Sr_7, Kenya 117A–Marquis[6] and Egypt Na101–Marquis[6], both which were moderately susceptible with 3^+ pustules. Marquis line possessing Sr_{10}, Egypt Na95–Marquis,[4] had moderate resistant with type 2 and type 3 infection. They also found that Marquis line with Sr_9, Red Egyptian-Marquis[6] was moderately resistant to race 38 while the Red Egyptian XIII carried Sr_9 had infection type 3. The other two genes, Sr_{11} and Sr_{12}, are not yet tested with race 38.

The F_3 results indicate at least two factor pairs and the monosomic analysis suggests that many were segregating in the cross between Chinese Spring and Kenya Farmer. A significant point in the present monosomic results is that certain monosomic F_2's had a much higher percentage, and others a much lower percentage of resistant plants than did the normal F_2. The former deviation is the usual one expected if a factor for resistance is carried on the univalent. The deviation to give a lower percentage requires some other explanation. If the factor for resistance fails to express itself when hemizygous, a low percentage of resistant plants is expected.

The use of different resistant and susceptible varieties in the various studies that has been conducted to determine the mode of inheritance to races of stem rust is major source of difficulty in trying to draw comparisons. There is, in addition, the difficulty imposed by the fact that the different studies have not used the same isolates of a given race. The taxonomic key used for identification of races does not insure a similar genotype for races with the same identification numbers. Stem rust race 38 may be comprised of several biotypes as demonstrated by Stakman (1954). Hayden (1956), Green *et al* (1960) have shown that rust reactions are greatly affected by different ecological conditions. An additional source of difficulty in attempting to compare the results of different workers is that the Kenya varieties and probably other varieties may not be pure. It is not certain that the parental material of the same variety was the same in all studies. The different biotypes of the stem rust organism, differences in the varieties used and ecological factors are among the possible reasons for the discrepancies in the results obtained by different workers.

More studies with the same material are needed in order to obtain a clear picture of the mode of inheritance. However, on the basis of present study, the transfer of individual chromosomes of Kenya Farmer into a susceptible commercial variety for breeding varieties resistant to stem rust race 38 would appear to be difficult or impossible if there are many chromosomes carrying factors for resistances which are needed to have a satisfactory degree of resistance.

Sumary

F_1, F_2 and F_3 of normal Chinese Spring×Kenya Farmer, and F_2 generations of the crosses of the 21 Chinese monosomics×Kenya Farmer were studied for seedling reaction to stem rust race 38.

For reaction to stem rust race 38, all plants of the Chinese Spring parent were highly susceptible, and all plants of the Kenya Farmer parent were highly resistant. The F_1 plants were all resistant, indicating that resistance is dominant. In F_2 there was a continuous range of variation from resistance to susceptibility. Of 99 F_3 lines tested, 27 had only resistant plants, 64 were segregating, and 8 has only susceptible plants. In the monosomic tests, six lines derived from monosomic F_1's deviated significantly from the normal F_2. The deviations were in two directions, one with a much higher and the other five with much lower percentage of resistant plants. These results also indicate more factors are segregating, but no hypothesis has been formulated on the number indicated by the monosomic tests.

There was no association between the seedling reaction to races 38 and 15B, and between the rust reactions, seed color and awn expression; or between seed color and awn expression.

利用中國春小麥單染色體品系分析 Kenya Farmer 小麥抗稈銹病菌之遺傳

畢 中 本

本文研究之目的爲分析 Kenya Farmer 小麥與中國春小麥雜交之 F_1, F_2, F_3 及與21組單染色體中國春小麥雜交之各 F_2 系統，藉以明瞭 Kenya Farmer 小麥抵抗稈銹病菌 race 38性狀之遺傳，並探求抗病因子存在之染色體。

親本 Kenya Farmer 小麥對於稈銹病菌 race 38極爲抵抗，另一親本中國春小麥極爲感染。苗期接種試驗結果，F_1 各株均爲抗病，此說明抗病爲顯性。F_2 各植株自抗病至傳染均有，呈連續變異。在99個 F_3 系統中，27系各植株均爲抗病，64個系分離，8系均屬感染。根據 F_2, F_3 觀察結果，似有許多因子分離，不能以簡單遺傳現象予以解釋。Kenya Farmer 小麥與21組單染色體中國春小麥雜交 F_2 各系中，有6系與 (正常中國春小麥×Kenya Farmer) F_2 之分離比例顯著不同，其中一系具有較多抗病植株，另5系則具有較少抗病植株。由於此21系單染色體植株分析結果，可說明 Kenya Farmer 抗稈銹病菌 race 38之性狀，由於多個因子支配，其中一個因子很可能存在於染色體 X 上。惟因分離比例過於複雜，無法說明其他因子存在之染色體。

F_3 苗期試驗結果，植株對於稈銹病菌 race 38 及 race 15B 間之抗病性狀並無連繫。抗稈銹病菌 race 38之性狀與種子色澤，芒之有無間均無連繫。種子色澤與芒之有無亦無連繫存在。（摘要）

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