Association of Certain Characters in a Collection of

WHEAT X WHEATGRASS HYBRIDS

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Association of Certain Plant Characters in a Collection of Wheat X Wheatgrass Hybrids

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In general, plant improvement through hybridization is limited by the range of variability in desirable characters in the material the plant breeder uses as a base for breeding. It has frequently been stated that variability in a normally self-fertilized crop such as wheat is usually slight. If true, interspecific and intergeneric hybrid material may be utilized by the breeder as a means of obtaining greater genetic diversity.

Numerous workers have called attention to a number of characters in the genus *Agropyron* which would be of value in the cultivated wheats. Such characters are: 1) resistance to heat and drought, 2) extreme winter-hardiness, 3) resistance to frost, 4) tolerance to alkaline and acid soils, 5) resistance to rusts and smuts, 6) resistance to wheat streak mosaic, yellow dwarf and soil borne mosaic viruses, 7) tolerance to excessive moisture, 8) resistance to lodging, 9) perennial growth habit, 10) wide geographic adaptation, 11) increased protein content, 12) resistance to insects, and 13) resistance to Septoria disease and to powdery mildew (2, 7, 10, 14, 15, 16, 17, 20, 27, 29, 36, and 38)[2]

Recently the Oklahoma Agricultural Experiment Station received from the United States Department of Agriculture over 500 wheat X wheatgrass hybrid derivatives of great genetic variability. These hybrids resulted from years of work by Mr. W. J. Sando (retired) of the U.S.D.A.,

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[1]Formerly Instructor (now Graduate Student at the University of Minnesota), Assistant Professor, and Professor in Agronomy and Professor in Botany and Plant Pathology respectively.

[2]Numbers in parenthesis refer to Literature Cited.

Based on material from a thesis submitted by the senior author in partial fulfillment of the requirements for the M.S. degree at Oklahoma State University, 1958. Support for this work was received from the Oklahoma Wheat Research Foundation in the form of a grant for a graduate assistantship to E. L. Smith.

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who crossed species of *Triticum, Agropyron* and other genera related to *Triticum* in various combinations.

This group of wheat X wheatgrass hybrids is one of the largest collections of this type of material in this country and represents a potentially valuable source of germplasm. Many of these hybrids possess characters which would be useful if incorporated into wheat and the propagation, maintenance, and distribution of this material to other interested breeders has become the responsibility of the Oklahoma Station.

At the time of receipt of this material very little was known concerning the nature of these hybrids other than their great genetic diversity and winter annual growth habit. Consequently, a real need existed for a classification of this material so that hybrid selections with similar characteristics could easily be grouped together for subsequent studies. Furthermore, personnel at this station were interested in securing some of the types resistant to wheat leaf rust for possible use in the wheat improvement program.

Studies were undertaken, therefore, to classify the Sando-derived hybrids with respect to a number of morphological characters and to isolate those lines or plants which possess resistance to wheat leaf rust caused by the plant pathogen *Puccinia recondita* Rob ex Desm.

As a result of these investigations a descriptive key to the morphological classification and leaf rust reaction of the collection of hybrids was prepared and published in a companion report (28). The present publication reports on the association of certain plant characters and reaction to leaf rust observed in the hybrid material.

Literature Review

Intergeneric Hybridization—General Considerations

The first intergeneric crosses involving *Triticum* were made for the purpose of determining the phylogenetic relationship of the genus. According to Armstrong (1), this involved the genera *Aegilops, Secale* and *Haynaldia*. In 1927, Leighty and Sando (13) reported a successful trigeneric cross of *Aegilops, Triticum* and *Secale*. Sando (25) hybridized Haynaldia *villosa* with 6 species of *Triticum* and with *Secale fragile*. He studied more than 52 morphological characters of the parents and hybrids.

In 1928, McFadden, according to McFadden and Sears (16) called attention to the many desirable attributes of the *Agropyron* species that might be transferred to wheats. The first successful cross of *Triticum* with *Agropyron* was made by Zizine of Russia, who crossed *T. vulgare* with *A. intermedium,* according to Verushkine and Shechurdine (42). Since 1930, extensive investigations have been concerned with the hybridization of *Triticum* and *Agropyon.* According to Vakar (39) hard and soft wheats were first crossed with *Agropyron elongatum* in 1932. Reitz, *et al* (22) reported that Canadian and United States breeders produced their first fertile *Triticum* X *Agropyron* hybrids in 1935. Vinall and Hein (43) presented an illustration of the first successful hybrid between wheat and *Agropyron* made in the United States by Sando and described his techniques used in producing the intergeneric hybrids.

Tschermak-Seysenegg, in 1938, according to Swarup *et al* (37), first suggested the term "agrotricum" for hybrids between *Triticum* and *Agropyron.* Since then, agrotricum has been used frequently in discussing hybrids of this nature.

Veruskin (41), reporting on the work in Russia, stated that *Agropyron intermedium, A. elongatum* and *A. trichophorum* would cross with wheat forms from all 3 sections of *Triticum* and that the *Agropyron* characters, in general, were dominant in the F_1. Armstrong (1), Johnson, McLennan and Armstrong (9), Vakar (39) and White (44) also found the *Agropyron* characters to be strongly expressed in the F_1.

Cicin (5) found *Agropyron junceum* to be compatible with wheat and reported that *A. repens,* after several unsuccessful attempts, had been crossed with wheat. Later Tzitzin (38) amassed nearly 100 species of *Agropyron* for intergeneric hybridization purposes but reported no new species compatible with wheat.

Smith (35) attempted crosses between *Triticum aestivum* L. and 15 species of *Agropyron.* He found only *A. elongatum, A. intermedium* and *A. trichophorum* to be compatible with common wheat. White (44) attempted to cross 12 species of diploid, tetraploid, and hexaploid wheats with 10 species of *Agropyron.* He reported that all of the species of wheat with the exception of *T. monococcum* were compatible with *A. elongatum.* Only *A. glaucum* (*A. intermedium*) and *A. trichophorum* in addition to *A. elongatum* were successfully hybridized with wheat. White (44) indicated that tetraploid wheats crossed twice as readily as did the 42 chromosome wheats. He also found *A. elongatum* more compatible with wheat than *A. glaucum* (*A. intermedium*).

Reitz, Johnston and Anderson (22) reviewed some of the agrotricum work and listed the following species of *Agropyron* compatible with wheat. 1) *A. elongatum* 2n = 70 and 2n = 56; 2) *A. intermedium* 2n = 42; 3) *A. trichophorum* 2n = 42; 4) *A. junceum* 2n = 28; 5) *A. repens* 2n = 42 and *A. amurense*.

According to Armstrong (1), the 2 *Agropyron* species that have been used extensively in crosses with wheat are *A. elongatum* and *A. glaucum* (*A. intermedium*). Armstrong and Stevenson (2) discussed breeding and selection involving agrotricums and stated that nearly all investigators found *Agropyron elongatum* and *A. intermedium* compatible with tetraploid and hexaploid wheats.

Marshall and Schmidt (15) stated that the most desirable agrotricum hybrids came from crosses with *Agropyron elongatum* as the wheatgrass parent.

Resistance to Diseases

Resistance to diseases of common wheat have been found in other species of *Triticum* as well as in related genera.

Shands (34) reported that *Triticum timopheevi,* native to southern Russia, was found to be resistant to several diseases and that resistance to leaf rust, stem rust and mildew have been transferred to fertile types of *T. vulgare*.

Johnston (10) found 12 species of *Agropyron* and several species of *Aegilops* resistant to the important leaf rust races in Kansas, and Sears (32), by use of irradiation, transferred leaf rust resistance from *Aegilops umbellulata* to wheat.

According to Lapin (12), agrotricum hybrids have been studied which are resistant to drought, salt and fungi. Certain hybrids derived from *Agropyron elongatum* showed particularly marked resistance to fungi, and Tzitzin (38) reported that bunt, smut, frost, lodging and shedding resistance and exceptionally high baking quality had been combined in one agrotricum hybrid.

Reitz, Johnston and Anderson (22), working with agrotricums in Kansas, indicated that a high type of disease resistance may be transferred from the *Agropyrons* to wheat. Love and Suneson (14) found high resistance to leaf and stem rust in certain hybrids between *Triticum* and *Agropyron trichophorum*. However, they stated that the fertile derivatives from one cross were not as resistant to rust as was the original hybrid. Suneson and Pope (36) reported on later investigations with agrotricums and observed five classes of stem rust reaction on the hybrids. The reactions ranged from immune to very susceptible.

In a seedling reaction test, Schmidt *et al* (29) found 40 out of 161 agrotricum lines immune or highly resistant to 8 races of leaf rust. Strains with spike characteristics intermediate between *Agropyron* and *Triticum* showed the highest frequency of rust resistance. Three wheat-like strains were found to be resistant to the 8 races of leaf rust. They also indicated that probably no one wheat source contains such a high order of rust resistance as the agrotricums. In addition, some segregates of the agrotricums were found to be resistant to the Hessian fly. Schmidt *et al* (29) stated that resistant and susceptible rust reactions were observed in plants with common parentage and similar morphological characteristics and suggested that the factors for rust resistance were segregating independently from those affecting morphological characters. This, they stated, indicates that the rust resistance in some strains is due to genetic factors and not to *Agropyron* chromatin material *per se.*

Elliott (6), by means of an X-ray induced translocation, transferred the stem rust resistance of a *Triticum* X *Agropyron* derivative to common wheat.

Resistance to the wheat streak-mosaic was reported by McKinney and Sando (17). They tested 50 selections from hybrids involving *Triticum, Agropyron, Aegilops* and *Secale,* and found resistance in 25 of the selections, 16 of which had been derived from *Agropyron elongatum.*

Fellows and Schmidt (7) and later, Schmidt, Sill and Fellows (30) reported on studies with the wheat streak-mosaic. *Agropyron elongatum* was found to be immune, the grasslike segregates of crosses with wheat to be immune and some of the intermediate types to be immune or highly resistant. The wheatlike segregates had a range in reaction from tolerant to susceptible.

Sando (26), in 1953, reported that 3 hybrid selections, derived from *Triticum and Agropyron elongatum,* were resistant to leaf rust, stem rust and soil-borne mosaic virus.

Classification

In dealing with the classification of wheat X wheatgrass hybrids, the most apparent characteristic is plant type. Marshall and Schmidt, (15), Schmidt *et al* (29) and others grouped agrotricums into the following 3 classes: 1) grasslike, 2) intermediate and 3) wheatlike on the basis of morphological characteristics. Also Schmidt *et al* (29) stated that the agropyrons differ sharply from wheat for some characters but that differences are not so pronounced for others. Agropyrons are usually characterized as having scabrous foliage, a long lax spike, straight-sided glumes that adhere to the kernels and a brittle rachis.

Vavilov (40), in his treatment of the homologous series in plants, listed 28 characters of rye and wheat that varied in the same direction. These characters included: 1) awned condition, 2) glume pubescence, 3) chaff color, 4) seed color and 5) leaf width. He also stated that with rye and wheat there is complete parallelism in variation to the last detail. In addition, the genera *Aegilops* and *Agropyron* show parallel variation with wheat for :1) awned condition, 2) glume color, 3) glume pubescence and other characters.

Hitchcock (8), in his classification in the genus *Agropyron* considered awned condition and pubescence of the lemma as important characters in separating species of *Agropyron*.

Percival (19) used awned condition, glume color, awn color, glume pubescence, kernel color and other characters in classifying species and varieties of wheat.

Pal, Ramanujam and Memon (18) studied the variation in the pattern, length and other qualities of the hairs of the auricles, sheath and leaf epidermis of species of *Triticum* and concluded that leaf hairiness can be used taxonomically since this character shows sufficient variation of a discontinuous nature.

Bayles and Clark (4) classified the varieties of wheat grown in the United States in 1949 and discussed the value of plant, stem, leaf, spike, glume, awn, kernel and other characters for use in classification. They used awned condition as the major character in their key, followed by glume pubescence, glume color, and kernel color.

Materials and Methods

Experimental Materials

The agrotricums concerned here are advanced generation hybrids and all are winter annuals. These derivatives resulted from intergeneric hybridization conducted by W. J. Sando of the United States Department of Agriculture who began his work early in the 1930's and continued until his retirement a few years ago.

Seed stocks of 317 hybrid derivatives previously grown at Sacaton, Arizona, were received from the U.S.D.A. in the fall of 1955. These hybrids were designated by 4-digit Sacaton (Sac.) numbers. Stocks of seed of 227 additional hybrids which carried 3-digit Sando stock numbers were received in the fall of 1956. On two different occasions, seed of two hybrids were inadvertently mixed together and thereafter these mixed lines were carried as composites of the two hybrids involved. Data, then, were recorded for 542 hybrid lines. Pedigrees for individuals of the latter collection only are presently available at this station. The parentage of the hybrids in this group includes species of *Triticum, Agropyron, Secale* and *Aegilops* in various combinations.

Experimental Methods

In October, 1955, 4 grams of seed of each of the 317 selections were planted on the Stillwater Agronomy Farm in 2-row plots, 4½ feet in length. Concho, C. I. 12517[3], was used as a wheat check and spaced every 25 plots.

Notes taken on these hybrids in 1957 included 1) heading date, 2) head type, 3) awned condition, 4) relative leaf roughness, 5) glume pubescence, and 6) leaf rust reaction. These hybrids were harvested and threshed as in 1956.

These hybrids were seeded in the fall of 1957, again on the Agronomy Farm. Plot size was the same as in the previous years, however, only 2.5 grams of seed of each hybrid was planted. Concho was again included as a wheat check. In addition, an advanced generation *Triticum-Agropyron elongatum* x Pawnee selection, C.I. 13020, was included as a leaf rust immune check. Notes taken in 1958 included 1) heading date, 2) head type, 3) awned condition, 4) relative leaf roughiness, 5) glume pubescence, 6) leaf rust reaction, and 7) ripening date. A discussion of the procedures used in measuring these characters follows.

Measurements for head type, awned condition, leaf roughness, glume pubescence and leaf rust reaction were observed in some detail. Segregation for one of these characters, if observed in a hybrid selection, was noted. For example, a hybrid population might be immune, susceptible or segregating for leaf rust reaction.

Head type. Throughout this investigation, the spikes were classified as wheatlike, intermediate or grasslike. Typical spikes representing each class are shown in Figure 1.

[3]C. I. numbers refer to the accession number of the Field Crops Research Branch, A.R.S., U.S.D.A. (Formerly Cereal Investigations)

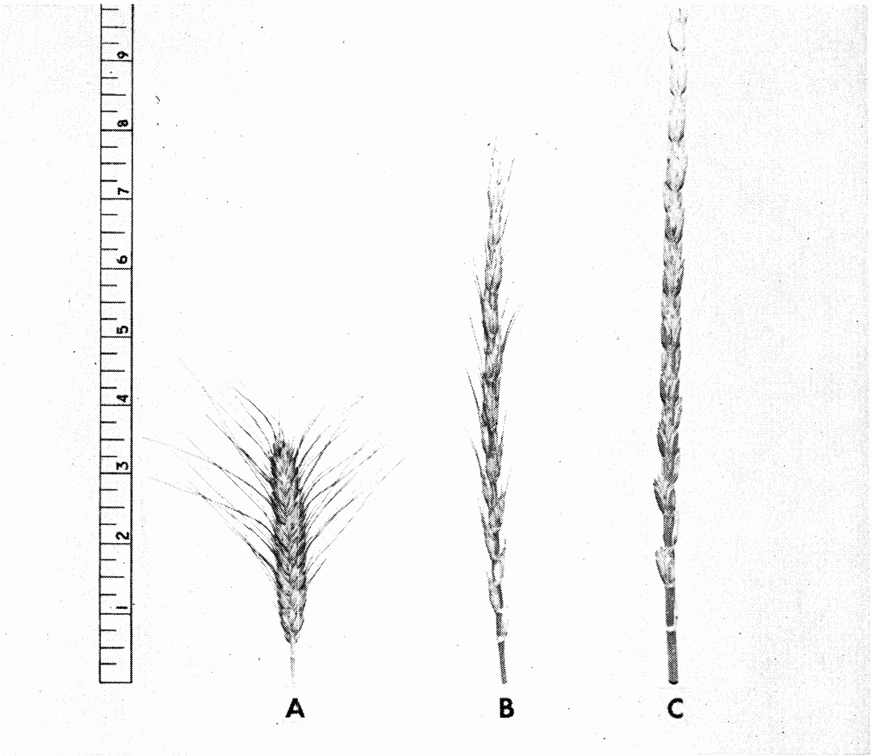

Figure 1. Typical spikes representing each class were classified as: (A) wheatlike, (B) intermediate and (C) grasslike.

Awned condition. Plants were classified as being fully awned, semi- or half awned, tip awned or awnless. Spikes representing the 4 classes of awning are shown in Figure 2.

Glume pubescence. Plants were classified as having either glabrous glumes or pubescent glumes. This character was observed in the field and if any glume hairs were observed, the glumes were considered pubescent.

Relative leaf roughness. This character was measured by drawing the green leaf blade between the thumb and index finger; hence this type of measurement gave only relative determinations, but there was readily a noticeable difference in leaf roughness between some of the grasslike plants and some of the wheatlike plants. Plants were classified as rough, intermediate or smooth.

Leaf rust reaction. No appreciable amount of wheat leaf rust was observed in this nursery in 1956, therefore no rust readings were made. In 1957 an attempt was made to classify these hybrids for pustule type and severity of infection. However, the rust was late in developing into epidemic proportions and, consequently, approximately 10% of the hybrids could not be classified because of drying and dead leaves. Some of the hybrids may have been misclassified because of the difficulty in trying to determine pustule type and severity on drying leaves. Three classes were used to determine rust reaction: 1) resistant (range of pustule types from 0 to 2+, 2) intermediate (2 to 3 or 2 to 4 type pustule range, and 3) susceptible (3 or 4 type pustules. In 1958, leaf rust in heavy proportions came early enough for reliable readings to be made. Based on the difficulty in determining pustule types the previous year, the plants were classified in 1958, as either immune or sus-

Figure 2. Awned condition of spikes were classified as: (A) fully awned, (B) semi- or half-awned, (C) tip awned and (D) awnless.

ceptible. If leaf rust pustules of any type were observed, the plant was considered susceptible.

Measurements of heading date and ripening date were taken on a plot basis and refer to an average reading of the entire plot.

Heading date. The month and day were recorded for each hybrid when approximately 75 percent of the spikes were exserted above the flag leaf.

Ripening date. The month and day were recorded for each plot when approximately 75 percent of the plants in the plot were dead ripe.

On the basis of the leaf rust readings made on mature plants in the field in 1957, certain Sando hybrids were marked for further rust studies and individual head selections were made in others. This material, based on leaf rust reaction and head type combinations has been treated as 4 separate groups as follows:

Group I. Hybrids classified as uniform for head type and resistant to leaf rust were placed in this group. No head selections were made in these hybrids. Seed of 26 selections were spaced-planted on the Agronomy Farm in a special nursery for closer observation and to facilitate the collection of samples for cytological investigations. In addition, seed of 23 of these lines were tested in the greenhouse as seedlings to 13 individual races of leaf rust according to standard procedures.[4]

Group II. The second group consisted of those hybrids classified as uniform for head type and segregating for leaf rust reaction. No head selections were made in these hybrids. Sixty-five seedlings, of each of 45 hybrids, were tested to leaf rust race 105B in the greenhouse by the cereal pathologists.

Group III. Those hybrids classified as segregating for head type and resistant to leaf rust were placed in group III. Head selections for wheatlikeness were made in these hybrids and the reselected heads from each line were threshed in bulk. Reselected seed of 50 hybrids were spaced planted on the Agronomy Farm. Seedlings from the reselected seed of 43 of the hybrids were tested to a composite of the most important leaf rust races in Oklahoma, including 105B.

Group IV. The fourth group consisted of those hybrids classified

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[4]Grateful acknowledgement is expressed L. E. Browder presently of ARS, USDA, Botany and Plant Pathology Department at Kansas State University, Manhattan, for his part in conducting these tests.

as segregating for both head type and leaf rust reaction. Head selections toward wheatlike types were made in these hybrids. The head selections from each hybrid were threshed in bulk and the reselected seed from 41 hybrids was spaced-planted in the field for further observations.

Based on leaf rust reaction in 1958, individual head selections were made from 79 of the original hybrids. These head selections were classified for several morphological characters and will be increased as head rows in order to secure sufficient seed for future leaf rust tests.

Results and Discussion

The data presented here relating to head type, awn condition, glume pubescence, relative leaf roughness and leaf rust reaction were assembled from readings made in 1958. The data for these characters were considered more representative of the hybrids at this time because: 1) closer observations were made in 1958 than had been made in previous years and 2) due to non-adaptation, competition, and perhaps other causes, some of the types observed in previous years could have been eliminated by 1958.

Leaf rust reaction was considered to be of minor taxonomic importance in the preparation of the key to the classification of the Sando hybrids (28). However, considerable effort was spent in isolating immune hybrid lines or plants. Plants considered immune were tagged in May, 1958, shortly after a general leaf rust infection had occurred. Thereafter and up until the leaves had dried, the tagged plants were observed at intervals of 5 to 7 days. Some plants which were initially classified as immune, later developed leaf rust pustules. Apparently this late rust development was due to some type of mature plant resistance and not merely to "escape" because in many cases these latent susceptible plants were found adjacent to plants with severe rust. This indicates that the inoculum was present but these particular plants maintained their immunity for a certain period and succumbed to leaf rust at a later time. Observations relating to the association of reaction to leaf rust and the several morphological characters will be presented later.

Considerable variability in head type was observed in this material. Several of the hybrids contained as many as 6 distinct head types based on size and shape. The range of head types observed in these 542 hybrids has been illustrated in a previous publication (28) and expresses to a certain degree the amount of genetic variability in this material. Hybrids were classified merely as wheatlike, intermediate or grasslike

(Figure 1). Size and shape *per se* were not considered in classifying the hybrids.

Data showing the frequency distributions of head type and leaf rust reaction of the 542 hybrids are presented in Table I. Only 6 of a total of 441 wheatlike hybrids were found to be homozygous for leaf rust immunity while 25 other wheatlike hybrids were segregating for rust reaction. Only 4 hybrids were classified as grasslike and all four were immune to leaf rust.

Leaf roughness, while not as accurately measured as other characters appeared to be stable in this material. This particular characteristic had been attributed to the hairiness of the leaves; however, from closer observations made in 1958, it was found that the roughness of the leaves of some plants was due to the enlargement of the leaf nerves and not to leaf pubescence.

Search of the literature revealed no information on this condition in material of this sort. White (44) examined leaves of agrotricum hybrids for texture and counted the number of primary leaf veins, but did not state how leaf texture was measured nor did he mention vein diameter. Unfortunately, this second factor contributing to leaf roughness was observed late in the crop season, and drying leaves precluded a re-examination of the hybrids in respect to this character. In this study, therefore, both leaf pubescence and enlargement of the leaf nerves must be considered as contributing to leaf roughness.

Data showing the frequency distribution of leaf rust reaction and leaf-roughness of the 542 Sando derived hybrids are presented in Table II. Observations indicated that leaf rust immunity and leaf roughness were associated to some extent. In general, the leaf rust immune hybrids were rough leaved. Of the 19 hybrids classified as immune, 12 were rough leaved, 5 were segregating for leaf roughness and 2 had smooth leaves.

Although maturity as a character was not considered in formulating the key to these hybrids (28) some consideration must be given to this character in selecting material to be used in a breeding program. Throughout this investigation heading date was used as an index to maturity. The maturity of each hybrid was established by adjusting the heading dates to the number of days earlier or later than the mean heading date of Concho. The adjusted heading date for each hybrid for the number of years grown was averaged. These adjusted average heading dates were then plotted on a frequency histogram. Compared with Concho (medium-early to mid-season) there seemed to be a logical classification for maturity as follows:

1) Very early = more than 7 days earlier than Concho.
2) Early = from 4 to 7 days earlier than Concho.
3) Mid-season = from 3 days earlier to 4 days later than Concho.
4) Late = from 5 to 10 days later than Concho.
5) Very late = more than 10 days later than Concho.

This is only an arbituary classification but still, it represents the relative maturity of these hybrids.

Observations on these hybrids indicated that those found to be immune to leaf rust were usually later in maturity than susceptible hybrids. This is undoubtedly also associated with head type because the grasslike segregates, with few exceptions matured late. Not one of the rust immune hybrids was classed as very early or early in maturity. Frequency distributions of leaf rust reaction and maturity are presented in Table III.

According to most investigators, awn condition and glume pubescence are reliable taxonomic characters, and are considered later in connection with other tests.

Certain hybrids based on leaf rust reaction-head type combinations observed in 1957, were studied for leaf rust reaction in the greenhouse and in special spaced-planted nurseries during 1958. These hybrids were handled as four different groups and the results are presented by group.

Group I. This group consisted of hybrids which had been classified in 1957 as being uniform for head type and resistant to leaf rust. Seed from 23 hybrids from group I were tested to 13 individual races of leaf rust in the seedling stage. Data pertaining to the results of these seedling tests together with data for certain morphological characters are given in Table IV. Of the 23 hybrids in this test, 7 were wheatlike and only 2 of these (S.S. nos. 840 and 843) were resistant as seedlings to all races of leaf rust to which they were tested. Both of these hybrids contain two, reportedly good, sources of leaf rust resistance *(Agropyron elongatum and Triticum timopheevi)* as part of their parentage.

In addition, plants of 25 hybrids from group I, including the 23 tested as seedlings were grown as spaced plants in the field. Leaf rust reaction and other data for these hybrids are presented in Table V. It is of interest to note that the 2 wheatlike hybrids which were resistant to 13 races of leaf rust as seedlings were found to be immune as mature plants to a natural infection of rust. A summary of the rust reaction and head types of these hybrids is given in Table VI. Of the 25 hybrids tested in the field, 7 out of 13 wheatlike hybrids were immune to leaf rust as mature plants. Head type classification of these hybrids in 1957 does not, in all cases, agree with the classification of this character in 1958. These misclassifications occurred for two reasons: 1) some hybrids classified in 1957 as intermediate for head type were, after closer observation in 1958, classified as wheatlike and 2) hybrids classified as uniform for head type in 1957 were found to be segregating for head type in 1958.

Group II. Hybrids in this group were classified in 1957 as uniform for head type and segregating for leaf rust reaction. Group II consisted of 45 hybrids. Sixty-five plants of each hybrid were tested in the greenhouse as seedlings to leaf rust race 105B. This particular race of leaf rust was selected as a tester race since previous work here indicated that seedlings resistant to race 105B[5] were generally resistant to most of the other common races of leaf rust in the seedling stage.

Seedlings, selected on the basis of resistant or intermediate type reaction, from 24 of the 45 hybrids tested were transplanted to the field. One hundred forty plants from the 24 hybrids matured as transplants and mature plant reaction was recorded. As shown in Table VII, a total of 77 plants from 19 of the hybrids were resistant in the mature stage. Forty-three plants were intermediate in reaction and 20 were susceptible to leaf rust.

Group III. This group consisted of those hybrids classified in 1957 as segregating for head type and resistant to leaf rust. In 1957, head selections of uniform wheatlike types were made from these hybrids and the selected heads from each hybrid were threshed in bulk. The following results were obtained from plants grown from these head selections. Individual plants from 43 of the hybrids in this group were tested as seedlings to a composite of the most important leaf rust races in Oklahoma, including race 105B. No leaf rust resistant seedlings were observed in 12 of the 43 hybrids tested. Seedling reactions by hybrid are presented in Table VIII. In addition, 50 hybrids from this group, including the ones tested in the greenhouse, were grown in the field for further investigation. Leaf rust reaction and other data for each of the hybrids are presented in Table IX and a summary of leaf rust reaction and head type is shown in Table X. Of the 30 lines classified as

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[5]A variant of **P. recondita** race 105 which attacks both Westar, C. I. 12110, and Wesel, C. I. 13090.

wheatlike, 6 were immune to leaf rust in the field, 9 were segregating and 15 were susceptible. Seven lines were intermediate for head type and 6 of these were immune. Only 2 lines were classified as grasslike and both of these were immune.

Group IV. This group consisted of hybrids classified in 1957 as segregating for both head type and leaf rust reaction. Head selections toward wheatlikeness were made in these hybrids in 1957. The selected heads from each hybrid were threshed in bulk and the results reported below were obtained from the plants grown from this selected seed. Plants from 41 hybrids were grown in the field in 1958. Rust reaction and head type by hybrid are presented in Table XI. Of the 41 hybrids grown, 36 were wheatlike and only one, Sac. No. 4239, was found to be immune. A summary of leaf rust reaction and head type for this group is shown in Table XII.

Agronomic Value

The results presented above illustrate that this collection of hybrids represents a valuable source of germplasm for resistance to wheat leaf rust. Rusts obtained by other workers at the Oklahoma Station reveal that certain of the present hybrids also are resistant to wheat streak mosaic virus. Undoubtedly these particular hybrids also contain genes governing resistance to other diseases as was referred to in the opening section. Adequate screening techniques should reveal the presence of these genes for disease resistance as well as other desirable traits such as insect resistance, drought and cold tolerance, etc.

The results presented serve merely to indicate to the breeder, material which may be used in a breeding program but do not indicate the actual feasibility of using the stocks. Workers in the past have shown that more or less wheatlike types with certain desired traits have been stabilized as far as behavior in respect to morphological characters and the sought-after trait is concerned. However, to the author's knowledge, no varieties of commercial value have thus far evolved after many years of work by many investigators. The problem of transferring the desirable genes from *Agropyron* into commercially acceptable wheats appears to be more difficult than first anticipated. Failure to achieve the desired results through conventional breeding procedures evidently is related to the lack of homology between the wheat chromosomes and those of *Agropyron*. Cytological investigations of Peto (20, 21) and Vakar (39) indicated that a certain degree of homology existed between the chromosomes of the two genera. However, Sears (31), in reviewing the problem of genome homologies of wheat with various related genera including *Agropyron* stated that no good evidence exists that the homology observed by the various investigators does not involve the chromosomes of wheat. More recently, Riley *et al* (24) stated "the bulk of the evidence indicates that there is no genome in *Agropyron* closely related to wheat." Further Knott (11) studied rust resistant plants carrying a single *Agropyron* chromosome and observed that "the added chromosome never appeared to pair with a wheat chromosome."

If the premise that there is no homology between the wheat and *Agropyron* chromosomes is accepted then the possibility of obtaining the hybrid variety of wheat with the desired character from *Agropyron* as a result of direct genetic recombination is remote indeed, if not impossible.

Certain techniques employed by several workers may be used, however, in which the desired end may eventually be attained but further investigations must be conducted before the efficacy of these methods is known.

One of the techniques involves the production of alien addition and alien substitution lines in which the *Agropyron* chromosome carrying the desired character is added to or substituted into the wheat complement as is being investigated by Knott (11).

The practicability of this method, however, will depend on the stability of the addition and substitution lines in question and whether or not the alien chromosome carries genes adversely affecting the quality of the grain and other characteristics such as yield, maturity, etc. One such substitution line, C. I. 13020, produced at the Oklahoma Station emphasizes the difficulties that may be encountered with this technique. C.I. 13020 represents a substitution line in which a pair of *Agropyron* chromosomes bearing the genes governing resistance to wheat leaf rust have replaced chromosome XVI pair of wheat (Bakshi and Schlehuber (3).

This particular line is generally poor in milling and baking quality, and low in yield and bushel weight. Whether the alien chromosomes carry genes adversely affecting agronomic quality in C.I. 13020 or whether the loss of chromosomes XVI is responsible for the generally poor characteristics of this otherwise rust immune line is unknown. Perhaps other wheat chromosomes may be substituted with less deleterious effect, or on the other hand, other *Agropyron* chromosomes may be found which are less deterimental.

Another technique which may prove of value in working with wheat and *Agropyron* hybrids is the use of X-rays or other types of irradiation to induce translocations as a mechanism of transferring *Agropyron,* chromatin into the wheat complement as was demonstrated by Sears (32) in a wheat-*Aegilops* hybrid. Elliott (6) also reported recently that a transfer of stem rust resistance from *Agropyron* to wheat had been accomplished through the use of X-rays but in a different manner from that of Sears (32)[6].

Although the method of Sears is involved and time-consuming, it may be the only means of utilizing the valuable germplasm found in the wheat-*Agropyron* hybrids.

Recently a chromosome was reported in wheat the absence of which allows a certain amount of pairing between non-homologous chromosomes to occur (23) and which has been identified as chromosome V (33). Riley (23) pointed to the possibility of the utilization of material lacking chromosome V as a means of obtaining pairing between alien chromosomes and thus increasing the possibility of obtaining genetic recombination in intergeneric hybrids.

This technique also has disadvantages as pointed out by Riley (23). Further investigation with this particular phenomenon will undoubtedly illustrate whether the condition of asynapsis and promotion of pairing of non-homologues by chromosome V can be used in intergeneric wheat breeding.

Which of these means will ultimately prove to be the most useful to the plant breeder in obtaining desirable types from wheat-*Agropyron* hybrids remains for the future. However, with increasing efforts being devoted to the development of alien addition and substitution lines and the utilization of these in breeding programs as well as to increased use of irradiation in modifying genetic systems, some means may be acquired in which the full value from intergeneric hybridization may be realized and effectively used for plant improvement in general.

Summary

A total of 542 advanced generation wheat x wheatgrass hybrids representing a potentially valuable source of germplasm was classified for

[6]According to A. T. Pugsley, Wagga Wagga, Australia, some doubt exists about the actual transfer of resistance from **Agropyron** in this material. (Oral communication).

leaf rust reaction and various morphological characters. Data relating to association of five of these characters viz., head type, maturity, leaf-roughness, awn condition and glume pubescence with leaf rust reaction in the mature plant stage are presented.

Certain hybrids were tested for leaf reaction in the greenhouse and in special field plantings.

Leaf rust immunity was found in less than 20 percent of the hybrids and the incidence of leaf rust immunity was higher in grasslike plants, in rough leaved plants and in late maturing plants.

Several wheatlike hybrids and plant selections were found to be highly resistant to leaf rust as seedlings and highly resistant or immune as mature plants.

The potential agronomic value of the wheat-wheatgrass hybrids is considered in light of recent work relating to cytogenetics of wheat-*Agropyron* hybrids.

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Table I.—Frequency distribution of leaf rust reaction and head type of 542 Sando-derived wheat x wheatgrass hybrids.

Head Type	Leaf Rust Reaction: Immune	Segregating	Susceptible	Total	% of Total
		(Number of hybrids)			
Wheatlike	6	25	410	441	81.37
Intermediate	1	2	3	6	1.11
Grasslike	4	0	0	4	0.74
Segregating	8	50	33	91	16.79
Total	19	77	446	542	
% of Total	3.51	14.21	82.29		

Table II.—Frequency distribution of leaf rust reaction and leaf roughness of 542 Sando-derived wheat x wheatgrass hybrids.

Leaf Roughness	Leaf Rust Reaction: Immune	Segregating	Susceptible	Total	% of Total
		(Number of hybrids)			
Smooth	2	17	331	350	64.53
Intermediate	0	0	21	21	3.87
Rough	12	11	16	39	7.20
Segregating	5	49	78	132	24.35
Total	19	77	446	542	

Table III.—Frequency distribution of leaf rust reaction and maturity of 542 Sando-derived wheat x wheatgrass hybrids.

Maturity	Leaf Rust Reaction: Immune	Segregating	Susceptible	Total	% of Total
		(Number of hybrids)			
Very early	0	1	14	15	2.77
Early	0	4	89	93	17.16
Mid-season	6	32	235	273	50.37
Late	6	29	101	136	25.09
Very late	7	11	7	25	4.61
Total	19	77	446	542	

Table IV.—Seedling reaction of 23 Sando selections to 13 races of leaf rust. — Group I

S. S. No.	Head Type 1957	Awned Condition 1957	Leaf* Rough-ness 1957	Glum** Pubes-cence 1957	Leaf Rust Reaction† Race 5	9	9A	15	15A	21	32	35	58	105	105A	105B	126
701	Inter.	Awned	R	G	R-X	R	R	R-S	R-S	S	I	R-S	S	R	R-S	R-X	R
763	do.	do.	I	G	S	X	R-X	I-S	S-I	S	S	X-S	S	S	S-X	X	S
797	Wheat	do.	R	G	R-S	I	S-R	I-S	R-S	I	R	S	S	I	S-R	R-S	S
799	Grass	Awnless	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
800	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
801	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
803	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
804	do.	do.	R	G	R	R	R	R	R-S	R	R	R	R	R	R	R	R
805	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
806	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
807	do.	Tip Awned & Awnless	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
808	do.	Awnless	R	G	R	R	R	R-S	R	R	R	R	R	R	R	R	R
809	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
834	Inter.	Awned & Semi-Awned	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
837	do.	Semi-Awned	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
838	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
839	do.	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
840	Wheat	do.	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
843	do.	Awned	R	G	R	R	R	R	R	R	R	R	R	R	R	R	R
847	do.	do.	R	G	S	S	S	S-I	S	S	I	I-S	S	S	S	S-X	S
848	do.	do.	R	G	S	S	S	S	S	S	S	I-S	S	S	S	S-I	S
866	do.	do.	S	G	S	S	S	S	S	S	S	X-S	S	S	S	S	S
869	do.	do.	S	G	S	S	S	S-I	S	S	S	S	S	S	S	S	S

*R = rough, I. = intermediate, S = smooth.
**G = Glabrous.
† R = resistant, I = intermediate, S = susceptible, X = meseothetic (both resistant and susceptible type pustules on same leaf.)

Table V.—Leaf rust reaction and head type of 25 space-planted Sando selections grown at Stillwater, 1958.
Group I

Sac. or S.S. No.	Head Type	Rust Reaction
3872	Segregating	Segregating
701	Wheatlike	Immune?
763	Wheatlike	Immune?
797	Wheatlike	Segregating
799	Grasslike	Immune
800	Segregating	Immune
801	Segregating	Segregating
803	Segregating	Segregating
804	Intermediate	Immune?
805	Grasslike	Immune
806	Segregating	Segregating
807	Grasslike	Immune
808	Segregating	Immune
809	Grasslike	Immune
834	Intermediate	Immune
837	Wheatlike	Immune
838	Wheatlike	Immune
839	Wheatlike	Immune
840	Wheatlike	Immune
843	Wheatlike	Immune
847	Wheatlike	Susceptible
848	Wheatlike	Susceptible
849	Wheatlike	Susceptible
866	Wheatlike	Susceptible
869	Wheatlike	Susceptible

Table VI.—Summary of leaf rust reaction and head type of 25 space-planted Sando selections.
Group I

	Leaf Rust Reaction				% of
Head Type	Immune	Segregating	Susceptible	Total	Total
		(Number of Plots)			
Wheatlike	7	5	1	13	52.0
Intermediate	2	0	0	2	8.0
Grasslike	4	0	0	4	16.0
Segregating	2	0	4	6	24.0
Total	15	5	5	25	
% of Total	60.0	20.0	20.0		

Table VII.—Leaf rust reaction and 4 morphological characters of 24 Sando hybrids reselected and transplanted to the field, Stillwater, 1958.

Group II

Sac. or S.S. No.	No. of Plants Matured	Mature Plant Rust Reaction R	I	S*	Head Type**	Awned Contd.†	Glume Pubes.††	Leaf Rough.***
			(No. of Plants)					
3383	1	0	0	1	W	Bdls.	G	R
3391	3	2	0	1	Seg.	Seg.	G	Seg.
3900	18	10	8	0	W	Ta	G	S
3903	1	0	1	0	W	Bd.	G	S
3933	26	1	14	11	Seg.	Seg.	G	Seg.
3952	8	8	0	0	I	Seg.	G	Seg.
3977	3	2	1	0	W	Seg.	Seg.	Seg.
3980	9	5	3	1	W	Ta	G	Seg.
4046	2	2	0	0	W	Seg.	G	S
4077	2	2	0	0	Seg.	Seg.	G	S
4295	1	0	1	0	W	Bd.	G	S
653	7	4	2	1	W	Bd.	G	Seg.
672	4	1	3	0	W	Bdls.	G	R
673	4	3	0	1	W	Seg.	G	R
693	1	0	1	0	W	Bd.	G	R
702	5	2	3	0	W	Bd.	G	R
713	11	10	0	1	W	Seg.	Seg.	R
728	9	5	2	2	W	Seg.	Seg.	Seg.
789	1	1	0	0	W	Bdls.	G	I
818	8	4	4	0	Seg.	Seg.	G	Seg.
821	2	2	0	0	I	Bdls.	G	Seg.
845	12	12	0	0	W	Bd.	G	R
851	1	0	0	1	W	Bdls.	G	S
865	1	1	0	0	I	Ta	G	R
Total		77	43	20				

*R = Resistant (reaction of 0 through 2+).
I = Intermediate (reaction of 2-3 or 2-4).
S = Susceptible (reaction of 3 or 4).
**W = Wheatlike; I = Intermediate.
†Bd= Awned; Ta = Tip awned; Bdls. = Awnless.
††G = Glabrous; P = Pubescent.
***S = Smooth leaf surface; R = Rough leaf surface.

Table VIII.—Seedling reaction of 43 Sando reselections to a composite of leaf rust races including 105B Stillwater, 1957.

Group III

Sac. or S.S. No.	Leaf Rust Reaction** R	I	S	NT	Total
		(No. of Plants)			
3928	--	14	9	-	23
3934	22	19	3		44
3992	1	7	34	1	43
4025	4	15	4	1	24
4045	12	17	--	3	32
4141	1	31	3	2	37
4146	--	--	29	1	30
4155	31	2	--	2	35
4157	9	10	1	3	23
4160	2	16	11	3	32
4161	21	9	--	3	33
4162	--	28	--	-	28
4166	--	29	12	2	43
4190	--	6	38	-	44
4193	--	--	47	-	47
4229	--	--	43	1	44
4244	2	32	1	-	35
4250	14	10	9	2	35
4251	17	17	--	8	42
4253	13	30	--	1	44
4254	5	37	--	1	43
4278	17	26	--	4	47
4281	17	21	5	4	47
4314	44	4	--	-	48
657	4	30	8	1	43
659	6	21	3	-	30
639	20	22	5	3	50
694	1	--	33	-	34
716	7	27	--	1	35
717	22	9	8	-	39
718	41	9	--	-	50
753	--	44	--	-	44
759	--	26	16	3	45
764	----	7	51	-	58
790	--	19	17	3	39
791	7	37	2	2	48
794	17	29	--	3	49
814	--	28	10	5	43
833	14	12	--	1	27
836	74	12	--	1	87
841	13	24	--	1	38
842	1	19	1	-	21
844	23	11	11	4	49

**R = Resistant.
I = Intermediate
S = Susceptible
NT = No Test

Table IX.—Leaf rust reaction and head type of 50 space-planted Sando reselections grown at Stillwater, 1958.

Group III

Sac. or S.S. No.	Head Type	Rust Reaction
3928	Wheatlike	Susceptible
3934	Wheatlike	Susceptible
3992	Wheatlike	Susceptible
4025	Segregating	Susceptible
4037	Grasslike	Immune
4045	Wheatlike	Susceptible
4141	Wheatlike	Susceptible
4146	Wheatlike	Susceptible
4155	Intermediate	Immune?
4157	Segregating	Segregating
4160	Segregating	Susceptible
4161	Intermediate	Susceptible
4162	Intermediate	Immune
4166	Segregating	Segregating
4190	Wheatlike	Segregating
4193	Wheatlike	Susceptible
4229	Wheatlike	Susceptible
4242	Segregating	Immune
4244	Segregating	Susceptible
4250	Intermediate	Immune
4251	Intermediate	Immune
4253	Wheatlike	Susceptible
4254	Wheatlike	Susceptible
4278	Wheatlike	Immune
4280	Wheatlike	Immune
4281	Segregating	Segregating
4314	Intermediate	Immune
657	Wheatlike	Susceptible
659	Wheatlike	Segregating
686	Wheatlike	Segregating
689	Segregating	Segregating
694	Wheatlike	Susceptible
709	Wheatlike	Immune?
716	Wheatlike	Segregating?
717	Wheatlike	Segregating
718	Wheatlike	Immune
753	Wheatlike	Immune
759	Wheatlike	Segregating
764	Wheatlike	Segregating
790	Wheatlike	Susceptible
791	Wheatlike	Susceptible
794	Wheatlike	Segregating
811	Wheatlike	Susceptible
814	Segregating	Segregating
833	Intermediate	Immune
836	Segregating	Segregating
841	Grasslike	Immune
842	Segregating	Immune
844	Wheatlike	Segregating
846	Wheatlike	Immune

Table X.—Summary of leaf rust reaction and head type of 50 space-planted Sando selections.
Group III

Head Type	Leaf Rust Reaction: Immune	Segregating	Susceptible	Total	% of Total
Wheatlike	6	9	15	30	60.0
Intermediate	6	0	1	7	14.0
Grasslike	2	0	0	2	4.0
Segregating	2	6	3	11	22.0
Total	16	15	19	50	
% of Total	32.0	30.0	38.0		

Table XI.—Leaf rust reaction and head type of 41 space-planted Sando reselections grown at Stillwater, 1958.
Group IV

Sac. or S.S. No.	Head Type	Rust Reaction
3927	Wheatlike	Susceptible
3929	Wheatlike	Susceptible
3930	Wheatlike	Susceptible
3931	Wheatlike	Susceptible
3935	Wheatlike	Susceptible
3953	Wheatlike	Susceptible
3978	Wheatlike	Susceptible
3993	Wheatlike	Susceptible
4020	Wheatlike	Susceptible
4021	Wheatlike	Susceptible
4029	Segregating	Segregating
4055	Segregating	Segregating
4073	Wheatlike	Susceptible
4088	Wheatlike	Susceptible
4098	Wheatlike	Susceptible
4101	Wheatlike	Segregating
4145	Wheatlike	Susceptible
4151	Segregating	Segregating
4156	Intermediate	Susceptible
4167	Wheatlike	Susceptible
4237	Wheatlike	Susceptible
4239	Wheatlike	Immune
4240	Wheatlike	Susceptible
4256	Wheatlike	Susceptible
4257	Wheatlike	Susceptible
4309	Wheatlike	Susceptible
3944 and 3949	Wheatlike	Susceptible
664	Wheatlike	Susceptible
667	Wheatlike	Segregating
669	Wheatlike	Segregating
690	Wheatlike	Susceptible
698	Wheatlike	Susceptible
711	Wheatlike	Susceptible
724	Wheatlike	Susceptible
725	Wheatlike	Susceptible
740	Wheatlike	Susceptible
788	Segregating	Susceptible
802	Wheatlike	Susceptible
812	Wheatlike	Susceptible
823	Wheatlike	Segregating
828	Wheatlike	Susceptible

Table XII.—Summary of leaf rust reaction and head type of 41 space-planted Sando reselections.
Group IV

Head Type	Leaf Rust Reaction			Total	% of Total
	Immune	Segregating	Susceptible		
		(Number of Plots)			
Wheatlike	1	4	31	36	87.80
Intermediate	0	0	1	1	2.44
Grasslike	0	0	0	0	----
Segregating	1	3	0	4	9.76
Total	2	7	32	41	
% of Total	4.88	17.07	78.05		

3-60/2½M