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Greenbug-resistance
STUDIES WITH SMALL GRAINS

THE AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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In cooperation with the U. S. Department of Agriculture

SUMMARY

The greenbug is one of the most damaging insects of small grains. Losses from reduced yields of grain and forage frequently have exceeded several million dollars in a single season. Because of the expense of presently available controls and the comparative low per-acre value of small grains, the development of greenbug-resistant varieties offers the most economical and practical means of controlling this pest. Studies on greenbug resistance in barley, oats and wheat were initiated at Substation No. 6, Denton, Texas, in 1951. Results of these studies through 1959 are presented in this bulletin.

All of the testing for greenbug resistance was done in a controlled-environment insectary. The insectary and testing technique are described. More than 18,860 varieties and strains of barley, oats and wheat of domestic and local origin, from hybrids and collections of the U. S. Department of Agriculture, have been tested for greenbug resistance during this period. Information on those having significant resistance and which may be of use to plant breeders is presented.

Greenbug resistance of significance was found first in Omugi, Kearney and several other varieties of barley. It was transferred to desirable domestic varieties by crossing. Several resistant strains selected from these hybrids and of potentially economic value have been included in state yield trials and in the U. S. winter barley nursery, and numerous strains from other crosses are being tested. Studies on the inheritance of greenbug resistance in barley indicate that a single gene is involved. Spring and winter-type collections of the U. S. Department of Agriculture have been screened for additional resistant germ plasm, and several varieties with resistance equal to or greater than that of Omugi were found. These are being incorporated into the breeding program in Texas.

Several oat varieties with significant resistance were found for the first time when the USDA world oat collection was screened for greenbug resistance. It is being transferred to domestic varieties through a breeding program at the Denton station. This breeding program has not been in progress long enough to indicate the successful development of adapted resistant oat strains.

Several greenbug-resistant wheats which had been screened from the USDA world wheat collection at Stillwater, Oklahoma, have been crossed with domestic varieties at Denton. However, the resistant parents of the crosses are spring-type wheats and of poor quality, so much more breeding work will be necessary before acceptable greenbug-resistant varieties will be available to hard red winter wheat growers. Studies on the inheritance of greenbug resistance in wheat indicate that a single dominant gene is involved, although the possibility of modifying genes in certain genetic backgrounds is suggested.

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Greenbug-resistance Studies with Small Grains

H. L. Chada, I. M. Atkins, J. H. Gardenhire and D. E. Weibel *

THE GREENBUG (*Toxoptera graminum* (Rond.)), among several aphids that attack small grains, is one of the most damaging insects of small-grain crops in the United States. Fifteen serious outbreaks have occurred since 1882, 10 involving parts of Texas. Estimated losses from reduced yields of grain and forage or total destruction of crops frequently have exceeded several million dollars in a single season.

The greenbug can be controlled by modern insecticidal sprays, but often these are impractical or are not effective because of weather conditions. Where grain yields are low, as frequently occurs in the low-rainfall, wheat-producing areas of the Midwest, the costs of insecticidal controls often are prohibitive. Many of these products are very toxic and must be used carefully where the small-grain crop is grazed or harvested for feed of any type. Most of these insecticides are not highly effective at temperatures below 50° F., but greenbugs feed and reproduce normally at such temperatures. Parasites and predators of the greenbug are relatively slow in development at temperatures of 50° or below. Temperatures in many seasons and locations, therefore, often are unfavorable for control by chemicals or natural enemies. Cultural control practices have some influence on greenbug populations, but often are not adequate. For these reasons, better measures are needed for a low-value crop such as small grains.

Greenbug-resistant varieties offer the most economical and practical means of control. Resistant varieties have been used against the hessian fly (*Phytophaga destructor* (Say)), and against several other insects. Such varieties may not be immune from attack, but insect populations increase on them more slowly; therefore, they are more readily controlled with chemicals when necessary.

Greenbug-resistance studies were initiated at Substation No. 6, Denton, Texas, in 1951. These investigations included: extensive screening of the domestic and U. S. Department of Agriculture world collection of small-grain varieties and hybrid lines in a search for resistant germ plasm; the testing of early generation lines from hybrids between commercial and greenbug-resistant varieties; studies of the inheritance of greenbug resistance in wheat and barley; and field tests of resistant varieties. More than 18,860 varieties and strains were tested. Complete records are on file with the U. S. Department of Agriculture and at the Denton station. Only those varieties and strains that showed some resistance and, therefore, are of value to other breeders or research workers are reported herein.

REVIEW OF LITERATURE

According to Hunter (18), the greenbug was described and named (*Toxoptera graminum* (Rond.)) by Rondani of Italy, who observed the aphid infesting grasses in 1847. Webster and Phillips (32) stated that the greenbug was first found in the United States in Virginia in 1882. These same authors reported that the first damage to wheat in Texas occurred in 1890 in Denton and nearby counties of North-central Texas. Damage to wheat and oats also was recorded in 1901, 1903, 1904 and 1906. These infestations were followed by the serious, widespread outbreak in 1907, when the insect damaged crops in Central Texas, then spread in a fan-shaped area extending northward through Oklahoma, Kansas, Missouri, Arkansas and into Illinois.

Less extensive outbreaks occurred in parts of Texas in 1916, 1922 and 1933, according to Bilsing (5) and Hyslop (19). A major outbreak in 1942 extended from Central Texas to Northern Oklahoma, and an estimated 61 million bushels of grain were destroyed. Major outbreaks occurred in 1950 and 1951 when most of the wheat in the Texas Panhandle was destroyed (14).

Since effective insecticides were not available, early research workers, Webster and Phillips (32), Bilsing (5), Hunter (18) and Whitehead and Fenton (33), recommended crop rotations, plowing and burning of early fall infested spots, and destruction of volunteer grains as control measures. Hunter (18) was the first to observe that the hymenopteron, (*Aphidius tritici* (Cress.)), was an important parasite, and he attempted to use this insect in biological control by spreading it in areas ahead of the advance of the greenbug. The importance of the convergent lady beetle (*Hippodamia convergens* G.-M.) and other coccinellids as predators of the greenbug and other aphids has long been recognized.

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Webster and Phillips (32) were perhaps the first to suggest chemical control. They reported that kerosene emulsion and whale-oil soap were effective on bluegrass lawns in Washington, D. C., in 1907. Dahms (12) tested many materials, but found that a parathion spray at 0.25 pound per acre was the most effective. Several insecticides reported by Daniels *et al.* (14) are now available where their cost is justified.

Resistance of plants to insect attack has been observed for more than 150 years. Extensive reviews of references on insect resistance in more than 100 plant species are given by Snelling (28, 29) and Painter (25, 26). LePelley (20) stated that as early as 1831 George Lindley observed that the Winter Majetin apple was resistant to the woolly apple aphid *(Eriosoma lanigerum* (Hausm.)). Bioletti *et al.* (6) also reported that certain grape stocks were resistant to the grape phylloxera *(Phylloxera vitifoliae* (Fitch)). The economic value and biological significance of insect resistance in plants were discussed by Painter (23).

Differences in reaction to attack were observed first by Wadley (30), in 1931. He found that it was difficult to rear greenbugs on Mindum durum wheat or Vernal emmer. On emmer, less than 10 percent of the insects matured, and no second generation developed. Fenton and Fisher (16) observed that barley was the preferred host and that oats and wheat followed. Varietal differences in reaction to greenbugs were observed among a large collection of barley, wheat and oats grown by Atkins and Dahms (4) during the 1942 outbreak. High resistance was found among barley varieties, especially certain ones of Oriental origin. A moderate resistance was observed in wheats; among the best were certain Marquillo x Oro strains, which also were resistant to the hessian fly. Varietal differences were observed among the oat strains, but no high degree of resistance was found. It was suggested by Atkins and Dahms (4) that a search be made among world sources of small grains for resistance.

Later Dahms *et al.* (13) tested several hundred varieties and strains of oats, barley and wheat in a search for greenbug resistance. None of the oat varieties showed appreciable resistance, but among plants of Dickinson durum wheat, No. 485 (C.I. 3707) they found some with high resistance. Seed of these were increased, and this strain is now being used in breeding programs at several locations. More recently a second unnamed resistant variety, C.I. 9058 from Iraq, was found.

Arriaga (1, 2, 3), working in Argentina, developed an insectary technique and tested small grains for resistance. He found varietal differences in barley, wheat and rye, but none in oats and concluded that the laboratory tests were superior to field trials for selecting resistant strains. Resistant rye strains have been developed and distributed to growers in Argentina. Silveira (27) reported differences in reaction among varieties of wheat and rye in Uruguay.

Some studies and observations have been made on the nature of resistance, but much more research is needed. MacLeod (21) and others stated that little is known about plant resistance to insects. Chatters and Schlehuber (8) found that resistant varieties of barley had thicker leaves, but insufficient evidence made these authors hesitate to conclude that this leaf character was associated with resistance. Painter (24) studied the food requirements necessary for growth and reproduction of greenbugs and observed that the absence or inaccessibility of any of many substances might be related to resistance. A correlation between plant vigor and degree of injury was observed by Walton (31). Maxwell and Painter (22) found that the rate of honeydew deposition by greenbugs was influenced almost directly in proportion to the known resistance of the host plants.

Dahms and Fenton (10) stated in 1939 that insect resistance in plants was inherited, but the cause was complex and sometimes influenced the biology of the insect itself. Studies on the inheritance of resistance to greenbugs in Omugi barley were conducted by Dahms *et al.* (13) and by Gardenhire and Chada (17). They found that resistance was conditioned by a single dominant gene. Tests are in progress, but have not yet indicated the linkage group involved. Inheritance studies of resistance in wheat were carried out by Daniels and Porter (15) and by Curtis *et al.* (9). These authors reported a single recessive gene for resistance in Dickinson Sel. 28A although there appeared to be modifiers or minor genes involved. Curtis *et al.* (9) stated that Dickinson Sel. 28A and C.I. 9058 appeared to have the same gene, but they were unable to find the chromosome involved. These studies showed that resistance can be transferred successfully to adapted varieties by normal breeding procedures or a backcross program. Such programs are in progress at the Texas Station.

The possibility of developing greenbug biotypes that might attack present resistant varieties has been investigated in a small way. In 1948, Dahms (11) obtained specimens from Oklahoma and Mississippi, but could find no differences in their ability to attack varieties. More recently, however, a strain of greenbugs developed in the greenhouse at Oklahoma State University was able to damage Dickinson Sel. 28A. Tests by Wood (34) proved that this strain behaved differently from former strains and he believed the insects of this strain to be a distinct biotype.

MATERIALS AND METHODS

Although outbreaks of greenbugs occur infrequently, they are a potential threat nearly every season in the principal grain-growing areas of Texas. Serious outbreaks may occur when summer and early fall rains assist early growth of volunteer small-grain plants as hosts for the insects, and when this kind of weather is followed by a dry, cool winter, in which natural parasites and predators are below normal in activity and numbers. Therefore, the testing or screening of material in the field has not been satisfactory in Texas.

All varieties and strains were tested in a controlled-environment insectary. Differences in reaction, then, were believed to be caused by inherent characteristics of the variety or strain under test. Complete details of this insectary technique were described by Chada (7), but are reported briefly following for easy reference.

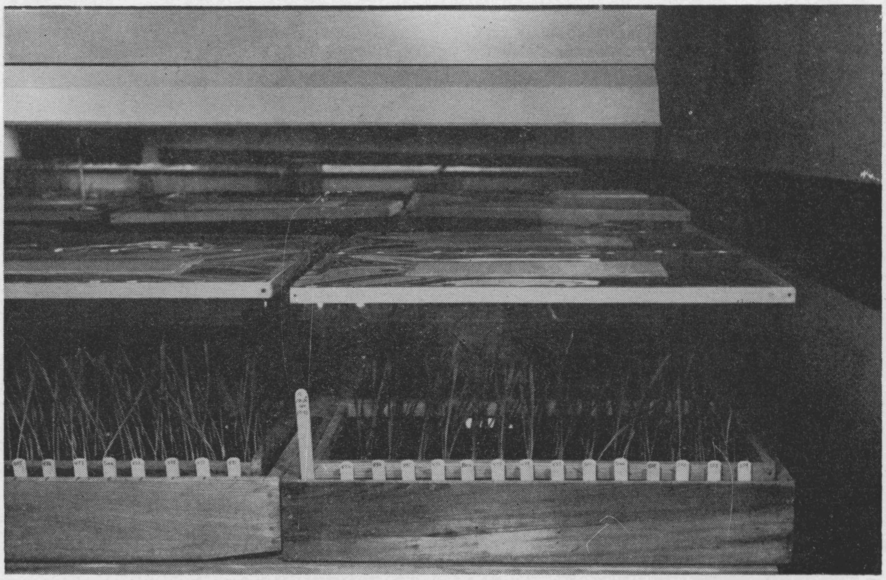

Figure 1. General view of flats, plastic cages and lights in the insectary.

The Insectary

The insectary consists of an insulated room 24 x 12 feet in which a uniform temperature of 75° F. is thermostatically controlled by means of two ¾-ton refrigerated air conditioners and an electric heater (Figure 1). Fluorescent light fixtures with two 40-watt daylight and two white bulbs hang approximately 12 inches above the flats on each bench and provide ample light for growing the seedlings. Artificial light, supplied from 6:00 a.m. to 10:00 p.m., is controlled automatically with an inexpensive brooder-house timeclock. The humidity is not artificially controlled, but usually remains between 50 and 60 percent.

Cypress flats, 22½ x 12½ x 3½ inches, are used for growing the plants. Each flat accommodates 14 rows of 10 plants each. To insure a uniform stand, seed are sprouted in a germinator between wet paper toweling. Ten vigorous sprouted seed are then transferred to each row for testing (Figure 2). Seedlings are covered with ½ inch of sand and watered. A wooden stake bears the entry number of each row.

Unsterilized local soil, classified as Kirvin fine sandy loam, is used in the flats. Clay soils are not satisfactory because they are sticky when wet and will not permit easy removal of the cages. Watering is done by lifting the side of the cage and inserting a perforated copper tube atttached to a rubber hose leading from an overhead water supply. Watering from the usual hydrant supply is not satisfactory because of soil washing.

A cage of cellulose nitrate plastic, 22 x 12 x 10 inches, fits inside the flat to cover the plants and confine the greenbugs. Acetone is used to close the joints, and wooden strips measuring ¾ x ½ inch, to which the plastic is attached by staples, serve as reinforcements. An opening, measuring 12 x 4½ inches, covered with 34-mesh plastic screen, is made in the top of the cage to provide ventilation. The cage is placed over the flat and pressed down into the sand to prevent entry or escape of the insects. A complete insectary testing unit is shown in Figure 3.

Greenbug Source

The original greenbugs used in these tests, descendants of one insect collected near Stillwater, Oklahoma, in 1947, were obtained in 1951 from R. G. Dahms, then located at Oklahoma State University. Greenbugs are maintained in the insectary on culture pots of

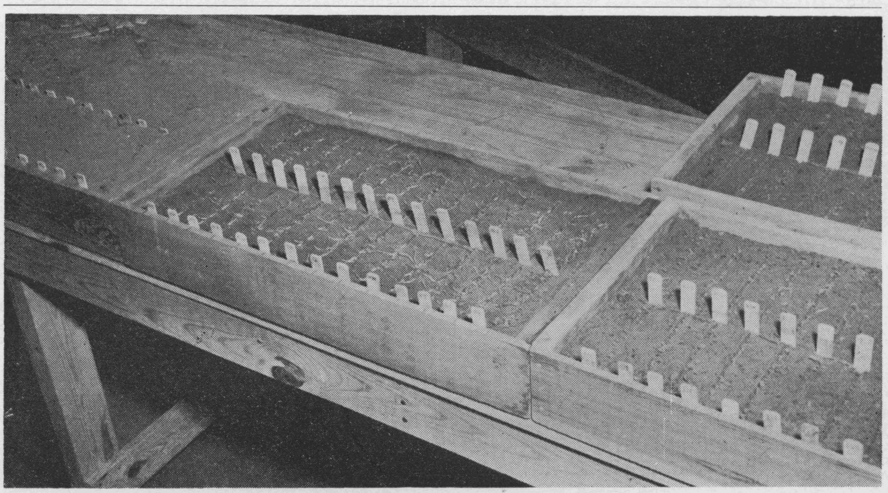

Figure 2. Placement of test grain seedlings of oats in flats before soil covering is added.

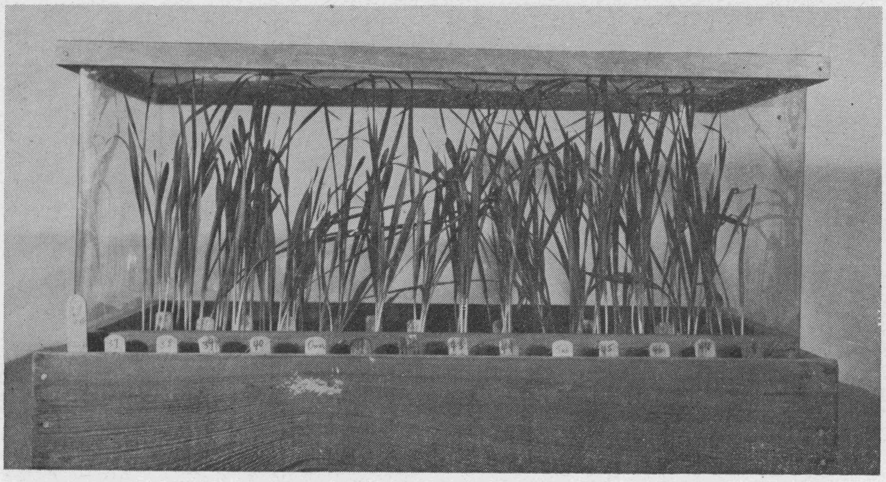

Figure 3. A complete insectary testing unit showing detail of flat and cage construction.

susceptible varieties of each of the crops and are transferred to new plants as often as necessary (Figure 4).

Source of Small-grain Varieties

Varieties and strains of domestic and local origin were taken from the nursery at Denton. Many hybrid lines were developed from crosses made for transferring resistance to locally adapted varieties of small grain.

Special groups, for example, the 200 Oriental wheat varieties and the world collections of oats and barley, were obtained from the Crops Research Division, U. S. Department of Agriculture.

The small grain varieties and strains tested for reaction to the greenbug during 1952-59 are shown in Table 1. This table does not include those strains given special tests for longevity and antibiosis or retested for different reasons.

Screening and Rating Varieties

Varieties to be tested, along with one resistant and one susceptible variety as checks, are grown in each flat. The flats are marked off into 14 rows and then divided lengthwise as well. Ten sprouted seed of each variety are planted, five on one side of the flat in regular order, and the other five on the other side in random order. The resistant check is placed in the fifth row and the susceptible one in the tenth row.

Growth in the insectary is rapid. In 1 week, the plants are 3 to 4 inches tall. They are then infested at the rate of five greenbugs per plant.

The rating for damage is made 10 to 14 days after infestation. All varieties are rated when plants of the susceptible check or other highly susceptible variety begin to die from damage by feeding. Tolerance ratings from 0 to 5 are based on the percentage of leaf area damaged, as follows:

TOLERANCE RATING	PERCENTAGE OF LEAF AREA DAMAGED
0	0-10
1	11-20
2	21-40
3	41-60
4	61-80
5	Beyond recovery

The average rating of each variety is expressed as a percentage of the resistant check variety. Some variation in greenbug reaction, as indicated by the average rating of the resistant check variety, was observed between flats. This probably was due to slight differences in the ages of greenbugs used in infesting flats. Only varieties with tolerance ratings lower than the resistant check are saved for further testing. Approximately 144 varieties can be tested per week with the facilities available.

Plant-longevity Tests

Varieties which appear equal to the resistant check variety in the screening tests are subjected to longevity tests to obtain additional information on their value. The procedure is the same as for the tolerance rating tests, except that greenbugs are allowed to feed and multiply until most of the plants are killed. The flats are inspected frequently, and the longevity of the variety is expressed as a percentage of the resistant check variety. The longevity test is severe for surviving plants since the insects concentrate on them as other plants die. Single plants of a variety frequently show a high degree of tolerance and are transferred to a greenhouse to produce seed. These segregates or mixtures may be valuable germ plasm.

TABLE 1. SMALL-GRAIN VARIETIES AND STRAINS TESTED IN THE CONTROLLED-ENVIRONMENT INSECTARY, DENTON, TEXAS, 1952-59

Crop	Source	Number tested
Barley	USDA world collection varieties	4,445
	USDA winter growth type barley varieties	1,230
	Hybrid lines involving resistant parents	4,214
	Miscellaneous	121
	Total tested	10,010
Oats	USDA world collection varieties	4,998
	Miscellaneous	107
	Total tested	5,105
Wheat	USDA collection of Oriental varieties	200
	Hybrid lines involving resistant parents	3,225
	Miscellaneous hybrids and varieties	320
	Total tested	3,745
Grand total, all crops		18,860

Antibiosis Tests

Resistant varieties also are tested for antibiosis by determining the rate of reproduction of a single greenbug on an individual plant. Six of each variety are planted—three in each of two 6-inch pots. When 1 week old, a single greenbug, which has not reproduced, is placed on each plant. The infested plant is then covered with a plastic cage measuring 10 x 2⅜ inches. Counts of the progeny are made 7 days later and are compared with progeny on the resistant and susceptible check varieties.

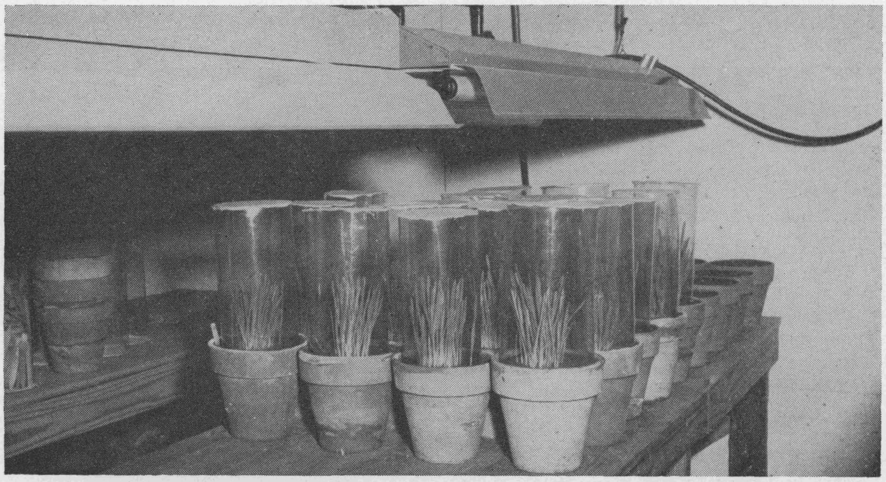

Figure 4. Uniform greenbug cultures maintained in the insectary on caged barley plants grown in pots.

EXPERIMENTAL RESULTS

Screening and testing for greenbug resistance among varieties and unnamed selections of barley, oats and wheat, together with genetic studies of resistance in barley and wheat, were carried out during 1952-59.

Barley

Barley is an important grain and forage crop in North-Central Texas. Observations of resistance among varieties of barley grown during the 1942 infestation indicated that an excellent opportunity existed to develop adapted varieties resistant to the greenbug. The tolerance of Smooth Awn 86 (C.I. 6268), Esaw (C.I. 4690) and Sunrise (C.I. 6272) to attack in 1942 is shown in Figure 5, and that of Malwet (C.I. 2459), Nipa (C.I. 2471), Omugi (C.I. 5144) and Sonbaku (C.I. 5151) in the same year is shown in Figure 6. These varieties survived to produced grain when all surrounding varieties and strains were killed.

Screening tests made by R. G. Dahms at Oklahoma State University (13) before 1952 had shown that Omugi (C.I. 5144), Kearney (C.I. 7580) and several other varieties had a higher degree of resistance than that found in Smooth Awn 86. A breeding program to transfer resistance to adapted varieties was initiated at Denton in 1952, but, since no testing facilities were available, the hybrids were grown in bulk. Eighteen barley hybrids were so grown and when insectary tests were started in 1953, random selections were made, screened and seed increased from resistant plants. The progenies were then rescreened in later generations. Considerable difference in resistance among random selections within each of the crosses was observed. Although no genetic analysis was attempted, it appeared that the Cordova x Omugi F_4 and F_5 selections indicated that a single gene was involved in the inheritance of resistance. Calculated percentages for resistant and susceptible segregates in F_4 and F_5 were 56.2 and 53.1, respectively; the observed percentages were 58.2 and 55.3. Data on reaction in these crosses are given in Tables 2 and 3. The resistance of Cordova x Omugi hybrids, compared with that of the parent varieties, is shown in Figure 7. The greatest tolerance was found in a cross of Cordova x Tongu, and several selections from this cross have reached yield trials.

Most barley in Texas is fall-sown; therefore, a search was made among 1,230 winter and intermediate-winter barleys for additional sources of resistance. These barleys were part of the USDA world collection. Wintex (C.I. 6127), a locally adapted susceptible variety, and Omugi, one of the most resistant, were used for com-

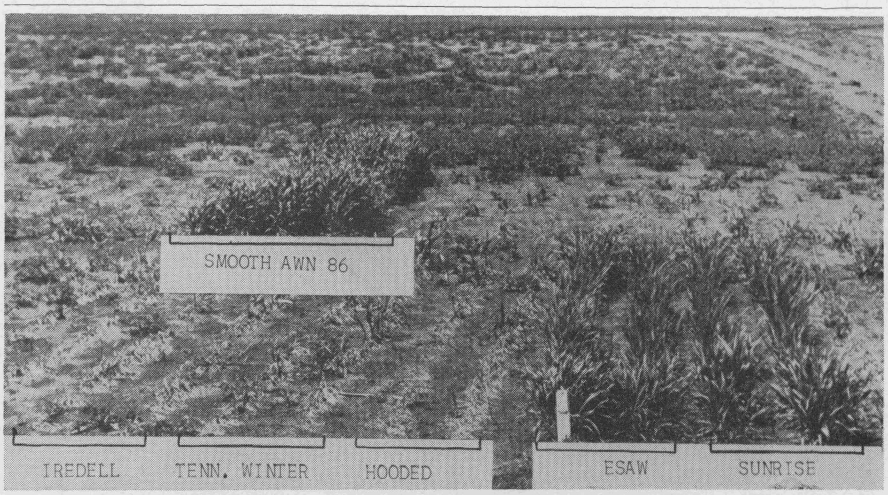

Figure 5. Survival of Smooth Awn 86, Esaw and Sunrise barleys at Denton in 1942 when surrounding varieties were killed by greenbugs.

TABLE 2. REACTION TO GREENBUG INFESTATION OF ADVANCED-GENERATION LINES OF BARLEY CROSSES, DENTON, 1954

Hybrid	Number of selections tested	Average tolerance rating
Cordova x Tongu	10	2.8
Wis. Barbless x Chevron 2x Bolivia 3x Chevron 4x Trebi 4x Smooth Awn 86	15	3.2
Wintex x Esaw	2	3.5
Wis. Barbless x Chevron 2x Bolivia 3x Trebi 4x Texan	1	3.8
Wintex x Smooth Awn 86	1	3.8
Texan x Smooth Awn 86	2	4.0
Gatami x Wintex	1	4.0
Wis. Barbless x Chevron 2x Bolivia 3x Dorsett 4x Wintex	2	4.1
Texan x Sunrise	6	4.2
Purdue x Wintex	1	4.2
Purdue x Tenkow	1	4.2
Gatami x Texan	22	4.3
Wis. Barbless x Chevron 2x Bolivia 3x Chevron 4x Trebi 4x Texan	3	4.3
Smooth Awn 86 x Wis. Barbless x Chevron 2x Bolivia 3x Dorsett	3	4.5
Wis. Barbless x Chevron 2x Bolivia 3x Dorsett 4x Texan	22	4.5
Texan x Dohadak	4	4.5
Texan x Esaw	3	4.5
Cordova x Kido	8	4.5
Missouri Early Beardless x Texan	2	4.9
Omugi (resistant check)	..	2.8
Wintex (susceptible check)	..	4.5

TABLE 3. GREENBUG RESISTANT AND SEGREGATING LINES OBTAINED FROM UNSELECTED ADVANCED-GENERATION BARLEY HYBRIDS

Hybrid	Generation	Number of selections tested	Percent resistant selections[1]	Percent segregating selections[2]
Cordova x Omugi	4	632	24.7	33.5
Cordova x Omugi	5	204	22.3	32.8
Cordova x Omugi[3]	5	1,349	48.2	38.8
Cordova x Omugi[4]	3	80	15.0	28.8
Cordova x Omugi[5]		69	34.8	8.7
Cordova x Kido	5	206	1.9	0.4
Cordova x Tongu	5	69	37.7	33.3
Texan x Omugi	4	110	13.6	23.6
Texan x Omugi	5	200	19.0	40.0
Texan x Omugi[5]		105	10.5	13.3
Texan x Ludwig	4	115	14.8	5.2
Texan x Ludwig	5	175	72.0	49.1
Texan x Ludwig[5]		87	17.2	6.9
Dicktoo x S-50-2-3[4,6]	3	29	0.0	20.7
Harbine x Omugi[4]	3	54	5.5	35.2
10-47-84 x Omugi[4,7]	3	21	47.6	38.1
10-47-136 x Omugi[4,8]	3	71	46.5	29.6
Goliad x Baitori[4]	3	35	2.9	57.1
46S.71-6-0-1-0-0-0 x Cordova[4,9]	3	23	0.0	4.3

[1]Selections showing as much or more resistance than Omugi.
[2]Selections with resistance average less than Omugi, but having at least one plant equal to or more resistant than Omugi.
[3]Reselections.
[4]Selections from spaced F_2 plants.
[5]Selections from advanced bulk populations.
[6]S-50-2-3—Wis. Barbless x Chevron 2x Bolivia 3x Chevron x Trebi 4x Texan.
[7]10-47-84—Missouri Early Beardless x Texan selection.
[8]10-47-136—Missouri Early Beardless x Texan selection.
[9]46S.71-6-0-1-0-0-0—"Cebada negra" selection from Argentina.

parison in all tests. The reactions of Wintex and Omugi to insectary infestations are shown in Figure 8. Of the 1,230 strains tested, 160 were found to be more resistant than Omugi. Longevity, plant injury and antibiosis tests of these varieties and strains showed that 76 were rated at least 10 percent more resistant than Omugi. The 14 most resistant varieties are shown in Table 4. Since their behavior in the three separate tests differed greatly and single types of resistance may be of value to other research workers, the complete record for these 76 strains is available in Special Report W-93, August 5, 1958, Entomology Research Division, Agricultural Research Service, U. S. Department of Agriculture.

Of the 76 varieties with resistance greater than Omugi, 69 were from foreign countries with 43 from the Orient (Japan 16, Korea 15 and China 12). Only seven originated in the United States; three came from Nebraska and one each from Georgia, New York, North Dakota and Missouri. The source of one, Abyss. Winter, is unknown. Atkins and Dahms (4) and Dahms *et al.* (13) also observed that most of the resistant germ plasm came directly or indirectly from Oriental barleys.

The U. S. Department of Agriculture world collection of 6,174 spring barleys was obtained in 1957 to screen for resistant germ plasm in the controlled-environment insectary, and 4,445 varieties and strains were screened before termination of the testing program in the spring of 1960. As with the winter barleys, almost all of the spring strains were highly susceptible to greenbug attack, but among this large group 36 were found equal or superior to Omugi in resistance. Data on these strains are given in Table 5. Several strains were much more resistant than Omugi and may offer a diversified source of germ plasm useful in the plant-breeding program.

Breeding programs to develop adapted greenbug-resistant barley varieties are now in progress in

Texas and several other states. Some strains are now included in yield trials at several locations and two were included in the USDA winter barley performance nursery in 1960.

Oats

Oats are an important grain and forage crop throughout North-central and Central Texas, and are grown on a much larger acreage than barley or wheat. Volunteer stands and the large acreage seeded for winter pasture provide favorable host material for the increase of greenbug populations. Observations by Atkins and Dahms (4) in 1945 failed to identify any varieties with a high type of resistance. Dahms *et al.* (13) tested 221 domestic oat varieties and strains in a search for resistance, but observed only small differences and no high degree of resistance.

The search for resistance in the present experiments started with locally adapted varieties and strains. Some 102 varieties and strains from the Denton oat nursery and germ plasm collection were tested in the insectary in 1954. Camellia (C.I. 4079) was used as the check because no highly resistant variety was known. Data on the reaction of the 14 most resistant varieties and strains are given in Table 6. Complete data are available in Special Report W-57, July 1, 1955, Entomology Research Division, Agricultural Research Service, U. S. Department of Agriculture. Most of the varieties were highly susceptible. The resistance of those varieties rating better than Camellia was not significant because of the low degree of resistance of Camellia. Andrew (C.I. 4170) and New Nortex (C.I. 3422) showed more resistance than any other varieties. Andrew was used as the resistant check in all subsequent oat tests. However, it is known from past experience in greenbug infestations that these varieties, although perhaps more tolerant than most others, do not have sufficient resistance to offer protection to the crop under field conditions.

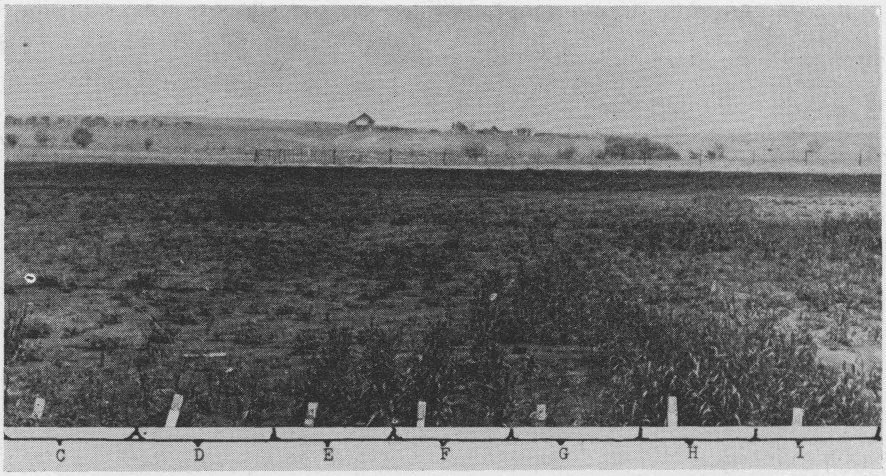

Figure 6. Survival of Malwet, Nipa, Omugi and Sonbaku barley varieties to the 1942 heavy greenbug infestation at Denton. (C) Texan, (D) May Nang, (E) Malwet, (F) Nipa, (G) Kashmir, (H) Omugi and (I) Sonbaku.

Figure 7. Reaction of resistant lines (center) from the cross of Cordova x Omugi to greenbug attack as compared with susceptible plants of Cordova and resistant plants of Omugi. Omugi plants are down but still green and alive. Cordova plants are dead.

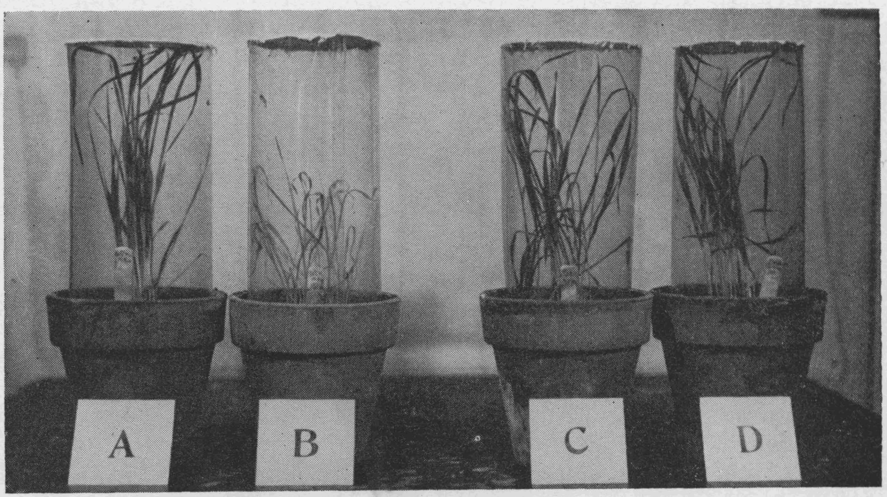

Figure 8. Reaction of Wintex (A and B) and Omugi (C and D) barleys to a 2-week greenbug infestation. B and D infested plants.

TABLE 4. FOURTEEN OF THE MOST GREENBUG-RESISTANT VARIETIES AND STRAINS OF WINTER BARLEY FROM A USDA COLLECTION OF 1,230

Variety or strain	C.I. or P.I. number[1]	Source	Resistance compared with Omugi (percent)			Rank
			Longevity[2]	Plant injury[3]	Antibiosis[4]	
Unknown	7530	Nebraska (hyb.)	153+	60	57	1
Suwon 3	7428	Japan	142+	84	43	2
Shokum	5233	Korea	123+	83	30	2
Unknown	7529	Nebraska (hyb.)	148+	61	86	4
Aizu No. 5	8926	Japan	132+	71	86	5
Unknown	9349	China	114+	97	20	6
Unknown	9355	China	106+	65	20	6
Suwon 31	7453	Japan	118+	86	86	8
Suwon 31	7454	Japan	117+	81	100	9
Kyo-bae 35	7418	Japan	156+	85	129	10
Yun-wol-yuc-kac	7458	Japan	122+	75	114	10
Chang-mang-ryuc-kao	7409	Japan	143+	89	114	12
Unknown	9224	Korea	137+	74	143	12
Suwon 15	7443	Japan	113+	87	86	12

[1]C.I. refers to accession number of Cereal Crops Research Branch, Crops Research Division, U. S. Department of Agriculture. P.I. refers to accession number of the Plant Introduction Section, Horticultural Crops Research Branch, U. S. Department of Agriculture.

[2]Based on the number of days the plants lived under infestation. "+" indicates some plants were alive at conclusion of the test. High percentages (more than 100) indicate plants lived longer than those in resistant check.

[3]Low percentages (less than 100) indicate plants were injured less than those in resistant check.

[4]Progeny of a single greenbug on an individual plant after 7 days. Low percentages (less than 100) indicate high degree of antibiosis.

The USDA world oat collection of 4,998 varieties and strains was screened in 1955-56 for greenbug resistance. Andrew was grown in all flats as the resistant and Mustang (C.I. 4660) as the susceptible check. A total of 683 varieties appeared to have as much tolerance as Andrew and 77 were rated at least 10 percent more resistant. All others were rated as susceptible.

Seventy-four of the 77 oats were subjected to plant longevity, plant injury and antibiosis tests in 1957, as described previously. When the strains were subjected to longevity tests, plants that survived longer than Andrew were saved as possible sources of superior germ plasm. Many were picked up in world markets and possibly seed of some varieties were mixed. Even where growing plants indicated the varieties were pure, they could have been mixed for greenbug resistance. Where mixed reaction to greenbugs was observed in seed lots, the resistant plants were tranplanted to greenhouse pots and grown to maturity to obtain seed and maintain the variety. The average longevity of the variety is expressed as a percentage of the resistant check.

Data on the 10 most resistant varieties and strains are given in Table 7. Complete data on the 74 oats are available in Special Report W-83, Nov. 11, 1957, Entomology Research Division, Agricultural Research Service, U. S. Department of Agriculture. The varieties and strains are arranged according to the average rank for the three categories shown. Several varieties and strains were superior to Andrew, particularly in longevity. According to Painter (25), "tolerance is the basis of resistance in which the plant shows an ability to grow and reproduce itself or to repair injury to a marked degree in spite of supporting a population approximately equal to that damaging a susceptible host." Most workers believe that tolerance to attack, especially as indicated by the plant-longevity test in these experiments, is a good index of resistance, because greenbug populations become heavy on these tolerant plants as other plants are killed. Some varieties survived even though they showed considerable injury after infestation for 10 days. Other varieties showing little injury after infestation for 10 days became stunted or died.

Of the 74 resistant varieties tested, 37 were from 18 states of the United States and 36 from foreign countries. The source of Siberian (C.I. 1712) is not recorded. Among foreign varieties, 12 came from Yugoslavia, 5 from Turkey, 4 from Argentina and 3 from Canada. Twenty-three of the 37 originating in the United States were Red Rustproof or related to it. Among the 10 most resistant varieties and strains shown in Table 7, only 2 were from the United States, 3 from Yugoslavia and 2 from Argentina. Since the Red Rustproof types are grown in all these areas, they may be a good source of resistant germ plasm.

These tests have provided plant breeders with a source of resistant germ plasm for use in breeding resistant oats. The transfer of this resistance to adapted varieties is now in progress at the Denton substation. Further search for germ plasm having even greater resistance is needed. Mixed varieties and strains from the world collection may be used to isolate single plants with superior resistance. No opportunity to test the resistance of these varieties under natural infestations in the field has occurred.

Wheat

Wheat is grown on extensive acreages throughout the Midwest, where greenbug outbreaks often occur. Because rainfall is relatively low and often poorly distributed, yields often are low and the value of the crop may not justify the use of insecticides.

Because many of the resistant barleys had their origin in the Orient, the first search for resistant germ plasm in this experiment was in wheat varieties and strains of Oriental origin. Some 200 Oriental wheats were selected from the USDA world wheat collection and tested at Denton in 1952-53. The procedure involved growing test plants in pots, and was that described by Dahms *et al.* (13), except that the plants were grown in the controlled-environment insectary instead of in a greenhouse. As no resistant varieties were then known, Pawnee (C.I. 11669), an important commercial variety, was the check. Data were obtained on plant condition on the day check plants died, greenbug preference, tolerance, antibiosis and growth index (as shown in Table 8). Most of the 200 wheats were susceptible, but several were superior to Pawnee in tolerance. Because they did not appear to offer promise as sources of resistant germ plasm, most of them are not listed. Complete data are available as Special Report W-31, April 22, 1954, Entomology Research Division, Agricultural Research Service, U. S. Department of Agriculture. A few of the more tolerant wheats are listed in Table 8. Although these wheats perhaps do not have high resistance, they may be of value for special studies, or resistant plants might be selected from them.

A second group of 120 Oriental wheats, ranging from C.I. 9370 to 9574 (some numbers omitted), were tested in comparison with Denton (C.I. 8265), a Mediterranean strain. Denton and certain other Mediterranean strains showed moderate tolerance in 1942, as shown in Figure 9. Although several showed slightly more resistance than Denton in these tests, none is considered to have sufficient tolerance to protect the crop.

After the discovery by Dahms *et al.* (13) of greenbug resistance in Dickinson Sel. 28A, a selection from Dickinson No. 485 (C.I. 3707) durum wheat, it was used extensively in breeding programs in Texas, Oklahoma and Kansas. Dickinson Sel. 28A and other resistant wheats were damaged severely in 1957 by a culture of greenbugs which developed in the greenhouse at Stillwater, Oklahoma. These same wheats were tested at Denton with the greenbug culture used there since 1951. They maintained the same resistance observed previously, as shown in Table 9. Wood (34) later proved that the Stillwater culture differed in size as well as ability to attack and damage formerly resistant wheats and that they constituted a biotype of the greenbug. The finding of the biotype by Wood emphasizes the need for several sources of greenbug resistance in wheat and other small grains; otherwise, the development of biotypes could nullify many years of breeding resistant varieties.

Wadley (30) reported in 1931 that greenbugs reared on Mindum (C.I. 5296) and Vernal emmer did not reproduce normally. A test was conducted in 1956 to determine whether certain tetraploid wheats were resistant to present greenbug cultures. Five varieties of durum wheat and Vernal emmer were compared with susceptible Pawnee, resistant Dickinson Sel. 28A and C.I. 9058. All proved to be susceptible, as shown in Table 10.

TABLE 5. THIRTY-SIX VARIETIES AND STRAINS OF BARLEY SHOWING HIGHEST RESISTANCE TO THE GREENBUG FROM 4,445 OF THE USDA BARLEY WORLD COLLECTION

Variety or strain	C.I. or P.I. number	Source	Resistance compared with Omugi: Average rating	Resistance compared with Omugi: Percent of rating of Omugi[1]
Nigrum	2338	Engeldow	1.9	64
	4015	Russia	2.2	55
	4205	China	2.2	71
	3982-2	Vavilov	2.4	81
	8778	Turkey	2.5	83
	4395	Manchuria	2.7	87
	4994	Iraq	2.8	88
	4015-1	Russia	2.9	72
	3979-2	Vavilov	2.9	81
Chinerme	1079	China	3.0	36
	4016-1	Russia	3.0	75
	9827	Ethiopia	3.0	77
	4166	Afghanistan	3.0	77
	6992	Iran	3.0	77
	4001-1	Russia	3.0	79
	10145	India	3.0	83
	6582	Afghanistan	3.0	89
	4012-2	Russia	3.1	78
	3982-3	Vavilov	3.1	85
Dubas	1460	Mesopotamia	3.1	89
	3991-1	Vavilov	3.2	84
White Gatami	920	Manchuria	3.2	87
	7769	India	3.2	87
Bano	2472	China	3.2	87
	3985-1	Vavilov	3.2	89
	9062	India	3.2	89
	3980-1	Vavilov	3.2	90
	6657	Iran	3.3	82
	9941	Ethiopia	3.4	74
	6319	Afghanistan	3.4	85
	6322	Afghanistan	3.5	88
	4168	Afghanistan	3.5	90
Scarab	995	Russia	3.6	72
	6658	Iran	3.6	90
	7774	India	3.7	84
	7604	India	3.7	89
Omugi	5144	(resistant check)	3.4[2]	....
Wintex	6127	(susceptible check)	4.5[3]	....

[1]Low percentages (less than 100) indicate plants more resistant than Omugi.
[2]Average rating of 3,574 Omugi plants in the test.
[3]Average rating of 3,511 Wintex plants in the test.

Figure 9. Survival of Denton (C.I. 8265), a Mediterranean strain, as compared with other commercial wheat varieties during the greenbug infestation of 1942 at Denton.

TABLE 6. FOURTEEN MOST GREENBUG-RESISTANT OATS AMONG 102 LOCAL AND DOMESTIC VARIETIES AND STRAINS TESTED AT DENTON, 1955

Variety or strain	C.I. or T.S. number[1]	Resistance compared with Camellia: Average rating	Resistance compared with Camellia: Percent of rating of Camellia
Andrew	4170	2.5	62
New Nortex	3422	2.7	90
Texas Red Rustproof	T.S. 1118-69	3.0	100
Appler Rustproof	1815	3.0	100
Ferguson 71	844	3.0	100
Ferguson 922	2150	3.0	100
Texas Red Rustproof	T.S. 6217-43	3.2	107
Texas Red Rustproof	953	3.3	89
Klein 693 W 1957	4118	3.3	92
Georgia Red Rustproof	233	3.4	114
Texas Red Rustproof	T.S. 2805-43	3.4	114
Ferguson 392	1038	3.5	108
Nortex	2382	3.5	117
Texas Red Rustproof	T.S. 1415-12	3.8	125
Camellia (check)	4079	3.0	....

[1]T.S. refers to Texas Selection.

TABLE 7. TEN MOST GREENBUG-RESISTANT OATS AMONG 4,998 VARIETIES AND STRAINS OF THE USDA WORLD COLLECTION

Variety or strain	C.I. or P.I. number[1]	Source	Resistance compared with Andrew (percent): Longevity[2]	Plant injury[3]	Anti-biosis[4]	Rank
Unknown	183992	Yugoslavia	171+	46	83	1
Avena Selecta M.C. 41374 I.F.	186270	Argentina	138+	65	50	2
Unknown	183990	Yugoslavia	143+	76	33	3
7505-43 C.I. 5608	186609	Brazil	186+	84	50	4
Russian No. 77	2898	Canada	129+	66	67	5
Unknown	183991	Yugoslavia	157+	52	150	6
Unknown	190584	Argentina	152+	85	17	7
(Bond-Rainbow) x (Hajira-Joanette)	5945	Minnesota	143+	82	17	8
Unknown	177788	Turkey	157+	86	67	9
Bonda x Sante Fe Sel. No. 3692-4	6443	Idaho	119+	65	67	10

[1, 2, 3, 4]See footnotes to Table 4.

A collection of 111 wheats that had shown resistance in tests at Stillwater, Oklahoma, was retested at Denton in 1958. These were compared with the resistant Dickinson Sel. 28A for longevity, plant injury and antibiosis. Detailed data on all strains are on file but are not given here. The ratings and composite rank of the 11 most resistant are given in Table 11. Several appear to have considerable promise as additional sources of resistance in wheat. Several resistant plants from certain lines were transferred to the greenhouse, but high temperatures in late spring prevented maturity of the seed. Since the present known greenbug resistance in wheats is not as great as desired, and was threatened in 1958 by the development of a biotype of the greenbug that was able to destroy Dickinson Sel. 28A and C.I. 9058, it appears that these 11 wheats, and perhaps the most resistant strains from other screening tests, should be screened thoroughly for possible resistant plants.

Genetic studies on the inheritance of greenbug resistance in wheat were started in 1954. The four crosses shown in Table 12 were made in the greenhouse with Dickinson Sel. 28A and Hopei (C.I. 11059). Two advanced selections from Cimarron hybrids and an F_1 of Kansas 7088 x Red Chief were used. Five seed from each of three crosses, X502, X503 and X504, involving Dickinson Sel. 28A, were sent to Aberdeen, Idaho, in May 1954 to be grown during the summer. Only one hybrid seed failed to produce a plant.

F_2 populations of individually spaced plants and F_2 bulk populations of three hybrids were grown in the field at Denton in 1954-55. The plants appeared vigorous and developed normally without observable differences between spring and winter-growing types. During this same period, F_1 plants of all four crosses were grown in the greenhouse and backcrossed to their common wheat parents.

Seed from individual F_2 plants harvested from the 1955 field were divided so that both field plantings of F_3 lines and greenbug insectary tests for resistance could be made. Approximately 350 such F_3 lines showed a predominance of spring-type plants in 1956. However, selection for further work was based entirely on reaction in insectary tests, not on plant characteristics. Four or five heads were selected from each F_3 line which showed resistance in the insectary tests. Additional seed of F_3-spaced plants were sown and harvested for testing. A large number of F_2 plants of the cross X501 involving C.I. 11059, a winter-growing type, and F_3 plants of the other three crosses were grown in bulk populations in the field in 1956. F_1 plants of backcrosses were grown in the greenhouse during the same season.

F_2 backcross plants and F_3 and F_4 lines were grown in the field in 1957. The season was so extremely wet that diseases and lodging made the crop abnormal; thus it was impossible to select among the 1,500 rows except on the basis of reaction to greenbugs. Four or five heads again were harvested from rows, the seed of which came from plants which showed resistance in the insectary, and the remainder of the plants in the rows were harvested in bulk for further insectary tests. New crosses were made in the greenhouse with C.I. 9058.

Selection for agronomic type was possible in 1958 when approximately 2,600 F_4 and F_5 rows were grown, the seed for each row being from individual heads. Only 64 rows were saved. All showed uniformly high resistance in insectary tests, were resistant or moderately resistant to the leaf rust prevalent during the season and stood up well after reaching maturity. Leaf rust and speckled leaf blotch were severe. F_3 backcross plants were grown in the field and F_1 hybrids of C.I. 9058 in the greenhouse.

Seed of the 64 selections were divided in 1959 into three parts; one for College Station for observations on reaction to rusts, one to Amarillo for hardiness tests and one kept at Denton for further

TABLE 8. FIFTEEN MOST GREENBUG-RESISTANT WHEATS SCREENED FROM 200 ORIENTAL VARIETIES OF THE USDA WORLD COLLECTION, DENTON, 1953

Variety or strain	C.I. or P.I. number	Source	Resistance compared with Pawnee (check): Plant condition rating[1]	Preference, percent[2]	Tolerance, percent[3]	Antibiosis, percent[4]	Growth index, percent[5]
C3b	10391	Shantung	4.2	41	123	50	103
C2b	10389	Shantung	4.0	5	119	65	87
F1b	10728	Kansu	4.0	82	117	65	99
F2a	10729	Kansu	4.2	50	114	58	80
C4a	10392	Shantung	4.4	72	113	46	80
	9165	Manchuria	4.7	105	111	113	21
C2a	10388	Shantung	4.2	23	111	50	70
N10a	11059	Hopei	4.2	172	110	41	92
N5a	11054	Hopei	4.0	190	108	53	72
	9160	Manchuria	4.7	52	108	42	65
G2b	10781	Hopei	4.2	70	107	112	49
N10b	11060	Hopei	4.2	156	107	50	149
	9163	Manchuria	4.2	52	107	29	41
E31	10671	Shansi	4.2	64	106	54	72
D3b	10510	Honan	4.6	70	106	67	80

[1]Average injury rating of test plant on day Pawnee (C.I. 11669) (check) was dead.
[2]Average number of greenbugs per plant on fourth day after infestation expressed as a percentage of the number on Pawnee. Low percentages (less than 100) indicate less preference for plant.
[3]Average number of days test plant lived after infestation expressed as a percentage of days for Pawnee. High percentages (more than 100) indicate more tolerance than Pawnee.
[4]Average progeny of a single female greenbug after 7 days on an individual plant expressed as a percentage of the progeny on Pawnee. Low percentages (less than 100) indicate most antibiosis.
[5]Calculated by dividing the average increase in height of test plants after infestation by the average increase in height of noninfested check plants of same variety during the same period, and expressed as a percentage of the increase in height of Pawnee.

TABLE 9. REACTION TO GREENBUGS AT DENTON OF WHEATS WHICH BECAME SUSCEPTIBLE TO GREENBUG CULTURE AT STILLWATER, OKLAHOMA

Variety of selection	Resistance compared with Dickinson Sel. 28A (Denton): Average rating	Percent of rating of Dickinson Sel. 28A (Denton)
Arabian Sel. C.I. 7261-15 (58 Stw. 15401)[1]	2.1	70
Dickinson Sel. 28A[2]	2.5	93
Dickinson Sel. 28A (58 G 1222-6)[1]	2.4	89
Dickinson Sel. 28A (57 G 1220-3)[1]	3.1	115
Bagdad C.I. 2202	2.7	100
Unnamed C.I. 9058 (57 G 1510)[1]	2.0	74
Unnamed C.I. 9058 (58 G 2351)[1]	2.7	100
Unnamed C.I. 7501 (58 Stw. 15403)[1]	3.8	140
Dickinson Sel. 28A (Denton) (resistant check)	2.7	....
Omugi barley (Stillwater) (resistant)[3]	2.5	....
Wintex barley (Denton) (susceptible)[3]	4.4	....

[1]1957 and 1958 Stw. (Stillwater-field) and G (greenhouse) selections made at Stillwater, Oklahoma.
[2]1959 Stillwater seed.
[3]Omugi and Wintex barleys included for comparison. Reaction to same greenbug culture was similar in previous years.

TABLE 10. REACTION OF SEVERAL TETRAPLOID WHEATS TO GREENBUG INFESTATION, 1956

Variety or selection	Resistance compared with Dickinson Sel. 28A		
	C.I. number	Average rating	Percent of rating of Dickinson Sel. 28A
Stewart	12066	3.8	152
Carleton	12064	4.4	191
Vernal emmer		4.1	178
Vernum	12255	4.6	196
Sentry	13102	4.0	187
Dickinson Sel. 28A (resistant check)		2.3	....
Unnamed (resistant)[1]	9058	3.1	....
Pawnee (susceptible)[1]	11669	4.8	....

[1]Included for comparison.

TABLE 11. MOST PROMISING GREENBUG-RESISTANT WHEATS SCREENED FROM A SELECTED GROUP OF 111 OF THE USDA WORLD COLLECTION

Variety or selection	C.I. or P.I. number[1]	Source	Resistance compared with Dickinson Sel. 28A (percent)			Rank
			Longevity[2]	Plant injury[3]	Anti-biosis[4]	
Unknown	9556	China	100+	111	40	1
Unknown	9573	China	100+	118	10	2
Unknown	9058	Iraq	100+	89	80	3
Unknown	7508	Egypt	94	101	20	4
Jenkin	5177	Oregon	107	95	113	5
Unknown	10594	China	95+	123	20	6
Unknown	7833	Ethiopia	95+	111	80	7
White Winter	5219	Oregon	107	90	125	8
Unknown	145720-1	Arabia	105+	104	120	9
Odessa	5240	Oregon	107	91	138	10
Unknown	194043	Ethiopia	111+	118	120	11

[1, 2, 3, 4]See footnotes to Table 4.

TABLE 12. PEDIGREE OF CROSSES FOR GREENBUG RESISTANCE

Cross no.	Pedigree
X501	Hopei C.I. 11059 x [(Kd-HF-Tq x Med-Hope) x Cheyenne Sel. 274-50-1]
X502	Dickinson Sel. 28A x (Cimarron x Hope-Cheyenne Sel. 256-50-7 C.I. 13022)
X503	Dickinson Sel. 28A x [(Kd-HF-Tq x Med-Hope) x Cheyenne Sel. 274-50-1]
X504	Dickinson Sel. 28A x (Ks-7088-Red Chief F_1)

TABLE 13. SUMMARY OF DATA ON THE INHERITANCE OF GREENBUG RESISTANCE IN CROSS X501, HOPEI C.I. 11059 x [(KD-HF-TQ x MED-HOPE) x CIMARRON SEL. 274-50-1]

Variety or generation	Plants in indicated resistance class					Total number of plants tested
	1	2	3	4	5	
C.I. 11059	0	14	17	6	0	37
Sel. 274-50-1	0	4	18	5	6	33
F_1	0	0	5	0	0	5
F_2	0	36	174	106	31	347
	Ratio = 9:7 (X^2 – 2.6)					
F_3	Res. 10; Seg. 88; Susc. 72					170
	Ratio = 1:8:7 (X^2 – .2)					
BC F_1	0	4	5	0	0	9
BC F_2	Res. 3; Seg. 2					5
	Ratio 1:1					

selection and testing. Crosses were made to initiate a second cycle of breeding. The most resistant of the 64 were crossed with commercial or promising varieties.

Data obtained from the crosses on the inheritance of greenbug resistance (with several generations for each) have been summarized. Table 13 presents data on cross number X501, Hopei (C.I. 11059) x [(Kd-HF-Tq x Med-Hope) x Cimarron Sel. 270-50-1]. C.I. 11059 was one of the Oriental wheats tested at Denton in 1953-54. Plants of C.I. 11059 fell into classes 2 and 3, whereas Selection 274-50-1 ranged from 2 to 5 with more than half the plants in class 3. This indicates a low level of resistance in Selection 274-50-1. F_1 plants were rated intermediate, or class 3. The F_2 population fell largely into classes 2, 3 and 4. By grouping classes 1, 2 and 3 as resistant and 4 and 5 as susceptible, the ratio of 9:7 (9 resistant and 7 susceptible) was obtained and was a plausible explanation of the resistance reaction of Selection 274-50-1. This indicates two genes must be present to give resistance. However, since C.I. 11059 was more resistant than the F_1 and F_2, some other interpretation seems possible; but tests of F_3 lines resulted in resistant, segregating and susceptible classes in a ratio of 1:8:7, as would be expected from a 9:7 ratio of F_2 plants. First-generation backcross plants fell into classes 2 and 3 as might be expected, and second-generation backcross lines also responded as expected from the two-factor hypothesis.

Table 14 presents data on cross X502, Dickinson Sel. 28A x (Cimarron x Hope-Cheyenne, Sel. 265-50-7, C.I. 13022). Most plants of Dickinson Sel. 28A were placed in class 1, but for some unexplained reason a few were fully susceptible. Plants of Sel. 256-50-7 fell largely in class 5, but some also ranged from 1 to 2. Tests of F_1 plants were not obtained. F_2 data, when grouped as before, fitted a ratio of 3:1. The F_3 lines did not fit a 1:2:1 ratio since the resistant classes contained too few plants, and the backcross generations showed more resistance than expected.

Data from cross X503, Dickinson Sel. 28A x [(Kd-HF-Tq x Med-Hope) x Cimarron Sel. 274-50-1], are shown in Table 15. Plants of Dickinson Sel. 28A were classified largely resistant, but a few were susceptible. Plants of Sel. 274-50-1 were largely susceptible, but some plants were in resistant classes, again suggesting the possibility of a low level of resistance. However, when classes 1 to 3 and 4 to 5 were grouped together, the data did not fit a 2-factor 9:7 ratio because too many resistant plants occurred. Nor did the data fit a 3:1 ratio because not enough resistant plants occurred. F_3 lines, classified into resistant, segregating and susceptible groups, fitted a 1:2:1 ratio, and the second-generation backcross lines fitted a 1:1 ratio. This indicated a single-factor inheritance ratio.

Cross X504, Dickinson Sel. 28A x (Kansas 7088-Red Chief F_1), also was studied and the data are presented in Table 16. Red Chief was used to represent the susceptible parent. It gave plants in more resistant classes than might have been expected, however. The F_2 data fitted neither the 9:7 nor the 3:1 ratios. F_3 lines fitted the 1:2:1 ratio and indicated a single-factor inheritance.

The resistance of C.I. 11059 was not comparable with that of Dickinson Sel. 28A, but its resistance did contribute to resistance in the hybrid populations studied and indicated some dominance.

Since data from F_3 lines were more critical than those from F_2, the resistance of Dickinson Sel. 28A could be attributed to a single factor, although enough conflicting evidence was obtained to cast some doubt on such a simple explanation and to suggest the possibility of modifying genes in certain genetic backgrounds. Resistance appeared to be dominant. This finding conflicts with published

TABLE 14. SUMMARY OF DATA ON THE INHERITANCE OF GREENBUG RESISTANCE IN CROSS X502, DICKINSON SEL. 28A x (CIMARRON x HOPE-CHEYENNE SEL. 256-50-7 C.I. 13022)

Variety or generation	Plants in indicated resistance class					Total number of plants tested
	1	2	3	4	5	
Sel. 28A	20	2	0	1	3	26
Sel. 256-50-7	4	3	4	4	12	27
F_2	99	34	29	16	30	208
	Ratio = 3:1 (X^2 – .9)					
F_3 lines	Res. 11; Seg. 73; Susc. 40					124
BC F_1	5	0	0	1	1	7
BC F_2	Res. 3; Seg. 5; Susc. 1.					9

reports, indicating that resistance is recessive (9, 15). The suggestion is made, however, that the methods of procedure might account for these conflicting reports. In the studies reported here, the insectary tests were allowed to proceed until a large portion of plants of the susceptible parent was killed, at which time readings were taken. If the tests had been allowed to continue, undoubtedly more of the heterozygous F_2 plants would have been killed. Thus ratios indicating one resistant to three susceptible plants in the F_2 generation might have been obtained.

FIELD TESTS

Varieties and strains of barley, oats, and wheat that had shown resistance in previous greenbug outbreaks and in insectary tests during 1955-57 were sown in replicated nursery plots having four rows 5 feet long. Shortly after the plants emerged, they were infested with insectary-cultured greenbugs at the rate of approximately 10,000 per plot. Climatic conditions, principally high winds and temperatures, were unfavorable for survival and reproduction of the insects; therefore, no infestation occurred. Unless conditions are favorable for natural infestation in North-central Texas, difficulty will be encountered in creating infestations. No data on the behavior of these small grains to field infestations were obtained.

Fifteen to 25 barleys ranging in reaction from susceptible to the most resistant have been seeded each season since 1954 in duplicate nursery plots at 6 to 10 locations in Texas to observe their reaction to natural greenbug infestations. Natural infestations of sufficient intensity to cause damage have not occurred in these plots; therefore, no data were obtained.

The only time when the effectiveness of greenbug resistance has been tested in Texas was in 1949 at Iowa Park. Smooth Awn 86 was placed in all state tests immediately after its tolerance was ob-

TABLE 15. SUMMARY OF DATA ON THE INHERITANCE OF GREENBUG RESISTANCE IN CROSS X503, DICKINSON SEL. 28A x [(KD-HF-TQ x MED-HOPE) x CIMARRON SEL. 274-50-1]

Variety or generation	Plants in indicated resistance class					Total number of plants tested
	1	2	3	4	5	
Sel. 28A	45	6	5	3	0	59
Sel. 275-50-1	0	1	12	13	33	59
F_2	182	69	80	77	130	538
	Ratio = 3:1 (X^2 – .2)					
F_3 lines	Res. 33; Seg. 71; Susc. 41					145
	Ratio = 1:2:1 (X^2 – .9)					
BC F_1	0	0	0	1	4	5
BC F_2	Seg. 3; Susc. 4					7
	Ratio = 1:1					

TABLE 16. SUMMARY OF DATA ON INHERITANCE OF GREENBUG RESISTANCE IN CROSS X504, DICKINSON SEL. 28A x (KANSAS 7088-RED CHIEF F_1)

Variety or generation	Plants in indicated resistance class					Total number of plants tested
	1	2	3	4	5	
Sel. 28A	45	2	3	0	0	50
Red Chief	0	4	10	18	18	50
F_2	177	75	122	95	119	588
F_3	Res. 17; Seg. 37; Susc. 19 Ratio = 1:2:1 (X^2 – .1)					73

served in 1942. A severe infestation occurred in the barley nursery at Iowa Park in 1949. Yields of Smooth Awn 86 are given in Table 17 to compare them with those of several commercial varieties. Smooth Awn 86 averaged 40.3 bushels per acre, compared with 28.4 for Wintex and only 19.6 for Reno. At other locations in 1949 and in other seasons, Smooth Awn 86 was not equal to Wintex and Reno and was not distributed commercially.

DISCUSSION

Varieties and strains of barley, oats and wheat having greenbug-resistant germ plasm have been found, and they offer opportunities for the breeding of adapted resistant varieties for the several growing areas of Texas. The highest resistance appears to be present in barleys. This situation might be expected since barley is the favored host. Resistant varieties and strains may develop from mixed seed as the result of natural selection over a long period when the plants are exposed to heavy infestations that exert a high degree of selection pressure. Barley is one of the oldest of cultivated food crops and has been grown for centuries in the Orient where many of the resistant varieties originated.

The observations of resistance to greenbugs in barley during the 1942 infestation by Atkins and Dahms (4) provided suggested sources of resistance. The high resistance found in Omugi, Kearney and Dobaku was used immediately in plant-breeding programs in Texas and several other states. Greater progress has been made in developing adapted resistant barley varieties than in oats and wheat. Fortunately, these resistant barley varieties were fairly well adapted to the Southwest, so the breeding procedures were not very complicated. Screening of the world collection has now furnished information on many other sources of greenbug-resistant germ plasm. This information should be used in the breeding programs with germ plasm from several sources combined into multiple-factor breeding stocks, which will aid in preventing a breakdown of resistance owing to development of greenbug biotypes.

Sources of resistance appear to be more limited in oats than in barley and have been less extensively tested. No observations on field reactions of these varieties and strains have been made to date; thus how effective their resistance is under natural infestations is not known. Several strains appear to have considerably more tolerance than Andrew and New Nortex. Russian No. 77 (C.I. 2898) and P.I. 183990 have been crossed to commercial varieties at Denton. Screening of the F_2 generation is now in progress. It is hoped that resistant varieties may be developed.

Until recently, only two resistant wheats had been found, Dickinson Sel. 28A and C.I. 9058. These have been used extensively in Texas and other states. Since these two wheats are spring-types and their grain quality inferior, considerable difficulty has been experienced in developing hard red winter-types with resistance. Results of tests reported in Table 9 verify findings at Oklahoma State University and show that some additional resistant germ plasm is available. However, much more breeding work will be necessary before acceptable varieties with greenbug resistance will be produced for Texas or the Southwest.

TABLE 17. COMPARISON OF GRAIN YIELDS OF GREENBUG-RESISTANT SMOOTH AWN 86 BARLEY WITH THOSE OF COMMERCIAL VARIETIES UNDER HEAVY INFESTATIONS, IOWA PARK, 1949

Variety	C.I. number	Grain yield, bushels per acre
Smooth Awn 86	6268	40.3
Wintex	6127	28.4
Ward	6007	22.1
Reno	6561	19.6

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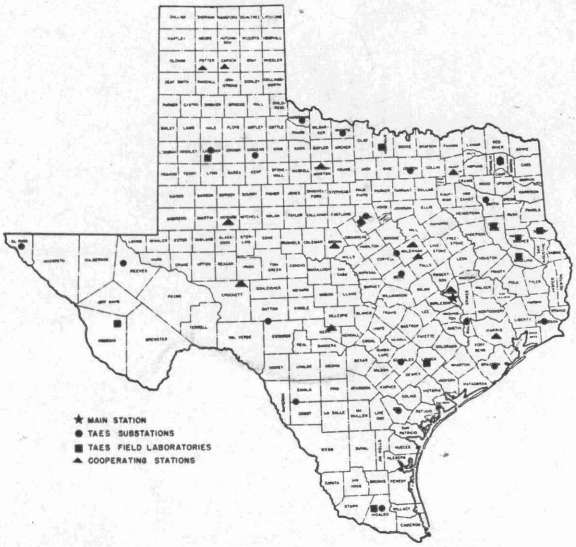

Location of field research units of the Texas Agricultural Experiment Station and cooperating agencies

State-wide Research

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The Texas Agricultural Experiment Station is the public agricultural research agency of the State of Texas, and is one of the parts of the A&M College of Texas.

ORGANIZATION

IN THE MAIN STATION, with headquarters at College Station, are 13 subject-matter departments, 3 service departments, 3 regulatory services and the administrative staff. Located out in the major agricultural areas of Texas are 20 substations and 10 field laboratories. In addition, there are 13 cooperating stations owned by other agencies. Cooperating agencies include the Texas Forest Service, Game and Fish Commission of Texas, Texas Prison System, U. S. Department of Agriculture, University of Texas, Texas Technological College, Texas College of Arts and Industries and the King Ranch. Some experiments are conducted on farms and ranches and in rural homes.

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THE TEXAS STATION is conducting about 450 active research projects, grouped in 25 programs, which include all phases of agriculture in Texas. Among these are:

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Conservation and use of water	Dairy cattle
Grasses and legumes	Sheep and goats
Grain crops	Swine
Cotton and other fiber crops	Chickens and turkeys
Vegetable crops	Animal diseases and parasites
Citrus and other subtropical fruits	Fish and game
Fruits and nuts	Farm and ranch engineering
Oil seed crops	Farm and ranch business
Ornamental plants	Marketing agricultural products
Brush and weeds	Rural home economics
Insects	Rural agricultural economics

Plant diseases

Two additional programs are maintenance and upkeep, and central services.

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AGRICULTURAL RESEARCH seeks the WHATS, the WHYS, the WHENS, the WHERES and the HOWS of hundreds of problems which confront operators of farms and ranches, and the many industries depending on or serving agriculture. Workers of the Main Station and the field units of the Texas Agricultural Experiment Station seek diligently to find solutions to these problems.

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