Effect of natural selection on winter survival and associated traits in winter barley composite cross CCXXVI

by Patrick Frank Hensleigh

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

Abstract:
There has been little improvement in winterhardiness of winter barley over the last 30 to 40 years. Previous research in Montana to improve the level of winter survival of winter barley utilized male sterile facilitated recurrent selection and natural selection. Composite Cross XXVI was .grown at various Montana locations from 1966-84 to expose it to different levels of winter selection pressure. A cycle of recombination and bulking was used to increase genetic variability.

The objective of this research was to estimate the effect of natural selection on different generations of Composite Cross XXVI. Level of winter survival, various agronomic and morphological traits, and snow mold resistance were evaluated. The association between various morphological traits and level of winter survival was also determined.

Field trials at ten locations in 1985-86 and 1986-87 were used to study the effect of natural selection on winter survival and agronomic traits. Experiments at three locations in 1986-87 were used to determine changes in snow mold resistance. The effect of natural selection on various morphological traits was studied under field and controlled environment experiments.

Natural selection improved level of winter survival in CCXXVI. Natural selection appeared to favor taller and later heading plants. No changes were detected in snow mold resistance. There were no apparent changes in seedling leaf width, seedling leaf number, or subcrown internode length. Seedling leaf length decreased in later generations of CCXXVI.

There was no significant correlation with seedling leaf width, seedling leaf number, or subcrown internode and mean winter survival. Shorter seedling leaf length was associated with enhanced winter survival.

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ABSTRACT

There has been little improvement in winterhardiness of winter barley over the last 30 to 40 years. Previous research in Montana to improve the level of winter survival of winter barley utilized male sterile facilitated recurrent selection and natural selection. Composite Cross XXVI was grown at various Montana locations from 1966-84 to expose it to different levels of winter selection pressure. A cycle of recombination and bulking was used to increase genetic variability.

The objective of this research was to estimate the effect of natural selection on different generations of Composite Cross XXVI. Level of winter survival, various agronomic and morphological traits, and snow mold resistance were evaluated. The association between various morphological traits and level of winter survival was also determined.

Field trials at ten locations in 1985-86 and 1986-87 were used to study the effect of natural selection on winter survival and agronomic traits. Experiments at three locations in 1986-87 were used to determine changes in snow mold resistance. The effect of natural selection on various morphological traits was studied under field and controlled environment experiments.

Natural selection improved level of winter survival in CCXXVI. Natural selection appeared to favor taller and later heading plants. No changes were detected in snow mold resistance. There were no apparent changes in seedling leaf width, seedling leaf number, or subcrown internode length. Seedling leaf length decreased in later generations of CCXXVI.

There was no significant correlation with seedling leaf width, seedling leaf number, or subcrown internode and mean winter survival. Shorter seedling leaf length was associated with enhanced winter survival.

CHAPTER 1

INTRODUCTION

Lower winter survival limits production of winter barley in the northern United States. Composite crosses containing male sterility have been utilized to maintain and increase genetic variability for disease resistance and other traits. The use of natural selection on composite crosses has been widely used to improve various agronomic, physiological, and morphological traits.

Research was initiated in 1966 at the Montana Agricultural Experiment Stations to increase the winterhardiness of winter barley. Winter barley Composite Cross XXVI was grown at various locations throughout Montana from 1966-1984 to expose it to different levels of winter severity. A cycle of genetic recombination and bulking was used to increase genetic variability.

This study was initiated to determine the effect of natural selection on level of winter survival, disease resistance, various agronomic and morphological traits, and the association of these morphological traits with winter survival of Composite Cross XXVI.

CHAPTER 2

LITERATURE REVIEW

Winter barley production in the northern United States is primarily limited by poor winter survival which makes production uncertain and inconsistent. New cultivars with improved winterhardiness have been developed using conventional breeding methods, but poor winter survival still limits commercial production in many northern areas.

Winter survival is an interaction between genotypic and environmental factors including low temperature, snow cover, heaving, desiccation, soil moisture, soil fertility, smothering, insect damage, and disease. Winter barley cannot tolerate temperatures as severe as winter wheat or winter rye. Fowler and Carles (1979) found that the maximum level of cold hardiness of fully acclimated winter oats, barley, wheat, and rye was -13, -15, -21, and -30C respectively. Thus, without significant improvement in the winterhardiness of winter barley, production will be limited to areas which do not experience extremely low temperatures.

The crown is the critical region for winter survival in winter cereals (Olien, 1964; Chen, 1983). In the Northern Great Plains low soil temperatures at crown level are the primary cause of winter-kill (Gusta and Chen, 1987). Snow cover modifies soil temperatures and stubble management affects snow cover. Aase and Siddoway (1979) in eastern Montana recorded crown level soil temperatures above -16C with 6 to 7 cm snow cover when air temperatures were -35C. On bare soil, with no snow cover, soil temperatures went below -16C when the air temperature reached -22C.

With prolonged snow cover, disease, especially snow mold (*Typhula spp.*) can cause severe stand losses. Snow cover will often provide an ideal environment for the fungi because of its insulating effect on the soil against outside air temperature. Snow mold spores survive on debris in the soil and infect plants by either basidiospores or infectious hyphae from soilborne sclerotia (Mathre, 1982). Symptoms of snow mold are dense white-gray mycelium with dark sclerotia on leaves and crowns. Since leaves can quickly disintegrate, effects can be attributed to winterkill if symptoms are not detected soon. Under mild infection conditions, leaves may die but regrowth can occur from crown, while under severe conditions the crown is infected and the plant dies (Mathre, 1982). Under severe conditions damage to resistant wheats can be widespread (Bruehl et al., 1975). No known resistance to snow mold has been reported in winter barley. Crop rotation, fungicide treatment, or avoiding planting in locations which often have long periods of snow cover are the current methods of control.

Little progress has been made in developing winter barley cultivars with adequate winterhardiness or resistance to snow mold by conventional breeding methods. 'Dicktoo' released in 1952 is still one of the more winter hardy cultivars (Johnson, 1953, Rhode and Pulham, 1960; Marshall, 1987).

Bulk population breeding has been promoted as an efficient way to preserve genetic and phenotypic diversity and obtain new genetic combinations. Florell (1929) concluded the bulk population method could be used to improve winterhardiness, rust resistance, and smut resistance. Harlan et al. (1940) found that composite crosses were equal to the pedigree method in producing cultivars. Jensen (1978) described composite crosses as a powerful and efficient breeding technique.

Suneson (1962) described an evolutionary breeding method which combined genetic male sterility for increased recombination with natural selection for improved yield and adaptation in composite crosses. Male sterility has been widely used to obtain genetic recombination in bulk populations (Eslick, 1977; Jain and Suneson, 1966; Ramage, 1977; Suneson, 1956).

Male sterile facilitated recurrent selection is a method to increase genetic variability and produce new germplasm with fewer inputs than conventional breeding.

Male sterile facilitated recurrent selection populations have been developed for improving drought tolerance, short straw, shatter resistance, disease resistance, earliness, and salt tolerance (Ramage, 1977).

The use of natural selection on composite crosses for improvement of various traits has had varying success. Finkner (1964) suggested that natural selection was not effective in isolating the most winter hardy plants in bulk oat populations. Marshall (1966) concluded that natural selection increased cold resistance in winter oat bulk populations with low initial survival level but not in populations with a high initial survival level. Suneson (1956) stated that using bulk hybrid populations and natural competitive selection was as effective as conventional and more costly breeding methods in increasing yield. Patel et al. (1987) found that natural selection reduced frequency of low-yielding genotypes and increased grain yields in a doubled-haploid mixture and a F3 composite cross of spring barley. Hockett et al. (1983) found that while natural selection increased composite cross yield over the original parental mixture, greater progress had been made with conventional breeding.

Jackson et al. (1978) found that composite crosses were effective in maintaining genetic variability in Composite Cross II (CCII), V (CCV), and XXI (CCXXI) for resistance to *Rhynchosporium secalis* (scald). Resistance to four scald isolates was maintained through the later generations in CCII, CCV, and CCXXI. Saghaai-Marouf et al. (1983) found increased resistance to powdery mildew (*Erysiphe graminis*), net blotch (*Helminthosporium teres*) and scald in CCII later generations. In addition, plants with multiple resistance to all three pathogens were found in the later generations that were not observed in the early generations of CCII. The frequency of these multiple resistant plants also increased over time.

De Smet, Scharen, and Hockett (1985) found that resistance to powdery mildew was better conserved (but not greatly improved) when grown in a location with selection pressure for powdery mildew than at location with no selection pressure. Resistance alleles may have been linked to gene complexes which were advantageous under the environmental conditions at each locations.

Although growing composite crosses in locations with selection pressure has been effective in maintaining and providing new genetic recombination for disease resistance, it is unclear whether it is effective in increasing the level of winterhardiness.

Morphological Traits Associated with Winterhardiness

Field survival is the ultimate measurement of winterhardiness but field survival tests are often characterized by complete or very little winterkill. Levitt (1956) estimated that winters severe enough to kill the most tender cultivars and selectivity damage the hardier cultivars, occurs every 10 location years. Even when differential winterkill occurs, experimental error is often high (Fowler et al., 1976, Fowler, 1979).

An accurate and consistent selection technique for winterhardiness is needed to improve barley winterhardiness. Ideally, the selection technique would be rapid, non-destructive, simple, repeatable, highly correlated with field survival, and could be conducted on single plants (Fowler et al., 1981).

Controlled freezing tests using temperature at which 50% of the plants are killed (LT50) are an effective method to estimate cold tolerance. However, detecting small but important differences in cold tolerance is difficult (Fowler et al., 1981).

In winter wheat and winter barley much research has been done on the association between winterhardiness and various biochemical, morphological and physiological traits. Leaf water content, crown water content, plant erectness, crown phosphorus, crown sugar content, crown depth, seedling height, and other plant characteristics have been shown to be associated with cold hardiness of winter wheat (Fowler et al., 1981; Gusta et al., 1983). Since winterhardiness is a complex genetic trait it would be expected that many traits would be associated with it.

The development of an accurate and efficient method of evaluating genotypes for cold hardiness would be extremely valuable in identifying superior cultivars.

The crown is the critical region necessary for winter cereal survival (Martin, 1927; Olien and Smith, 1981; Grafius, 1981; Chen et al., 1983). It has been suggested that plants with deeper crowns are more able to survive the winter (Levitt, 1956; Dobrenz, 1967; Dofing and Schmidt, 1984). Dobrenz (1967) theorized that winter barley cultivars with deep crowns are protected from severe winds and low temperatures and have higher survival rates and therefore produce higher yields.

Crown depth formation is influenced by temperature, light, cultivar, and seeding depth. In winter wheat and winter barley, crown depth generally increases as temperature decreases, however, crown depth is strongly influenced by cultivar (Ferguson and Boatwright, 1968; Kail et al., 1972). Kail et al. (1972) found that field survival of winter barley cultivars was correlated ($r = 0.65^*$) with crown depth of cultivars grown at 10C controlled environment conditions. As temperature increased the correlation with crown depth and field survival decreased. Dofing and Schmidt (1984) also found a highly significant correlation coefficient ($r= -0.57$) between subcrown internode length and mean winter survival of twenty-nine winter barley cultivars. They concluded crown depth varied considerably and that the hardy lines had the deepest crowns. Fowler et al. (1981) found a positive correlation (r = 0.38*) between crown depth and field survival of winter wheat. However, Hunt et al. (1983) in a study involving seventeen diverse winter wheat cultivars theorized that either the genetic variation for crown depth had not been fully utilized or that the advantages of deep crowns were not conclusive.

Fowler and Carles (1979) found a significant correlation (r = 0.61*) with plant erectness and LT50. Fowler et al. (1981) found a negative correlation (r = -0.68**) of seedling plant height and field survival. Plant erectness measured at approximately two months after seeding and field survival was also (r = -0.85**) negatively correlated. They concluded that both plant erectness and leaf water content would be useful as a selection method for winterhardiness.

CHAPTER 3

MATERIALS AND METHODS

Montana Winter Barley Composite Cross Project 1966-1984

Composite Cross XXVI was released (Reid et al., 1971) in 1964 and first planted at the Northwestern Agricultural Research Center at Kalispell, Montana in the fall of 1966. The female parent for this population was over 70 male sterile (ms1ms1) winter barley genotypes and the male parent was a bulk of 1,295 of winter barley lines from the world collection. The population was grown at Havre, Bozeman, Sidney, Moccasin, Kalispell, and Huntley, MT. to expose the populations to environments with differing levels of winter severity (Table 1).

Seed from male sterile plants grown at Kalispell was used for planting at all other locations the same fall. Bulk seed harvested from each of the other locations other than Kalispell was used for planting at Kalispell the same year. The amount of seed used from each location was proportional to the level of winter-kill at each location. Generally, this cycle of genetic recombination at Kalispell and bulking at the other locations was followed throughout the duration of the experiment.

No conscious selection was done at any location and natural selection and possibly drift should have been the major forces modifying gene frequencies in these populations.

Table 1. Estimation of winter selection pressure of CCXXVI generations in Montana from 1969-84.

Generation or Cultivar	Sample Year	Winter selection Pressure (a)
G1	1969-70	Mild
G4	1969-70	Mild
G4a	1969-70	Mild
G5	1970-71	Moderate
G9	1974-75	High
G10	1975-76	High
G11	1976-77	High
G11a	1976-77	High
G12	1977-78	High
G15	1980-81	Mild
G16	1981-82	Mild
G18	1983-84	Mild

(a) Based on percent winter wheat acres reseeded to spring wheat from 1969-84 (Caprio, 1984; Montana Dept of Ag., Ag Stat. 1979-84) and notes on percent winterkill of winter barley (N. W. Agr. Exp. Sta. Ann. Reps. 1969-82).

Winter Survival and Agronomic Field Studies

In the fall of 1984, remnant seed representing generations grown from 1969-1984 was planted at Kalispell and at Bozeman. Twelve (G1, G4, G4a, G5, G9, G10, G11, G11a, G12, G15, G16, G18) generations from this composite cross were used in the experiment in both 1985-86 and 1986-87 (Table 2). Because of differential winterkill at Sidney in 1976-77 two samples were taken for G11 (G11 and G11a).

Table 2. Description of Composite Cross XXVI barley generations and cultivars.

Generation or Cultivar	Sample year	Description
G1	1969-70	Remnant seed from 1969-70 increase of original 1966 sample of CCXXVI.
G4	1969-70	Remnant seed from 1969-70 increase. First seeded in 1966, harvested in bulk in 1967; seeded in 1967, bulk harvested in 1968; seeded in 1968, bulk harvested in 1969.
G4a	1969-70	Remnant seed from 1969-70 increase. First seeded in 1966, harvested in bulk in 1967; seeded in 1967, male steriles harvested in 1968; seeded in 1968, bulk harvested in 1969.
G5	1970-71	Remnant seed, planted at Kalispell in 1970, male steriles harvested in 1971.
G9	1974-75	Remnant seed, planted at Kalispell in 1974, male steriles harvested in 1975.
G10	1975-76	Remnant seed from bulk population planted at Sidney in 1975, 22 surviving plants harvested in 1976 after severe winterkill.
G11	1976-77	Remnant seed, planted at Sidney in 1975, bulk harvested in 1976 from field with differential winterkill.
G11a	1976-77	Remnant seed (sample #2), planted at Sidney in 1975, bulk harvested in 1976 from field with differential winterkill.
G12	1977-78	Remnant seed, planted at Sidney in 1977, bulk harvested in 1978.
G15	1980-81	Remnant seed, planted at Kalispell in 1980, harvested in 1981.
G16	1981-82	Remnant seed, planted at Kalispell in 1981, male steriles harvested in 1982.
G18	1983-84	Remnant seed, planted at Moccasin in 1983, bulk harvested in 1984.
G1b	1985-86	Generation 1 bulked for 1 year.
G10b	1985-86	Generation 10 bulked for 1 year.
G12b	1985-86	Generation 12 bulked for 1 year.
G16b	1985-86	Generation 16 bulked for 1 year.
Winridge		Hard red winter wheat rated hardy under Montana conditions.
Oregon Feed		Soft white winter wheat rated non-hardy under Montana conditions.
Schuyler		Short straw, mid-late maturity, six-rowed feed, rated as a relatively hardy winter barley. Released in 1968.

Seed from 1984-85 Kalispell was used for all generations except G18 which was from Moccasin 1983-84 seed. 'Winridge', 'Oregon Feed' winter wheat, and 'Schuyler' winter barley were included as winter survival checks. Seed for Winridge, Oregon Feed, and Schuyler was from Bozeman 1984-85. Schuyler was included twice to further estimate the variation of winterkill within the nursery. In 1986-87 an additional 4 generations (G1b, G10b, G12b and G16b) which had been bulked for 1 year were added to the experiment (Table 2). A randomized complete block design with 4 replications was used. Seeding rate was 66 pure live seeds per meter of row. Six locations (Bozeman, Huntley, Kalispell, Lodge Grass, Moccasin, and Sidney) were planted in 1985-86 and 5 locations (Bozeman, Huntley, Kalispell, Moccasin, and Sidney) were planted in 1986-87. Planting dates in 1985-86 were: Bozeman (9/21/85), Huntley (9/26/85), Kalispell (9/20/85), Lodge Grass (10/17/85), and Moccasin (9/16/85). In 1986-87 planting dates were: Bozeman (9/16/86), Huntley (10/7/86), Moccasin (9/23/86), Kalispell (9/16/86), and Sidney (9/11/86). Plot sizes were: Bozeman (4 rows 4.3 m long), Moccasin (3 rows 4.9 m long), Huntley and Lodge Grass (4 rows 6.1 m long), Kalispell (4 rows 4.3 m long), and Sidney (4 rows 3.0 m long). Row spacing was .30 m for all locations. Harvest dates in 1985-86 for Bozeman, Huntley, Kalispell, Lodge Grass, and Moccasin were: 8/6/86, 7/8/86, 7/30/86, 8/14/86, and 8/1/86, respectively. In 1986-87 harvest dates were: 8/4/87, 7/20/87, 7/27/87, and 8/4/87, for Bozeman, Huntley, Kalispell, and Moccasin, respectively. The experiment was fertilized at the generally accepted levels for winter wheat and winter barley at each location. To determine percent winter survival, plant counts were taken from 2 rows (0.91 m each) 4 to 6 weeks after planting and in the spring after all winterkill had occurred. Percent winter survival was calculated on each row using:

$$1.00 - \left[\frac{(\#\ \text{plants/fall} - \#\ \text{plants/spring})}{\#\ \text{plants/fall}}\right] \times 100$$

Winter survival percent was the mean of 2 individual rows. Fall and winter stand counts were obtained at 8 of the 10 locations. Winter survival, mean plant height, mean heading date, yield, kernel weight (weight of 1000 seeds), test weight, and other pertinent data was taken at all locations if possible. No data was obtained at Sidney in 1985-86 due to late planting and subsequent winterkill of the entire nursery. No plant counts were obtained at Lodge Grass in 1985-86 due to early snow cover.

Individual locations were analyzed as a randomized complete block. Subsequent analyses were combined over environments.

Morphological Trait Studies

Field Studies

Leaf length and leaf width were measured on 20 plants per plot for generations (1, 4, 4a, 5, 9, 10, 11, 11a, 12, 15, 16, 18) and Schuyler approximately 6 weeks after planting at Bozeman and Moccasin in 1985-86. Leaf length was the distance between the stem or leaf sheath area and the tip of the longest leaf. Leaf width was the distance at the widest point of the longest leaf. In 1986-87, leaf length, leaf width, and total number of leaves were measured on 20 plants per plot at Moccasin and Bozeman approximately 6 weeks after seeding. In addition, subcrown internode length (distance between the seed and the base of the crown) was measured at Bozeman in 1986-87.

Experiments to measure percent male steriles, heading date, and plant height on individual plants were abandoned in 1985-86 and 1986-87 at Bozeman because of winterkill. Heading date, days to maturity, and grain-fill period were measured at Marana, Arizona in 1986-87 on approximately 40 plants per generation. Percent male steriles and heading date were measured on approximately 90 plants vernalized under controlled environment conditions and transplanted at Bozeman in 1986-87. Plants were vernalized at 5C for 4 weeks with a 12 hr photoperiod.

Controlled Environment Studies

Cold Conditions.

Four generations (G1, G10, G12, G16), and Schuyler winter barley were planted in the Controlled Environment Center at Montana State University. Fifty seeds of each generation and 25 of the check, Schuyler, were planted in flats 8 cm long and 4 cm wide at a depth of 6 cm in "Sunshine Mix # 3." A randomized complete block design with 5 replications was used. Temperature was 5C and photoperiod was 12 hours. The plants were watered as needed and flats were rotated every 4 days. Coleoptile length (distance from seed to coleoptile tip) and seedling height (distance between stem or leaf sheath area without chlorophyll and tip of the longest leaf) measurements were taken 60 days after planting. Leaf width, leaf length, and total number of leaves were measured as in the field studies.

Warm Conditions.

One hundred seeds of four generations (G1, G10, G12, G16) and 50 seeds of the check, Schuyler, were planted in flats 33 cm wide and 48 cm long in rows 5 cm apart with 2.0 cm spacing between plants. A randomized complete block design with 3 replications was used. Seeds were planted 9 cm deep and grown at 20C day and 15C night temperatures (12 hour photoperiod) for 6 weeks. Soil temperature varied from 20-24C. Plants were watered as needed and rotated every 2 days.

Leaf length, leaf width, total number of leaves, subcrown internode length, seedling height and coleoptile length were measured approximately 40 days after planting.

Snow Mold Experiment

The winter barley generations in this experiment had been exposed to high snow mold selection pressure at Kalispell in 1971-72, 1972-73, and moderate pressure in 1977-78. Schuyler winter barley, 'Daws', 'John' and 'Lewjain' winter wheat were included as snow mold checks. Seed for all generations and Schuyler was obtained from seed planted at Kalispell in 1985-86. Seed for the winter wheat checks were obtained from Dr. Clarence Peterson at Washington State University.

A randomized complete block design was used with 4 replications. Seeding rate was 76 seeds per meter of row and plots consisted of 4 rows 10 feet long. The nursery was planted at 3 locations: Bozeman and Kalispell, Montana; and at Prosser, Washington.

Sterile oat seed inoculated with *Typhula Idahoensis Remsb.* and *Typhula ishikariensis Imai* (obtained from Dr. Don Mathre) was stored at 4C for 105 days and allowed to air dry at 18C for 7 days. Inoculum was mixed together at a ratio 3 (*T. idahoensis*) to 1 (*T. ishikariensis*). Inoculum was sprinkled over the 2 center rows with a push type row seeder with the shoe removed. Application rate was 7 grams of inoculum per meter of row. Inoculum was applied 35 days after seeding at Bozeman and 25 days after seeding at Kalispell. No inoculum was used at the Washington site. Occupancy counts (percent 3.8 x 3.8 cm squares occupied out a total of 20 squares, 0.76 m total length) were taken on all 4 rows at each location in Montana in fall and again in the spring. The non-inoculated rows were used to determine stand reduction due to winterkill, and the inoculated rows were used to determine snow mold damage. At Prosser, stand readings were taken in the fall and snow mold readings were taken in the spring after snow cover was gone.

CHAPTER 4

RESULTS AND DISCUSSION

Male Sterility

Composite crosses containing male sterility bulk harvested for up to 6 generations retained 20-25% male steriles, while after 14 generations male sterile plants declined to 2% (Jain & Suneson, 1964). In this study percent male sterile plants ranged from 11 to 39% (Appendix Table 18).

Individual Locations Results

Complete results of the winter survival and field agronomic experiments from individual locations are given in Appendix Tables 18-28.

Yield

Winridge winter wheat had a significantly higher mean yield over all locations than Schuyler, Oregon feed wheat and all winter barley generations (Tables 3 & 4). Schuyler winter barley yielded the same as Oregon feed wheat and yielded significantly higher than all generations of winter barley (Table 4). Male sterility should reduce yield of the winter barley generations and could partly explain the lower yields in comparison to the other cultivars. Generations 1b, 10b, 12b and 16b were bulked for 1 year and should have a lower percent male sterile plants than G1, G10, G12, and G16, respectively. Bulking did not affect yields, except at Huntley where it increased yields for G10 and at Moccasin where it decreased yields for G1 (Table 4).

Table 3. Mean yield of generations of CCXXVI and cultivars at five Montana locations in 1985-86.

Generation or Cultivar	Kalispell	Moccasin	Huntley	Bozeman	Lodge Grass
	Yield Mg/ha				
Winridge	5.65	3.86	3.13	6.75	3.63
Oregon feed	5.40	3.06	2.90	5.08	3.33
Schuyler	5.26	2.61	4.04	5.08	3.73
G1	4.34	2.00	3.67	2.98	2.67
G4	4.03	1.81	3.09	2.13	2.34
G4a	4.29	1.98	3.69	2.56	2.60
G5	3.76	1.90	3.42	3.54	2.33
G9	4.48	1.86	3.58	2.85	2.52
G10	4.58	1.96	3.85	4.24	2.41
G11	5.04	2.17	3.12	4.46	2.92
G11a	4.88	2.01	3.07	4.66	2.51
G12	4.57	2.25	3.35	4.59	2.70
G15	4.63	1.96	3.14	4.39	2.81
G16	4.32	1.83	3.09	4.53	2.44
G18	4.34	1.95	2.65	4.69	1.59
Schuyler	4.97	2.59	3.98	4.83	3.90
Mean	4.66	2.24	3.36	4.21	2.78
F-value	4.44	28.91	3.18	5.39	11.60
CV	10.42	9.42	13.49	24.59	12.83
P-value	.000	.000	.001	.000	.000
LSD (0.05)	0.69	0.29	0.64	1.42	0.51

Yields of Winridge, Oregon Feed, and Schuyler ranged from 3.13 to 9.33, 2.90 to 7.20, and 2.51 to 7.55 Mg/ha, respectively. Winridge yielded higher than Schuyler at

Moccasin and Bozeman in 1985-86 (Table 3) and at Kalispell, Moccasin, and Huntley in 1986-87 (Table 4).

Table 4. Mean yield of generations of CCXXVI and cultivars at four Montana locations in 1986-87.

Generation or Cultivar	Kalispell	Moccasin	Huntley	Bozeman	Mean 1985-87
		------Yield	Mg/ha------		
Winridge	9.33	5.56	4.13	3.18	5.03
Oregon feed	7.20	4.30	3.60	2.69	4.17
Schuyler	7.55	4.33	3.71	2.79	4.34
G1	5.24	3.00	1.93	2.10	3.10
G4	4.34	3.33	2.05	1.75	2.77
G4a	4.90	2.98	1.68	2.14	2.98
G5	5.21	2.62	1.81	2.31	2.99
G9	6.26	2.98	1.94	2.02	3.16
G10	5.62	2.79	1.54	1.88	3.21
G11	5.62	3.10	1.56	1.89	3.32
G11a	5.01	3.06	2.03	2.13	3.26
G12	6.10	3.48	1.77	2.06	3.43
G15	5.94	2.76	1.50	2.06	3.24
G16	6.42	2.89	1.86	1.89	3.25
G18	6.00	2.56	1.37	1.71	2.94
Schuyler	7.38	4.99	3.25	2.51	4.27
G1b	5.60	1.87	2.20	2.07	NA
G10b	5.45	2.98	2.02	1.98	NA
G12b	6.13	2.80	1.68	2.05	NA
G16b	5.65	3.02	1.71	2.06	NA
Mean	6.05	3.27	2.17	2.16	3.42
F-value	9.56	8.42	63.53	6.30	11.34
CV	11.91	18.52	9.362	13.60	29.38
P-value	.000	.000	.000	.000	.000
LSD (0.05)	1.03	0.86	0.29	0.41	0.44

NA = Not Available

At Huntley in 1985-86 Schuyler yielded significantly higher than Winridge. The original generation (G1) was not significantly different than any of the other generations in overall 1985-87 mean yield (Table 4).

Kernel Weight

Natural selection on bulk populations has increased kernel weight in some environments and reduced kernel weight in other environments (Suneson et al., 1963, Mak & Harvey, 1982; Hockett et al., 1983). Kernel weights decreased in the later generations under these environmental conditions (Table 5 & 6). G1 had higher overall mean kernel weight than G15, G16, G18 (Table 6).

Table 5. Mean kernel weight of generations of CCXXVI and cultivars at five Montana locations in 1985-86.

Generation or Cultivar	Kalispell	Moccasin	Huntley	Bozeman
	-------Kernel Weight (g/1000 ----------			
Winridge	29.9	27.5	20.4	35.1
Oregon feed	33.8	31.3	19.8	35.6
Schuyler	34.2	27.7	23.7	34.8
G1	40.2	30.5	26.4	41.7
G4	39.2	30.5	26.6	39.8
G4a	39.1	28.8	26.9	38.9
G5	37.7	28.3	27.0	38.3
G9	38.1	29.8	24.8	36.8
G10	38.9	29.3	25.6	39.0
G11	39.4	29.4	24.0	40.6
G11a	38.9	27.6	24.4	39.4
G12	38.9	29.3	24.2	39.9
G15	37.8	27.2	25.1	37.8
G16	35.9	27.7	24.2	38.7
G18	38.7	29.2	23.3	37.2
Schuyler	35.5	28.2	23.1	35.5
Mean	37.2	28.9	24.3	38.1
F-value	14.05	2.50	10.91	3.06
CV	3.94	4.15	4.7	6.20
P-value	.000	.008	.000	0.002
LSD (0.05)	2.08	2.21	1.79	3.38

Table 6. Mean kernel weight of generations of CCXXVI and cultivars at four Montana locations in 1986-87.

Generation or Cultivar	Kalispell	Moccasin	Huntley	Bozeman	Mean 1985-87
	----------Kernel Weight (g/1000 ------------				
Winridge	33.8	31.7	31.5	28.3	29.8
Oregon feed	35.1	31.4	30.0	25.6	30.3
Schuyler	31.6	30.5	28.8	25.1	29.5
G1	37.5	32.6	34.9	29.6	34.1
G4	35.8	32.5	34.4	29.7	33.5
G4a	37.0	31.9	33.2	27.8	32.9
G5	27.0	32.5	33.1	28.7	32.7
G9	36.2	32.7	31.8	28.4	32.3
G10	36.8	33.1	32.7	26.1	32.7
G11	36.7	31.5	33.3	25.1	32.5
G11a	37.9	32.8	32.9	27.5	32.7
G12	37.8	31.8	32.6	25.3	32.5
G15	36.4	31.0	33.0	24.8	31.6
G16	35.9	31.0	32.0	25.5	31.4
G18	34.1	31.6	33.6	25.3	31.6
Schuyler	31.7	30.5	28.7	25.7	29.8
G1b	36.9	33.4	34.1	29.6	NA
G10b	37.1	33.3	33.4	29.1	NA
G12b	38.3	31.4	31.8	26.3	NA
G16b	35.8	31.3	32.1	25.4	NA
Mean	35.5	31.9	32.4	26.9	31.9
F-value	1.70	2.79	8.81	11.92	4.51
CV	11.79	3.30	3.46	3.83	12.76
P-value	.060	.000	.000	.000	.000
LSD (0.05)	5.91	1.49	1.59	1.46	2.12

NA = Not available

Because of the presence of male sterility and differential winterkill it is difficult to assess differences among generations in kernel weight. Since thousand kernel weight is affected by nutrients and water availability, one would expect a higher thousand kernel weight with a higher percent winterkill. With a lower percent winterkill more plants would survive and plants would have less resources available resulting in lower thousand kernel weight.

Plant Height and Heading Date

The original population (G1) was significantly shorter than G10, G11, G11a, G15, G1b at Kalispell in 1986-87 (Table 7).

Table 7. Mean plant height of generations of CCXXVI and cultivars at three Montana locations in 1986-87.

Generation or Cultivar	Kalispell	Huntley	Bozeman	Mean
	------------Plant Height cm ----------			
Winridge	114.1	79.2	69.7	87.7
Oregon feed	70.2	61.4	60.7	64.1
Schuyler	79.2	66.9	57.0	67.7
G1	90.5	77.3	64.3	77.3
G4	92.6	77.5	59.1	76.4
G4a	94.3	79.5	64.2	78.7
G5	99.8	77.3	64.0	80.4
G9	97.6	77.4	62.5	79.2
G10	94.4	78.6	60.0	77.7
G11	96.8	80.7	64.0	80.5
G11a	98.7	80.9	64.7	81.4
G12	98.2	80.1	64.7	81.0
G15	98.8	80.4	63.4	80.9
G16	99.9	79.0	62.0	80.3
G18	94.7	81.3	62.9	79.6
G1b	92.5	76.3	63.5	77.4
G10b	98.7	78.9	62.2	79.9
G12b	100.1	78.8	63.5	80.8
G16b	94.0	79.5	64.3	79.3
Mean	94.5	76.8	62.4	78.2
F-value	31.43	22.05	5.43	43.85
CV	3.36	3.06	5.19	3.78
P-value	.000	.000	.000	.000
LSD (0.05)	4.50	3.32	4.63	2.44

At Huntley in 1986-87 G1 was significantly shorter than G11, G11a, and G18. At Bozeman there were no differences in plant height among the generations. This was probably due to drought conditions which reduced plant height of all generations and check cultivars. G1 was shorter in overall mean plant height than G5, G11, G11A, G12, G15, G16, G10b, and G12b (Table 7).

Heading date of G1 was significantly earlier than G10, G12, and G16, at Marana, Arizona in 1985-86 (Table 8). In maturity date, G1 was earlier than G12. G1 also had a significantly longer grain-fill period than G10, G12 and G16. There were no differences among G10, G12 and G16 in grain-fill period.

At Bozeman in 1986-87; G1, G4, G4a, and G5, headed earlier than G9, G11, G11a, G12, G15, G16, and G18 (Table 9).

Table 8. Heading date, maturity date, and grain-fill period of selected generations of CCXXVI grown at Marana, Arizona 1985-86.

CCXXVI Generation	Heading date	Maturity date	Grain-fill period
	----Days from Jan 1----		Days
G1	70.4	118.0	47.6
G10	83.2	123.0	39.8
G12	86.6	127.9	41.3
G16	78.5	121.1	42.6
LSD (0.05)	6.9	5.7	3.9

Table 9. Mean heading date of generations of CCXXVI and cultivars vernalized and transplanted at Bozeman, MT in 1986-87.

Generation	Heading date
	Days from Jan 1
G1	208.7
G4	206.8
G4a	208.8
G5	207.7
G9	215.0
G10	213.4
G11	220.2
G11a	221.7
G12	218.7
G15	220.7
G16	223.0
G18	220.9
Mean	216.0
F-value	15.29
CV	7.57
P-value	.000
LSD (0.05)	5.20

Mean plant height (Table 7) and heading date (Tables 8 & 9) increased in the later generations indicating possible selection pressure for taller and later maturing plants. This agrees with other studies showing that natural selection favors taller and later heading plants (Bal et al., 1959; Mak & Harvey, 1982; Patel et al., 1987).

Snow Mold

Snow mold was moderate at Prosser, Washington, severe at Kalispell, and extreme at Bozeman (Table 10). Mean percent kill from snow mold was 33.6, 51.1, and 100.0%, respectively.

Differences were detected among the winter barley generations under moderate snow mold conditions at Washington, but under severe snow mold conditions at Kalispell differences among generations was less noticeable. Under extreme snow mold conditions at Bozeman, all barley and winter wheat checks were killed.

Bruehl et al. (1975) concluded that seeding date and subsequent plant growth stage at the time of infection is correlated with snow mold damage in the Northwest.

Table 10. Percent kill from snow mold of generations of CCXXVI at three locations in 1987-88.

Generation or Cultivar	Prosser Washington	Kalispell	Bozeman	Snow mold Selection Pressure
		Montana		
	------Percent kill---------			(a)
G1	42.2	58.3	100.0	none
G4	46.6	55.8	100.0	none
G4a	44.1	56.9	100.0	none
G5	36.9	50.1	100.0	none
G9	50.6	47.3	100.0	high
G10	49.4	75.0	100.0	none
611	27.2	49.8	100.0	none
G11a	20.0	53.3	100.0	none
G12	45.0	58.6	100.0	high
G15	51.9	61.5	100.0	none
G16	30.3	62.2	100.0	Moderate
G18	33.8	60.0	100.0	none
Schuyler	42.8	52.1	100.0	----
Daws	8.3	28.1	100.0	----
John	4.1	17.3	100.0	----
Lewjain	3.8	31.0	100.0	----
Mean	33.6	51.1	100.0	
F-value	10.5	4.1	--	
CV	30.45	28.04	--	
P-value	.000	.000		
LSD (0.05)	14.55	20.39	--	

(a) Based on Snow mold damage at Kalispell from 1969-82. (N. W. Agr. Exp. Sta. Ann. Reps. 1969-82).

Early seeding produces more vigorous and more resistant plants while intermediate sized plants are highly susceptible and late seeded plants often escape damage. Planting date at Kalispell and Bozeman was approximately 2 weeks later than at Prosser, Washington. This may partly explain why snow mold damage was more severe at Kalispell and Bozeman than at Prosser.

The winter wheats have been previously classified for snow mold resistance as follows: John = resistant, Lewjain = intermediate, and Daws = susceptible under Washington conditions (Dr. Clarence Peterson verbal comm). No differences were detected among winter wheats at any of the locations. John winter wheat was significantly lower (.05 level) in percent kill than Schuyler and all winter barley generations at Prosser and Kalispell. Lewjain had less snow mold damage than all winter barley generations except G5, G9, and G11 at Kalispell. Daws winter wheat was significantly lower in percent snow mold kill than all the barley generations except G11a at Prosser, and G9 at Kalispell. Although G11 and G11a had lower damage from snow mold than G1 at Washington, it is unclear whether there was significant improvement in resistance to snow mold in these generations.

Under severe conditions even the winter wheats classified as resistant were completely killed by snow mold. Clearly, development of winter wheat and barley resistant to snow mold has not proven totally successful.

Morphological Traits

Leaf width

There were no significant differences in leaf width at Moccasin in 1985-86 and 1986-87 among G1 and the other generations except G18 had narrower leaves than G1 (Table 11).

Table 11. Leaf width of generations of CCXXVI approximately six weeks after planting under field and greenhouse conditions.

Generation or Cultivar	Moccasin 1985-86	1986-87	Bozeman 1985-86	1986-87	Greenhouse Cold	Warm
	---------------Leaf width (mm)-------------					
Winridge	3.9	--	3.4	---	---	---
Oregon Feed	4.1	---	3.5	---	---	---
Schuyler	5.4	---	4.8	---	---	---
G1	5.8	4.9	5.2	5.8	3.9	5.4
G4	5.8	5.1	5.2	6.0	---	---
G4a	5.8	5.2	5.3	6.3	---	---
G5	5.7	5.2	5.3	6.2	---	---
G9	5.5	4.6	5.1	6.1	---	---
G10	5.6	4.6	5.3	6.2	3.7	5.6
G11	5.9	4.9	5.2	5.8	---	---
G11a	5.7	5.2	5.1	5.9	---	---
G12	5.8	4.9	4.8	5.9	3.5	5.4
G15	5.4	4.4	5.0	5.6	---	---
G16	5.5	4.8	4.9	6.0	4.0	5.4
G18	4.7	3.6	4.2	5.4	---	---
Schuyler	5.5	5.2	5.1	5.5	3.6	5.9
Mean	5.4	4.8	4.8	5.9	3.7	5.6
F-value	15.13	3.29	20.21	3.04	3.74	0.96
CV	5.82	10.16	5.68	5.39	5.91	7.33
P-value	.000	.002	.000	.005	.020	.495
LSD (.05)	0.445	0.700	0.391	0.454	0.296	NS

NS = Non-significant.

G18 was also significantly narrower than G1 at Bozeman in 1985-86. In the greenhouse under cold conditions (5C), G1 leaves were significantly wider than G12, but there were no differences among G1, G10 and G16. Under warm conditions (20C day/15C night) no differences in leaf width were detected. Evidently, natural selection did not affect mean leaf width in CCXXVI.

Number of leaves

There were no differences detected in number of seedling leaves among CCXXVI generations under field or controlled environment conditions (Table 12).

Table 12. Total number of leaves per plant of generations of CCXXVI under field and greenhouse conditions.

Generation or Cultivar	Moccasin 1986-87	Bozeman 1986-87	Greenhouse Cold	Greenhouse Warm
	----Number of leaves per plant----			
Schuyler	2.0	5.9	3.9	4.5
G1	2.1	6.6	3.6	5.0
G4	2.0	6.3	---	---
G4a	2.0	6.1	---	---
G5	1.9	6.1	---	---
G9	1.8	6.3	---	---
G10	2.0	6.5	3.7	4.9
G11	2.1	6.2	---	---
G11a	2.1	5.7	---	---
G12	1.9	6.0	3.6	5.0
G15	2.0	5.4	---	---
G16	1.7	6.5	3.6	5.4
G18	2.0	5.9	---	---
Mean	2.0	6.1	3.7	5.0
F-Value	1.12	1.29	6.10	1.93
CV	11.09	9.41	2.67	8.16
P-Value	.379	.266	.002	.195
LSD (.05)	NS	NS	0.13	NS

NS = Non-significant.

Subcrown Internode

There were no differences among barley generations in subcrown internode at Bozeman in 1986-87 (Table 13).

Table 13. Subcrown internode length of generations of CCXXVI under field and greenhouse conditions.

Generation or Cultivar	Bozeman 1986-87	Greenhouse Cold	Greenhouse Warm
	----Subcrown internode length (mm)----		
Schuyler	16.5	27.0	34.7
G1	12.5	30.7	37.1
G4	13.0	----	----
G4a	10.6	----	----
G5	12.5	----	----
G9	14.1	----	----
G10	7.9	29.9	33.3
G11	11.4	----	----
G11a	18.3	----	----
G12	12.5	35.6	32.3
G15	8.5	----	----
G16	10.7	32.4	33.7
G18	11.0	----	----
F-value	1.42	10.69	0.97
CV	41.74	6.96	9.29
P-value	.199	.000	.491
LSD (.05)	6.89	2.91	5.99

Coefficient of Variation's were high reflecting the difficulty in measuring this trait under field conditions. Fowler et al. (1981) found similar difficulties in accurately measuring traits such as subcrown internode, crown depth, and number of leaves per plant in the field trials.

Under cold conditions, G12 had a significantly longer mean subcrown internode than the other barley generations but the other generations had similar subcrown internode lengths. No differences were detected in length of subcrown internode under the warm conditions.

Leaf Length

There were significant differences among generations in leaf length at all field locations and under cold conditions but none were detected under warm conditions (Table 14). At Bozeman in 1985-86, G1 had longer leaves than G10, G11, G11a, G12, G15, G16 and G18 and Schuyler. In 1986-87 at Bozeman, G1 had longer leaves than G11, G12, G15, G18 and Schuyler. Under cold conditions, all generations and Schuyler had shorter leaves than G1. At Moccasin in 1985-86, G1 had longer leaves than G15, G18 and Schuyler. In 1986-87 at Moccasin, G1 had longer leaves than G18. This lack of difference in leaf length at Moccasin in 1985-86 and 1986-87 and under warm conditions may be due to lack of hardening conditions.

Generally, leaf length decreased in the later generations of CCXXVI. Under these environmental conditions, natural selection favored plants with shorter seedling leaves .

Table 14. Leaf length of generations of CCXXVI approximately six weeks after planting under field and greenhouse conditions.

Generation	Moccasin		Bozeman		Greenhouse	
or Cultivar	1985-86	1986-87	1985-86	1986-87	Cold	Warm
	-------------Leaf length (mm)---------------					
Winridge	63.8	----	81.7	----	----	----
Oregon Feed	74.8	----	98.9	----	----	----
Schuyler	50.2	----	76.0	----	----	----
G1	69.8	73.6	102.6	107.4	89.4	139.1
G4	73.9	79.4	98.2	107.8	----	----
G4a	69.5	72.8	96.0	103.5	----	----
G5	70.7	75.9	100.6	106.4	----	----
G9	71.8	70.6	98.3	108.1	----	----
G10	73.2	65.1	94.2	101.3	82.1	145.3
G11	65.5	75.4	94.5	95.9	----	----
G11a	69.5	72.7	92.3	105.2	----	----
G12	65.9	72.1	93.3	92.7	----	----
G15	64.4	65.6	92.2	95.3	69.6	143.2
G16	66.9	74.0	90.7	100.7	----	----
G18	56.7	54.8	87.0	83.8	74.2	153.2
Schuyler	53.6	68.9	79.6	84.3	54.6	138.4
Mean	66.2	70.8	92.2	99.2	74.0	143.8
F-value	15.05	2.70	15.19	9.93	51.0	0.54
CV	5.62	10.70	4.27	5.38	5.60	9.79
P-value	.000	.009	.000	.000	.000	.744
LSD(0.05)	5.30	10.87	5.61	7.65	5.56	NS

NS = Non-significant.

Winter Survival

Differential (.05 level) winter survival occurred at 7 of 9 locations in the 2 years (Tables 15 and 16). Mean winter survival ranged from 4.9 to 84.1% with the lowest winter survival occurring at Sidney in 1987. Coefficient of Variations (s/mean) ranged from 2.9 to 59.9% and the overall mean CV was 39.0%.

Table 15. Mean percent winter survival of generations of CCXXVI and cultivars at four Montana locations in 1985-86.

Generation or Cultivar	Kalispell	Moccasin	Huntley	Bozeman
	--------Percent winter survival---------			
Winridge	84.9	93.3	87.4	98.5
Oregon feed	59.8	90.4	84.3	43.0
Schuyler	54.0	76.9	80.1	39.7
G1	36.8	73.3	85.2	5.8
G4	51.8	63.8	87.4	10.1
G4a	44.9	73.4	80.7	23.0
G5	40.6	69.3	79.6	23.3
G9	48.0	77.3	82.5	2.7
G10	53.1	85.2	77.3	38.7
G11	38.4	72.7	82.0	29.4
G11a	46.1	79.6	85.4	26.4
G12	55.6	73.2	73.9	35.0
G15	46.2	82.8	80.6	31.0
G16	45.0	80.0	84.3	16.4
G18	72.0	65.2	73.1	26.9
Schuyler	58.6	89.8	74.0	40.2
Mean	52.2	77.9	81.1	30.6
F-value	2.14	1.61	.83	6.89
CV	31.52	59.88	53.62	22.57
P-value	.035	.105	.645	.000
LSD (0.05)	24.62	19.58	NS	23.75

NS = Non-Significant.

High CV's are often experienced when measuring winter survival because of the irregular nature of winterkill within a field. Fowler et al. (1976) reported mean CV's of 38% and a range from 4 to 81% in a series of trials. The overall winter survival average of the two Schuyler winter barley checks was 67.4 and 66.7% with no significant differences between the two checks at any location (Table 16).

Table 16. Mean winter survival percent of generations of CCXXVI and cultivars at five Montana locations in 1986-87.

Generation or Cultivar	Sidney	Kalispell	Moccasin	Huntley	Bozeman	1985-87 Mean
	----------Percent winter survival----------					
Winridge	87.3	92.8	84.9	95.2	79.9	89.5
Oregon feed	2.8	74.8	90.2	96.1	75.5	68.8
Schuyler	0.0	84.3	94.4	88.9	78.7	66.7
G1	0.0	82.3	66.2	53.0	47.9	50.4
G4	0.3	81.0	64.1	57.2	43.6	51.0
G4a	0.0	86.0	68.8	59.4	62.5	55.7
G5	0.0	88.8	70.4	62.9	68.7	56.4
G9	0.0	82.5	72.8	80.1	46.5	57.7
G10	0.0	86.7	90.0	80.1	79.3	65.9
G11	1.4	92.3	87.5	67.3	82.2	62.1
G11a	0.3	87.7	82.8	69.4	77.3	62.1
G12	1.0	80.7	78.6	77.3	78.2	61.7
G15	0.7	93.2	79.0	71.4	77.3	62.9
G16	0.3	80.0	67.8	67.8	71.1	59.8
G18	3.7	80.0	73.7	53.2	67.5	56.8
Schuyler	0.0	85.0	93.1	83.4	79.9	67.4
G1b	0.0	69.9	65.6	64.8	47.0	--
G10b	0.0	86.1	86.5	85.1	73.5	--
G12b	0.0	82.9	78.0	68.0	70.9	--
G16b	1.2	74.8	75.6	81.3	63.1	--
Mean	4.9	84.1	79.1	73.1	68.5	59.9
F-value	202.7	1.99	4.65	3.51	5.96	7.12
CV	2.88	54.49	42.44	50.97	32.41	48.83
P-value	.000	.022	.000	.000	.000	---
LSD (0.05)	3.86	12.38	12.38	19.68	14.71	8.83

Generally, there was a increase in winter survival from the early generations to the later generations of CCXXVI. G10, which originally had severe cold tolerance pressure, had the highest mean percent winter survival of all the generations. G10 had higher winter survival than G1 at Bozeman in 1985-86 and at Moccasin, Bozeman, and Huntley in

1986-87. The first generation (G1) had the lowest mean percent winter survival (50.4%) which was significantly lower (.05 level) than G10, G11, G11a, G12, G15, G16 and Schuyler. Generations 1 and 4 were lower in mean percent winter survival than G10, G11, G11a, G12 and G15. Generations 1, 4, 4a, 5, 9, 18 were significantly lower in mean winter survival than Oregon feed wheat.

Increased winter survival was obtained by using male sterile bulk populations and natural selection. However, there is still considerable difference in winterhardiness between winter barley and a hardy winter wheat. There was no difference in overall mean winter survival among the generation with the highest mean survival (G10), Schuyler, and the non-hardy winter wheat (Oregon Feed wheat). Winridge winter wheat, which is rated hardy under Montana conditions, was significantly higher in mean winter survival than Oregon feed wheat, Schuyler, and all of the winter barley generations (Table 16).

Finkner (1964) found that advances in winter survival made in one year were reversed in later years in bulk hybrid winter oat populations. This was theorized to be due to a lack of competitive advantage of the hardier types later in the growing season. In this study the last generation was similar in winter survival to the first generation.

Even after severe selection pressure, the non-hardy types were not eliminated from the population and quickly became a major component in this composite cross.

Winter survival of Schuyler and CCXXVI generations was still too low to warrant commercial production in areas with severe temperatures. This is evident at Sidney in 1986-87. Winter survival for all of the winter barley generations, Schuyler, and Oregon feed wheat was less than 5% while Winridge winter wheat had a winter survival of 87%. The low winter survival at this location was probably due to low temperatures (-27C) and lack of snow cover. The entire nursery was lost in 1985-86 at Sidney due to late planting and temperatures which reached -37 C.

Association of Morphological Traits with Winter Survival

There was no significant correlation with leaf number under field conditions and mean winter survival (Table 17).

Leaf width was not significantly correlated with mean winter survival percent under field conditions at Moccasin or Bozeman for 1985-86 and 1986-87 (Table 17).

Subcrown internode was not significantly correlated with mean winter survival percent under field conditions at Bozeman in 1986-87 or under cold conditions (Table 17).

Table 17. Correlation coefficients of various traits with mean winter survival percent.

	Moccasin		Bozeman		Greenhouse	
Trait	85-86	86-87	85-86	86-87	Cold	Warm
Leaf number	---	.21	---	.41	-.68	.53
Leaf length	.57*	.39	.65*	.57*	.66	.01
Leaf width	.39	.08	.32	.26	.65	-.71
Subcrown internode	---	---	---	.03	.30	.66
Coleoptile Length	---	---	---	---	-.15	-.02
Seedling Height	---	---	---	---	.65	.03

* Denotes significance at the .05 level.

Leaf length at Bozeman was highly correlated with mean winter survival in 1985-86 (r = 0.65*) and 1986-87 (r = 0.57). At Moccasin in 1985-86 and 1986-87 values were r = 0.57*,; and r = 0.39, respectively. The non-significant correlation at Moccasin in 1986-87 may have been due to lack of hardening conditions.

Under the cold controlled environment conditions the correlation for leaf length was r = 0.65 while the correlation for seedling height was r = 0.66. These correlations were not significant, possibly due to smaller sample size.

Fowler and Carles (1979) found that winter wheat seedling height was correlated (r = 0.61*,) with LT50 (lethal temperature which 50% of the plants die) in controlled freezing. Fowler et al. (1981), found a highly significant correlation between seedling height and LT50 and a negative correlation between seedling height and field survival of winter wheat.

The association between leaf length or seedling height with level of winter survival is also significant in these winter barley generations. The more winter hardy plants may channel metabolic energy into activities other than leaf growth.

Further investigations of the association between seedling height or plant erectness and winter survival may be beneficial in developing a selection method for cold hardiness of winter barley.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Male sterile facilitated recurrent selection resulted in significant changes in agronomic and morphological traits in CCXXVI. Changes in snow mold resistance were not consistent, but differences were found a few generations after selection pressure for snow mold. Level of winter survival as measured by the conditions of this experiment was increased, especially in the generations which experienced severe selection pressure.

Natural selection did not appear to improve mean population yield. The introgression of newer and higher yielding cultivars which have been developed since the release of this composite cross might have been helpful. Desirable gene combinations selected under certain conditions can be quickly diluted in these populations because of survival of non-hardy or non-resistant plants which also produce seed.

Commercial production of winter barley is still very risky in environments with low winter temperature or no snow cover. Schuyler winter barley and the most winter hardy generation had overall winter survival levels similar to a non hardy winter wheat. Individual plants with superior winterhardiness may be present in the generations with the lowest winter survival. Further investigations to determine winterhardiness of individual plants in these populations would seem to be warranted.

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