The effect of three factors (row spacing, hail damage, or pedicel length) on different isogenic lines of barley (Hordeum vulgare L.)
by Kenneth Michael Gilbertson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:
Barley (Hordeum vulgare L.) has many uses and is adapted to many areas. The objectives of this study were: (1) determine if it is necessary to change management practices to test short statured barleys; (2) evaluate the effect of hail damage on isogenic lines of barley; and (3) determine the effect of pedicel length on segregates from two-six rowed isogenic barley lines.

In this comparison it was not necessary to reduce row spacing to test short statured barleys unless very short statured lines were used.

In this study hail caused a significant amount of stem bending, as well as significantly affecting the percentage of plump kernels, and the amount of kernel shattering on several isogenic lines of barley.

Long pedicel length has a detrimental effect on seed size of lateral florets of barley on six-rowed segregates with the genotype vvii from two-six rowed crosses.

THE EFFECT OF THREE FACTORS (ROW SPACING, HAIL DAMAGE, OR PEDICEL LENGTH) ON DIFFERENT ISOGENIC LINES OF BARLEY (*HORDEUM VULGARE* L.)

by

Kenneth Michael Gilbertson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Agronomy

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1982

APPROVAL

of a thesis submitted by

Kenneth Michael Gilbertson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dec 29, 1982
Date

Eugene G Hockett
Chairperson, Graduate Committee

Approved for the Major Department

12/29/82
Date

Dwane G Miller
Head, Major Department

Approved for the College of Graduate Studies

1-3-83
Date

Michael Malone
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Kenneth Michael Gilbertson

Date Dec. 30, 1982

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude to the following:

Dr. E. A. Hockett, for his guidance, encouragement, and friendship while serving as major professor during the course of this study and the preparation of this thesis;

Dr. R. L. Ditterline, for all his academic and personal advice, and friendship;

R. F. Eslick for the use of his material, as well as his valuable knowledge.

The author also wishes to thank three important ladies in his life; his wife Mary for her love and patience, his mother Alma, and mother-in-law Charlotte for always having faith in him, as well as the rest of his family for their continued support.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Barley (*Hordeum vulgare* L.) has many uses and is adapted to many areas. The objectives of this study were: (1) determine if it is necessary to change management practices to test short statured barleys; (2) evaluate the effect of hail damage on isogenic lines of barley; and (3) determine the effect of pedicel length on segregates from two-six rowed isogenic barley lines.

In this comparison it was not necessary to reduce row spacing to test short statured barleys unless very short statured lines were used.

In this study hail caused a significant amount of stem bending, as well as significantly affecting the percentage of plump kernels, and the amount of kernel shattering on several isogenic lines of barley.

Long pedicel length has a detrimental effect on seed size of lateral florets of barley on six-rowed segregates with the genotype *vvii* from two-six rowed crosses.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is the world's fourth most important cereal grain, and has a broad range of adaptation. Along with its broad range of adaptation, barley has a wide range of uses, from animal feed to human food, fiber or fuel.

With this large amount of adaptation and uses, a good understanding of barley's behavior under different conditions is necessary. With the introduction of new short statured barley cultivars to improve lodging resistance, the management practices used on these new cultivars may have to be changed. Hail continues to be a serious problem for small grain producers. Continued research on this problem may help find hail tolerant cultivars or indicate which cultivars to avoid. Crosses between two-rowed and six-rowed barley cultivars have been made to produce new six-rowed cultivars, but with limited success. The reasons for this limited success need to be found so that improved cultivars may be bred. Isogenic lines can be used to study the problems listed above. Comparison of the phenotypic 'worth' of a particular gene can be accomplished by isogenic analysis, in which the contrasting alleles are introduced into a common genetic background, usually by backcrossing (8, 16, 17).

The objectives of this study were to: (1) determine if it is necessary to change the management practice of row spacing to test short statured barleys, (2) evaluate the effect of hail damage on isogenic lines of barley, and (3) determine the effect of pedicel length on segregates from two-six rowed isogenic barley lines.

2

LITERATURE REVIEW

LITERATURE REVIEW

Barley (*Hordeum vulgare* L.) mainly grows in the more temperate parts of the world. It is also found on agricultural frontiers, such as the higher plateaus of Tibet and Ethiopia, or the Andes, and can be found on the fringes of the Sahara or North of the Arctic Circle (30).

As the fourth most important cereal grain, barley has many uses. Its most important uses worldwide are grain feed for livestock and poultry; as malt for beverages or food production; as seed; and as human food (30).

Row Spacing

Researchers have reported that small grain yields are sensitive to planting pattern. Most researchers have found a consistent increase in yield at row spacings narrower than the normal range of 18 to 23 cm (10, 15, 18, 19, 23, 24, 25). Holliday (18), in his review, found a yield increase of 2-10% among small grains (wheat, barley, oats, and rye) when row spacings were reduced to 10-13 cm. In contrast, Holliday found a 2-17% decrease in yield when row spacings were widened to 31 cm. Harrington (15) (on wheat, oats and barley) and Finlay et al. (10) (on barley) found no change in yield when increasing row spacing from 15 cm to 31 cm. Natr (24) found that the effect of row spacing (15 cm or 7.5 cm) on grain yield of spring barley depends on the genotype, weather conditions and N rates. He found a strong effect of row spacing on yield and its components, as well as on the photosynthetic characteristics of plants and stand.

These tests were all conducted on normal height barley. With the advent of more sprinkler irrigation, shorter stature barley cultivars are being considered both for their lodging resistance and ability to fit under most sprinkler systems.

Erectoides lines are one possible source of germplasm to provide the shorter stiffer strawed lines desired. Persson and Hagberg (26) found that along with a denser spike, erectoides lines also are shorter, due to reduced internode length, and stiffer strawed. Bannier and Scholz (3) found that induced erectoides mutants had very high lodging resistance. These same mutants yielded about the same as the standard cultivar tested. However, the erectoides mutants were inferior to the standard height cultivars in plumpness and 1000 kernel weight.

Ali et al. (2) testing semi-dwarf lines with a 'Jotun' background (Jotun is an irradiation derived mutant from Norway) found a 3% yield increase in these semidwarf lines compared to normal height cultivars. They also found a 7% increase in number of tillers in the semidwarf lines, but the normal lines had 8% heavier kernels.

Hail Damage

Hail damage to grain crops has been studied using both natural hail and artificial methods. These studies, conducted using just a few small grain cultivars, indicate the stage of growth as well as environmental conditions have an effect on subsequent grain yield and quality.

Simulated hail studies with small grains (wheat, barley, and oats) have shown that yield losses were greatest when hail occurred as the plants approached the heading to soft dough stage (1, 5, 6, 7). Studies of damage caused by natural hail (12, 22) also indicated that the critical growth stage for cereals (wheat, barley) is heading to soft dough. If hail occurs before or after these critical stages it does not reduce yield as much as hail during heading to soft dough.

Pedicel Length and Lateral Kernel Weight

Much research has been conducted to determine the causes and consequences of lateral fertility in barley (*Hordeum vulgare* L.).

Woodward (31) found that the fertility of lateral florets in barley is controlled by the *I* gene, in conjunction with the *V* gene for two-rowed or the *v* gene for six-rowed spike type. When in the six-rowed background either *I* or *i* genotypes have complete lateral fertility. In the two-rowed background the *ii* gene causes total lateral infertility, preventing the development of lateral ovules and awns or hoods, while the *II* gene produces inflated laterals which contain anthers and an occasional seed. Gymer (13) studying the genetics of the six-row/two-row character made crosses of the four genotypes (*VVII, VVii, vvII, vvii*) in all possible combinations and identified the classes which can be obtained as pure breeding lines. Sessile lateral six-row, *vvII*; pedicelled lateral six-row, *vvii*; normal two-row, *VVii*; and intermediate, *VVII*.

When progeny of two-row X six-row crosses were tested, Harlan and Martini (14) found yields of the six-rowed segregates had lower yields than their six-rowed parent. They theorized this loss was due to the small size of the lateral kernels, since the full size of the lateral kernels of the six-rowed parent is seldom recovered in the six-rowed segregates.

Takahashi, et al. (27) found that genetic background had a significant effect on grain yield. They found two-rowed 'Compana,' which is its normal row type, exceeded the six-rowed Compana by 10-15 percent, while the six-rowed 'Vantage,' which is its normal row type, out-yielded the two-rowed Vantage by more than 20 percent. This indicates that when a six-row is put in a two-row background it does not yield up to its potential and vice versa. However, Wells (29) found that yield was not affected by backcrossing *vv* in place of *VV* into Compana, but yield was greatly reduced when *VV* was substituted for *vv* in 'Glacier.' Hockett and Standridge (17) agreed with Wells in finding that the unfavorable tillering capacity of the six-rowed barley background greatly reduces yield of the two-rowed gene in the six-rowed background. Preliminary work with the six-rowed *v* backcrossed into the two-rowed cultivar 'Hannchen' indicates a yield advantage for *VV* compared to *vv* (unpublished data R. F. Eslick). Thus, the background in which the *VV* and *vv* genes are compared is very important.

Kirby and Rymer (21) found that vascular bundles leading to the lateral spikelets of barley were similar to those of the central spikelets except they were smaller in size. Bonnett (4) found two-rowed barley cultivars had lateral spikelets which were pedicellate while laterals in the six-rowed cultivars were not. Viedman (28) found, in the groups of barley he studied (*H. hexastichym, H. nutantes, H. polystichum,* and *H. deficientes*), the cause for the sterility of the small kernel size of lateral florets was due to the length of pedicel upon which these kernels were formed. He found the longer the pedicel, the weaker the development of the lateral kernel.

PART I

THE EFFECT OF ROW SPACING ON ERECTOIDES LINES OF BARLEY

THE EFFECT OF ROW SPACING ON ERECTOIDES LINES OF BARLEY

Shorter statured barley cultivars are being developed to use under irrigation, both for their lodging resistance and their ability to fit under most sprinkler systems.

One method proposed to develop these shorter cultivars is the use of erectoides genes. As these shorter cultivars are developed, information is needed to determine the best way to manage them. The objectives of this study was to determine if it is possible to test these cultivars, developed from erectoides lines, under normal conditions, or if it would be necessary to reduce row spacing to adequately test them.

Materials and Methods

The cultivar used in the study was 'Betzes' (CI6398, "normal isoline") and its erectoides isolines, 'Erectoides Betzes II' (MT72654), and 'Betzes Double Erectoides' (MT87148). Two spontaneous erectoides mutants occurred in Betzes-'Erectoides Betzes I' CI 10871, *ert-a* found by Wiebe and Ramage and Betzes Erectoides II found by Hockett (Hockett, unpublished data). They are non-allelic (9) and formed Betzes Double Erectoides which is homozygous for both erectoides genes (Hockett, unpublished data).

The isolines were planted at Bozeman, Montana from 1972 through 1976 on Amsterdam silty clay loam soil (fine-silty, mixed Typic Cryoboroll). Weather during all five seasons was favorable for barley production and no diseases were present. The 1973 soil analysis indicated a nitrogen deficiency. In 1974 and 1975 the nurseries were not irrigated and had 274 and 458 mm of plant available moisture in 1.2 m of soil, respectively. In 1972 and 1976, 566 and 613 mm of plant available moisture was present in 1.2 m of soil.

Each isoline was planted in two row spacings in a split plot design with spacings as main plots, and cultivars as subplots. One main plot was planted at a normal rate (1 gram per 0.1 m^2) and area (4 rows 30 cm apart, 3.1 m in length). The other main plot was planted in seven rows 15 cm apart and 3.1 m in length at the same rate (1 gm per 0.1 m^2).

The center two rows of the 30 cm spacing plots and the middle four rows of the 15 cm plots were trimmed to 2.5 m in length and harvested. This gave 1.5 m^2 harvested for each plot.

The experiment was analyzed as a factorial analysis of variance with row spacings as one factor and isolines as the other factor randomized within spacings. The comparison over years was analyzed by a 3 factorial analysis of variance with years, spacings, and isolines as factors.

Data collected include counts, measurements, or calculations of:

Heading date (number of days from Jan. 1 until 50% of the spikes emerged from the boot).

Plant height (measured to tip of spikes at maturity).

Tillers (number of spiked tillers were counted in 0.7 m^2).

Number of kernels per spike (average of 25 spikes per plot).

Length and width of the leaf below the flag leaf (average of 25 leaves per plot).

Straw weight (bundles threshed, straw collected, oven dried, and weighed and converted to 9 percent moisture).

Leaf area (leaf length × width × 0.75).

Grain yield (measured after samples reached a moisture equilibrium of approximately 9 percent moisture).

Biological yield (straw weight plus grain weight).

Test weight (grain weight in one hectoliter).

Kernel weight (30 grams of seed counted and weight divided by the number of kernels).

Percentage of plump kernels (weight of kernels remaining on a 2.4-by 19.0 mm screen).

Percentage of thin kernels (weight of kernels passing through a 2.2-by 19.0 mm screen).

Percent protein (by UDY dye binding method, 6.25 × N on an as is basis).

RESULTS AND DISCUSSION

Significant differences were found between years for all characteristics measured over isolines and spacings.

Narrow row spacing has varying effects on agronomic traits of barley (10, 15, 18, 24). In this study, row spacing over isolines and years significantly affected tillers/m^2, heading date, and leaf length, width, and area (Table I-1).

Table I-1. Spacing comparisons over isolines and years of agronomic traits in the spacing study grown at Bozeman, Montana, in 1972-1976.

Spacings, cm	Tillers per m^2	Heading date[1]	Leaf length cm	Leaf width cm	Leaf area cm^2
30	735b[2]	186.1b	15.9a	1.0a	9.3a
15	823a	187.1a	15.3b	0.9b	8.3b

[1] Days from Jan. 1.
[2] Means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

Tillers/m^2, kernels/spike, and kernel weight, are the components of yield. Even though there were significantly more tillers at the 15 cm spacing (Table I-1), yields at the narrow row spacings were not significantly higher. Heading date was also significantly affected by row spacing. The 15 cm spaced isolines headed 1.0 of a day later (Table I-1). This result is statistically significant because of the low standard errors for heading date, but probably not significant biologically. The only other characteristic significantly affected by row spacing was leaf size (length, width, and area). The isolines planted at the 15 cm spacing had significantly shorter and narrower leaves with less leaf area than those isolines planted at the 30 cm spacing (Table I-1). Because of the narrower spacings, there are more tillers and thus more competition for substrate at the leaf initiation and growth stages. There is also shading at the narrower spacings that could affect leaf size. These data agree with that of Natr (24), and disagree with that of Ali et al. (2).

Isolines over years and spacings were significantly different for all characteristics except yield (Tables I-2 and I-3), leaf width, and percent protein.

There were significant differences among isolines for all the yield components (Table I-2). There was an increase in tillers/m^2 and a decrease in kernel weight with an increase in number of erectoides genes, which is in agreement with Persson and Hagberg (26) since they found an additive effect with the homozygous double erectoides genes.

Table I-2. Isoline comparisons over years and spacings of yield and yield components in the spacing study grown at Bozeman, Montana, in 1972-1976.

Cultivar	Yield q/ha	Tillers per sq. m.	Kernels per spike	Kernel weight mg.
Betzes	36.2a[1]	755c	22.6b	39.8a
Betzes Erectoides II	36.5a	784b	21.8a	35.6b
Betzes Double Erectoides	37.2a	800a	21.6a	33.1c

[1] Means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

Although there were fewer kernels/spike on the erectoides isolines than on Betzes, they did not significantly differ from each other for kernels/spike. With the compensating effects of tillers/m^2 and kernel weight for all three isolines and the decreased kernels/spike of the erectoides isolines no significant yield differences were found. Eslick and Hockett (9) did not find a yield difference between Betzes and Betzes Erectoides II in a 102 station comparison.

The significant difference between the erectoides lines and Betzes for plant height is to be expected (Table I-3), as erectoides lines are shorter genetically. This is due to the

Table I-3. Isoline comparisons over years and spacings of agronomic traits in the spacing study grown at Bozeman, Montana, in 1972-1976.

Cultivars	Test weight kg/hl	Head Date da 1/1[1]	Plant height cm.	Percent plump kernels	Percent thin kernels	Leaf length cm	Leaf width cm	Leaf area cm^2
Betzes	70.0a[2]	186.8a	68.6a	78.6a	5.0 b	18.0a	0.9a	9.9a
Betzes Erectoides II	69.9a	186.2b	58.1b	68.1b	7.9 a	14.7b	0.9a	8.3b
Betzes Double Erectoides	68.7b	187.8a	52.2c	46.0c	11.5 a	14.2b	1.0a	8.2b

[1] Days from January 1.

[2] Means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

compaction of the internodes, caused by the erectoides gene (2, 3, 9, 11, 26). The height response was not quite linear since the Erectoides II gene reduced height by 10.5 cm while the addition of the *ert a* gene only reduced height 6.9 cm.

The same general pattern described above occurred for the percentage of plump and percentage of thin kernels. The Betzes Double Erectoides isoline has two erectoides genes and has a significantly lower percentage of plump kernels and a higher percentage of thin kernels than Betzes Erectoides II and Betzes, (Table I-3). This agrees with the results found by Ali et al. (2) and Eslick and Hockett (9). Betzes had significantly longer leaves than either erectoides line, 18.0, 14.7 and 14.2 cm respectively (Table I-3). Although there was no significant difference between the three cultivars for leaf width, the difference in leaf length was great enough to give Betzes significantly more leaf area than the two erectoides isolines (Table I-3). There were no significant differences between isolines for percent protein in the grain, therefore no data are shown.

The erectoides lines had no lodging, while Betzes lodged in every year, therefore no data shown. It appears that with more compact nodes, and overall shorter plants, erectoides lines are less susceptible to lodging. This agrees with the data of Ali et al. (2), Bannier and Scholz (3), Eslick and Hockett (9), and Persson and Hagberg (26).

There were no significant interactions for spacings by isolines, or years by spacings. Under stress conditions for moisture or fertility, the isolines behaved similarly at the two different spacings (Table I-4). However, in non-stress years the Betzes Double Erectoides isoline yielded significantly more than Betzes and Betzes Erectoides II at the 15 cm spacing. This spacing X isoline interaction difference was probably masked by the noninteraction during the 3 stress years.

There were significant interactions for years X isolines for yield, percent plump, kernel weight, tillers, and percent protein. The year X isoline interaction for yield is shown in Table I-4. Betzes yielded 6% more than the erectoides isolines in stress years, while the

Table I-4. Mean yields in q/ha of isolines, at two row spacings during non-stressed years (1972 and 1976) versus stressed years (1973-1975) grown at Bozeman, Montana.

	Non-Stress Years			Stress Years[1]		
	30 cm	15 cm	$\bar{x}$	30 cm	15 cm	$\bar{x}$
Betzes	49.6b[2]	49.6b	49.6b	28.1a	26.7a	27.4a
Betzes Erectoides II	53.9b	51.6b	52.8b	25.9a	25.7a	25.8a
Betzes Double Erectoides	50.9b	58.2a	54.6b	26.2a	25.2a	25.7a
$\bar{x}$	51.5	53.1	52.3	26.7	25.9	26.3

[1] Stress was either moisture (1974, 75) or fertility (1973).
[2] Means in columns followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

erectoides isolines yielded 6 to 10% more than Betzes in non-stress years. Since there were 3 stress and 2 non-stress years, these data counteracted each other and resulted in non-significant yield differences over years. Similar results were found by Irvine (20), where the tall genotypes yielded significantly more grain and dry matter than the semidwarf genotypes when grown on dryland.

Table I-5. Comparisons of biological yield data of isolines at two row spacings, at Bozeman, Montana in 1976.

Isoline	Grain yield, q/ha	Straw yield, q/ha	Biological yield, q/ha	Harvest index
Betzes	43.2b[1]	44.7a	87.9b	1.05
Betzes Erectoides II	53.4a	44.5a	97.9a	1.31
Betzes Double Erectoides	54.3a	48.3a	102.6a	1.23

[1] Means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

Biological yield (grain weight plus straw weight) data were collected only 1 year (Table I-5). In 1976, a non stress year, the Betzes erectoides lines had significantly higher biological and grain yields than Betzes, and thus a higher harvest index. Straw yields were not significantly different. In third world countries where straw yield is as important as grain yield for animal feed, fiber, and fuel, growth of these erectoides lines would not be a disadvantage.

PART II

THE EFFECT OF HAIL DAMAGE ON ISOGENIC LINES OF BARLEY

THE EFFECT OF HAIL DAMAGE ON ISOGENIC LINES OF BARLEY

Hail damage is an important hazard to small grain production. The effects of hail damage in a grain field may not be immediately observable.

The objective of this study was to evaluate differences in response to hail damage by isogenic lines of barley.

Materials and Methods

Isogenic lines (Table II-1) for row type (*v* vs. *V*), lateral fertility (*i* vs. *I*), spike density (*l* vs. *L*), awn type (*r* vs. *R*), and spike length were used in this study. Hockett (16), and Hockett and Standridge (17) described the mutant gene, and reported on the size of the gene blocks in the isolines of sets 1 through 5 (Table II-1). Each cross in set 1 through 4 (Table II-1) contains all four isolines. The gene blocks in set 6 are similar to sets 1 through 5 except for the *r* vs. *R*, smooth vs. rough awns, (chromosome 7) genotypes and long vs. short spike (chromosome location unknown) phenotype.

The isogenic lines were planted at Bozeman, Montana on May 1, 1978, except for the Bonneville lines which were planted April 24. They were planted (10 gr/row) in four-row plots with 30 cm between the 3.1 m long rows. The isolines headed from June 26 (177 days from Jan. 1) through July 4 (185), and on July 16 (197, soft dough stage) a hail storm struck. The plots were harvested by hand sickle Sept. 26 (269), 1978, by cutting 2.5 m of one row. Harvested culms which still had spikes were divided into four separate groups:

1. Erect shattered—culms not broken or bent over but some seed shattered from the spike.
2. Erect Unshattered—culms not broken or bent over and spikes not shattered.

Table II-1. Description of isogenic lines evaluated for hail damage at Bozeman, Montana.

Set	Crosses	Isolines within crosses	Phenotype
1	Glacier*7/Compana	VVii, VVII, vvii, vvII	2-rowed, lateral infertility and fertility; 6-rowed, lateral infertility and fertility in each set
2	Traill*7/Betzes	VVii, VVII, vvii, vvII	
3	Trebi*7/Munsing	VVii, VVII, vvii, vvII	
4	Unitan*7/Piroline	VVii, VVII, vvii, vvII	
5	Bonneville*7/Compana	VViill	2-rowed, lateral infertility, club head
		VViiLL	2-rowed, lateral infertility, lax head
		VVIIll	2-rowed, lateral fertility, club head
		VVIILL	2-rowed, lateral fertility, lax head
		vviill	6-rowed, lateral infertility, club head
		vviiLL	6-rowed, lateral infertility, lax head
		vvIIll	6-rowed, lateral fertility, club head
		vvIILL	6-rowed, lateral fertility, lax head
6	Vantage*7/Freja	VVii Long spike	2-rowed, lateral infertility, long spike
		VVii Short spike	2-rowed, lateral infertility, short spike
		VVII Long spike	2-rowed, lateral fertility, long spike
		VVII Short spike	2-rowed, lateral fertility, short spike
		vvii Long spike	6-rowed, lateral infertility, long spike
		vvii Short spike	6-rowed, lateral infertility, short spike
		vvII Long spike	6-rowed, lateral fertility, long spike
		vvII Short spike	6-rowed, lateral fertility, short spike
		VViiRR Long spike	2-rowed, lateral infertility, rough awned, long spike
		VViiRR Short spike	2-rowed, lateral infertility, rough awned, short spike
		vviiRR Long spike	6-rowed, lateral infertility, rough awned, long spike
		vviiRR Short spike	6-rowed, lateral infertility, rough awned, short spike

3. Bent Shattered—culms bent or broken over, and some seed shattered from the spike.

4. Bent Unshattered—culms bent or broken over but spikes not shattered.

Spikes with seeds missing were considered shattered, while spikes without seeds missing were considered unshattered. Each group was evaluated for: percentage of spiked culms remaining per 3 m row; percentage of plump kernels (the percentage of seeds remaining on a 2.4- by 19.0-mm screen). The two shattered groups were also evaluated for average number of flowers and seeds per spike. The average number of seeds per spike were divided by average number of flowers per spike and subtracted from 100 giving percent kernel shattering. The percentage of culms with missing spikes was also recorded for each isogenic set.

The data was set up in a completely random design, as only one row of each isoline was sampled there was only one replication. A partial analysis of variance was computed for each of these comparisons.

RESULTS AND DISCUSSION

Hail affected percentage of: spiked culms per m^2; plump kernels; shattering; and spikes lost (Table II-2). Isogenic sets 'Bonneville,' 'Glacier' and 'Vantage' had significantly more erect than bent culms; however, isogenic sets 'Traill,' 'Trebi,' and 'Unitan' had significantly more bent than erect culms. Cultivar differences for stem bending or breaking over agrees with the results of Busch (5), Deckard and Hammond (6), and Eldredge (7). The cultivars with many bent culms would be more difficult to harvest after a hail storm. There was a significantly higher percentage of unshattered than shattered spikes for all isogenics sets. Isogenic set Glacier had significantly more shattered spikes per m^2 than any other isogenic set. Glacier headed 20 days before the hail storm, and five to eight days before the other isogenic sets (Table II-3) and therefore the kernels were more advanced in filling and more susceptible to shatter by hail (12).

Table II-2. Significance of mean squares for hail damage to isogenic barley lines grown at Bozeman, Montana in a partial analysis of variance.

Source of variation	Spikes remaining: Per m^2	Spikes remaining: Plump kernels	Spikes remaining: Kernel shattering	Spikes lost
	%	%	%	%
Isogenic sets	ns	**	ns	*
Row type, (V vs v)	ns	**	**	ns
Lateral fertility, (I vs i)	ns	ns	ns	ns
Iso. set X Row type	ns	ns	ns	ns
Iso. set. X Lateral fert.	ns	ns	ns	ns
Row type X Lateral fert.	ns	ns	ns	ns
Erect (Erect vs bent culms)	ns	ns	*	ns
Erect X Iso. set	*	ns	ns	ns
Erect X Row type	ns	ns	ns	ns
Erect X Lateral fert.	ns	ns	ns	ns
Erect X Iso. set X Row	ns	ns	ns	ns
Erect X Iso. set X Lateral	ns	ns	ns	ns
Erect X Row X Lateral	ns	ns	ns	ns
Shattered (shattered vs Unshattered spikes)	**	**	—	ns
Shattered X Iso. set	*	**	—	ns
Shattered X Row type	**	*	—	ns
Shattered X Lateral fert.	ns	ns	—	ns
Shattered X Iso. set X Row	ns	ns	—	ns
Shattered X Iso. set X Lateral	ns	ns	—	ns
Shattered X Row X Lateral	ns	ns	—	ns

* Significant at 5% level.
** Significant at 1% level.
ns, non-significant.

Two row isolines had significantly more spikes with some kernel shattering (shattered spikes) than six row isolines, 18.9 to 8.2 percent respectively (Tables II-2 and II-3). The six row isolines had fewer shattered spikes because when the hail strikes a six-rowed spike, it is more likely to strike awns than seed and thus bounce off and not cause kernel shattering. In the two-rowed spike there are fewer awns so the seeds are less protected and are more susceptible to shattering caused by hail.

Isogenic sets were significantly different for percentage of plump kernels (Table II-2). These differences can be best attributed to genetic differences between cultivars rather

Table II-3. Effect of hail on percentage of damaged spikes and culms per m² of isolines of barley following a July 16 hailstorm at Bozeman, Montana.

Isogenic set or genotype	Heading Date[1]	Spikes		Horiz. LSD[2]	Culms	
		Shattered	Unshattered		Erect	Bent
		%	%		%	%
Bonneville	184	10.8	89.2	8.7	55.0	45.0
Glacier	177	29.2	70.8	12.3	62.5	37.5
Traill	185	6.7	93.3	12.3	37.6	63.4
Trebi	182	8.5	91.5	12.3	46.0	54.0
Unitan	182	9.2	90.8	14.1	32.6	67.4
Vantage	182	15.3	84.7	7.4	57.7	42.3
Overall $\bar{x}$		13.3	86.7	10.2	48.6	51.6
LSD		9.1	9.1	–	ns	ns
All VV		18.9	81.1	5.8	54.2	45.8
All vv		8.2	91.8	5.8	47.8	52.2
LSD		9.2	9.2	–	ns	ns
All ii		13.9	86.1	5.8	54.9	45.1
All II		13.5	86.5	5.8	49.8	50.2
LSD		ns	ns	–	ns	ns

[1] Days from January 1
[2] LSD values are at the 5% level.

than hail (Hockett, unpublished data). All isogenic sets except Glacier had a higher percentage of plump kernels on unshattered than shattered spikes with two of the differences significant (Table II-4). Since Glacier headed earlier than the other isogenic sets, the kernel plumpness was already determined when the hail struck. Isogenic set Traill had the largest reduction in kernel plumpness in all categories. Traill is a 'Manchuria' type malting barley which has a thinner lemma and palea than feed barley. This thinner covering may make Traill's kernels more susceptible to hail damage.

Two rowed isolines are significantly plumper than six rowed, averaged over isogenic sets (Tables II-2 and II-4). This difference is probably not due to the effects of hail, but to the genetic differences found by previous investigators between *VV* and *vv* isolines (16, 17, 29). Also, the Traill six-rowed isolines kernel plumpness was reduced more than any other

Table II-4. Effect of hail on percentage of plump kernels on shattered or unshattered spikes, or on spikes on erect or bent culms, of isogenic lines of barley, following a July 16 hailstorm at Bozeman, Montana.

Isogenic set or genotype	Spikes		Horiz. LSD[1]	Culms	
	Shattered	Unshattered		Erect	Bent
Bonneville	75.2	79.4	ns	78.0	77.8
Glacier	86.0	84.0	ns	84.7	85.3
Traill	39.4	59.3	7.1	49.3	49.4
Trebi	65.4	68.2	ns	66.3	67.4
Unitan	72.2	75.1	ns	73.6	73.6
Vantage	70.9	75.6	4.2	78.1	68.4
Overall $\bar{x}$	68.2	73.6	4.3	71.7	70.3
LSD	11.0	11.0	—	11.0	11.0
All VV	77.4	80.6	3.5	83.6	78.4
All vv	63.6	69.3	3.5	66.0	64.4
LSD	5.8	5.8	—	5.8	5.8
All II	68.1	72.4	3.5	70.6	69.3
All ii	72.8	77.6	3.5	76.8	73.4
LSD	ns	ns	—	ns	ns

[1] LSD values are at the 5% level for comparison of means of shattered vs unshattered spikes and erect vs bent culms.

six-rowed isolines plumpness which also may have made the six-rowed isolines less plump. Averaged over isogenic sets, there were significantly plumper kernels on unshattered than on shattered spikes (Tables II-2 and II-4). This indicates that if the hail knocked seeds out of the spike, it also damaged the transport system of the spike limiting nutrient uptake and thus inhibiting kernel filling. This was also found by Deckard and Hammond (6), and Knowles (22) on different cultivars of barley.

There were significant differences between row types and erect and bent culms for percentage of kernel shattering due to hail (Table II-2). Again, this difference is probably due to the larger amount of awns on six rows than two rows and thereby shielding the seeds from being knocked out by hail. Within either erect or bent culms with shattered spikes, there were no significant differences between isogenic sets. While all isogenic sets except Bonneville shattered more if their culms were erect than bent, only isogenic sets