An Inheritance and Linkage Study of 19 Factor Pairs in Barley

Francis Cheney LeBaron

Utah State University

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AN INHERITANCE AND LINKAGE STUDY
OF 19 FACTOR PAIRS IN BARLEY
by
Francis Cheney LeBaron

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
Agronomy

UTAH STATE UNIVERSITY
Logan, Utah
1959
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INTRODUCTION

Barley, during the past three decades, has been used considerably for the study of linkage groups and character inheritance. The commercial varieties are diploids, having seven pairs of chromosomes. Six linkage groups have been established. According to studies on interchange by Kramer et al. (1954), two linkage groups, formerly designated as III and VII, may be separate arms of the same chromosome. They are now generally considered as one linkage group.

Though more than two hundred characters have been investigated, less than sixty have been assigned relative positions on genetic maps. In many cases, selection for good characters is difficult and time consuming; however, a knowledge of linkages between desirable characters can greatly facilitate the work of the plant breeder.

The objectives of this study have been to determine new linkages, investigate several reported ones, and to further an understanding of the inheritance of unit characters in barley. Of the 19 factor pairs selected for this study, four have not been previously assigned to linkage groups.
REVIEW OF LITERATURE

A number of reviews of genetic research in barley have been published: Griffee (1925), Hayes and Garber (1927), Buckley (1930), Daane (1931), Robertson (1933, 1937), and Smith (1951).

Reviews of linkage studies have been presented by Robertson, Wiebe, and Immer (1941), Immer and Henderson (1943), Smith (1951), Robertson, Wiebe and Shands (1947, 1955), and Robertson (1957). Smith's (1951) review of the genetics and cytology of barley is the most comprehensive in the field. He perused about 1400 articles, of which over 900 are listed in his bibliography.

This review will present work on only those 19 factor pairs which are pertinent to this study.

Inheritance of Factor Pairs

Linkage group I

Normal vs triple-awned lemma (Tr tr). Reports by Immer and Henderson (1943), Heiner (1958) and Imam (1959) indicate that triple-awned lemma is recessive, segregating in a 3:1 ratio.

Deficiens (Vt) vs two-rowed (V) vs six-rowed (v). The complicated problem of fertility of the lateral florets and of the number of kernel rows in barley received a plausible explanation by Woodward (1947). Whereas Hor (1924) and Huber (Smith 1951), among others, had earlier concluded that the number of rows of florets was determined by an allelic series of three genes, Woodward (1947)
demonstrated that an allelic series of four genes \((V_t, V^d, V, v)\) were located in Linkage Group I. The deficiens character for rudimentary floral structures in the lateral florets behaves as an allele of the \(V, v\) factor for the two-rowed vs six-rowed condition and is at least partially dominant to them.

The studies of Buckley (1930), Daane (1931), Neatby (1926), and Heiner (1958) indicated that a single pair of genes was involved. Robertson (1929) suggested a two factor-pair inheritance. A ratio of one deficiens to two intermedium to one six-rowed was obtained by Byington (1940) and Waddoups (1949).

**Purple vs white lemma and pericarp** \((Re_2, re_2)\). In most ratios involving purple and white lemmas, purple is a simple dominant over non-purple (Woodward 1949). Biffen (1907) found that purple lemma, while inherited in some crosses as a simple dominant, could in other crosses be inhibited by two dominant complementary genes. Waddoups (1949) observed a 3:1 ratio in the \(F_2\) of a cross between purple- and white-chaffed parents, but one cross between two white-chaffed parents gave a 9:7 ratio of purple to white in \(F_2\). So et al. (Smith 1951) reported 9:7, 15:1, and 1:2:1 ratios for deep purple, light purple and colorless in different crosses.

Woodward and Thieret (1953) and Heiner (1958) found both 3:1 and 9:7 ratios in the \(F_2\), suggesting that two complementary factors were involved. Woodward (1949) obtained one 9:6:1 for dense, dilute purple and white, and another ratio of 12 purple, 3 blue to 1 white for pericarp and blue aleurone in \(F_2\) segregation. Environmental factors, including sunlight, according to Woodward (personal communication), can cause considerable variation in color expressions involving
purple and red.

Lax vs dense spike (L l). At the present time there is no all-inclusive explanation as to what factors determine the length and density of the barley spike. Smith's (1951) review of the subject indicated that one, two, three, four and six gene pairs have been reported.

The laxness or denseness of a spike, according to Rasmusson (1956), is determined by measuring the length of the ten internodes just above the second node. However, Aberg and Wiebe (Rasmusson 1956) stated that internode length varies greatly within a variety. Variations from year to year, place to place, and from spike to spike, they concluded, limited its usefulness as a very stable character. Earlier, Harlan and Hayes (1920) had reported that internode length in barley was a very stable character.

Normal vs long-awned glume (E e). There is general agreement that the non-awned glume is dominant and follows a simple Mendelian ratio. Workers reporting the involvement of a single gene pair were: Hor (1924), Neatby (1926), Immer and Henderson (1943), Robertson, Immer, Wiebe and Stevens (1944), Gill (1951), Woodward (1957), Andersen (1958), Heiner (1958), and Imam (1959).

Normal vs reduced laterals (Lr lr). Varied opinions were expressed in the literature as to the number of gene pairs which affected the presence or absence of lateral awning. Leonard (1942), after reviewing some of the earlier studies, decided that appendages (awns or hoods) on lateral florets were determined by one gene pair. He noted that normal was dominant over reduced appendages but that they were present only in six-rowed types. Smith (1951) quoted Dasananda
and Fung as believing that "... one factor was mainly responsible for the development of the lateral lemma appendages." Smith continued:

But Chia interpreted his data on awn inheritance in crosses among varieties differing in awn length on both central and lateral florets as the result of five gene pairs; one affected awn length on central florets, and four determined awnedness of lateral florets.

**Linkage group II**

**Black vs white lemma and pericarp (B b).** Smith (1951) listed 30 articles reporting that black glume is dominant to non-black glume and segregates in a 3:1 ratio in many crosses. Studies by Woodward (1941, 1942) revealed evidence of an allelomorphic series of three genes for degree of black pigmentation of lemma and pericarp: black, gray and white. The darker color, in each combination, was dominant over the lighter and segregated monofactorially.

**Linkage Group III**

**Hulled vs hull-less caryopsis (N n).** A single gene difference was recorded by Robertson (1929), Buckley (1930), Daane (1931), Byington (1940), Waddoups (1949), Woodward (1955), Heiner (1958), Al-Jibouri (1953), and Imam (1959). All reported that the $F_2$ generations segregated in a three hulled to one hull-less ratio.

**Linkage Group IV**

**Hoods vs awns (K k).** Several researchers, among them Buckley (1930), Daane (1931), Woodward (1949), Al-Jibouri (1953), and Heiner (1958), have observed that in most crosses hoods are dominant over awns in a 3:1 ratio. Wheatley (1955), however, reported both 3:1 and 9:7 ratios in $F_2$. In another $F_2$ study, Rasmusson (1956) obtained 9
hoods to 3 long awns to 4 short awns.

After studying data from the $F_2$ generation and a small $F_3$ population of crosses involving hooded and short-awned, hooded and long-awned, and long and short-awned plants, Albrechtsen (1957) concluded:

The inheritance of hoods (K) and awns (k) in these crosses was determined by two factor pairs (KK and $K_2k_2$). One or more dominant genes from each of the two pairs is necessary for the development of hoods. Therefore there are four possible genotypes for the hooded plants (KK $K_2K_2$, Kk $K_2k_2$, KK $K_2k_2$, and Kk $k_2k_2$). Short awns develop when the recessive (kk) factor is present with the second factor in either a homozygous dominant ($K_2K_2$), heterozygous ($k_2k_2$), or homozygous recessive ($k_2k_2$) condition. Long ($K_1$) awns are developed when the recessive ($k_2k_2$) factor is present in combination with the first factor in the homozygous dominant (KK) or heterozygous (Kk) condition.

Long vs short awns ($k_1 k_2$). Bussell (1936) and Myler (1942) concluded that two gene pairs were responsible for the difference between certain long- and short-awned (or awnless) varieties. Miyake and Imai (Smith 1951) believed that there was only a single factor difference for length of awns in some crosses but that three genes determined the presence and length of awns in crosses between certain awned and awnless varieties.

Elevated hoods vs awns ($K^e k$). It was shown by Takahashi et al. (1953) that the normal (subjacent) hood, the elevated hood and the long-awn were governed by a multiple allelic series K, $K^e$ and k. The gene K for normal hood was almost completely dominant over $K^e$ for elevated hood and k for long-awn, while $K^e$ was only slightly dominant over k. The multiple allelic hypothesis seemed to be supported by the fact that K and $K^e$ are both linked with almost equal intensity with Bl for blue aleurone in linkage group IV.
Non-zoned vs zoned leaf (Z z). A simple Mendelian ratio of 3 non-zoned to 1 zoned leaf have been recorded by Immer and Henderson (1943), Wheatley (1955), and Heiner (1958). Woodward (1957), however, reported another factor pair for zoned leaf which has shown no linkage with any other gene pair.

Blue vs white aleurone (Bl bl). Buckley (1930), Daane (1931), Woodward (1949), Al-Jibouri (1953), Wheatley (1955), and Heiner (1958) have reported a 3 blue to 1 white ratio. Smith (1951) observed that not only is the expression of the character frequently influenced by environment but because the blue color is in the aleurone, xenia may be observed when the cross is made on the white seeded parent.

Factor pairs not classified

Long vs short glume hairs (Gh gh). From F₂ data on the inheritance of glume hair length, Woodward (1950), Isom (1951), Al-Jibouri (1953), and Heiner (1958) received 3:1 ratios. Gill (1951) took hard-to-classify-material into the F₃ from which he received a 1:2:1 ratio with a good chi-square fit. When Waddoups (1949) received 3:1, 1:2:1 and 1:1 F₂ ratios, he concluded that as many as three factor pairs were involved.

Non-glossy vs glossy sheath and spike (Gs gs). Simple inheritance in a 3:1 ratio, non-glossy being dominant, has been recorded by Immer and Henderson (1943), Waddoups (1949), Gill (1951) Wheatley (1955), Andersen (1958), and Heiner (1958).

Purple vs white auricle (Prₐ prₐ). Since the three references to auricle color were printed in German, Smith's (1951) review will be quoted in full:
Presence and absence of red pigment in the auricle was found to segregate in 3:1 and 10:6 ratios in different crosses (Huber 1920). It was assumed that one gene was mainly responsible for formation of anthocyanin in the auricle, but this gene did not express itself except in the heterozygous condition, unless the other, intensifier gene, was also present in the dominant condition. Ubisch (1919) observed that red color in the auricle, nodes and other places was dominant. Gassner and Straib (1937) observed that a deficiency of N or a higher concentration of CO₂ increased anthocyanin development, but that K or P by themselves were relatively ineffective in changing the concentration of the pigment.

Normal vs many-noded dwarf (Mnd mnd). In the summer of 1918, according to Harlan and Pope (1922), a two-rowed barley plant having a large number of extremely short internodes and an abundance of fine leaves was found in the World Collection at Aberdeen, Idaho. A few months earlier, Hor (1922) had described a variation of the same type, in a six-rowed barley which had been found in California. Harlan and Pope suggested:

The double appearance of the variation seems to have one plausible explanation, namely, that it is a mutation where all the modifications which occur in the plant are caused by the same factor.

Out of four separate variety crosses made by Harlan and Pope, involving 233 F₂ plants, 181 normal and 52 "dwarfs" were observed. This is a 3.48:1 ratio.

Previously Reported Linkages

A summary of linkages pertinent to this study, as reported by various research workers, is presented below. The majority were taken directly from published reports of the workers themselves. A few linkages were found in unpublished Masters' theses at Utah State University. Where original reports were not available for personal
study, the reference sources have been indicated.

**Linkage group I**

Purple vs white lemma and pericarp \((Re_2 re_2)\) in relation to two-rowed vs six-rowed \((V v)\).

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<th>Percent Recombination</th>
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<td>13.9 ± 2.17</td>
<td></td>
<td>Myler and Stanford (1924)</td>
</tr>
<tr>
<td>13.0 ± 1.2</td>
<td>Coupling</td>
<td>Gill (1951)</td>
</tr>
<tr>
<td>4 to 8</td>
<td></td>
<td>Woodward and Thieret (1953)</td>
</tr>
<tr>
<td>13.2 ± 0.9</td>
<td>Coupling</td>
<td>Woodward and Thieret (1953)</td>
</tr>
<tr>
<td>12.0 ± 3.0 ((F_3))</td>
<td>Coupling</td>
<td>Al-Jibouri (1953)</td>
</tr>
<tr>
<td>12.5 ± 2.4 ((F_3))</td>
<td>Coupling</td>
<td>Al-Jibouri (1953)</td>
</tr>
<tr>
<td>17.1 ± 0.7</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>14.0 ± 1.3</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>10.0 ± 4.8</td>
<td>Repulsion</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>22.1 ± 16.3</td>
<td>Repulsion</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>26.5 ± 1.89</td>
<td>Coupling</td>
<td>Albrechtsen (1957)</td>
</tr>
<tr>
<td>12.0 ± 1.3</td>
<td></td>
<td>Andersen (1958)</td>
</tr>
<tr>
<td>33.0 ± 4.0</td>
<td></td>
<td>Andersen (1958)</td>
</tr>
<tr>
<td>15.0 ± 2.2</td>
<td>Coupling</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>14.5 ± 6.5</td>
<td>Repulsion</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>15.6 ± 1.5</td>
<td>Coupling</td>
<td>Imam (1959)</td>
</tr>
</tbody>
</table>
Purple vs white lemma and pericarp ($Re_2 re_2$) in relation to deficiens vs six-rowed.

<table>
<thead>
<tr>
<th>Percent Recombination</th>
<th>Phase</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.0 ± 3.2</td>
<td>Coupling</td>
<td>Waddoups (1949)</td>
</tr>
<tr>
<td>12.0 ± 2.6</td>
<td>Coupling</td>
<td>Waddoups (1949)</td>
</tr>
<tr>
<td>32.36 ± 1.59</td>
<td>Coupling</td>
<td>Imam (1959)</td>
</tr>
</tbody>
</table>

Purple vs white lemma and pericarp ($Re_2 re_2$) in relation to normal vs long-awned glume ($E e$).

<table>
<thead>
<tr>
<th>Percent Recombination</th>
<th>Phase</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.5 ± 2.0</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>27.0 ± 5.7</td>
<td>Repulsion</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>None</td>
<td>Repulsion</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>28.5 ± 5.2</td>
<td>Coupling</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>47.0 ± 5.3</td>
<td>Repulsion</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>44.7 ± 6.06</td>
<td>Coupling</td>
<td>Imam (1959)</td>
</tr>
</tbody>
</table>

Purple vs white lemma and pericarp ($Re_2 re_2$) in relation to lax vs dense spike ($L l$).

<table>
<thead>
<tr>
<th>Percent Recombination</th>
<th>Phase</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3 ± 2.6</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>35.0 ± 5.8</td>
<td>Coupling</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>36.0 ± 5.9</td>
<td>Repulsion</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>46.05 ± 7.16</td>
<td>Coupling</td>
<td>Imam (1959)</td>
</tr>
</tbody>
</table>
Normal vs long-awned glume (E e) in relation to lax vs dense spike (L l).

<table>
<thead>
<tr>
<th>Percent Recombination</th>
<th>Phase</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.8 ± 5.9</td>
<td>Repulsion</td>
<td>Waddoups (1949)</td>
</tr>
<tr>
<td>21.2 ± 1.5</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>31.5 ± 4.0</td>
<td>Repulsion</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>18.13 ± 2.5</td>
<td>Coupling</td>
<td>Imam (1959)</td>
</tr>
</tbody>
</table>

Linkage group IV

Hoods vs awns (K k) in relation to blue vs white aleurone (Bl bl).

<table>
<thead>
<tr>
<th>Percent Recombination</th>
<th>Phase</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.6 ± 2.26</td>
<td>Repulsion</td>
<td>Buckley (1930)</td>
</tr>
<tr>
<td>22.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24.72 ± 1.73</td>
<td></td>
<td>Myler and Stanford (1942)</td>
</tr>
<tr>
<td>44.0 ± 6.3</td>
<td></td>
<td>Immer and Henderson (1943)</td>
</tr>
<tr>
<td>30.4 ± 4.07</td>
<td>Coupling</td>
<td>Gill (1951)</td>
</tr>
<tr>
<td>26.5 ± 1.5</td>
<td>Coupling</td>
<td>Isom (1951)</td>
</tr>
<tr>
<td>21.8</td>
<td></td>
<td>Takahashi (1953)</td>
</tr>
<tr>
<td>30.0 ± 2.0</td>
<td>Coupling</td>
<td>Al-Jibouri (1953)</td>
</tr>
<tr>
<td>35.5 ± 1.9</td>
<td>Coupling</td>
<td>Wheatley (1955)</td>
</tr>
<tr>
<td>28.5 ± 0.9</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>31.5</td>
<td></td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>37.0 ± 3.3</td>
<td></td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>None</td>
<td>3:1:3:1</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>37.0 ± 3.58</td>
<td>Coupling</td>
<td>Albrechtsen (1957)</td>
</tr>
<tr>
<td>43.4 ± 3.35</td>
<td>Repulsion</td>
<td>Imam (1959)</td>
</tr>
</tbody>
</table>
Hoods vs awns (K k) in relation to non-zoned vs zoned leaf (Z z).

<table>
<thead>
<tr>
<th>Percent Recombination</th>
<th>Phase</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 ± 0.8</td>
<td>Coupling</td>
<td>Immer and Henderson (1943)</td>
</tr>
<tr>
<td>38.0 ± 9.7</td>
<td>Repulsion</td>
<td>Gill (1951)</td>
</tr>
<tr>
<td>27.0 ± 4.6</td>
<td>Repulsion</td>
<td>Wheatley (1955)</td>
</tr>
<tr>
<td>38.0 ± 1.4</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>35.5 ± 2.5</td>
<td>Repulsion</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>None</td>
<td>Coupling</td>
<td>Woodward (1957)</td>
</tr>
<tr>
<td>18.2 ± 2.54</td>
<td>Repulsion</td>
<td>Albrechtsen (1957)</td>
</tr>
<tr>
<td>4.5 ± 2.4</td>
<td>Coupling</td>
<td>Heiner (1958)</td>
</tr>
<tr>
<td>17.5 ± 7.4</td>
<td>Repulsion</td>
<td>Heiner (1958)</td>
</tr>
</tbody>
</table>
MATERIALS AND METHODS

The seven crosses used in this study were made during 1957 by Dr. Rollo W. Woodward at Utah State University. The $F_1$ plants were harvested and kept separate so that each plant constituted a family. There were two to eleven families in each cross.

In the Spring of 1958 the $F_2$ generation was thinly planted in 35-foot rows, one foot apart, by means of a four-row cone seeder.

Plants having characteristics subject to change before maturity were tied with colored strings. These particular characteristics were: glossy leaf, glossy sheath and head, purple auricle, and zoned leaf. At maturity all plants were pulled, bundled, tied into family groups, and properly labeled.

The material was classified according to phenotypic expressions. Two or three heads from particular character combinations were kept for future plantings. Two factor pairs were then studied in relation to each other for independent inheritance or linkage. Chi-square was calculated as a test for goodness of fit for each segregating factor pair and for every dihybrid combination of factor pairs. The probability values for chi-square were taken from Ostle (1956). Linkages were determined by the product method, as reported by Fisher and Balmukand (1928).
Factor Pairs Used in This Study and Their Gene Symbols

**Linkage group I**

<table>
<thead>
<tr>
<th>Factor Pair</th>
<th>Gene Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal vs triple-awned lemma</td>
<td>Tr tr</td>
</tr>
<tr>
<td>Deficiens vs two-rowed spike</td>
<td>V⁺ V</td>
</tr>
<tr>
<td>Two-rowed vs six-rowed spike</td>
<td>V v</td>
</tr>
<tr>
<td>Purple vs white lemma and pericarp</td>
<td>Re₂ re₂</td>
</tr>
<tr>
<td>Normal vs long-awned glume</td>
<td>E e</td>
</tr>
<tr>
<td>Lax vs dense spike</td>
<td>L l</td>
</tr>
<tr>
<td>Normal vs reduced lateral</td>
<td>Lr lr</td>
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</tbody>
</table>

**Linkage group II**

<table>
<thead>
<tr>
<th>Factor Pair</th>
<th>Gene Symbols</th>
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</thead>
<tbody>
<tr>
<td>Black vs white lemma and pericarp</td>
<td>B b</td>
</tr>
</tbody>
</table>

**Linkage group III**

<table>
<thead>
<tr>
<th>Factor Pair</th>
<th>Gene Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hullled vs hull-less</td>
<td>N n</td>
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</tbody>
</table>

**Linkage group IV**

<table>
<thead>
<tr>
<th>Factor Pair</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Hoods vs long awns</td>
<td>K₁</td>
</tr>
<tr>
<td>Elevated hoods vs awns</td>
<td>K⁺₁</td>
</tr>
<tr>
<td>Elevated hoods vs long awns</td>
<td>K⁺₁</td>
</tr>
<tr>
<td>Long awns vs short awns</td>
<td>k₂</td>
</tr>
<tr>
<td>Non-zoned vs zoned leaf</td>
<td>Z z</td>
</tr>
<tr>
<td>Blue vs white aleurone</td>
<td>Bl bl</td>
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</tbody>
</table>

**Non-classified factor pairs**

<table>
<thead>
<tr>
<th>Factor Pair</th>
<th>Gene Symbols</th>
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</thead>
<tbody>
<tr>
<td>Long vs short glume hairs</td>
<td>Gh gh</td>
</tr>
<tr>
<td>Non-glossy vs glossy sheath and spike</td>
<td>Gs gs</td>
</tr>
<tr>
<td>Purple vs white auricle</td>
<td>Pr a pr a</td>
</tr>
<tr>
<td>Normal vs many-noded dwarf</td>
<td>Mnd mnd</td>
</tr>
</tbody>
</table>
Crosses With Their Segregating Factor Pairs
as Used in This Study

<table>
<thead>
<tr>
<th></th>
<th>T 258</th>
<th>re₂</th>
<th>E</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1619</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 339</td>
<td>Re₂</td>
<td>e</td>
<td>n</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>T 258</th>
<th>re₂</th>
<th>v</th>
<th>N</th>
<th>Gh</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1620</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>T 365</td>
<td>Re₂</td>
<td>V</td>
<td>n</td>
<td>gh</td>
<td></td>
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<table>
<thead>
<tr>
<th></th>
<th>T 258</th>
<th>E</th>
<th>L</th>
<th>k₁</th>
<th>Z</th>
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<tbody>
<tr>
<td>B 1629</td>
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<tr>
<td>T 104</td>
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<td>1</td>
<td>K</td>
<td>z</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>T 665</th>
<th>e</th>
<th>tr</th>
<th>k₁</th>
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</thead>
<tbody>
<tr>
<td>B 1632</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>T 352</td>
<td>E</td>
<td>Tr</td>
<td>K</td>
<td></td>
<td></td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>T 336</th>
<th>re₂</th>
<th>k</th>
<th>bl</th>
<th>Gs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1642</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 202</td>
<td>Re₂</td>
<td>Kₑ</td>
<td>Bl</td>
<td>gs</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>T 417</th>
<th>re₂</th>
<th>V</th>
<th>n</th>
<th>b</th>
<th>k₁</th>
<th>Prₐ</th>
<th>Gs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1643</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 202</td>
<td>Re₂</td>
<td>Vᵗ</td>
<td>N</td>
<td>B</td>
<td>Kₑ</td>
<td>prₐ</td>
<td>gs</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>T 609</th>
<th>Re₂</th>
<th>Lr*</th>
<th>Mnd</th>
<th>k₂</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>T 742</td>
<td>re₂</td>
<td>lr</td>
<td>mnd</td>
<td>k₁</td>
<td></td>
</tr>
</tbody>
</table>

* Phase as suggested by the author
EXPERIMENTAL RESULTS

The data from this study will be presented in the following sequence:

1. The inheritance of individual characters.
2. Factor pairs suggesting independent inheritance.
3. Factor pairs suggesting linkage.

Inheritance of Individual Characters

Linkage group I

Normal vs triple-awned lemma (Tr tr). Table 1 indicates that simple Mendelian inheritance is present. The 3:1 ratio is in accord with earlier research data.

Two-rowed vs six-rowed spike (V v). Each of the 11 families in table 2 presents substantial evidence that a single factor is operating in this cross.

Deficiens vs two-rowed spike (V^t v). Deficiens is dominant to two-rowed, segregating in a 3:1 ratio (table 3). Though the literature revealed inheritance data regarding only deficiens vs six-rowed spike, it follows reason that since the two-rowed factor is an allele of the one for six-rowed, either factor should segregate alike in the expected 3:1 ratio. Apparently, the hypothesis is confirmed.
Table 1. Segregation of normal vs triple-awned lemma (Tr tr) in the $F_2$ generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1632

<table>
<thead>
<tr>
<th>Family</th>
<th>Tr</th>
<th>tr</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63</td>
<td>22</td>
<td>85</td>
<td>.035</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>15</td>
<td>40</td>
<td>2.133</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>Sum of 2 chi-squares</td>
<td></td>
<td></td>
<td></td>
<td>2.168</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>Total</td>
<td>88</td>
<td>37</td>
<td>125</td>
<td>1.536</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
<td></td>
<td>.632</td>
<td>.4 - .5</td>
</tr>
</tbody>
</table>

Table 2. Segregation of two-rowed vs six-rowed spike (V v) in the $F_2$ generation. Chi-square and P values are based on a 3:1 ratio. B 1620

<table>
<thead>
<tr>
<th>Family</th>
<th>V</th>
<th>v</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58</td>
<td>22</td>
<td>80</td>
<td>.267</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>2</td>
<td>106</td>
<td>31</td>
<td>137</td>
<td>1.229</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>3</td>
<td>79</td>
<td>20</td>
<td>99</td>
<td>1.338</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>13</td>
<td>50</td>
<td>.027</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>9</td>
<td>52</td>
<td>1.640</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>6</td>
<td>92</td>
<td>35</td>
<td>127</td>
<td>1.129</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>7</td>
<td>75</td>
<td>22</td>
<td>96</td>
<td>.209</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>8</td>
<td>94</td>
<td>24</td>
<td>118</td>
<td>.915</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>9</td>
<td>104</td>
<td>37</td>
<td>141</td>
<td>.091</td>
<td>.7 - .8</td>
</tr>
<tr>
<td>10</td>
<td>96</td>
<td>23</td>
<td>119</td>
<td>2.042</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>11</td>
<td>34</td>
<td>12</td>
<td>46</td>
<td>.224</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>Sum of 11 chi-squares</td>
<td></td>
<td></td>
<td></td>
<td>9.111</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>Total</td>
<td>817</td>
<td>248</td>
<td>1065</td>
<td>1.624</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
<td></td>
<td>7.487</td>
<td>.6 - .7</td>
</tr>
</tbody>
</table>
### Table 3. Segregation of deficiens vs two-rowed spike (V\textsuperscript{t} V) in the F\textsubscript{2} generation. Chi-square and P values are based on a 3:1 ratio. Cross No. 1643

<table>
<thead>
<tr>
<th>Family</th>
<th>V\textsuperscript{t}</th>
<th>V</th>
<th>Total</th>
<th>(x^2)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43</td>
<td>13</td>
<td>56</td>
<td>0.095</td>
<td>0.7 - 0.8</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>13</td>
<td>47</td>
<td>0.177</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>27</td>
<td>100</td>
<td>0.303</td>
<td>0.5 - 0.6</td>
</tr>
<tr>
<td>4</td>
<td>85</td>
<td>22</td>
<td>107</td>
<td>1.125</td>
<td>0.2 - 0.3</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>15</td>
<td>51</td>
<td>0.529</td>
<td>0.4 - 0.5</td>
</tr>
<tr>
<td>6</td>
<td>43</td>
<td>12</td>
<td>55</td>
<td>0.257</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>7</td>
<td>85</td>
<td>19</td>
<td>104</td>
<td>2.508</td>
<td>0.1 - 0.2</td>
</tr>
</tbody>
</table>

Sum of 7 chi-squares 4.994 \(< 0.01\)

<table>
<thead>
<tr>
<th>Total</th>
<th>399</th>
<th>121</th>
<th>520</th>
<th>0.831</th>
<th>0.3 - 0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction</td>
<td>4.163</td>
<td></td>
<td></td>
<td>0.6 - 0.7</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4. Segregation of purple vs white lemma and pericarp (Re\textsubscript{2} re\textsubscript{2}) in the F\textsubscript{2} generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1619

<table>
<thead>
<tr>
<th>Family</th>
<th>Re\textsubscript{2}</th>
<th>re\textsubscript{2}</th>
<th>Total</th>
<th>(x^2)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>79</td>
<td>21</td>
<td>100</td>
<td>0.853</td>
<td>0.3 - 0.4</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
<td>48</td>
<td>164</td>
<td>1.593</td>
<td>0.2 - 0.3</td>
</tr>
<tr>
<td>4</td>
<td>91</td>
<td>41</td>
<td>132</td>
<td>2.585</td>
<td>0.1 - 0.2</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>17</td>
<td>81</td>
<td>1.337</td>
<td>0.2 - 0.3</td>
</tr>
<tr>
<td>8</td>
<td>46</td>
<td>45</td>
<td>91</td>
<td>28.161</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

Sum of 5 chi-squares 34.529 \(< 0.01\)

<table>
<thead>
<tr>
<th>Total</th>
<th>350</th>
<th>127</th>
<th>477</th>
<th>8.451</th>
<th>&lt; 0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction</td>
<td>26.078</td>
<td></td>
<td></td>
<td>&lt; 0.01</td>
<td></td>
</tr>
</tbody>
</table>


Purple vs white lemma and pericarp (Re<sup>2</sup> re<sub>2</sub>). One cross (table 5) shows 3:1 segregation while four crosses (table 6) give 9:7 ratios. Evidently, there are one and two genes, respectively, operating within these crosses. Differences in the concentration of color were observed; unfortunately, these were not distinguished between during the classification period.

The low P value for Cross 1643 results from 3 families having low P values themselves. Deviations among the small number of plants in two of the families increased the chi-square values considerably.

The cross B 1640, as recorded in table 6, was affected by the factor pair for many-noded dwarf. The F<sub>2</sub> population of 483 plants was made up of 322 normal plants and 161 dwarfs. Because one third of the dwarfs failed to head and some of the remaining two-thirds were somewhat green, only the normal plants were analyzed for purple vs white chaff.

In addition to white, three aleurone colors were observed within this cross. In the order of most frequent occurrence or amount of dominance when two or all three colors appeared to be present, were the colors purple, red and blue.

Lax vs dense spike (L 1). The data of table 7 suggests a 3:1 ratio for Cross B 1619. It may or may not be the true case since internode length appeared to be too flexible as a standard. In this cross there were not just long and short internodes but quite a gradation of them. This prompts the author to believe that there are more than one pair of contributing genes and/or that environment exerts some influence.
### Table 5. Segregation of purple vs white lemma and pericarp (Re₂ re₂) in the F₂ generation. Chi-square and P values are based on a 9:7 ratio.

<table>
<thead>
<tr>
<th>Cross No.</th>
<th>No. of Families</th>
<th>Re₂</th>
<th>re₂</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1620</td>
<td>11</td>
<td>388</td>
<td>284</td>
<td>672</td>
<td>557</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>B 1642</td>
<td>9</td>
<td>192</td>
<td>150</td>
<td>342</td>
<td>200</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>B 1643</td>
<td>7</td>
<td>190</td>
<td>121</td>
<td>311</td>
<td>17,632</td>
<td>.01</td>
</tr>
</tbody>
</table>

Sum of 3 chi-squares 18.389 < .01

Total 27 770 555 1325 .306 .5 - .6
Interaction 18.083 < .01

### Table 6. Segregation of purple vs white lemma and pericarp (Re₂ re₂) in the F₂ generation. Chi-square and P values are based on a 9:7 ratio. Cross No. B 1640

<table>
<thead>
<tr>
<th>Family</th>
<th>P</th>
<th>p</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>41</td>
<td>21</td>
<td>62</td>
<td>2.458</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>8</td>
<td>59</td>
<td>42</td>
<td>101</td>
<td>.192</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>11</td>
<td>59</td>
<td>31</td>
<td>90</td>
<td>3.067</td>
<td>.05 - .1</td>
</tr>
<tr>
<td>12</td>
<td>36</td>
<td>33</td>
<td>69</td>
<td>1.466</td>
<td>.4 - .5</td>
</tr>
</tbody>
</table>

Sum of 4 chi-squares 6.183 .1 - .2

Total 195 127 322 2.975 .05 - .1
Interaction 3.208 .3 - .4
Table 7. Segregation of lax vs dense spike (L l) in the $F_2$ generation. Chi-square and $P$ values are based on a 3:1 ratio.
Cross No. B 1619

<table>
<thead>
<tr>
<th>Family</th>
<th>L</th>
<th>l</th>
<th>Total</th>
<th>$x^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>56</td>
<td>44</td>
<td>100</td>
<td>19.253</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>3</td>
<td>107</td>
<td>57</td>
<td>164</td>
<td>8.325</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>4</td>
<td>101</td>
<td>31</td>
<td>132</td>
<td>.161</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>5</td>
<td>59</td>
<td>22</td>
<td>81</td>
<td>.200</td>
<td>.6 - .7</td>
</tr>
</tbody>
</table>

Sum of 4 chi-squares

Total 323 154 477 13.501 < .01

Interaction 1.138 < .01
Normal vs long-awned glume (E e). Three ratios were observed for this character pair: 3:1 (table 8), 9:7 (table 9), and 15:1 (table 10). The 9:7 ratio loses some importance because all of the heterozygotes were included in with the homozygous recessives. Cross B 1619 which gave the 15:1 ratio, produced very few long awns or hoods on the glumes when the character was manifested. Not one plant of the 568 which were classified was completely glume-awned or -hooded as was expected for the homozygous recessive. B 1632, the cross having the 3:1 ratio, appeared to be the only cross where the spike was fully glume-awned or -hooded, depending, of course, upon whether the same spike was normally awned or hooded. Therefore, it appears that one to two factor pairs conditions this characteristic within these crosses.

Normal vs reduced lateral (Lr l r). The 1:2:1 ratio in table 11 suggests a monofactorial inheritance for this characteristic. This cross, B 1640, had the many-noded dwarf factor present; consequently, only the 322 normal plants were classified. Very few of the dwarfs appeared homozygous recessive for the reduced laterals.

Linkage group II

Black vs white lemma and pericarp (B b). A single factor difference is indicated in table 12 for the inheritance of black vs white lemma and pericarp.

Linkage group III

Hulled vs hull-less (N n). Table 13 suggests a monofactorial inheritance for this factor pair.
Table 8. Segregation of normal vs long-awned glume (E e) in the F2 generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1632

<table>
<thead>
<tr>
<th>Family</th>
<th>E</th>
<th>e</th>
<th>Total</th>
<th>$x^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>25</td>
<td>85</td>
<td>.883</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>18</td>
<td>40</td>
<td>8.533</td>
<td>&lt; .01</td>
</tr>
</tbody>
</table>

Sum of 2 chi-squares

9.416 < .01

Total

88 43 125 1.411 .2 - .3

Interaction

8.005 < .01

Table 9. Segregation of normal vs long-awned glume (E e) in the F2 generation. Chi-square and P values are based on a 9:7 ratio. Cross No. B 1629

<table>
<thead>
<tr>
<th>Family</th>
<th>E</th>
<th>e</th>
<th>Total</th>
<th>$x^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>27</td>
<td>16</td>
<td>43</td>
<td>.746</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>3</td>
<td>71</td>
<td>43</td>
<td>114</td>
<td>1.664</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>5</td>
<td>54</td>
<td>60</td>
<td>114</td>
<td>.606</td>
<td>.4 - .5</td>
</tr>
</tbody>
</table>

Sum of 3 chi-squares

3.036 .3 - .4

Total

152 119 271 .002 .95 - .975

Interaction

3.034 .2 - .3
Table 10. Segregation of normal vs long-awned glume (E e) in the F<sub>2</sub> generation. Chi-square and P values are based on a 15:1 ratio. Cross No. B 1619

<table>
<thead>
<tr>
<th>Family</th>
<th>E</th>
<th>e</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>94</td>
<td>6</td>
<td>100</td>
<td>.016</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>3</td>
<td>156</td>
<td>8</td>
<td>164</td>
<td>.463</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>4</td>
<td>127</td>
<td>5</td>
<td>132</td>
<td>2.134</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>5</td>
<td>73</td>
<td>8</td>
<td>81</td>
<td>1.922</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>8</td>
<td>79</td>
<td>12</td>
<td>91</td>
<td>7.460</td>
<td>&lt; .01</td>
</tr>
</tbody>
</table>

Sum of 5 chi-squares 11.995 .025 - .05

Total 529 39 568 .368 .5 - .6

Interaction 11.627 .01 - .025

Table 11. Segregation of normal vs reduced lateral (lr lr) in the F<sub>2</sub> generation. Chi-square and P values are based on a 1:2:1 ratio. Cross No. B 1640

<table>
<thead>
<tr>
<th>Family</th>
<th>Normal</th>
<th>Intermediates</th>
<th>Reduced</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>23</td>
<td>23</td>
<td>16</td>
<td>62</td>
<td>5.710</td>
<td>.01 - .025</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>51</td>
<td>22</td>
<td>101</td>
<td>.723</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>11</td>
<td>23</td>
<td>49</td>
<td>18</td>
<td>90</td>
<td>1.267</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>35</td>
<td>9</td>
<td>69</td>
<td>7.435</td>
<td>&lt; .01</td>
</tr>
</tbody>
</table>

Sum of 4 chi-squares 15.135 < .01

Total 99 158 65 322 7.244 < .01

Interaction 7.891 .025 - .05
### Table 12. Segregation of black vs white lemma and pericarp (B b) in F$_2$ generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1643

<table>
<thead>
<tr>
<th>Family</th>
<th>B</th>
<th>b</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>20</td>
<td>56</td>
<td>3.428</td>
<td>.05 - .1</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>14</td>
<td>47</td>
<td>.575</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>24</td>
<td>100</td>
<td>.053</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>23</td>
<td>107</td>
<td>.695</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>5</td>
<td>34</td>
<td>17</td>
<td>51</td>
<td>1.888</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>7</td>
<td>55</td>
<td>1.417</td>
<td>.025 - .05</td>
</tr>
<tr>
<td>7</td>
<td>81</td>
<td>23</td>
<td>104</td>
<td>.461</td>
<td>.4 - .5</td>
</tr>
</tbody>
</table>

Sum of 7 chi-squares: 11.517

Total: 392 128 520  P: .044  .8 - .9

Interaction: 11.473  P: .05 - .1

### Table 13. Segregation of hulled vs hull-less (N n) in the F$_2$ generation. Chi-square and P values are based on a 3:1 ratio.

<table>
<thead>
<tr>
<th>Cross No.</th>
<th>No. of Families</th>
<th>N</th>
<th>n</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1619</td>
<td>5</td>
<td>425</td>
<td>143</td>
<td>568</td>
<td>.009</td>
<td>.95 - .975</td>
</tr>
<tr>
<td>B 1620</td>
<td>11</td>
<td>780</td>
<td>285</td>
<td>1065</td>
<td>1.953</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>B 1643</td>
<td>4</td>
<td>272</td>
<td>95</td>
<td>367</td>
<td>.153</td>
<td>.7 - .8</td>
</tr>
</tbody>
</table>

Sum of 3 chi-squares: 2.115

Total: 20 1477 523 2000  P: .1269  .2 - .3

Interaction: .746  P: .6 - .7
Linkage group IV

Hoods vs awns (K k). The data in tables 14, 15, and 16 indicate that hoods and awns are inherited in a ratio of 3 hoods to 1 awn, regardless of the length of the appendage.

Long vs short awns (k₁ k₂). Long awns are dominant to short awns, according to table 17. Simple Mendelian inheritance is suggested.

This is another characteristic which was classified from the normal plants of B 1640. While this characteristic was evident among the dwarfed plants, it was felt that since one-third of the dwarfs had no spikes a more accurate ratio would be gained through classifying only the normal plants.

Non-zoned vs zoned leaf (Z z). Table 18 suggests that one factor pair is involved in this cross for this character. The low probability values are very probably influenced by the mortality of some immature chlorophyll-deficient plants.

Blue vs white aleurone (B₁ b₁). The data in table 19 substantiates the reports of previous workers. This character pair is manifested in the ratio of 3 blue to 1 white aleurone. Some difficulty was encountered in determining the homozygous recessive whites.

Factor pairs not classified

Long vs short glume hairs (Gh gh). Long glume hairs are dominant to short glume hairs and segregate in a 3:1 ratio (table 20).

Non-glossy vs glossy sheath and spike (Gs gs). This factor pair segregated in a 3:1 ratio, as is evidenced in table 21.

Purple vs white auricle (Prₐ prₐ). Purple auricles are dominant to white auricles. Data in table 22 suggest a single factor difference.
Table 14. Segregation of hoods vs long awns (K k₁) in the F₂ generation. Chi-square and P values are based on a 3:1 ratio.

<table>
<thead>
<tr>
<th>Cross No.</th>
<th>No. of Families</th>
<th>K</th>
<th>k₁</th>
<th>Total</th>
<th>X²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1629</td>
<td>2</td>
<td>192</td>
<td>79</td>
<td>271</td>
<td>2.363</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>B 1632</td>
<td>2</td>
<td>97</td>
<td>28</td>
<td>125</td>
<td>.385</td>
<td>.5 - .6</td>
</tr>
</tbody>
</table>

Sum of 2 chi-squares 2.748 .2 - .3
Total 4 289 107 396 .961 .3 - .4
Interaction 1.787 .1 - .2

Table 15. Segregation of elevated hoods vs awns (Kₑ k) in the F₂ generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1642

<table>
<thead>
<tr>
<th>Family</th>
<th>Kₑ</th>
<th>k</th>
<th>Total</th>
<th>X²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>83</td>
<td>29</td>
<td>112</td>
<td>.048</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>19</td>
<td>70</td>
<td>.172</td>
<td>.6 - .7</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>7</td>
<td>35</td>
<td>.467</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>4</td>
<td>47</td>
<td>20</td>
<td>67</td>
<td>.841</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>5</td>
<td>91</td>
<td>30</td>
<td>121</td>
<td>.003</td>
<td>.95 - .975</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>1</td>
<td>8</td>
<td>.667</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>7</td>
<td>66</td>
<td>28</td>
<td>94</td>
<td>1.149</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>8</td>
<td>98</td>
<td>29</td>
<td>127</td>
<td>.317</td>
<td>.5 - .6</td>
</tr>
<tr>
<td>9</td>
<td>71</td>
<td>26</td>
<td>97</td>
<td>.168</td>
<td>.6 - .7</td>
</tr>
</tbody>
</table>

Sum of 9 chi-squares 3.832 .9 - .95
Total 542 189 731 .263 .6 - .7
Interaction 3.569 .8 - .9
### Table 16. Segregation of elevated hoods vs long awns (K\textsuperscript{e} k\textsubscript{1}) in the F\textsubscript{2} generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1643

<table>
<thead>
<tr>
<th>Family</th>
<th>K\textsuperscript{e}</th>
<th>k\textsubscript{1}</th>
<th>Total</th>
<th>x\textsuperscript{2}</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34</td>
<td>22</td>
<td>56</td>
<td>6.095</td>
<td>.01 - .025</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>11</td>
<td>47</td>
<td>0.054</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>24</td>
<td>100</td>
<td>0.053</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>27</td>
<td>107</td>
<td>0.003</td>
<td>.95 - .975</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>19</td>
<td>51</td>
<td>4.085</td>
<td>.025 - .05</td>
</tr>
<tr>
<td>6</td>
<td>34</td>
<td>21</td>
<td>55</td>
<td>5.097</td>
<td>.01 - .025</td>
</tr>
<tr>
<td>7</td>
<td>74</td>
<td>30</td>
<td>104</td>
<td>1.820</td>
<td>.3 - .4</td>
</tr>
</tbody>
</table>

Sum of 7 chi-squares 16.207 < .01

Total 366 154 520 5.907 .01 - .025

Interaction 11.300 < .01

### Table 17. Segregation of long vs short awns (k\textsubscript{1} k\textsubscript{2}) in the F\textsubscript{2} generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1640

<table>
<thead>
<tr>
<th>Family</th>
<th>k\textsubscript{1}</th>
<th>k\textsubscript{2}</th>
<th>Total</th>
<th>x\textsuperscript{2}</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>42</td>
<td>20</td>
<td>62</td>
<td>1.771</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>38</td>
<td>101</td>
<td>8.584</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>11</td>
<td>58</td>
<td>32</td>
<td>90</td>
<td>5.348</td>
<td>.01 - .025</td>
</tr>
<tr>
<td>12</td>
<td>46</td>
<td>23</td>
<td>69</td>
<td>2.556</td>
<td>.1 - .2</td>
</tr>
</tbody>
</table>

Sum of 4 chi-squares 18.259 < .01

Total 209 113 322 17.494 < .01

Interaction 0.765 .8 - .9
### Table 18. Segregation of non-zoned vs zoned leaf (Z z) in the F2 generation. Chi-square and P values are based on a 3:1 ratio. Cross No. 1629

<table>
<thead>
<tr>
<th>Family</th>
<th>Z</th>
<th>z</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>100</td>
<td>14</td>
<td>114</td>
<td>9.836</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>3</td>
<td>39</td>
<td>4</td>
<td>43</td>
<td>5.652</td>
<td>.01 - .025</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
<td>22</td>
<td>114</td>
<td>1.976</td>
<td>.1 - .2</td>
</tr>
</tbody>
</table>

Sum of 3 chi-squares: 17.464 < .01

Total: 231 40 271 $X^2 = 15.155$ < .01

Interaction: 2.309 .3 - .4

### Table 19. Segregation of blue vs white aleurone (B1 bl) in the F2 generation. Chi-square and P values are based on a 3:1 ratio. Cross No. 1642

<table>
<thead>
<tr>
<th>Family</th>
<th>B1</th>
<th>bl</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>37</td>
<td>112</td>
<td>3.857</td>
<td>.025 - .05</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>20</td>
<td>70</td>
<td>.476</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>9</td>
<td>35</td>
<td>.007</td>
<td>.9 - .95</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>24</td>
<td>67</td>
<td>4.184</td>
<td>.025 - .05</td>
</tr>
<tr>
<td>5</td>
<td>87</td>
<td>34</td>
<td>121</td>
<td>.620</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>.000</td>
<td>1.0</td>
</tr>
<tr>
<td>7</td>
<td>67</td>
<td>27</td>
<td>94</td>
<td>.696</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>8</td>
<td>98</td>
<td>29</td>
<td>127</td>
<td>.317</td>
<td>.5 - .6</td>
</tr>
<tr>
<td>9</td>
<td>75</td>
<td>22</td>
<td>97</td>
<td>.268</td>
<td>.6 - .7</td>
</tr>
</tbody>
</table>

Sum of 9 chi-squares: 10.425 .3 - .4

Total: 527 204 731 $X^2 = 3.295$ .05 - .1

Interaction: 7.130 .5 - .6
Table 20. Segregation of long vs short glume hairs (Gh gh) in the F<sub>2</sub> generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1620

<table>
<thead>
<tr>
<th>Family</th>
<th>Gh</th>
<th>gh</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>18</td>
<td>80</td>
<td>.866</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>2</td>
<td>111</td>
<td>26</td>
<td>137</td>
<td>2.503</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>3</td>
<td>83</td>
<td>16</td>
<td>99</td>
<td>5.320</td>
<td>.025 - .01</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>13</td>
<td>50</td>
<td>.027</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>5</td>
<td>46</td>
<td>6</td>
<td>52</td>
<td>5.025</td>
<td>.025 - .01</td>
</tr>
<tr>
<td>6</td>
<td>95</td>
<td>32</td>
<td>127</td>
<td>.003</td>
<td>.95 - .975</td>
</tr>
<tr>
<td>8</td>
<td>75</td>
<td>21</td>
<td>96</td>
<td>.500</td>
<td>.4 - .5</td>
</tr>
<tr>
<td>9</td>
<td>87</td>
<td>31</td>
<td>118</td>
<td>.045</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>10</td>
<td>107</td>
<td>34</td>
<td>141</td>
<td>.038</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>11</td>
<td>93</td>
<td>26</td>
<td>119</td>
<td>.712</td>
<td>.3 - .4</td>
</tr>
<tr>
<td>12</td>
<td>42</td>
<td>4</td>
<td>46</td>
<td>5.854</td>
<td>.010 - .025</td>
</tr>
</tbody>
</table>

Sum of 11 chi-squares 20,893 .025 - .05
Total 838 227 1065 7.610 < .01
Interaction 13.283 .2 - .3
Table 21. Segregation of non-glossy vs glossy sheath and spike (Gs gs) in the F₂ generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1643

<table>
<thead>
<tr>
<th>Family</th>
<th>Gs</th>
<th>gs</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41</td>
<td>15</td>
<td>56</td>
<td>0.95</td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>15</td>
<td>47</td>
<td>1.22</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>14</td>
<td>100</td>
<td>0.53</td>
<td>0.3-0.9</td>
</tr>
<tr>
<td>4</td>
<td>78</td>
<td>29</td>
<td>107</td>
<td>0.81</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>16</td>
<td>51</td>
<td>1.09</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>10</td>
<td>55</td>
<td>1.36</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>7</td>
<td>77</td>
<td>27</td>
<td>104</td>
<td>0.53</td>
<td>0.4-0.5</td>
</tr>
</tbody>
</table>

Sum of 7 chi-squares 5.186 0.6-0.7

Total 384 136 520 0.369 0.5-0.6

Interaction 4.917 0.5-0.6

Table 22. Segregation of purple vs white auricle (Prₐ prₐ) in the F₂ generation. Chi-square and P values are based on a 3:1 ratio. Cross No. B 1643

<table>
<thead>
<tr>
<th>Family</th>
<th>Prₐ</th>
<th>prₐ</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>18</td>
<td>56</td>
<td>1.52</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>17</td>
<td>47</td>
<td>0.58</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>20</td>
<td>100</td>
<td>1.33</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>27</td>
<td>107</td>
<td>0.03</td>
<td>0.95-0.975</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>8</td>
<td>51</td>
<td>2.36</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>6</td>
<td>37</td>
<td>18</td>
<td>55</td>
<td>1.75</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>7</td>
<td>68</td>
<td>36</td>
<td>104</td>
<td>0.52</td>
<td>0.4-0.5</td>
</tr>
</tbody>
</table>

Sum of 7 chi-squares 8.075 0.3-0.4

Total 376 144 520 2.010 0.1-0.2

Interaction 6.065 0.4-0.5
Normal vs many-noded dwarf (Mnd mnd). This character warrants a lengthier report than do the other factor pairs because it has been studied less.

Many of the same typical characters possessed by the Aberdeen, Idaho mutant appeared in the F₂ generation of this study. One exception was that the plants of this study were all six-rowed whereas the original had a two-rowed spike.

The non-normal plants, contrary to their name, were more like brachytics than true dwarfs. From crown to tip of awns the plants measured about 18 inches. Whereas the number of nodes in ordinary varieties of barley varies from three to seven, with the uppermost node being always the longest - this freak had from 10 to 26 nodes on each tiller without an elongation of the uppermost internode. Branching from the approximately 17 culms per plant was profuse, with 49 branches being the maximum number observed.

The factor governing the "dwarf" habit appears (from data in table 23) to be a simple one for it follows a 3:1 ratio. Usually, one expects the number of dwarf plants to be less than the expected ratio for recessives. Contrariwise, in each of the four families which were classified the total of many-noded dwarfs exceeded the expected number, insomuch that they almost fit a 2:1 ratio. However, a 2:1 ratio was not probable because of the great number of recessive plants; this also indicated that there were no lethal factors present.

Three colors besides white were observed in the caryopses: purple, red, and blue. These were readily examined because the cross was all hull-less. If chemical tests had been run on the pericarp
and aleurone colors, a greater amount of information could have been gathered on the inheritance of these factors.

Out of the 162 dwarfed plants, 56 failed to produce spikes in any degree of development. Some developed spikes were yet green; this prevented a total classification of chaff and caryopsis colors. It was because of this that the classifications for purple vs white chaff, long vs short awns, and normal vs reduced lateral were presented from data on the normal plants only.

Table 23. Segregation of normal vs many-noded dwarf (Mnd mnd) in the F_2 generation. Chi-square and P values are based on a 3:1 ratio. Cross No. 1640

<table>
<thead>
<tr>
<th>Family</th>
<th>Mnd</th>
<th>mnd</th>
<th>Total</th>
<th>( \chi^2 )</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>62</td>
<td>26</td>
<td>88</td>
<td>1.387</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>8</td>
<td>110</td>
<td>58</td>
<td>168</td>
<td>8.127</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>11</td>
<td>101</td>
<td>46</td>
<td>147</td>
<td>3.104</td>
<td>.05 - .01</td>
</tr>
<tr>
<td>12</td>
<td>80</td>
<td>32</td>
<td>112</td>
<td>.761</td>
<td>.3 - .4</td>
</tr>
</tbody>
</table>

Sum of 4 chi-squares 13.379 < .01

Total 353 162 515 11.449 < .01

Interaction 1.930 .5 - .6
Factor Pairs Suggesting Independent Inheritance

Linkage group I

Normal vs triple-awned lemma (Tr tr) in relation to normal vs long outer glume (Ee). Data in table 24 indicate independent inheritance between these factor pairs. This is contrary to the reports of other workers. The recombination percentage is 56.7.

Two-rowed vs six-rowed spike (V v) in relation to other factor pairs. Independent inheritance is suggested in table 25 between V:v and N:n as well as between V:v and Gh:gh.

Deficiens vs two-rowed spike (Vt V) in relation to other factor pairs. Table 26 lists four factor pairs which are inherited independent of deficiens vs two-rowed. They are: B:b, N:n, Ke:k1, and Gs:gs. None showed recombination percentages of any significance.

Purple vs white lemma and pericarp (Re orientations) in relation to other factor pairs. Those factor pairs which were found to segregate independently in relation to purple vs white lemma and pericarp were: N:n, B:b, Ke:k1, Ke:k, B1:b1, Gs:gs, and Gh:gh. Three characters from Cross No. B 1643 show unusually high chi-square values yet their percentages of recombination were never lower than 45.1. These characters, as shown in table 27, are: B:b, Ke:k1, and Gs:gs.

Normal vs long-awned glume (Ee) in relation to other factor pairs. Linkages were not found in either of the two crosses, according to table 28, between normal vs long-awned glume and Tr:tr, K:K, L:l, and N:n. Cross B 1632 has such few numbers that the low P value can be regarded as insignificant, especially when the percent of recombination for both Tr:tr and K:k1 is above 56.7.
Table 24. Normal vs triple-awned lemma (Tr tr) in relation to normal vs long-awned glume (E e). Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>Cross Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1632 C</td>
<td>55</td>
<td>27</td>
<td>33</td>
<td>10</td>
<td>125</td>
<td>8.338</td>
</tr>
</tbody>
</table>

Table 25. Two-rowed vs six-rowed spike (V v) in relation to other factor pairs. Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>Cross Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1620 R</td>
<td>60</td>
<td>213</td>
<td>176</td>
<td>72</td>
<td>1065</td>
<td>4.813</td>
</tr>
<tr>
<td>B 1620 R</td>
<td>637</td>
<td>180</td>
<td>201</td>
<td>47</td>
<td>1065</td>
<td>9.980</td>
</tr>
</tbody>
</table>

Table 26. Deficiens vs two-rowed spike (V^t V) in relation to other factor pairs. Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>Cross Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1643 C</td>
<td>301</td>
<td>98</td>
<td>91</td>
<td>130</td>
<td>520</td>
<td>.875</td>
</tr>
<tr>
<td>B 1643 C</td>
<td>211</td>
<td>75</td>
<td>61</td>
<td>20</td>
<td>367</td>
<td>2.826</td>
</tr>
<tr>
<td>B 1643 C</td>
<td>289</td>
<td>110</td>
<td>77</td>
<td>144</td>
<td>520</td>
<td>5.995</td>
</tr>
<tr>
<td>B 1643 R</td>
<td>298</td>
<td>101</td>
<td>86</td>
<td>35</td>
<td>520</td>
<td>1.777</td>
</tr>
</tbody>
</table>
Table 27. Purple vs white lemma and pericarp (Re<sub>2</sub> re<sub>2</sub>) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>Re&lt;sub&gt;2&lt;/sub&gt;:re&lt;sub&gt;2&lt;/sub&gt; in relation to:</th>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>X&lt;sup&gt;2&lt;/sup&gt;</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Chi-square is based on a 9:3:3:1 ratio**

N:n  B 1619 R 272 102 76 27 477 4.000 <.025

Chi-square is based on a 27:21:9:7 ratio

B:b  B 1643 R 254 86 138 42 520 28.846 <.01

N:n  B 1620 R 456 155 324 130 1065 6.131 <.025

N:n  B 1643 C 174 62 98 33 367 10.342 <.01

K<sup>e</sup>:k  B 1642 C 307 235 98 91 731 1.764 <.01

K<sup>e</sup>:k<sub>1</sub>  B 1643 C 248 92 118 62 520 25.296 <.01

Bl:bl  B 1642 R 306 99 221 105 731 9.489 <.01

Gs:gs  B 1642 R 298 107 243 83 731 1.727 <.01

Gs:gs  B 1643 R 251 89 133 47 520 18.015 <.01

Gh:gh  B 1620 R 471 140 367 87 1065 10.028 <.025
Table 28. Normal vs long-awned glume (E e) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>E:e in relation to:</th>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>( \chi^2 )</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>XY</td>
<td>Xy</td>
<td>xY</td>
<td>xy</td>
<td>Total</td>
<td>( \chi^2 )</td>
<td>p</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>125</td>
<td>8.388</td>
<td>.025</td>
</tr>
<tr>
<td>Chi-square based on a 9:3:3:1 ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tr:tr</td>
<td>B 1632</td>
<td>C</td>
<td>55</td>
<td>27</td>
<td>33</td>
<td>27</td>
<td>125</td>
<td>8.388</td>
<td>.025</td>
</tr>
<tr>
<td>K:k₁</td>
<td>B 1632</td>
<td>C</td>
<td>59</td>
<td>23</td>
<td>38</td>
<td>5</td>
<td>125</td>
<td>11.379</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>Chi-square based on a 15:15:3:1 ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L:l</td>
<td>B 1619</td>
<td>R</td>
<td>277</td>
<td>130</td>
<td>44</td>
<td>26</td>
<td>477</td>
<td>80.258</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>N:n</td>
<td>B 1619</td>
<td>C</td>
<td>325</td>
<td>49</td>
<td>82</td>
<td>21</td>
<td>477</td>
<td>64.648</td>
<td>&lt; .01</td>
</tr>
</tbody>
</table>
A linkage between E:e and L:l in Cross No. B 1619 is doubtful because the two factor pairs have a recombination of 54.0 ± 7.4 percent. Classification of head density was not as accurate as the author wishes it could have been. That, undoubtedly, has influenced the data of table 28. Recombination of E:e in relation to N:n is 41.0 ± 8.0 percent.

**Lax vs dense spike (L l) in relation to other factor pairs.**

Table 29 shows lax vs dense heads in relation to hoods vs awns, and hulled vs hull-less. The high chi-square value is definitely influenced by the method of classification. The author places little faith in the accuracy of the data in this table.

**Linkage group II**

**Black vs white lemma and pericarp (B b) in relation to other factor pairs.** The data reported in table 30 indicate an independent inheritance of B:b in relation to: V:t:V, N:n, K:e:kl, Gs:gs, Pr:a:pra, and Re2:re2. The data for B:b in relation to Re2:re2 show a low probability value but the percentage for recombination does not indicate linkage.

**Linkage group III**

**Hulled vs hull-less (N n) in relation to other factor pairs.** The two crosses, B 1620 and B 1643, in which hulled vs hull-less were present, have reliable probability values which suggest that this factor pair is inherited independent of: V:v, V:t:V, B:b, K:e:k1, Gs:gs, and Re2:re2 (table 31).
Table 29. Lax vs dense spike (L l) in relation to other factor pairs. Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>L:l in relation to:</th>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>K:k</td>
<td>B 1629</td>
<td>R</td>
<td>66</td>
<td>126</td>
<td>36</td>
<td>43</td>
<td>271</td>
<td>374.371</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>N:n</td>
<td>B 1619</td>
<td>R</td>
<td>250</td>
<td>124</td>
<td>73</td>
<td>30</td>
<td>477</td>
<td>17.617</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

Table 30. Black vs white lemma and pericarp (B b) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>B:b in relation to:</th>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square based on a 9:3:3:1 ratio</td>
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<tr>
<td>V^t:V</td>
<td>B 1643</td>
<td>C</td>
<td>301</td>
<td>91</td>
<td>98</td>
<td>30</td>
<td>520</td>
<td>.875</td>
<td>.8 -.9</td>
</tr>
<tr>
<td>N:n</td>
<td>B 1643</td>
<td>C</td>
<td>204</td>
<td>73</td>
<td>68</td>
<td>22</td>
<td>367</td>
<td>.324</td>
<td>.95 -.975</td>
</tr>
<tr>
<td>K*:k_1</td>
<td>B 1643</td>
<td>C</td>
<td>276</td>
<td>116</td>
<td>90</td>
<td>38</td>
<td>520</td>
<td>5.949</td>
<td>.1 -.2</td>
</tr>
<tr>
<td>Gs:gs</td>
<td>B 1643</td>
<td>R</td>
<td>287</td>
<td>105</td>
<td>97</td>
<td>31</td>
<td>520</td>
<td>.752</td>
<td>.8 -.9</td>
</tr>
<tr>
<td>Pr_a:pra</td>
<td>B 1643</td>
<td>R</td>
<td>277</td>
<td>115</td>
<td>99</td>
<td>29</td>
<td>520</td>
<td>1.535</td>
<td>.5 -.6</td>
</tr>
<tr>
<td>Chi-square based on a 27:21:9:7 ratio</td>
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<tr>
<td>Re_2:re_2</td>
<td>B 1643</td>
<td>C</td>
<td>254</td>
<td>138</td>
<td>86</td>
<td>42</td>
<td>520</td>
<td>28.846</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>
Table 31. Hulled vs hull-less (N n) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>N:n in relation to:</th>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>xY</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square based on a 9:3:3:1 ratio</td>
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<tr>
<td>V:v</td>
<td>B 1620</td>
<td>R</td>
<td>604</td>
<td>176</td>
<td>213</td>
<td>72</td>
<td>1065</td>
<td>4.183</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>v^L:v</td>
<td>B 1643</td>
<td>C</td>
<td>211</td>
<td>61</td>
<td>75</td>
<td>20</td>
<td>367</td>
<td>2.826</td>
<td>.4 - .6</td>
</tr>
<tr>
<td>B:b</td>
<td>B 1643</td>
<td>R</td>
<td>204</td>
<td>68</td>
<td>73</td>
<td>22</td>
<td>367</td>
<td>.324</td>
<td>.95 - .975</td>
</tr>
<tr>
<td>K^k1:K^k1</td>
<td>B 1643</td>
<td>R</td>
<td>190</td>
<td>82</td>
<td>74</td>
<td>21</td>
<td>367</td>
<td>4.100</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>Gs:Gs</td>
<td>B 1643</td>
<td>R</td>
<td>199</td>
<td>73</td>
<td>73</td>
<td>22</td>
<td>367</td>
<td>.317</td>
<td>.8 - .9</td>
</tr>
<tr>
<td>Chi-square is based on a 27:21:9:7 ratio</td>
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<tr>
<td>Re^2:re^2</td>
<td>B 1620</td>
<td>R</td>
<td>456</td>
<td>324</td>
<td>155</td>
<td>130</td>
<td>1065</td>
<td>6.131</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>Re^2:re^2</td>
<td>B 1643</td>
<td>C</td>
<td>174</td>
<td>98</td>
<td>62</td>
<td>33</td>
<td>367</td>
<td>10.342</td>
<td>.01 - .025</td>
</tr>
</tbody>
</table>
Linkage group IV

Hoods vs long awns (K1k1) in relation to normal vs long-awned glume. There is no linkage between K1k1 and E1e although table 32 data suggest the possibility of it. The calculated recombination is greater than sixty percent.

Elevated hoods vs awns (k6k) in relation to other factor pairs. The relationship of K6:k to other characters is considered in table 33. Spike appendages in the form of awns or hoods were found to be independent of Gs:gs and Re2:re2.

Elevated hoods vs long awns (K6k1) in relation to other factor pairs. As is shown in table 34, K6k1 is inherited independently of: Vt:Vt, B:b, N:n, Gs:gs, Prα:pra, and Re2:re2. However, there is a suggestion of linkage between K6:k1 and Prα:pra, and K6:k1 and Re2:re2. Not only do these two factor pairs, Prα:pra and Re2:re2, have low probability values but they recombine with 41.2 and 45.1 percentage, respectively. However, they are very closely linked in group I; therefore, it is suggested that there is no association with group IV.

Non-zoned vs zoned (Z z) leaf in relation to other factor pairs.

Table 35 considers the relationship of Z:z with E:e and L:l, respectively. The nature of the data may suggest linkage especially when Z:z recombines with E:e (33.77 ± 10.1), and with L:l (30.58 ± 5.4). Nonetheless, according to table 18, some mortality of the immature chlorophyll-deficient plants may have occurred. Improper classification for L:l and E:e would cause bias. In interpreting the data, these extraneous factors must be considered.
Table 32. Hoods vs long awns (K_1 K_2) in relation to other factor pairs. Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>K:K in relation to:</th>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>x²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>to: E:e</td>
<td>B 1632</td>
<td>C</td>
<td>59</td>
<td>38</td>
<td>23</td>
<td>5</td>
<td>125</td>
<td>11.874</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

Table 33. Elevated hoods vs awns (K^1 k) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>K^1 :k in relation to:</th>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>x²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>to: Gs:gs</td>
<td>B 1642</td>
<td>R</td>
<td>409</td>
<td>133</td>
<td>132</td>
<td>57</td>
<td>731</td>
<td>4.871</td>
<td>.1 -.2</td>
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<td>731</td>
<td>1.764</td>
<td>.6 -.7</td>
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</tbody>
</table>

Chi-square based on a 9:3:3:1 ratio

Chi-square based on a 27:21:9:7 ratio
Table 34. Elevated hoods vs long awns \( (K^eK_l) \) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>K^e:K_l in relation to:</th>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>( x^2 )</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
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<tr>
<td>V:v</td>
<td>B 1643</td>
<td>C</td>
<td>289</td>
<td>77</td>
<td>110</td>
<td>4h</td>
<td>520</td>
<td>5.995</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>B:b</td>
<td>B 1643</td>
<td>C</td>
<td>276</td>
<td>90</td>
<td>116</td>
<td>38</td>
<td>520</td>
<td>5.949</td>
<td>.1 - .2</td>
</tr>
<tr>
<td>N:n</td>
<td>B 1643</td>
<td>R</td>
<td>190</td>
<td>74</td>
<td>82</td>
<td>21</td>
<td>367</td>
<td>4.390</td>
<td>.2 - .3</td>
</tr>
<tr>
<td>Os:gs</td>
<td>B 1643</td>
<td>R</td>
<td>272</td>
<td>94</td>
<td>112</td>
<td>42</td>
<td>520</td>
<td>6.496</td>
<td>.05 - .1</td>
</tr>
<tr>
<td>Pr_a:Pr_b</td>
<td>B 1643</td>
<td>R</td>
<td>252</td>
<td>114</td>
<td>124</td>
<td>6</td>
<td>520</td>
<td>15.794</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

Chi-square based on a 9:3:3:1 ratio

| Re_2:re_2             | B 1643 | C     | 248| 118| 92 | 62 | 520   | 25.296 | <.01   |   |

Table 35. Non-zoned vs zoned leaf \((Z^z)\) in relation to other factor pairs. Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>Z:z in relation to:</th>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>( x^2 )</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E:e</td>
<td>B 1629</td>
<td>C</td>
<td>136</td>
<td>95</td>
<td>16</td>
<td>24</td>
<td>271</td>
<td>18.430</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>L:l</td>
<td>B 1629</td>
<td>C</td>
<td>103</td>
<td>9</td>
<td>138</td>
<td>31</td>
<td>281</td>
<td>21.7629</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>
Blue vs white aleurone (Bl bl) in relation to other factor pairs. Table 36 presents data showing that Bl:bl is independent of Gs:gs and Re₂:re₂.

Factor pairs not classified

Long vs short glume hairs (Gh gh) in relation to other factor pairs. Two factor pairs, V:v and Re₂:re₂, were found to be inherited independent of Gh:gh, according to table 37.

Non-glossy vs glossy sheath and spike (Gs gs) in relation to other factor pairs. Seven of nine factor pairs in table 38 may be seen to segregate readily in relation to Gs:gs. These are: Vᵗ:v, B:b, N:n, kₑ:k, kₑ:k₁, Prₐ:Prₐ, and Re₂:re₂ of Cross B 1642. The other two pairs of factors, Bl:bl and Re₂:re₂ of Cross B 1643, show low probability values. However, both characters are in the less reliable phase, that of repulsion. In addition, their percent of recombination is not significant enough to suggest linkage.

Purple vs white auricle (Prₐ Prₐ) in relation to other factor pairs. Three factor pairs were found to have no linkage with the color of auricles. Table 39 lists them as: B:b, Kₑ:k₁, and Gs:gs. Since auricle color was found to be closely linked with Re₂:re₂, it is doubtful that the low probability value found for Kₑ:k₁ carries much weight, especially when it is in the repulsion phase.
Table 36. Blue vs white aleurone (Bl bl) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Chi-square based on a 9:3:3:1 ratio

| Gs:gs | B 1642 | R | 365 | 142 | 152 | 52 | 731 | $4.345$ | .2 - .3 |

Chi-square based on a 27:21:9:7 ratio

| Re₂:re₂ | B 1642 | R | 306 | 221 | 99 | 105 | 731 | $9.345$ | .025 - .05 |

Table 37. Long vs short glume hairs (Gh gh) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

Chi-square based on a 9:3:3:1 ratio

| V:v   | B 1620 | R | 637 | 201 | 180 | 47 | 1065 | $9.980$ | .01 - .025 |

Chi-square based on a 27:21:9:7 ratio

| Re₂:re₂ | B 1620 | R | 471 | 367 | 140 | 87 | 1065 | $10.028$ | .01 - .025 |
Table 38. Non-glossy vs glossy sheath and spike (Gs gs) in relation to other factor pairs.

<table>
<thead>
<tr>
<th>Gs:gs in relation to:</th>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xy</th>
<th>Total</th>
<th>(X^2)</th>
<th>P</th>
</tr>
</thead>
<tbody>
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<tr>
<td></td>
<td>No.</td>
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<td></td>
</tr>
</tbody>
</table>

Chi-square based on a 9:3:3:1 ratio

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
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<tbody>
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<tr>
<td></td>
<td>No.</td>
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</tbody>
</table>

Chi-square based on a 27:21:9:7 ratio

<p>| | | | | | | | | |</p>
<table>
<thead>
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<tr>
<td></td>
<td>No.</td>
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</tbody>
</table>

Table 39. Purple vs white auricle (Pr\(_a\):Pr\(_a\)) in relation to other factor pairs. Chi-square and P values are based on a 9:3:3:1 ratio.

<table>
<thead>
<tr>
<th>Pr(_a):Pr(_a) in relation to:</th>
<th>Cross</th>
<th>Phase</th>
<th>XY</th>
<th>Xy</th>
<th>xy</th>
<th>Total</th>
<th>(X^2)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>B:b</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>K(_e):k(_1)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Gs:gs</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
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</tr>
</tbody>
</table>

46
Factor Pairs Suggesting Linkage

Linkage group I

Purple vs white lemma and pericarp (Re<sub>2</sub> re<sub>2</sub>) in relation to other factor pairs. Table 40 summarizes five suggested linkages for this factor pair. The associations of Re<sub>2</sub>:re<sub>2</sub> of this study with L:l, V:v, V<sup>+</sup>:V, and E:e are in accord with previous reports. One new linkage was found to exist between Re<sub>2</sub>:re<sub>2</sub> and L:r:lr. Their recombination value is 31.3 ± 8.5 percent. A note of caution, however, is in order. When the many-noded dwarf cross, B 1640, was being classified, the author observed that the prominent reduced lateral characteristic had not been listed for the parents. It was known from Leonard's (1942) studies that L:r:lr was associated with linkage group I. If the normal vs reduced lateral was appearing in the repulsion phase, the recombination value would be greater than 60 percent. If, on the other hand, the characters appeared in the coupling phase then linkage may be presumably established.

Normal vs long-awned glume (E:e) in relation to lax vs dense spike (L:l). The observed percent recombination in table 40 is overly high, compared with results from other workers. The spikes of Cross B 1629 were difficult to classify for outer glume appendages (awns or hoods) and for spike density. Consequently, the values for each demonstrated character recessive may be considered unreliable, and will not be listed in the summary.

Linkage group IV

Hoods vs long awns (K:k<sub>1</sub>) in relation to other factor pairs. According to table 40, a recombination of 18.8 ± 4.1 percent was
Table 40. Factor pairs suggesting linkage. Chi-square, P values, and recombination percentages are calculated for the indicated ratios.

<table>
<thead>
<tr>
<th>Cross Phase No.</th>
<th>XY</th>
<th>Xy</th>
<th>xy</th>
<th>Total</th>
<th>$X^2$</th>
<th>P</th>
<th>Percent Recomb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Re$_2$:re$_2$) in relation to (L:l) - (9:3:3:1 ratio):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1619 C 244 106 74 50 477 9.299 0.025 ≤ 0.05 43 1.1 ≤ 3.7</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(Re$_2$:re$_2$) in relation to (V:v) - (27:21:9:7 ratio):</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1643 C 306 34 93 87 520 164.958 &lt; 0.01 14.6 ≤ 2.5</td>
<td></td>
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<tr>
<td>(Re$_2$:re$_2$) in relation to (V:v) - (27:21:9:7 ratio):</td>
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<td></td>
</tr>
<tr>
<td>B 1620 C 572 39 2h1 209 1065 443.746 &lt; 0.01 11.0 ≤ 1.5</td>
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<tr>
<td>(Re$_2$:re$_2$) in relation to (E:e) - (45:15:3:1 ratio):</td>
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</tr>
<tr>
<td>B 1619 R 421 84 179 6 690 94.969 ≤ 0.01 31.3 ≤ 8.5</td>
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<td></td>
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<tr>
<td>(Re$_2$:re$_2$) in relation to (Lr:lr) - (27:21:9:7 ratio):</td>
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<tr>
<td>B 1640 C 173 22 84 43 322 28.020 ≤ 0.01 23.6 ≤ 3.9</td>
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</tr>
<tr>
<td>(E:e) in relation to (L:l) - (27:21:9:7 ratio):</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>B 1629 C 90 12 1h1 28 271 53.510 ≤ 0.01 42.0 ≤ 5.9</td>
<td></td>
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<tr>
<td>(K:k$_1$) in relation to (E:e) - (27:21:9:7 ratio):</td>
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<tr>
<td>B 1629 R 82 110 70 8 271 56.623 ≤ 0.01 ≤ 1.00</td>
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</tr>
<tr>
<td>(K:k$_1$) in relation to (Tr:tr) - (9:3:3:1 ratio):</td>
<td></td>
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</tr>
<tr>
<td>B 1632 C 76 21 12 16 125 19.943 ≤ 0.01 29.7 ≤ 5.0</td>
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<tr>
<td>(K:k$_1$) in relation to (Z:z) - (9:3:3:1 ratio):</td>
<td></td>
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</tr>
<tr>
<td>B 1629 R 307 77 155 3 5h2 62.257 ≤ 0.01 18.8 ≤ 4.1</td>
<td></td>
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</tr>
<tr>
<td>(K':k) in relation to (El:bl) - (9:3:3:1 ratio):</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1642 C 452 90 75 11h 731 186.890 ≤ 0.01 24.9 ≤ 1.9</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
observed for $K_k$ in relation to $Z_z$. This is within the range of previously reported values.

Associations of $K_k$ in relation to $Tr_{tr}$ and $E_{e}$ were observed. in Cross B 1629. The literature revealed no close relationships, as are indicated in table 40. The values recorded for $Tr_{tr}$ are believed to be accurate. On the other hand, those for $E_{e}$ are not reliable because all heterozygotes, recognized when only a portion of the spike is glume-awned or -hooded, were included with the homozygous recessive totals. This latter recombination percentage will not be included in the summary.

Elevated hoods vs awns ($K^e k$) in relation to blue vs white aleurone ($Bl bl$). The recombination percent of 24.9 ± 1.9 between these two factor pairs is in general agreement with the results of other workers.

Factor pairs not classified

Long vs short glume hairs ($Gh gh$) in relation to hulled vs hull-less ($N n$). Table 41 data indicate that these two factor pairs may be in the same linkage group. A recombination of 37.9 ± 2.0 was observed.

Purple vs white auricle ($Pr_A pr_a$) in relation to other factor pairs. Auricle color, according to table 41, may have an association with two linkage groups. It is found to be rather tightly linked with $Re_2 re_2$, loosely with $V^t V$, and there is a suggestion of linkage with $N:n$. An examination of the data, however, indicates that the high chi-square value for $Pr_A pr_a$ in relation to $N:n$ is actually due to chance alone, and not because the two factor pairs are linked.
Normal vs many-noded dwarf (Mnd mnd) in relation to purple vs white lemma and pericarp (Re² re²). Data in table 41 indicate that the factor for many-noded dwarf is located in linkage group I. A recombination value of 12.0 ± 2.9 exists between the two factor pairs.

In classifying the dwarfed plants for lemma color, the author found that he could use only 100 out of 162 dwarfs because 56 plants had failed to develop spikes in any noticeable degree of development and six plants had spikes too green to classify.

Table 41. Factor pairs suggesting linkage. Chi-square, P values, and recombination percentages are calculated for the indicated ratios.

<table>
<thead>
<tr>
<th>Cross No.</th>
<th>Phase</th>
<th>XY</th>
<th>Iy</th>
<th>xY</th>
<th>xy</th>
<th>Total</th>
<th>X²</th>
<th>P</th>
<th>Percent Recomb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Gh:gh) in relation to (N:n) - (9:3:3:1 ratio):</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>B 1620 C 647</td>
<td>190</td>
<td>133</td>
<td>95</td>
<td>1065</td>
<td>38.730</td>
<td>&lt;.01</td>
<td>37.9 ± 2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Prₐ:prₐ) in relation to Vₜ:V) - (9:3:3:1 ratio):</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1643 R 278</td>
<td>98</td>
<td>121</td>
<td>23</td>
<td>520</td>
<td>9.162</td>
<td>.025 - .05</td>
<td>41.3 ± 3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Prₐ:prₐ) in relation to (Re²:re²) - (27:21:9:7 ratio):</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1643 R 223</td>
<td>153</td>
<td>117</td>
<td>27</td>
<td>520</td>
<td>52.9 ± 3</td>
<td>&lt;.01</td>
<td>42 ± 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Prₐ:prₐ) in relation to (N:n) - (9:3:3:1 ratio):</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1643 R 183</td>
<td>83</td>
<td>89</td>
<td>12</td>
<td>367</td>
<td>16.728</td>
<td>&lt;.01</td>
<td>32.1 ± 3.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mnd:mnd) in relation to (Re²:re²) - (27:21:9:7 ratio):</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1640 C 147</td>
<td>175</td>
<td>7</td>
<td>93</td>
<td>422</td>
<td>112.111</td>
<td>&lt;.01</td>
<td>12.0 ± 2.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SUMMARY

Seven crosses, involving from two to eleven families each, were studied in the $F_2$ generation for independent inheritance and linkage of factor pairs.

Simple Mendelian inheritance was observed for: $Tr:tr$, $V_t:V$, $V:v$, $L:l$, $Lr:lr$, $B:b$, $N:n$, $K:k_1$, $K^e:k$, $K^e:k_1$, $k_1:k_2$, $Z:z$, $Bl:bl$, $Gh:gh$, $Gs:gs$, $Pr_a:pr_a$, and $Mnd:mnd$.

A mono- and dihybrid inheritance is suggested for the following factor pairs:

$Re_2:re_2$ (One 3:1 and four 9:7 out of five crosses)

$E:e$ (One 3:1 and one 15:1 out of two crosses)

Factor pairs showing independent inheritance were:

$Tr:tr$ in relation to $E:e$.

$Re_2:re_2$ in relation to $B:b$, $K^e:k$, and $Bl:bl$.

$E:e$ in relation to $L:l$ and $N:n$.

$B:b$ in relation to $V_t:V$, $Re_2:re_2$, and $N:n$.


$K:k_1$ in relation to $E:e$ and $L:l$.

$K^e:k_1$ in relation to $V_t:V$, $Re_2:re_2$, $E:e$, and $B:b$.

$Z:z$ in relation to $E:e$ and $L:l$.

$Gh:gh$ in relation to $V:v$ and $Re_2:re_2$.

$Gs:gs$ in relation to $V_t:V$, $Re_2:re_2$, $B:b$, $N:n$, $K^e:k$, $K^e:k_1$, and $Bl:bl$.

$Pr_a:pr_a$ in relation to $B:b$, $N:n$, $K^e:k_1$, and $Gs:gs$. 
Factor pairs which suggested linkage, together with their phases and recombination percentages, were as follows:

**Linkage group I**

<table>
<thead>
<tr>
<th>Factor pairs</th>
<th>Phases</th>
<th>Recombination percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Re}_2^{\text{e}} : \text{re}_2 ) in relation to ( \text{L}:\text{l} )</td>
<td>Coupling</td>
<td>43.1 ± 3.6</td>
</tr>
<tr>
<td>( \text{Re}_2^{\text{e}} : \text{re}_2 ) in relation to ( \text{V}^{\text{t}} : \text{V} )</td>
<td>Coupling</td>
<td>14.6 ± 2.5</td>
</tr>
<tr>
<td>( \text{Re}_2^{\text{e}} : \text{re}_2 ) in relation to ( \text{V} : \text{v} )</td>
<td>Coupling</td>
<td>11.0 ± 1.5</td>
</tr>
<tr>
<td>( \text{Re}_2^{\text{e}} : \text{re}_2 ) in relation to ( \text{E} : \text{e} )</td>
<td>Repulsion</td>
<td>31.3 ± 8.5</td>
</tr>
<tr>
<td>( \text{Re}_2^{\text{e}} : \text{re}_2 ) in relation to ( \text{Lr}:\text{lr} )</td>
<td>Coupling</td>
<td>23.6 ± 3.9</td>
</tr>
<tr>
<td>( \text{E} : \text{e} ) in relation to ( \text{L}:\text{l} )</td>
<td>Coupling</td>
<td>42.0 ± 5.9</td>
</tr>
</tbody>
</table>

**Linkage group IV**

<table>
<thead>
<tr>
<th>Factor pairs</th>
<th>Phases</th>
<th>Recombination percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{K}:\text{k}_1 ) in relation to ( \text{Tr}:\text{tr} )</td>
<td>Coupling</td>
<td>29.7 ± 5.0</td>
</tr>
<tr>
<td>( \text{K}:\text{k}_1 ) in relation to ( \text{Z}:\text{z} )</td>
<td>Repulsion</td>
<td>18.8 ± 4.1</td>
</tr>
<tr>
<td>( \text{K}^{\text{o}}:\text{k} ) in relation to ( \text{Bl}:\text{bl} )</td>
<td>Coupling</td>
<td>24.9 ± 1.9</td>
</tr>
</tbody>
</table>

**Factor pairs not classified**

<table>
<thead>
<tr>
<th>Factor pairs</th>
<th>Phases</th>
<th>Recombination percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Gh}:\text{gh} ) in relation to ( \text{N}:\text{n} )</td>
<td>Coupling</td>
<td>37.9 ± 2.0</td>
</tr>
<tr>
<td>( \text{Pr}_a:\text{pr}_a ) in relation to ( \text{V}^{\text{t}} : \text{V} )</td>
<td>Repulsion</td>
<td>41.3 ± 3.6</td>
</tr>
<tr>
<td>( \text{Pr}_a:\text{pr}_a ) in relation to ( \text{Re}_2^{\text{e}} : \text{re}_2 )</td>
<td>Repulsion</td>
<td>4.2 ± 0.5</td>
</tr>
<tr>
<td>( \text{Mnd}:\text{mnd} ) in relation to ( \text{Re}_2^{\text{e}} : \text{re}_2 )</td>
<td>Coupling</td>
<td>12.0 ± 2.9</td>
</tr>
</tbody>
</table>
LITERATURE CITED


1957. Summary of linkage studies in barley, 1953-1956. (Mimeographed)


