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THE DEVELOPMENT OF SORGHUMS RESISTANT TO MILO DISEASE



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SUMMARY

1. A destructive milo disease occurs in the Southern Plains area. It was first reported from Kansas in 1926 where its cause and control have been studied. In Kansas it occurs most commonly in the western half of the state. It is found likewise in Texas, Oklahoma, New Mexico, Colorado, California.

2. The diagnostic symptoms of milo disease are described. They are easily confused with chinchbug or drought injury, and alkali spots in the field.

3. The cause of milo disease has not been fully determined. Recent investigations show that it is a highly complex problem in which more than one organism may be concerned and that various extenuating factors are operating.

4. Milo, darso, and certain milo hybrids are highly susceptible, while other sorghums as kafir, sorgo, feterita and Sudan grass are resistant. A list is given of commercially grown sorghums in the United States which were tested for their susceptibility.

5. The methods used for obtaining resistant strains of milos and milo hybrids are discussed. A greenhouse seedling method of testing the reaction of field selections is described. The same method is used as a means of selecting resistant strains from the standard susceptible varieties of sorghums.

6. The importance to the sorghum-improvement program of obtaining and distributing resistant selections is discussed. The plant breeder needs to be fortified with a knowledge of the susceptibility or resistance of the hybrid material with which he is working in early generations. The method for obtaining this information is discussed.

7. Genetic aspects of the milo disease problem are briefly presented. In Kansas resistant selections have been obtained from all standard milos and varieties of sorghum having milo parentage with which the writers have worked. Among these are resistant selections of Dwarf Yellow milo, Wheatland, Day, Sooner, Beaver, Quadroon, Pygmy, and Colby.

8. Two resistant selections, Finney and Westland, have been distributed by the Kansas Agricultural Experiment Station. Descriptions of these varieties and their adaptation are given in the text.

9. The seedling "disease test" is applied to all certified seed lots of Finney and Westland, as a prerequisite to certification.

10. County agents and sorghum growers may learn whether or not their fields are infested with milo disease by sending representative soil samples from questionable fields. From the results of the test, it is possible to state whether it will be necessary to grow a resistant variety.

THE DEVELOPMENT OF SORGHUMS RESISTANT TO MILO DISEASE¹

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INTRODUCTION

The sorghum crop ranks second in value and third in acreage in Kansas. Kansas is surpassed only by Texas and Oklahoma in the production of sorghum. Any disease, therefore, that attacks the sorghum crop is a matter of importance, especially when there is no specific method of control. Milo disease has been one factor limiting the production of sorghum in Kansas. Because of the potential importance of this disease to the sorghum crop of the Southern Plains area, investigations for its control have been conducted at the Kansas Agricultural Experiment Station and at other stations in the sorghum-producing area.

Crown, shoot, and root rot of milo, or *Pythium* root-rot, more commonly known as "milo disease," was reported from Kansas in 1926 where its cause and control were first studied (3, 4, 10, 13).⁴ Investigations proved that soil treatments, crop rotations, or the use of specifics would not control the disease, but that breeding for resistance offered a solution (8, 11, 13). This bulletin is a report on breeding sorghums resistant to the milo disease in Kansas.

Milo, darso, and certain milo hybrids⁵ are susceptible to the milo disease, while all other sorghums as kafir, sorgo, feterita, and Sudan grass are resistant (3,9). Early in the investigations it was learned that resistant selections could be isolated from bulk seed of the standard varieties of milo instead of resorting to hybridization. The methods used in obtaining resistant selections from standard susceptible milos and milo hybrids, genetic aspects of the milo disease problem, how certified seed lots are increased and tested for disease reaction, and the method used in testing field samples of soil for the presence of milo disease are described herein. Several of the resistant milo selections made in Kansas and Texas are now grown extensively in the south central Plains area where milo disease is widespread (5, 12).

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⁴ Figures in parentheses refer to Literature Cited, page 24.

⁵ The term milo hybrid as used in this publication means a fixed line derived from a cross involving milo.

CAUSE AND SYMPTOMS OF MILO DISEASE

One difficulty in recognizing milo disease in the field is that it may be confused with chinchbug, drought, and alkali injury. A typical seedling blight under field conditions has not been associated with milo disease. Diseased plants show the first symptom 35 to 45 days after planting when 8 to 12 inches tall. The leaves roll slightly and develop a yellowish tinge on the margins and tips of the lower leaves. Growth is retarded and diseased plants may die gradually, or if they continue to live, produce poor grain. By September in Kansas badly attacked plants are dead. The crown and roots of wilting or "firing" plants, when opened, show a distinct dark red tissue discoloration.

At one stage of the investigations (1937-1939) it was believed that the causal organism was *Pythium arrhenomanes* Drechs., a fungus which is widely distributed in soils and known to be parasitic on various crops (4, 7). Recent studies show that the cause cannot be attributed to this fungus alone, but that several other organisms and extenuating factors form a complex which is concerned in the production of a disease that has been called the *Pythium* root rot, but which more properly should be called "milo disease" (10).

DISTRIBUTION AND ECONOMIC IMPORTANCE OF MILO DISEASE

Milo disease is known to occur in Kansas, Oklahoma, Texas, California, Colorado and New Mexico. It is believed that eventually milo disease will be found in other states where milo or susceptible milo hybrids are grown. The known distribution in Kansas by counties is shown in Figure 1.

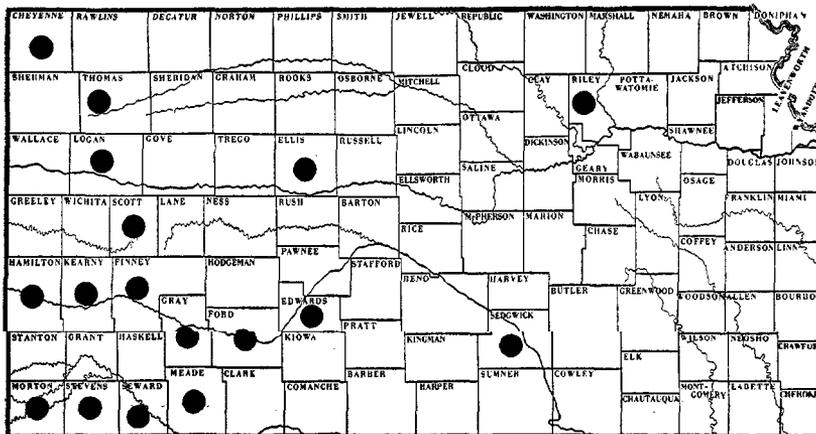


Figure 1.—The known distribution of milo disease by counties in Kansas, 1942.

At the present time milo disease is not so widespread or serious in Kansas as in Texas where it has become the most devastating of all sorghum diseases. Through the results of the studies on the control of this disease by the Kansas Agricultural Experiment Station, in cooperation with the Texas, New Mexico and Oklahoma Agricultural Experiment Stations, several resistant selections of milo are established (2, 5, 12) and are now replacing the standard susceptible varieties from which they came. These new varieties are being grown on about 2,500,000 acres in these states.

EXPERIMENTAL METHODS AND RESULTS

Earlier studies indicated that the milo disease as it occurs in Oklahoma, Texas and California is identical with the disease in Kansas (4, 7). Messrs. John B. Sieglinger, Stillwater, Okla., R. E. Karper, College Station, Texas, and J. B. Kendrick, Berkeley, Calif., submitted soil samples for testing to learn whether the sorghum disease present in their states is the same as the milo disease in Kansas. Table 1 gives the results of these tests. Not only was the disease reaction similar for the same varieties used in the test, but the symptoms of the diseased seedlings were also indistinguishable.

Table 1.—A comparative test of soil samples for the presence of milo disease. Greenhouse seedling test, Manhattan, Kansas.

Source of soil	Year	Susceptible Dwarf Yellow milo		Resistant Dwarf Yellow milo	
		Total number of plants	Percent killed	Total number of plants	Percent killed
Texas	1935	30	100	35	0
Kansas	1935	49	100	51	0
Oklahoma	1936	23	100	16	0
Kansas	1936	39	100	40	0
California	1936	49	100	52	0

Greenhouse tests were found indispensable in a study of the phytopathologic phases of the problem. Investigations in Kansas (4) have proved that sorghum varieties react identically towards the milo disease when grown in the seedling stage in the greenhouse, or in the field (Figs. 2 and 6).

Essentially all the selections which have been made in Kansas have passed through stages of greenhouse tests in infested soil, thereby eliminating susceptible lines. Hundreds of head selections made in the field in Kansas, Oklahoma, and Texas are being grown in infested flats of soil (Fig. 3). The susceptible selections die, while those displaying resistance continue to grow. It is thus possible to determine which selections are resistant, susceptible, or segregating, and which should be planted

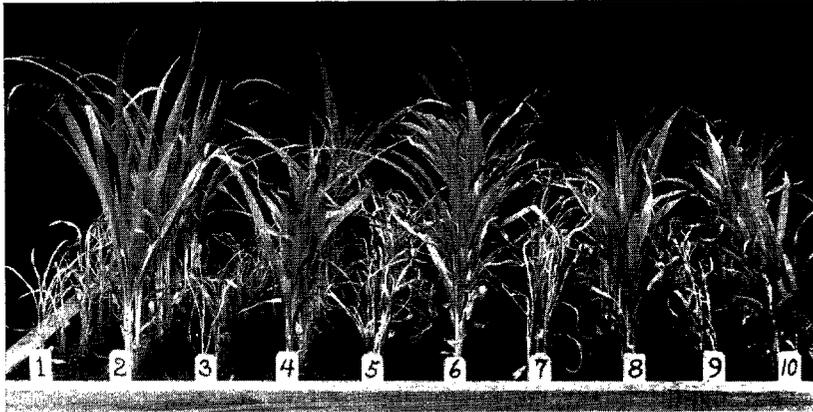


Figure 2.—Resistant selections of milo growing in “diseased soil” alongside the susceptible standard varieties from which the resistant selections were made. Row 1, Dwarf Yellow milo; row 2, Finney; row 3, Wheatland; row 4, Westland; row 5, Day milo; row 6, resistant Day; row 7, Beaver; row 8, resistant Beaver; row 9, Pygmy milo; row 10, resistant Pygmy.



Figure 3.—Flats of infested soil in the greenhouse, Manhattan, Kans., are used for testing head selections made in the field. It is possible to eliminate the susceptible and segregating lines from the resistant. These selections were made in Kansas, Oklahoma, and Texas.

in the field the following crop season. By this means time and funds are conserved and much work is done during the winter months. The seedling method is also used in a study of the inheritance of resistance to the milo disease (1) and in testing the populations of crosses in different filial generations (Fig. 7).

Greenhouse flats filled with infested soil from the field are used for all phases of the greenhouse work. At the end of a test the aerial portions of the plants are removed; the decayed roots are left in the soil. This medium is sifted through a coarse screen and placed in flats for future use. As a rule, the same soil is not used more than once or twice each year. Soil several years old has continued to be useful in these studies, although it becomes necessary to apply a complete artificial fertilizer which, in as far as selection for resistance is concerned, does not change the disease reaction. Figures 4, B and 4, C show that sorghum plants may be grown to the heading stage if desired in the shallow flats, but the plants are naturally short and produce small heads with relatively few seeds. The grain that is produced, however, is almost normal in size and of satisfactory quality for further use.

To test selections, 15 to 20 seeds of each are planted in rows crosswise of the flat in infested soil in the greenhouse during the winter. In 4 to 6 weeks the susceptible plants begin to die, while resistant individuals continue their growth. Final notes on the reaction to milo disease may be taken in from 6 to 8 weeks (Fig. 3). Temperatures ranging from 70° to 90° F. should be maintained although fluctuations do not affect the results of the testing.

In the region of Manhattan, Kansas, it has been found that the best time for the greenhouse studies is from October to April. The other months, because of light and heat intensities, do not lend themselves so satisfactorily for this work. No special measured quantity of moisture is necessary, but the plants should be kept growing rapidly and free of insect pests which are troublesome on the sorghum crop under greenhouse conditions.

Methods of Obtaining Disease-Resistant Selections of Milos

If the soil is not uniformly infested, as generally is the case, field selection of resistant milo plants is not easy. F. A. Wagner, formerly of the Garden City, Kansas, Branch Agricultural Experiment Station, made several selections of Dwarf Yellow milo and Wheatland milo in fields that were badly "diseased." Seed of selected heads was sent for greenhouse tests to Manhattan, Kansas, for verification of the disease reaction. Some selections proved to be susceptible and were eliminated. When selections are made in the field, many plants are accidental "escapes," others are slightly susceptible, or, in some cases, hybrids that will segregate the following generation, giving rise to desirable resistant plants. This was clearly shown by

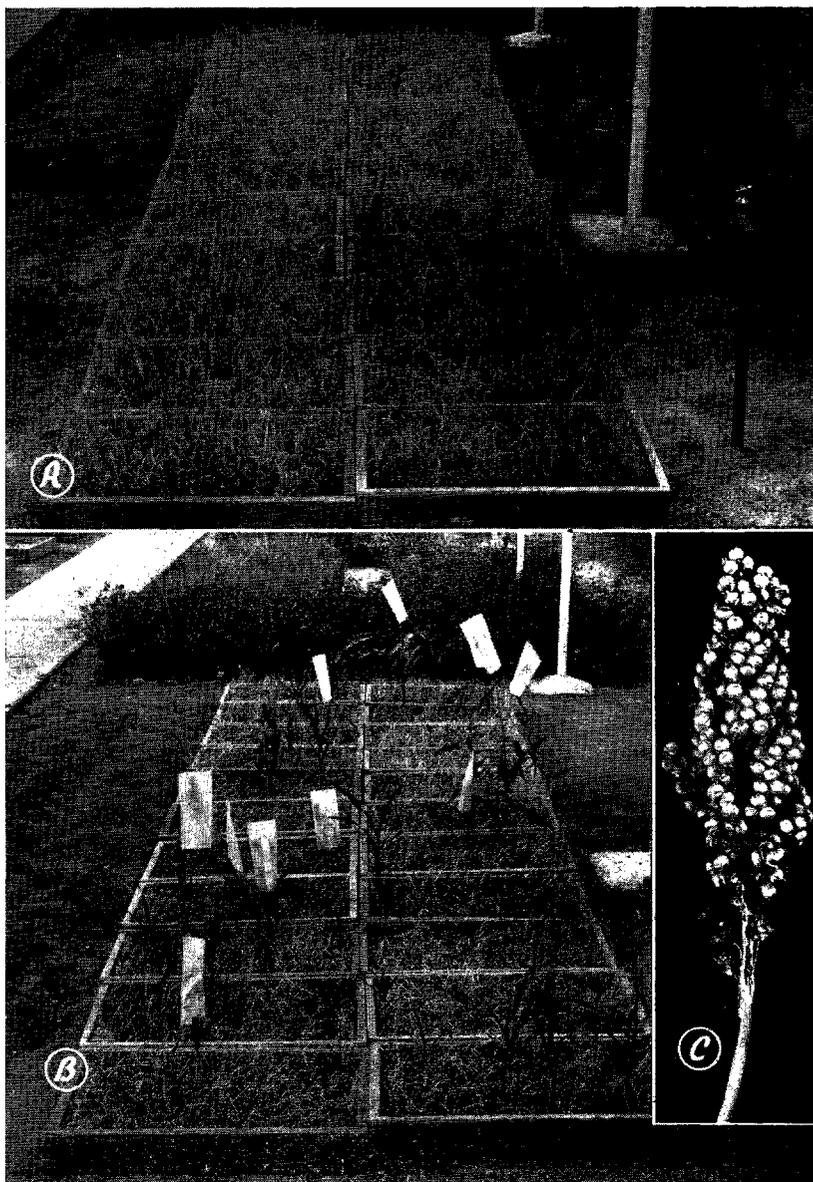


Figure 4.—A. Twenty-two flats of infested soil were heavily sown to certified seed of Standard Colby milo which is susceptible to milo disease. Twelve thousand five hundred plants started to grow. B. Two and one-half months later 25 plants remained alive (resistant), 20 of which proved to be typical Colby. C. A well-matured head of one of the resistant plants that survived in infested soil.

the greenhouse disease readings made on the field selections. Many head selections of Dwarf Yellow milo were made in the field by R. E. Karper, of the Texas Agricultural Experiment Station (2), who requested that they be given the seedling test at Manhattan, Kansas, before they were planted in the field in Texas. Figure 3 shows hundreds of head selections of Kansas, Texas, and Oklahoma material, representing selections of the varieties Dwarf Yellow milo, Sooner, Beaver, Wheatland, Darso, Day milo, Pygmy and others being grown in the greenhouse at Manhattan. By eliminating the susceptible and segregating selections, useless field testing was avoided. Mr. Karper later adopted this method in making the selection of Dwarf Yellow milo at the Texas Agricultural Experiment Station. The selection was named Texas milo and was released for commercial production in 1941.

The seedling method offers a rapid and dependable way of isolating milo disease resistant lines. Selections of resistant plants are made from the bulk seed of standard susceptible varieties growing in infested soil. This procedure was followed with milo and certain milo hybrids comprising Dwarf Yellow milo, Wheatland, Day, Darso, Pygmy, Colby, Sooner, Beaver, and Quadroon.

After the resistance of the selections has been determined, they are grown in the field plots in comparison with the standard varieties from which they came, and their yield, type and other agronomic characters evaluated. Many of these selections so obtained are similar to the standard varieties except that they are resistant.

Colby milo, which is susceptible, will be used to illustrate the procedure. This variety is an early combine type, having originated from a cross between Early White milo and Dwarf Yellow milo. The variety matures in 90 days, produces good grain, is dwarf in growth habit and because of its earliness, is especially adapted to northwestern Kansas and western Nebraska. It is susceptible to the milo disease. It seemed desirable to obtain, if possible, a resistant Colby milo. Figure 4, A illustrates 22 flats of infested soil which were heavily sown with seed of Colby milo early in October. The 22 flats required 48 square feet of area in the greenhouse. About 12,500 seedlings started to grow from the sowing in this area and represent about as many plants as could be grown on half an acre in the field. All but 25 individuals died from the milo disease. The photograph in Figure 4, B was taken 2½ months after planting and shows that about 0.2 of 1 percent survived. Since all the soil was heavily infested, there was little opportunity for escape from infection and all susceptible plants were killed. Of the 25 plants remaining, 20 resembled Colby milo, while the others were resistant hybrids or a mechanical mixture of some other resistant sorghum as determined by plant and head characters. Since all Colby plants have short awns on their glumes, it could

easily be determined whether the plant in question was a Colby type milo. The 20 heads of the resistant Colby plants were bagged to assure self-pollinated seed, after which they were allowed to mature. Since very few plants survived in a flat, there was ample nourishment in the soil to produce heads bearing from 25 to 150 seeds (Fig. 4, C).

When plantings are started early in October a second generation may be grown during late winter or early spring, otherwise the first generation may be planted out of doors in spring in infested soil. If the latter procedure is followed, it is advisable to grow the selections once more in infested soil in the greenhouse before conclusive evidence is obtained of their disease reaction. In the instance above, 15 seeds from each of the 20 selfed heads were planted in flats in infested soil in the greenhouse. Final notes showed that of the 20 plants, 19 were resistant and one was segregating. One flat showing 10 of these selections is illustrated (Fig. 5). The following spring the remnant

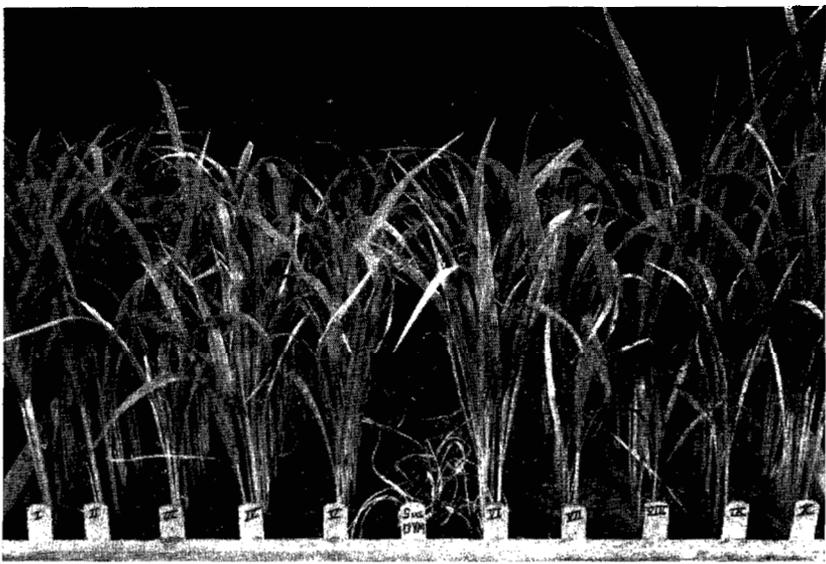


Figure 5.—Plantings of 10 of the surviving plants in Figure 4-B made in infested soil. All were completely resistant except row 8, which was segregating. The control, Dwarf Yellow milo (center row), was completely killed. The remnant seed of each of the 19 resistant heads (Fig. 4-B), was planted in the field in infested soil for further observation (Fig. 6-A).

seed of the 19 resistant plants was planted in the field and carefully observed for agronomic characters and for seed increase. These selections were resistant under field conditions as illustrated in Figure 6, A where they were grown in heavily infested soil at the Garden City Branch Agricultural Experiment Station. There was some variability among these selections as to

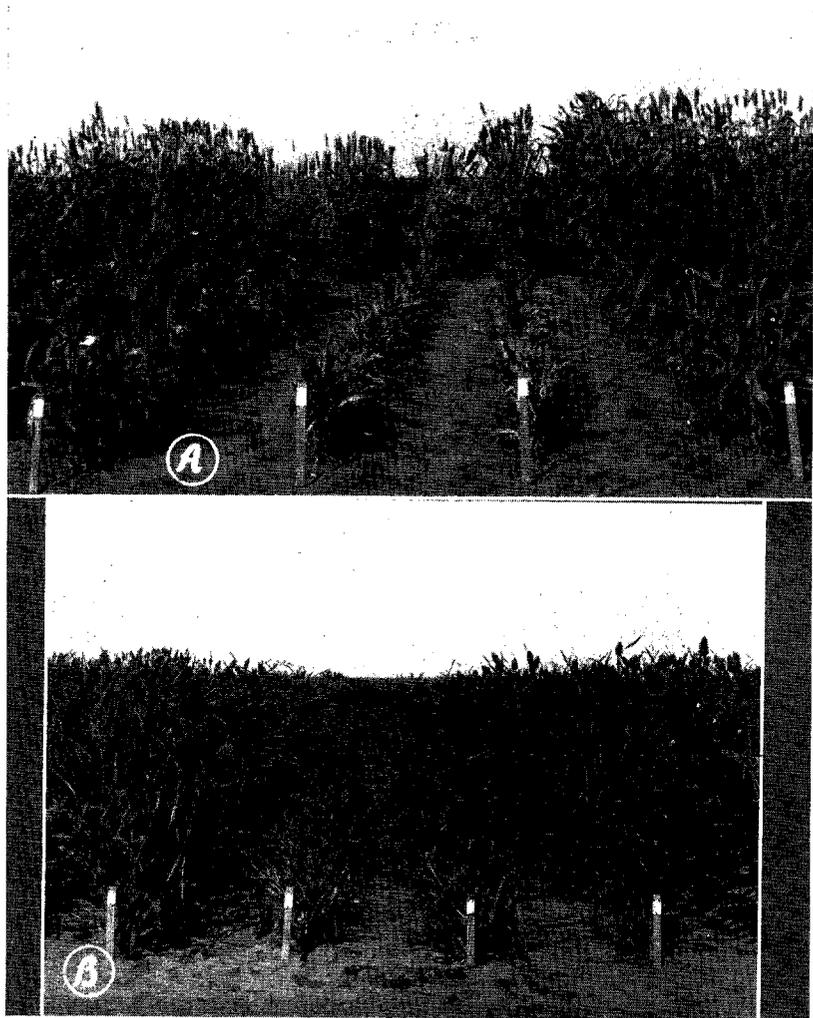


Figure 6.—A. Resistant Colby milo selections in foreground on either side of two dead center rows of standard susceptible Colby. B. Resistant Finney produces a good crop when the ordinary Dwarf Yellow milo (center) is killed. Plantings at Garden City, Kansas, in badly infested field. The field reaction of these varieties to milo disease is identical with that in the greenhouse (Fig. 2).

earliness, leaf character and general habits of growth. Several of the resistant selections, however, appeared very similar to standard Colby milo in general appearance. These are being tested further in order to determine whether a single resistant selection, or several resistant selections, should be bulked and used to replace the present standard susceptible Colby milo.

Importance of Using Disease-Resistant Selections in the Sorghum Improvement Program

Investigators engaged in sorghum improvement have become aware of the importance of milo disease. The matter of selecting parents for hybridization that are resistant to milo disease is receiving consideration. Melchers and Lowe (9) have published a list of sorghum varieties, selections and hybrids with respect to their reaction to the milo disease. Before a new sorghum selection is distributed for general use, its susceptibility or resistance to milo disease should be known. This is a matter that should concern the sorghum breeder as much as the plant pathologist. It should be even more important to know in the early generations whether a hybrid line is susceptible or resistant. For example, there may be a dozen hybrid lines of the same sorghum cross involving a susceptible parent. Agronomically, these lines may be homozygous for most plant characters and equally desirable in yield. Part of these hybrids, however, may be susceptible, resistant, or segregating for resistance to the milo disease. It is highly desirable that susceptible lines be eliminated early and thus concentrate on which line should be chosen. The reaction to the milo disease remains undetermined until the selections have been tested in infested soil. It is here that the greenhouse seedling test functions.



Figure 7.—The seedling method is used to pick out resistant hybrids growing in infested soil. An F_2 planting of populations of the cross White Darso x Darso C. I. 615. Segregation is occurring. Parents White Darso (resistant) and Darso C. I. 615 (susceptible). Rows 8, 10, 11 and 14 segregating; rows 9 and 12 susceptible; rows 13 and 15 are resistant. With this knowledge the sorghum breeder can select the proper lines for a resistant variety.

Homozygous resistant lines may be obtained which have all the agronomic characters that are desirable. Figure 7 illustrates a flat of F³ populations of the cross White Darso (Has-ton's sel.) x Darso C. I. 615. The seed was sent in for testing by John B. Sieglinger, of Stillwater, Okla., who is connected with the Division of Cereal Crops and Diseases, United States Department of Agriculture. He wanted to know which lines were resistant to the milo disease. As will be observed, the White Darso parent was resistant, while Darso C. I. 615 was sus-

Table 2.—Milo disease reaction of a group of sorghum selections and hybrids developed in sorghum breeding. Seedlings were tested in infested soil in the greenhouse, Manhattan, Kans., 1940-41.

Variety or hybrid	Identification No. ¹	Final disease reaction ²
FROM A. F. SWANSON, HAYS, KANSAS		
Kalo Sel.	H.C. 38-613	R
Kalo Sel.	H.C. 38-617	R
Backcross x Kalo	H.C. 38-590	R
Dwarf Yellow milo x Dwarf Freed	H.C. 399	R
Dwarf Yellow milo (control)		S
Dwarf feterita x Dwarf Freed	H.C. 336	R
Weskan x Greeley	H.C. 384	R
Farr's No. 9	R
Dwarf Yellow milo x Dwarf Freed (yellow seeded)	H.C. 396	R
Club x Western	H.C. 385	R
Dwarf Club	H.C. 380	R
Dwarf Yellow milo (control)		S
Wonder Club	H.C. 3810	R
Early Kalo	Lin. 1130A-3	R
Club x Day	H.C. 40-232	R
FROM J. R. QUINBY, CHILLICOTHE, TEXAS		
Early Dwarf Yellow milo x (Hegari x Texas milo)	SA 7088-2	R
Manko x Early Yellow milo	SA 7070-3-1	R
Quadroon x Birdbill x milo ₂	SA 5185	R
Texas milo	Sel. 561-1-4	R
Dwarf Yellow milo (control)		S
Leoti x milo ₃	SA 1182-2-2-3	R
Do.	SA 1182-2-2-4	R
Do.	SA 1182-14-3-2	R
Do.	SA 1182-14-3-5	R
Do.	SA 1182-14-3-6	R
Do.	SA 1182-14-4-4	R
Do.	SA 1182-14-4-5	R
Do.	SA 1182-14-6-1	R
Do.	SA 1182-14-6-2	R
Dwarf Yellow milo (control)		S
Leoti x milo ₃	SA 1182-14-6-3	R
Do.	SA 1182-14-7-2	R
Do.	SA 1182-14-7-4	R
Hegari x milo ₂	SA 1159-4-3-2	R
Do.	SA 1159-4-5-1	Seg
Do.	SA 1159-4-6-3	S
Do.	SA 1159-16-3-1	R
Milo ₂ x Hegari ₂	SA 5135	S
Dwarf Yellow milo (control)		R
Kafir x milo ₃	SA 1294-9-2	Seg
Do.	SA 1294-9-4	Seg mostly S
Do.	SA 1294-11-4	Seg mostly S
Do.	SA 1294-13-2	R

¹ SA and HC are identification numbers for the Texas Agricultural Experiment Station and the Fort Hays branch of the Kansas Agricultural Experiment Station, respectively.

² R = resistant; S = susceptible; Seg = segregating.

ceptible. Rows 8, 10, 11, and 14 were segregating, rows 9 and 12 were susceptible, and rows 13 and 15 were resistant.

The reaction of various hybrids in the F^{10} or later generations involving resistant and susceptible parents sent in by A. F. Swanson, of the Fort Hays branch of the Kansas Agricultural Experiment Station are shown in Table 2. They were homozygous resistant or susceptible. It was an easy matter to determine which were resistant. With this assurance it was possible to proceed with the more desirable lines. A similar test of sorghum-breeding material comprising F^3 crosses was made for J. R. Quinby of Chillicothe, Texas, with the results shown in Table 2.

Certain milo selections and hybrids were distributed to growers years ago before the potentialities of milo disease were known. Some of these have since proved susceptible. This is illustrated in the case of Wheatland (kafir x milo) and Quadron (kafir x milo). Undoubtedly a resistant hybrid or selection could have been chosen had the potentialities of milo disease been realized. Unconsciously this was done when Kalo, a natural cross between Pink kafir and Dwarf Yellow milo, was selected and distributed. Kalo is a segregate that is resistant to the milo disease and is commercially grown in Kansas and Nebraska.

Although the foregoing discussion and tables have mentioned some of the susceptible and resistant strains and varieties, they do not include many of the important varieties of sorghums that have been tested. Table 3 gives the reaction to milo disease of the varieties of forage, grain, grass, and broom-corn sorghums most widely grown in the United States. They are arranged in two general groups: Those that are resistant and those susceptible to milo disease. While the list may not be complete, it is believed that it contains the more important varieties grown at the present time in the United States.

Genetic Aspects of the Milo Disease Problem

It is noteworthy that hybridization of sorghums in the field is very common. The tendency to cross creates difficulties in maintaining pure seed in commercial practice and in producing certified seed. It has not been necessary to resort to a program of planned hybridization in order to secure milo disease resistant lines of milos and milo hybrids. Resistant lines occur and may be isolated in all the milo varieties and in many of the milo hybrids.

It is of interest to formulate a genetic explanation of how it happens that resistant lines occur in otherwise susceptible standard varieties of milo and certain milo hybrids. Studies in the field and greenhouse in Kansas of several sorghum crosses have shown that susceptibility is partly dominant and controlled by a single major factor (1). On the basis of these experimental

Table 3.—Sorghums most widely grown in the United States, showing their reaction to milo disease, as determined in Kansas.

Varieties resistant to milo disease		
Forage sorghum		
Atlas	Honey ? ¹	Sapling
Black Amber	Kansas Orange	Silver Top (Iceberg)
Clubhead	Jones	Sourless (African millet)
Collier	Leoti Red	Standard Sumac
Colman (Young)	McLean	Straightneck
Denton	Norkan	Sugar Drip
Early Sumac	Planter	White African
Folger	Red Amber	
Gooseneck	Rex (Red X)	
Hodo	Rox (Orange)	
Grain sorghum		
Alliance	Finney	Shallu
Bonita	Freed sorgo	Spur feterita
Cache feterita	Greeley	Standard Blackhull
Caprock	Grohoma	Standard feterita
Cheyenne	Hegari	Sunrise kafir
Club	Heileman 40 milo	Sweet Maize (Higgins, Altland)
Coes	Highland	Texas Double Dwarf milo
Dawn kafir	Kaferita	Texas milo
Double Dwarf 38 milo	Kalo	Texas Sooner No. 8
Dwarf feterita	Manko	Tricker
Dwarf Freed	Martin	Weskan
Dwarf White 39 milo	Modoc	Western Blackhull
Dwarf White durra	Pink kafir	Westland
Early Hegari	Plainsman	White Durra
Early Kalo	Red kafir	Wonder kafir
Early White milo	Reed kafir	
S.A. 1170	Schrock	
Extra Early Sumac	Sedan Red	
Grass sorghum		
Sudan grass	Sudan grass (Cal-approved 23)	Sudan grass (Tift)
Broomcorn		
Black Spanish	Evergreen Dwarf (Acme)	Japanese Whisk
Evergreen	Fulltip	Scarborough
Varieties susceptible to milo disease		
Grain sorghum		
Beaver	Double Dwarf milo	Quadroon
Colby	Dwarf White milo	Sooner
Darso	Dwarf Yellow milo	Wheatland
Day	Early White milo	

¹ All seed lots tested had a small percentage of susceptible plants. The reaction of this variety is questionable.

results, genetically pure susceptible varieties should continue to be susceptible unless they are either hybridized with resistant varieties or unless mutation occurs. If susceptible and resistant varieties are hybridized and the selections grown on noninfested soil, there would be a 25 percent chance of selecting a resistant segregate. Such a resistant segregate was accidentally chosen in 1927 when Kalo (Pink kafir x Dwarf Yellow milo) was selected. From this same cross Early Kalo was isolated in 1931 and it is also resistant.

In any sorghum breeding program, milo disease resistant varieties such as kafirs, sorgos, and resistant milo derivatives are often grown near homozygous susceptible milo varieties

and some cross pollination takes place. After two or more years some of these lines will carry homozygous recessive genetic factors for disease resistance.

In one large planting (12,500 plants) of standard Colby milo (Dwarf Yellow milo x Early White milo) growing in infested soil in the greenhouse, 1 resistant to 620 susceptible plants occurred (Fig. 4). In a similar planting of standard Wheatland (milo x kafir) a higher ratio of resistant plants was obtained. These differences may be explained by differences in parentage and in locations for natural cross-pollination during the years prior to these tests in the greenhouse.

Also, if seed of Colby or Wheatland is planted for several seasons in fields that have infested areas, there would be a tendency for susceptible plants to die or fail to produce seed, while the resistant plants survive, thereby changing the numerical ratio between susceptible and resistant individuals in the seed lot.

Other hypotheses, in addition to natural hybridization, may be formulated. An exact history of the standard varieties of milo and milo hybrids would aid in explaining how the resistant lines which they contain came to exist. In some cases several agronomic lines may have been bulked before they were genetically pure for the factor of resistance. Perhaps the genetic explanation given above may be complicated by one or several complementary factors.

Another possibility is that of recurring mutation giving rise to resistant lines in some of the standard varieties of milo and milo hybrids. If the entire explanation of this problem were to be based on this hypothesis, however, the mutation of the dominant gene to the recessive condition undoubtedly occurs very frequently. It would be classified as a highly unstable gene. Karper (6) has shown that this may operate for certain other characters in sorghums.

One, several, or none of these hypotheses may be the true explanation of this genetic problem. The fact, however, that these resistant selections can be readily isolated is important to sorghum production and is a sharp, clear-cut example of how disease-resistant lines in this crop may be obtained.

Two Milo Disease-Resistant Varieties, Finney and Westland

The seed of two milo disease-resistant selections of milo has been increased at the Garden City Branch Agricultural Experiment Station for commercial use. The history of the Dwarf Yellow milo selection, later named Finney, was described by Wagner (13). It is a resistant selection made in the fall of 1930 from susceptible Dwarf Yellow milo. Two plants of Dwarf Yellow milo, apparently normal in every way, were found growing on an infested plot of irrigated ground where all other Dwarf

Yellow milo plants had been killed by the milo disease. A head from each plant was grown in head rows on heavily infested soil the following year. One head row produced both healthy and diseased plants. The other produced only healthy, normal plants and the progeny of this plant was increased and upon extensive testing both in the field and the greenhouse at Manhattan over a period of years, continued to be resistant to the milo disease. In 1937, it was named "Finney" after the county in which it originated and was distributed to farmers the same spring.

A field (Fig. 8, A) of Finney has been grown at the Garden City station every year since 1937 to maintain a source of pure

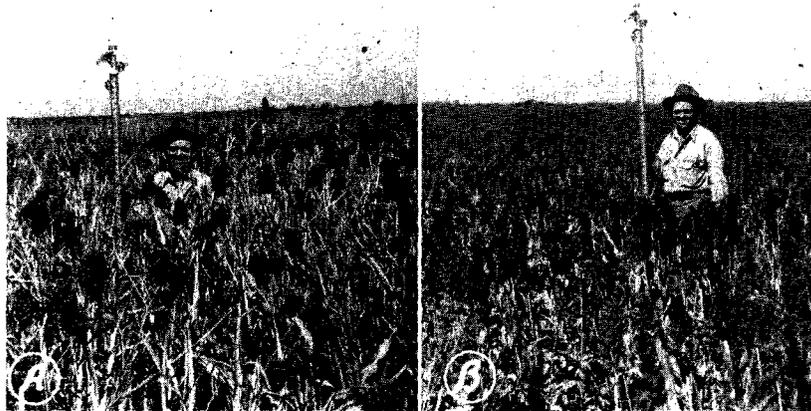


Figure 8.—A. Field of Finney, and B. field of Westland. The former produced 52.8 bu., the latter 70.5 bu. per acre.

seed eligible for certification by the Kansas Crop Improvement Association. The variety has been popular with the irrigation farmers in the Arkansas valley who have milo disease on their farms and who desire to bind their grain sorghum crops. However, according to a survey made among the irrigation farmers of the Arkansas valley in Finney county, about two-thirds of the farmers were growing a combine type of grain sorghum even though susceptible to milo disease because combining is cheaper than binding.

The other milo disease resistant selection is a combine type recently named "Westland." This particular selection from Wheatland also was made in 1930 by Mr. Wagner. However, when grown in the greenhouse and in head rows in 1931 it was only partially resistant. It took several years of testing in disease-infested soil, followed by selection of the resistant

plants, to make the selection pure for resistance to milo disease.

The exact origin of Westland is unknown. It may be a natural hybrid or it may be a direct selection out of true Wheatland. Regardless of the origin, Westland differs in several characteristics from Wheatland. It was still segregating for several characters in 1937 when the junior author took charge of the selection. Following a rigid selection and testing program by the writers, it was named "Westland" in 1941. The same year an increase field of 35 acres was grown, producing 71,500 pounds of clean seed, all of which was released to farmers in the spring of 1942. This seed went to 483 farmers in 49 counties in Kansas and to one or more farmers in the states of Texas, Oklahoma, Colorado, Nebraska, Idaho, Missouri and Wisconsin.

Westland resembles its parent Wheatland except for the following differences: It is about three inches taller than Wheatland as it exserts farther out of the boot, placing the head well above the upper leaves, which is advantageous in combine harvesting. The seed of Westland is similar in size and shape to that of Wheatland but is brighter in color, more closely approaching the color of Dwarf Yellow milo. Westland tillers less than Wheatland, usually having only one or two tillers which produce heads of a uniform height, like Wheatland. Westland matures earlier than Wheatland, probably because there are not so many late-maturing sucker heads. It is resistant to milo disease. The stalks of Westland are short and sturdy like Wheatland and so resist lodging equally well. An irrigated field yielding 70.5 bu. per acre is shown in Figure 8, B.

On land so heavily infested with milo disease that Dwarf Yellow milo and Wheatland were complete failures when grown in short, single rows, Finney and Westland produced excellent yields in one-forty-fifth acre plots when grown under full irrigation at Garden City, Kansas. These results are given in Table 4. Dwarf Yellow milo and Wheatland were not included in the larger plots because the soil is known to be heavily infested

Table 4.—Yield of sorghum varieties on fully irrigated soil badly infested with milo disease. Garden City, Kansas.

Variety	Bushels per acre			
	1940	1941	1942	Three-year average
Dwarf Yellow milo (a) ¹	0.0	0.0	0.0	0.0
Finney	73.0	71.9	32.0	59.0
Wheatland (a)	0.0	0.0	0.0	0.0
Westland	51.7	53.7	36.2	47.2
Westland ²	80.2	82.9	48.2	70.4

¹ All plots were one-forty-fifth acre in size except those planted to the susceptible parents (a) which were only single 26-foot rows.

² Grown in rows spaced 22 inches apart; other plots 44 inches apart.

with milo disease and these varieties would have been a total failure as proved by the single row plots.

Yields on land fallowed one year before seeding at Garden City are given in Table 5. The intensity of milo disease varies from year to year and from plot to plot in any one year on non-irrigated land so in some years, especially in 1941, the differences between susceptible parents and resistant offspring are largely due to milo disease injury. The yields of Dwarf Yellow milo and Finney are almost identical except in 1941 when the milo disease was so severe it seriously injured the susceptible parent. Westland out-yielded Wheatland in all years and especially in 1941 when milo disease reduced the yield of Wheatland. Thus, Westland outyields Wheatland at Garden City on dry land when milo disease is not a factor and greatly outyields it when milo disease is present in the soil.

Table 5.—Yield of sorghum varieties grown on one year fallow, non-irrigated soil. Garden City, Kansas.

Variety	Bushels per acre				
	1939	1940	1941	1942	Four-year average
Dwarf Yellow milo	8.7	0.3	36.2	30.0	18.8
Finney	8.0	0.4	50.3	29.0	21.9
Wheatland	8.4	7.0	34.5	12.2	15.5
Westland	9.5	10.4	49.0	19.9	22.2

The present seed sources of Finney and Westland came from single plants. It is not uncommon, however, to find other equally good lines in the bulk seed lots of the standard susceptible varieties from which they came. Several other lines of Dwarf Yellow and Wheatland milo have been selected that are resistant and might have been chosen in place of the present lines called Finney and Westland. This has been the case of the numerous resistant selections that are available of Colby, Day, Beaver, Darso, Sooner, Pygmy, and Quadroon which have been obtained in the last six years. All these have been tested in the greenhouse at Manhattan as well as in the field at Garden City and all are completely resistant to milo disease and many are typical of the variety. Of these, the Sooner selection is being increased in Oklahoma, while the Day and Beaver selections are being tested in Oklahoma, New Mexico, Texas, and Nebraska.

Testing Seed of Resistant Varieties for Certification

The Kansas Crop Improvement Association has approved for certification Finney and Westland which were primarily developed for their resistance to milo disease. Since these resemble the standard susceptible Dwarf Yellow milo and Wheat-



Figure 9.—A. Disease test is made of all certified seed lots of Finney and Westland. Rows 1 and 2, 5 and 6, 9 and 10 are samples of certified Finney. Growing in heavily infested soil they prove resistant. Rows 3 and 4, 7 and 8, 11 and 12 are ordinary Dwarf Yellow milo used as susceptible controls. When certified seed of Finney is planted in "diseased fields" the variety is resistant (Fig. 6, B). B. Testing soil samples suspected of having milo disease. Pot on left contains soil from a field in Stevens county. Both resistant and susceptible varieties of milo were planted in it. This soil is badly infested. On the right is a sample of soil from a field in Hamilton county. It was planted in the same manner. Note that all plants grew and the soil is not infested.

land, respectively, in their general growth habits and appearance, the disease test is important. It is imperative to determine the purity for resistance to milo disease, i. e., to detect mixtures and natural hybrids. When Finney and Westland are grown for certified seed production, there is no reliable field determination of their resistance since they may or may not be grown on infested soil. Therefore, the disease reaction must be checked in infested soil in the greenhouse during the early fall. Two rows from seed of a certified field and two rows of a susceptible control constitute a test. In Figure 9, A, three different samples of Finney milo are represented, and, as will be noted, they are all resistant. The results from the disease test determine whether the seed lot from which the sample came is eligible for certification and whether the grower's name is to be placed on the approved list. A field of Finney producing 52.8 bu. per acre which is being grown for pure seed is shown in Figure 8, A.

Testing Soil Samples of Fields Suspected of Having Milo Disease

When county agents or farmers are not certain whether milo disease occurs in a field, they are advised to send in a five-pound composite sample of soil from the field suspected of carrying the disease. If a field has even a trace of milo disease in it, the seedling test will show its presence.

A flower pot of soil from a field in Stevens county, Kansas, in which half of the soil was planted to susceptible Dwarf Yellow milo and the other half to Finney is shown in Figure 9, B. There is no question but that the field has the milo disease present. A second pot of soil on the right was taken from a field in Hamilton county, Kansas. It was planted in a similar manner, but it is apparent that no sign of infestation exists. The susceptible plants grew as normally as the resistant plants. The county agent thought the second field had been injured by milo disease, yet he was not certain from the symptoms of the plants. It frequently happens that milo disease symptoms are confused with other injuries. This seedling-testing method of soils from questionable fields is being put into use in Kansas and has been found helpful and reliable.

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