INHERITANCE OF SEMI-DWARFISM IN TWO LINES OF WINTER WHEAT AND THE ASSOCIATION OF OTHER CHARACTERS

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INTRODUCTION

Renewed interest by the plant breeder in the development of lines of winter wheat of shorter stature than those currently commercially grown can be attributed to at least two factors. The increased acreage of irrigated wheat in Oklahoma and the Southern Great Plains has accented the problem of producing wheat under conditions of high soil fertility and optimum soil moisture. Lodging results in losses of test weight, in grain yield, and sometimes ends in complete crop failures. Reducing the height of the straw, by certain breeding procedures, is one method of attacking the lodging problem. By developing high yielding and adaptable winter wheats with short, stiff straw the grower could greatly reduce one hazard in the production of winter wheat. Another reason for interest in short stature wheats is that recent combinations of the very short Norin wheats, introduced from Japan, with commercially grown United States varieties have produced some very remarkable yields of over 100 bushels per acre (42)[1]. Not only do these wheats contribute short stature, but they contribute factors for yield as well.

In a breeding program of wheat improvement, whether emphasis is on quality, maturity, greenbug resistance, height of straw or all of these, progress can usually be made most rapidly if the genetics of these characters are known. The mechanisms of inheritance determine, to a large

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[1] Figures in parenthesis refer to "Literature Cited" page 78.

extent, which breeding method is best suited to combine the character or characters in question into a commercially adaptable variety of wheat.

A study of height inheritance was undertaken with the primary objective of gaining some knowledge of the genetics of height in 2 lines of semi-dwarf wheat. The secondary objective was to determine the association of other plant characters with height, since it is desirable for the plant breeder to know how selection for reduced height affects other plant characters, which in turn may effect the yield potential of the short-statured types.

REVIEW OF LITERATURE

In an attempt to clarify types of dwarfism, Cook (6) suggested that brachysm be used to describe plants with shortened internodes with the remainder of the plant being somewhat normal. Dwarfism was suggested to be used for plants having a characteristic reduction of all plant parts. Vogel et al. (42) classified an introduced wheat variety from Japan as semi-dwarf, while crediting Watanabe as having previously classified it as dwarf. Since this variety was intermediate in height, between the very short varieties grown in the Pacific Northwest and the dwarf types, the semi-dwarf classification was felt to be more descriptive of stature. In reviewing the literature, no attempt is made to separate types of dwarfism since a range of heights from grass clumps of a few inches in height to plants of a height not easily distinguishable from tall types have been classified as dwarfs.

One Factor Difference

Culter (8) found a 9-inch dwarf plant in a field of Marquis wheat. Upon testing the progeny of several dwarf plants originating from 200 normal type plant selections he found approximately 25% dwarfs. He concluded that dwarfness was inherited as a simple Mendelian character with dominance for tallness.

According to Neethling (27), in an earlier article, dwarfs were reported in Gluyas Early wheat which segregated 3:1 with dwarfness as recessive. Later, some of the dwarfs segregated for tall plants, refuting the hypothesis of a single gene for dwarfness.

Two Factor Difference

Hayes and Aamodt (16) reported that the F_1 plants of a Kota-Marquis cross were normal. Dwarfs appeared in the F_2 generation in the ratio of approximately 3:13, dwarfs and normal plants. This fits a 2 factor hypothesis of an inhibitor and a dominant dwarf factor, one parent having both dominant factors while the other parent carries the recessive factors.

Goulden (14), using Hayes and Aamodt's (16) F_1 and F_2 material, studied the F_3 generation and made backcrosses of true breeding dwarf lines with parents. Results tended to confirm the two factor hypothesis when cytological evidence of irregular chromosome behavior was considered to explain the deviations from normal segregation occurring more frequently than would be expected by chance alone.

Stewart and Tingey (38) reported the appearance of dwarf plants at the approximate ratio of 3:13, dwarfs to tall in a Marquis X Federation cross. The F_3 data confirmed the hypothesis that one dominant factor for dwarfing (Dd) and a dominant inhibiting factor were acting to produce dwarfs. The number and genotypes of the F_2 and their reaction in the F_3 were reported as follows:

1 IIDD (Tall in F_2; Tall in F_3)
2 IIDd (Tall in F_2; Tall in F_3)
2 IiDD (Tall in F_2; 3:1 in F_3)
4 IiDd (Tall in F_2; 13:3 in F_3)
1 IIdd (Tall in F_2; Tall in F_3)
2 Iidd (Tall in F_2; Tall in F_3)
1 iidd (Tall in F_2; Tall in F_3)
1 iiDD (Dwarf F_2; Dwarf F_3)
2 iiDd (Dwarf F_2; 3:1 in F_3)

Clark and Quisenberry (5), studying Marquis X Kota F_2 and F_3 generations, observed segregation for dwarf and normal plants. Inheritance was explained on the basis of 2 factor pairs.

Stewart and Bischoff (36), using (Sevier X Dicklow) X Dicklow, failed to show segregation groups in the F_2 other than dwarfs. Data from F_3 progenies supported the postulate that 2 genes were involved; a dominant dwarfing factor (Dd) and an inhibitor (Ii).

Tingey (40) found that in dwarf plants the second and third internodes were greatly reduced in length. Upper internodes were shorter than in normal plants. Studying more than 50 strains of wheat and classifying plants as dwarf or tall, he found one tall X dwarf wheat cross in which there was incomplete dominance and a progressive range of height. Most of the crosses studied confirmed the 2 factor inhibitor theory. Other factors than those for dwarfing were thought to effect length of culm.

According to McMillian (26), Waterhouse recorded many cases of the F_1 plants being grass clumps, while crossing a great many different varieties of wheat. Most of the F_2 data fit a 13:3 ratio, although 3 crosses fit a 15:1 ratio more closely.

Everson et al. (9) found the F_1 of the cross Norin 10 - Brevor - 14 Sel. X Burt to be intermediate in height. Results confirmed the hypothesis that the parents differed by two genes; a dwarfing gene (D), and a dwarfism inhibitor (I), which when present produces tall plants.

Three Factor Difference

Waldron (43), using a Marquis-Kota cross, found ratios of segregating F_3 lines, which suggested a three gene difference, to explain the occurrence of dwarfs. His explanation of gene action was that both D, a factor for dwarfness, and A, an activating factor had to be present in the dominant condition to produce dwarfs. N, a factor for normal height, was dominant over all the other genotypes. Only the nnA_D_ types produced dwarfs. The dwarf plants studied ranged from 9 to 43 cm. Classification of some dwarfs was based on a bimodal curve. Above 9 cm was considered normal, while below was considered dwarf.

Florell (10) found a 3 factor difference between varieties in an inheritance study of dwarfs occurring in the F_2 of Jenkins X Quality and Jenkins X Marquis wheat. Backcrosses of (Quality X Jenkins) X Jenkins and (Jenkins X Marquis) X Marquis were also studied. He explains his results by assuming that two dominant factors D_1D_2 are complementary for dwarfs, while N, a factor for tallness, is dominant over D_1D_2. Normal types would be $NND_1D_1D_2D_2$, $nnd_1d_1d_2d_2$, $NND_1D_1d_2d_2$, and $nnd_1d_1D_2D_2$. The genotype $nnD_1d_1D_2d_2$ would be dwarf. Both D_1 and D_2 must be present to produce dwarfs.

Several years later Florell and Martin (11), using crosses made between tall varieties, found the F_1 plants to be dwarf, ranging in height from 15 to 17 inches. Expected ratios of normal and dwarf plants in the F_2 and F_3 generations verified the assumption that parents differed by 3 genes acting on a complementary factor basis. They state that "a second dwarfing factor, E, may be assumed, which with the established D factor, is dominant over I. The E factor alone, unlike the dominant D, is not capable of producing dwarfs in the absence of I."

Everson et al. (9) observed in the cross Norin 10 - Brevor 1978 (a sister selection of Norin 10 - Brevor - 14 Sel) X Burt that all F_1 plants were dwarf (3 to 6 inches in height). Parents were assumed to be differentiated by three gene pairs. Genotypes were designated as follows: Burt, DDIIee; Norin 10 - Brevor 1978, ddiiEE and Norin 10 - Brevor - 14 Sel, ddiiee. E was assumed to inhibit the expression of the

(I) inhibitor producing dwarfism.

Other Factor Differences

Pao et al. (28), studying Quality and P165 wheat, found normal F_1 plants and a segregation of 4.8:1 tall to dwarf plants in the F_2 generation. Three complementary factors, 2 duplicate factors and an inhibitor were assumed to be operating. The presence of all 3 complementary factors or a substitute of its respective duplicate was necessary for dwarfism. A recessive of one of these 3 essential factors would produce normal height and the presence of an inhibitor with the 3 essential factors produced normal plants. It was suggested that dwarfism may be inherited similar to grain color.

Freeman (12) measured the height of the tallest head of the varieties Algerian, Red Algerian, Baart and Sonora. In the Red Algerian X Sonora cross, the mean height of the F_1, F_2 and F_3 generations were taller than the tallest parent, while in the Red Algerian X Baart wheat cross the F_1 was intermediate. In no case was the coefficient of variation of the F_2 and F_3 generations significantly higher than the most variable parent. There was a distinct lowering of the variability of the tall cultures. He explained this by assuming that factors, which suppress variability either partially or completely, mask the effect of heterozygosity of the F_2 and F_3 progenies; both averaged as tall as or taller than either parent.

Clark (3), using Kota X Hard Federation, found the mean height of the F_3 generation to be nearer the shorter Hard Federation, while the F_2 were closer to Kota. He explained this by concluding that tallness is partially dominant, but due principally to heterosis and easily affected by environment.

Clark and Hooker (4) studied plant height of the F_2 and F_3 generations of Marquis - Hard Federation Crosses excluding dwarfs. Height was concluded to be inherited in intermediate degrees, having no greater significant variability than the parents. This was explained by assuming multiple genetic factors.

Neethling (27) discussed the inheritance of dwarfing in wheat. He gave evidence that dwarfing is inherited with relatively few genes controlling the height of the plant in contrast to the idea that inheritance is quantitative in nature and that a considerable number of factors are contributing to height of the plant.

Stewart and Heywood (37), while studying correlations in wheat, found that height groups could not be separated in the F_2 generation of a cross Hard Federation X III C-18.

An intensive study of dwarfing in wheat was made by McMillian (26). Results obtained from a large number of crosses were explained by assuming four pairs of interacting genes. 1) Gg_G must be present for grass clumps to be produced; g is normal. 2) Ii_I in the absence of A_B_ inhibits the expression of G producing normals; i has no effect on G. 3) Aa and Bb, two pairs of complementary genes, inhibit the action of I when both capital A and B are present. ABIG genotypes produce grass clumps, while a and b have no affect on I. McMillian also submitted the data reported by Waterhouse (44), Waldron (43), Goulden (14), Florell (10) and Thompson (39) to a four factor hypothesis to test whether these data could be explained also by using this hypothesis. He concluded that, with the possible exception of Goulden's data, the hypothesis advanced was suitable to explain the results of these 5 investigators; if assumptions were made concerning semi-lethals and differential viability.

Chromosome Analysis

Sears (32) reported genes for normal internode vs. short internode length occurring on the left arm of chromosome II. Also genes for normal height vs. reduced height were reported on chromosome III.

Kuspira and Unrau (21) found eight different chromosomes which gave significantly different height responses by using Chinese Spring as the recipient variety for Thatcher, Hope and Timstein selections of substitution lines. Apparently 8 genes or groups of genes were found to affect height in these substitution series.

Findings in Other Crops

According to Powers (29), Keeble and Pellew studied the genetics of plant height in peas. A short plant having a large number of internodes was crossed with a tall plant having few internodes. Internode number and internode length were found to be controlled by different pairs of genes.

Powers (29) used the component and partitioning method of studying weight per fruit in tomatoes. Locule number and weight per locule (components of weight per fruit) were studied separately. Genes controlling locule number and weight per fruit were found to be acting in opposition to one another. This method of analysis clarified the complex inheritance of weight per fruit.

Zimmerman (46), working with castor beans, studied the relationship of internode number to various agronomic characters. He found an interaction of internode number and plant height. A dwarf-internode gene was thought to suppress internode elongation, while other genes were responsible for internode elongation.

Association of Other Characters with Plant Height

Love (22) reported a correlation coefficient of 0.294 ± 0.032 for height of plant and yield using a pure line of wheat. Correlation of height of plant and average weight of grain was found to be 0.278 ± 0.033.

Meyers (25) studied variations and correlations in Dawson's Golden Chaff, finding that tall plants produced heavier kernels than shorter ones. Correlation coefficients were found to be higher when computed on plots grown on poor soil.

Roberts (30) investigated 3 purelines of wheat and reported correlation coefficients between culm length and the characters: number of grains per spike, spike length, and number of culms per plant to be 0.6684, 0.2922 and 0.2810, respectively.

Gaines (13), using a bearded, long-headed, red grained, winter wheat crossed with a beardless, club-headed, white wheat of spring growth habit, found beard characteristics and head length to be independently inherited. Club-headed plants were 8 inches shorter on the average than the long-headed plants. Straw length was more variable than either beards or head length.

Vestergaard (41) associated several plant characters using a plant having loose, elongated, ears selected from 40 pure lines of "Abed" wheat having compact heads. This plant segregated producing 27 compact and 27 loose-eared plants. Loose-eared types were found to have fewer tillers, longer ears, less number of spikelets and were taller than the compact-ear type.

Arny and Garber (1), using Marquis wheat over a 4-year period, found consistent positive correlations between average height of culms and weight of kernels. An increase in culm length was accompanied by a corresponding increase in yield of kernels. Correlation of number of culms and average height of plant was always low. A substantial correlation was found between average height and average weight of kernels, and a moderate correlation between average height of culm and total length of spike.

Clark (3), using Kota and Hard Federation crosses, did not find date of heading to be correlated with height under favorable growing conditions of the F_2 generation. Under droughty conditions there was a significant correlation. Early plants tended to be short while later plants were tall. Height was found to be significantly positively correlated with yield in the F_2 and F_3 generations. Heights of F_2 plants were found to be highly correlated with the F_3 lines the following year.

Hume et al. (18), using Marquis wheat, found length of culm correlations with yield to be 0.0960 ± 0.0418; -0.0132 ± 0.412; -0.0618 ± 0.0395; and 0.0129 ± 0.0421 during four growing seasons. Correlations between length of culm and head was found to be 0.4822 ± 0.0323 and -0.0061 ± 0.421 during two seasons.

Clark and Hooker (4) reported correlations of 5 plant characters in Marquis - Hard Federation crosses. A study of heading, ripening, fruiting, height and crude protein revealed plant height to be most highly correlated with yield. Positive height correlations with heading period (from heading to fruiting) were not considered to be very important. Significant positive correlations were found between ripening period and height. Plant height was found to be significantly correlated one year with another.

Correlation studies by Sprague (34) revealed culm length to be significantly correlated with spike length, but correlation coefficients fluctuated from 0.308 to 0.710. Culm length was found to be significantly correlated with number of fertile spikelets per spike in 4 out of 6 tests. Grain yields per unit area for Nebraska No. 60 wheat showed a low positive correlation with culm length. Correlations were computed for 3 locations, which resulted in significant correlations of length of culm and average weight per kernel at only 2 locations. Culm length correlations were not stable at all locations. Length of culm was found to be more highly correlated with grain yield per spike in the variety Kanred, than in the variety Red Rock.

Stewart (35) found evidence of segregation for height of plant in the F_2 generation of a cross Federation X Sevier. The nature of inheritance was not determined. Using Blakeman's test of linearity, significant correlations were found between the following characters: spike density and length of longest culm, spike density and number of culms, spike density and total culm length, spike density and awn classes, spike density and thickness of neck, and awn classes and length of longest culm. Correlations of length of longest culm and total length of culms, as well as length of longest culm and number of culms, were thought to be physiological rather than genetic.

Hayes et al. (17), using both simple and partial correlations in 50 spring wheat varieties, found plant height and heading date to be positively significantly correlated. Using 27 lines of winter wheat, significant positive correlations were found between height and yield. Only low correlations were found between heading date and plant height.

Stewart and Heywood (37) reported correlations of several characters in a cross Hard Federation X III C-18. Culm length and spike density was found to have some association, but complex. Culm length and number of culms was not very significantly correlated.

Bridgford and Hayes (2) studied 61 varieties of spring wheats, using partial correlations holding constant date of heading, weight of 1000 kernels, plumpness, number of heads per row and number of kernels per spike, found a very high correlation of height and yield (0.56 ± 0.06). A negative correlation was found between date of heading and height (-0.61 ± 0.05); more than 3 times the probable error. Weight of 1000 kernels correlated with height was not significant. They found no significance of height and number of heads per row.

Florell (10) found in a cross with Little Club that lax-spike dwarf plants were much more numerous than club-type heads in his backcross material. Spikes of the lax dwarfs were usually extremely lax, while spikes of club dwarfs were intermediate or long club.

Rosenquist (31), studying F_1 plants, found plant height associated with yield. Of 19 crosses in which the F_1 was taller than either parent, 14 yielded higher than either parent.

Granhall (15) studied height of straw, culms per plant, and grain weight per plant in a Hindi X Extra-Kolben II cross and found a significant difference in height of F_2 bearded homozygous plants, F_2 half-bearded heterozygous and F_2 beardless homozygous plants. The mean height of the F_2 plants was higher than the mean of both parents.

Jackson (19) found height and heading date associated in F_3 families of a Triumph X C.I. 12516 cross. The chi-squared test for independence was significant at the 1 percent level.

Mekasha (24) studied the morphological characteristics of a number of semi-dwarf and tall-growing lines of winter wheat grown at 3 locations. An inverse relationship was found between height of lines and yield, with the negative correlation coefficient significant at the one percent level. The number of tillers per one foot of plot was also found to be significantly negatively correlated with yield. Number of spikelets per head were found to be greater in Seu Seun derived semidwarfs than Pawnee or Cheyenne, but fewer spikelets per head were found in the Norin 16 derived lines. Head length and number of spikelets per head were not found to be significantly correlated with yield when the 3 locations at which the plots were grown were considered.

MATERIALS AND METHODS

Experimental Materials

The Small Grains Section of the Department of Agronomy at Stillwater received 6 selections of Norin 10 - Brevor from The State College of Washington, all of which had outyielded commercially grown wheat varieties in the Pacific Northwest[2]. Two individual plant selections from one of the 6 selections received were used, along with a commercially adapted local variety, in this study.

The origin of the semi-dwarf wheat used in this study is the result of an original cross made at The State College of Washington between Norin 10, a very short wheat introduced from Japan by Dr. S. C. Salmon (42), and Brevor, also a short winter wheat commercially adapted in the Pacific Northwest.

Norin 10 - Brevor selection Stw. 554382-2[3] and Norin 10 - Brevor selection Stw. 554387-20 are very similar in all morphological characteristics. They are white chaffed, awned, amber seeded, and of winter growth habit. Both are of medium maturity under field conditions and are extremely susceptible to prevalent races of leaf rust in Oklahoma. The heads tend to be long, and culms short. Beaks are medium to short

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[2] Correspondence of Dr. A. M. Schlehuber with Dr. A. O. Vogel, September 15, 1953.

[3] Stillwater selection number.

in length with shoulders narrow and wanting. Plant height is about 60% of the height of Concho C.I. 12517[4]. Both lines were selected from a head row nursery grown at Stillwater in 1954. Individual plant selections were made in 1955.

Concho C.I. 12517 is a selection of the cross Comanche X Blackhull - Hard Federation. It is a bronzed chaff, awned, red seeded variety of winter habit. It is of a medium maturity with resistance to the more important races of bunt, and has some leaf rust resistance. The variety is medium-tall with mid-dense heads. The beak length is medium-long and shoulders are wide and oblique. The original cross and early selections, which resulted in Concho, were made at the Southern Great Plains Field Station, Woodward, Oklahoma.

The parents, F_1 and F_2 generations of two crosses, Stw. 554387-20 X Concho and Concho X Stw. 554382-2, were grown in 1957 and the F_1, B_1, F_2 and F_3 generations of the two crosses were grown in 1958. The populations grown during these two years, and the number of seed planted and emerged are listed in Tables 1 and 2.

Experimental Methods

This study was continued over a period of 2 growing seasons, and the material used was subjected to two very different environments; that of greenhouse conditions and that of field conditions.

F_1 seeds of two crosses, 55 X 64a and 55 X 57b, each having remnant F_0 seed and parent seed available, were chosen for the 1956-57

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[4] Accession numbers are those of the Division of Cereal Crops and Diseases, U.S. Department of Agriculture.

Table 1.—Number of parent and hybrid seed planted and emerged in field and greenhouse studies on inheritance of height and other character associations conducted on the Agronomy Farm, Stillwater, Oklahoma during the 1957 crop season.

Variety or Cross	C.I. Sel. or Cross No.	Ghse Sown	Ghse Emer.	Field Sown	Field Emer.
Concho	12517	30	30	34	34
Norin 10 - Brevor	Stw. 554382-2	15	14	-	-
Norin 10 - Brevor	Stw. 554387-20	15	15	34	34
(Concho X Stw 554382-2) F_1	55 X 64a	3	2	-	-
(Stw 554387-20 X Concho) F_1	55 X 57b	3	3	-	-
(Concho X Stw 554382-2) F_2	55 X 64a	113	101	-	-
(Stw 554387-20 X Concho) F_2	55 X 57b	-	-	309	305

Table 2.—Number of parent and hybrid seed planted and emerged in field and greenhouse studies on inheritance of height and other character associations conducted on the Agronomy Farm, Stillwater, Oklahoma during the 1958 crop season.

Variety or Cross	C.I. Sel. or Cross No.	Ghse		Field	
		Sown	Emer.	Sown	Emer.
Concho	12517	42	21*	160	154
Norin 10 - Brevor	Stw 554382-2	-	-	160	155
Norin 10 - Brevor	Stw 554387-20	42	21*	-	-
(Stw 554387-20 X Concho) F_1a	57 X 52a	21	21	-	-
(Concho X Stw 554387-20) F_1b	57 X 48g	21	21	-	-
Concho X (Stw 554387-20 X Concho F_1) B_1	57 X 50d	21	20	-	-
Stw 554387-20 X (Stw 554387-20 X Concho F_1) B_1	57 X 54g	21	20	-	-
(Stw 554387-20 X Concho) F_2c	55 X 57b	84	42*	-	-
(Stw 554387-20 X Concho) F_3	55 X 57b	798	399*	-	-
(Concho X Stw 554382-2) F_1c	57 X 47a, b, c, f	-	-	62	60
(Stw 554382-2 X Concho) F_1d	57 X 51c, g, h, n, o	-	-	80	75
Concho X (Concho X Stw 554382-2 F_1) B_1	57 X 49e, h, i, j, o	-	-	80	78
Stw 554382-2 X (Concho X Stw 554382-2 F_1) B_1	57 X 53c, d, e, f, h, o	-	-	79	77
(Concho X Stw 554382-2) F_2a	55 X 64a	-	-	120	114
(Concho X Stw 554382-2) F_2b	55 X 64a	-	-	120	115
(Concho X Stw 554382-2) F_3	55 X 64a	-	-	2000	1960

* Plants remaining after thinning.

plantings. F_2 cross 55 X 57b along with parents was seeded in the field using six-inch spacings within rows and 12-inch spacings between rows. The nursery received 3 overhead sprinkler irrigations during the fall of 1956-57. No further irrigations were needed throughout the remaining growing season. Soil analysis/5 of top soil indicated a pH of 4.6, 11 pounds per acre available phosphorus, 292 pounds per acre available potassium and 2.05 percent organic matter. One hundred forty pounds per acre of 10-20-0 fertilizer was top-dressed over the nursery on November 10, 1956.

The greenhouse plantings included the seeds from the F_1 plant of cross 55 X 64a along with remnant F_0 and parent seed from both crosses 55 X 57b and 55 X 64a. The F_2 plants of the cross 55 X 64a were arranged with parents, after emergence, into a randomized block design with blocks extending the length of the greenhouse bench. Parents were randomized within each block. Supplemental light was provided the plants about 5 weeks prior to heading. An automatic timer was set to interrupt the darkness for 2 hours each night. Lights were turned off at heading initiation and parents were moved for crossing. The F_0 and parent seeds were planted at 3 week intervals to provide a longer period of heading and to facilitate crossing.

The "approach method" of crossing, described by Curtis and Croy (7), was used to provide ample quantity of seed for subsequent use. Backcrosses were made to both parents using the pollen of the F_1 plants. The original crosses and reciprocals of both lines were made again to provide F_1 seeds for the 1957-58 plantings. Determination of whether

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/5 Soil analysis performed by Oklahoma State Soil Test Laboratory. Dr. Robert M. Reed, Soil Scientist in charge.

plants were crosses or selfs in the F_1 was easily established by height, beak, shoulder shape, and chaff color (chaff color expressed in the field). Possible selfs in the backcrosses were more difficult to positively identify, because of the segregation and recombination of characters. A genetic marker was not found which would positively identify a cross or self in the backcross populations. Of all F_1 seed grown, where identification of selfs was easily determined, only one was found.

All height measurements were made using a centimeter scale. Plants in the field and greenhouse were tagged as the first 3 tillers of each plant headed and the date of exertion was recorded. After first pulling the plants, internode lengths of the tagged tillers as well as the total length of the tillers remaining were measured from the crown to the tip of the spike, excluding awns. Hybrid plants were harvested individually while parent plants were bulked within respective lines after harvesting the crossed seed.

In 1957-58, plants seeded in the greenhouse were arranged in a randomized block design. Parents, F_1, F_2, F_3 and backcrosses were designated by line numbers and randomized within each block. Three separate greenhouse benches were used as replicates. Seeding was accomplished on October 31. All replicates were given the same treatment throughout the growing season, whether watering, treating for insects or controlling mildew. Each pot received 1 gram of 10-20-10 fertilizer as temperatures in the greenhouse were raised to near 70° from the cool vernalizing temperatures of from 35° to 50° F.

Clay pots of 6 inches in diameter were used in all greenhouse plantings. A soil mixture of 3 parts Kirkland loam, 1 part sand, 1 part peat moss and 1 part sterilized manure was used. Seeds were planted at a depth of about one-half inch.

Ten measurements were made on each plant grown in the greenhouse in 1957-58. Plant height measurements were made on the first tiller to head and are the sum of the components of head length, peduncle length and culm length (less peduncle). Peduncle length measurements were made in cm from base of spike to first node below spike. Culm length (less peduncle) measurements were made in cm from the first node below the spike to soil level. Head length measurements in cm were made from base of spike to the top rachis node. Heading date was recorded in days from February 1 on the day the base of spike was exerted to uppermost auricles. Ripening date was recorded in days from March 1 on the day kernels were found to be firm to the pinch. Tiller number consisted of counting the seed producing tillers. Seed weight was recorded in grams for each plant. Spikelet number per spike was recorded, using the first head to exert for the count. Fertile as well as unfertile spikelets were counted. This is also a measure of rachis internodes, since there is one spikelet per rachis internode excluding the basal spikelet. The above-ground node number was recorded using the first head to exert for the count. Node number is synonymous with internodes elongated if peduncle is not considered.

On some of the greenhouse material, it was very difficult to establish limits for peduncle length and head length. Rachis internodes elongated very abnormally, sometimes producing a miniature flag-leaf where a basal spikelet normally appears. The criterion for measurements of these abnormal plants was as follows: the peduncle was considered as the internode appearing above the last normal flag-leaf; the remaining was classified as head length.

Field plantings were similar to greenhouse plantings, except for endeavor on a much larger scale. Two replications were used in the field and lines were randomized within each replication. Ten-foot rows were used with 1 foot between plants in a row and 1 foot between rows. An awnless variety of wheat was used to transplant seedlings where plants failed to emerge. Space planted guard rows were seeded on all sides of the plots to minimize any border affect on plant height. Notes taken in the field did not include ripening date, tiller number or weight. Heading date was recorded as days from May 1. Otherwise, measurements were recorded using the same methods described for the greenhouse material.

Correlation coefficients were computed on each population grown, both in the field and greenhouse for each replication. Replicate correlation coefficients were then pooled. Degrees of freedom for test of significance are based on n-2-(reps) degrees of freedom. The number of observations in each line are recorded in App. Tables 1-8. Formulas used in the computations of theoretical means and standard deviations of means are shown in Table 3. Tests of significance are those used by Snedecor (33).

All plots, during the two years of this study, were grown on the Agronomy Farm, Stillwater, Oklahoma

Table 3.--Formulas used in calculating theoretical means and standard deviation of means.

Populations	Theoretical means	Theoretical standard deviations
B_1 to P_1	$\bar{X}_{B_1P_1} = (\bar{X}_{P_1} + \bar{X}_{F_1})/2$	$\bar{s}_{B_1P_1} = \sqrt{(\bar{s}_{P_1}^2 + \bar{s}_{F_1}^2)/4}$
F_1	$\bar{X}_{F_1} = (\bar{X}_{P_1} + \bar{X}_{P_2})/2$	$\bar{s}_{F_1} = \sqrt{(\bar{s}_{P_1}^2 + \bar{s}_{P_2}^2)/4}$
F_2 (1)[1]	$\bar{X}_{F_2} = (\bar{X}_{P_1} + 2\bar{X}_{F_1} + \bar{X}_{P_2})/4$	$\bar{s}_{F_2} = \sqrt{(\bar{s}_{P_1}^2 + 2\bar{s}_{F_1}^2 + \bar{s}_{P_2}^2)/16}$
F_2 (2)[2]	$\bar{X}_{F_2} = (\bar{X}_{B_1P_1} + \bar{X}_{B_1P_2})/2$	$\bar{s}_{F_2} = \sqrt{(\bar{s}_{B_1P_1}^2 + \bar{s}_{B_1P_2}^2)/4}$
F_3 (1)[1]	$\bar{X}_{F_3} = (3\bar{X}_{P_1} + 2\bar{X}_{F_1} + 3\bar{X}_{P_2})/8$	$\bar{s}_{F_3} = \sqrt{(3\bar{s}_{P_1}^2 + 2\bar{s}_{F_1}^2 + 3\bar{s}_{P_2}^2)/64}$
F_3 (2)[2]	$\bar{X}_{F_3} = (\bar{X}_{P_1} + 2\bar{X}_{F_2} + \bar{X}_{P_2})/4$	$\bar{s}_{F_3} = \sqrt{(\bar{s}_{P_1}^2 + 2\bar{s}_{F_2}^2 + \bar{s}_{P_2}^2)/16}$
B_1 to P_2	$\bar{X}_{B_1P_2} = (\bar{X}_{F_1} + \bar{X}_{P_2})/2$	$\bar{s}_{B_1P_2} = \sqrt{(\bar{s}_{F_1}^2 + \bar{s}_{P_2}^2)/4}$

[1] 1st estimate.

[2] 2nd estimate.

RESULTS AND DISCUSSION

Internode Pattern of Parents

Internode pattern measurements on the first 3 tillers to head for parents used in this study are presented in Fig. 1. The average number of internodes for the semi-dwarf lines and for Concho are the same. Both parents grown in the greenhouse have 5, while the field-grown parent lines have an average of 6 internodes. This internode number for the greenhouse parents are in accord with Johnson's (20) findings, while the internode number for the field averaged one greater.

Length of individual internodes are markedly affected by conditions of the two environments. Internode elongation of the semi-dwarf lines apparently are not affected as much as is Concho by the change in environments. The peduncle length of Concho increased in length from approximately 28 cm to 45 cm, while the semi-dwarf lines increased from approximately 18 cm to 20 cm.

The pattern of internode elongation shows that, without exception, internodes from the base of the tiller to the head are progressively longer. The peduncle contributes a major portion of plant height in Concho, while the peduncle of the semi-dwarf lines contributes a lesser amount.

Components of Height--Analysis of Means

In a study of a character which tends to be quanitative in nature,

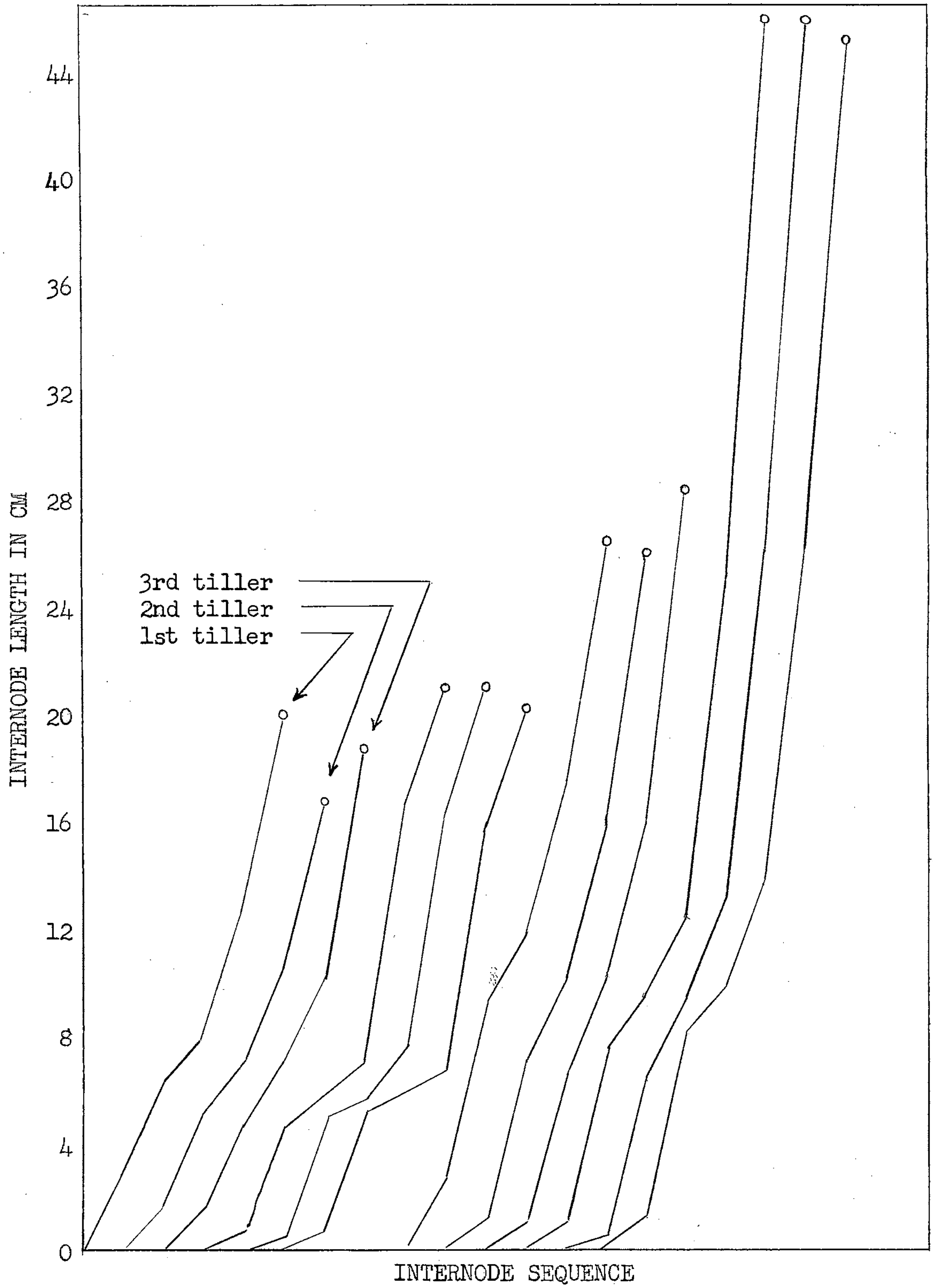

Fig. 1.—Internode pattern of first 3 tillers to head of parent lines grown in greenhouse and field. Groups of 3 tillers from left are: Stw 554382-2 (Ghse), Stw 554387-20 (Field), Concho (Ghse) and Concho (Field).

that is, those in which overlapping of classes occur, it is desirable to not only study the character as a whole, but also to divide the character into several components. An examination of each component clarifies the genetic relationship of each component character to the whole, as Powers (29) has pointed out.

Plant height in wheat is usually measured from the soil level to the apex of the head. This measurement consists of the 2 components, head length and culm length. Culm length can be further divided into component lengths of specific internodes. Since the 1956-57 data showed that the peduncle contributed a very large portion of plant height (Table 3), the components into which plant height was divided are culm length (less peduncle), peduncle length, and head length.

Culm length (less peduncle)

The means and standard deviations of means for culm length (less peduncle) are presented in Table 4 for 7 populations grown in the field. The mean culm length of Concho is 46.6 cm; while the mean culm length for the semi-dwarf (Stw. 554382-2) is 33.1 cm. The F_2 mean is intermediate between the parents, and both backcross means fall between the F_2 and the recurrent parent. The F_1 and F_3 means are both greater than the B_1 to Concho.

Table 5 presents the means and standard deviation of means for culm length (less peduncle) for 7 populations grown in the greenhouse. The means of culm length increase in order from the shortest (Stw. 554387-20) to the tallest (Concho). This suggests that genes controlling culm length are additive in nature, and little or no dominance of genes exists.

Table 4.--Obtained and theoretical means and standard deviation of means, along with differences and standard deviations of differences for the component characters of plant height measured in the field.

Character and Population	Means and standard deviations of means			
	Obtained		Theoretical	Difference
Culm Length (less peduncle)				
Concho	46.6±0.471		-----------	----------
B_1 to Concho	42.1±0.780		44.7±0.398	2.6±0.876
F_1d	42.8±0.641		40.0±0.304	2.8±0.710
F_2b	40.9±0.716	(1)*	41.3±0.273	0.4±0.766
		(2)*	39.9±0.599	1.0±0.933
F_3	43.4±0.194	(1)	40.5±0.523	2.9±0.806
		(2)	40.4±0.313	3.0±0.369
B_1 to Stw. 554382-2	37.6±0.909		38.0±0.374	0.4±0.983
Stw. 554382-2	33.1±0.386		-----------	----------
Peduncle Length				
Concho	45.4±0.332		-----------	----------
B_1 to Concho	41.2±0.621		41.4±0.251	0.2±0.670
F_1d	37.3±0.376		34.2±0.188	3.1±0.420
F_2b	36.0±0.587	(1)	35.8±0.163	0.2±0.609
		(2)	35.5±0.445	0.5±0.737
F_3	36.0±0.169	(1)	35.0±0.105	1.0±0.199
		(2)	35.1±0.721	0.9±0.740
B_1 to Stw. 554382-2	29.7±0.638		30.2±0.653	0.5±0.913
Stw. 554382-2	23.0±0.178		-----------	----------
Head Length				
Concho	9.6±0.018		-----------	----------
B_1 to Concho	10.0±0.028		10.2±0.018	0.2±0.273
F_1d	10.7±0.030		10.8±0.015	0.1±0.034
F_2b	10.4±0.028	(1)	10.8±0.013	0.4±0.031
		(2)	10.5±0.019	0.1±0.034
F_3	10.5±0.023	(1)	10.8±0.027	0.3±0.040
		(2)	10.6±0.103	0.1±0.032
B_1 to Stw. 554382-2	11.0±0.028		11.4±0.019	0.4±0.282
Stw. 554382-2	12.0±0.024		-----------	----------
Total Height				
Concho	99.7±1.059		-----------	----------
B_1 to Concho	93.4±1.565		95.3±0.686	0.9±1.709
F_1d	90.9±0.873		84.0±0.588	6.9±1.079
F_2b	87.5±1.191	(1)	87.4±0.426	0.1±1.265
		(2)	86.0±1.057	1.5±1.592
F_3	89.9±0.330	(1)	85.7±0.942	4.2±0.998
		(2)	85.7±0.514	4.2±0.515
B_1 to Stw. 554382-2	78.5±1.420		79.6±0.506	1.1±1.507
Stw. 554382-2	68.2±0.513		-----------	----------

* (1) and (2) refer to different estimates.

Table 5.—Obtained and theoretical means and standard deviation of means, along with differences and standard deviations of differences for the component characters of plant height measured in the greenhouse.

Character and Population	Means and Standard deviations of means		
	Obtained	Theoretical	Difference
Culm Length (less peduncle)			
Concho	69.8±1.936	————	————
B_1 to Concho	61.5±2.945	62.4±1.107	0.9 ±3.146
F_1b	55.0±1.076	52.9±1.033	2.1 ±1.492
F_2c	53.0±1.848	(1)* 54.0±0.642	1.0 ±1.956
		(2)* 55.2±1.165	2.2±2.475
F_3	55.8±0.666	(1) 53.4±0.486	2.4± 0.823
		(2) 53.0±0.830	2.8 ±1.063
B_1 to Stw. 554387-20	48.9±1.471	45.5±0.648	3.4±1.607
Stw. 554387-20	36.0± 0.724	————	————
Peduncle Length			
Concho	30.0±0.731	————	————
B_1 to Concho	30.7±1.608	33.0±0.416	2.7 ±1.661
F_1b	35.9±0.398	27.5±0.459	8.4±0.599
F_2c	30.3±1.361	(1) 31.7±0.851	1.4±1.605
		(2) 31.9±0.974	1.6±1.673
F_3	30.2±0.492	(1) 29.6±0.211	0.6±0.535
		(2) 28.8± 0.850	1.4± 0.982
B_1 to Stw. 554387-20	33.0±1.098	30.4±0.341	2.6 ±1.150
Stw. 554387-20	24.9± 0.554	————	————
Head Length			
Concho	13.9±0.605	————	————
B_1 to Concho	12.0± 0.725	11.9±0.337	0.1 ±0.800
F_1b	9.8± 0.299	11.8± 0.308	2.8±0.429
F_2c	11.8± 0.748	(1) 10.8 ±0.187	1.8 ±0.771
		(2) 10.8± 0.393	1.8 ±0.845
F_3	11.6± 0.252	(1) 11.3±0.143	0.3±0.290
		(2) 11.8±0.306	0.2±0.396
B_1 to Stw. 554387-20	10.2±0.305	9.7±0.160	0.5 ±0.344
Stw. 554387-20	9.6± 0.114	————	————
Total Height			
Concho	113.8± 2.080	————	————
B_1 to Concho	104.3 ±3.189	107.3 ±1.487	3.0±3.519
F_1b	100.8±1.003	92.2 ±1.132	8.6 ±1.512
F_2c	95.1± 0.821	(1) 96.5±0.663	1.4±1.055
		(2) 98.2±1.907	3.1 ±2.076
F_3	97.7±0.903	(1) 94.4±0.517	3.3 ±1.040
		(2) 93.7±0.631	4.0 ±1.102
B_1 to Stw. 554387-20	92.1± 2.093	85.7±0.655	6.4 ± 2.193
Stw. 554387-20	70.6±0.834	————	————

* (1) and (2) refer to different estimates.

Peduncle length

Means and standard deviations of means are presented in Table 4 for the field-grown populations. Means occur in order from the semi-dwarf parent to Concho. Again, genes affecting peduncle length suggest that effects are additive throughout the range of genotypes.

For the greenhouse-grown populations (Table 5) this same trend is not recorded. The mean for peduncle length of Concho reflects the abnormal development, which occurred in the greenhouse, discussed earlier in the section on "Experimental Methods".

Head length

Head length means of 7 populations grown in the field are recorded in Table 4. Concho has a mean head length of 9.6 cm; while Stw. 554382-2 has a head length of 12.0 cm. Both backcross means fall between the F_1 mean and their respective recurrent parents. Although Stw. 554382-2 is shorter in stature, it has a longer head under field conditions. The means of the F_2 and F_3 generations are almost identical (10.4 cm. and 10.5 cm.).

The greenhouse data for head length (Table 5) are not reliable for assuming certain genetic relationships, since head length and peduncle length reacted very unfavorably with environment.

Total height

Table 4 shows the means of the field grown populations for total height (sum of components). Concho is the tallest with a mean of 99.7 cm. The B_1 to Concho has a mean height of 93.4 cm. For the F_1d, F_2b and F_3 respectively, the means are 90.9, 87.5 and 89.9 cm. The B_1 to

Stw. 554382-2 mean is 78.5 and the semi-dwarf is 68.2. It is apparent that genes affecting plant height on the whole seem to be additive with partial phenotypic dominance. Figure 2 shows the F_1 as intermediate between the two parents.

For greenhouse-grown material, found in Table 5, the means all fall into the same relationship with respect to one another, as did the field-grown plants. The mean of the semi-dwarf is 70.6 cm in length, while the mean of Concho is 113.8 cm. There is a wider spread in plant height in the greenhouse than was found in the field. All evidence seems to indicate that gene effects are additive.

To test this assumption, an analysis of means is made using the theories of inbreeding largely developed by Wright (45) and applied to tomato hybrids by Powers (29). Affects of genes are considered to cumulate additively. Epistatic and interallelic interactions of genes are assumed to be non-existing on the scale used in measuring (cm scale). Calculations of theoretical means and standard deviations of means are from formulas presented in Table 3.

Tables 4 and 5 give the means and standard deviations of the obtained and theoretical means, along with difference and standard deviation of the differences. The difference between the theoretical mean and the obtained mean gives a measure of the failure of populations to react in the manner expected, if gene effects cumulate additively. The standard deviation of the means give a test for significant differences between either obtained and theoretical means or between population means. A difference of over twice the standard deviation would be cause for rejection of the hypothesis at the 5% level.

It is not necessary to compute the standard deviations for differ-

(Facing Page 31)

Fig. 2.--From left to right: Norin 10 - Brevor, F_1 and Concho C.I. 12517.

Fig. 2

ences between means of the obtained populations to see that most populations are significantly different. This indicates that the variation is low enough and population size large enough to detect small differences of means.

Total height measurements (Table 4) show the B_1 to Concho, both estimates of F_2b, and the B_1 to Stw. 554382-2 theoretical means are non-significant. The F_1d and F_3 estimates are significant at the 5% level. The components of culm length and peduncle show similar relationships. The F_1d population in all 3 components is significant, although with head length all are significant, except the backcross generations.

The greenhouse data (Table 5) follow rather closely that recorded for the field. Significant differences of the F_1b and F_3, as well as the B_1 to Stw. 554387-20, are recorded for total height. The components, head length and peduncle length, probably do not yield reliable genetic relationships because of the abnormal elongation of the heads on some plants. Most of the differences between observed and theoretical means, however, are not significant; only the F_1b means for peduncle length and the F_1b and F_2c means for head length have differences of twice the standard deviations. Culm length (less peduncle) populations have 3 means with significant differences. These include both estimates of the F_3 means and the B_1 to Stw. 554387-20 populations.

The analysis of means has permitted the examination of certain observed population means. Only with the F_1 and F_3 means is there a question as to whether differences are genetically real, or are the function of interaction with environment, scaling or chance sampling. The differences between means of observed and theoretical means are in no case very great, giving strong indications that gene effects for plant height cumulate additively under the conditions of the 2 very different types of environment in the crop year 1957-58.

Component Frequency Distributions--Effective Factor Analysis

Components of height and total height frequencies are shown in percent of population, and were calculated from App. Tables 1 - 8. The 2 populations of F_2 were combined, as well as the reciprocal F_1 generations, for purposes of plotting the percentages in each class.

Culm length (less peduncle)

Figures 3 and 4 show the frequency distributions of the 7 populations grown in the field. Stw. 554382-2 is distributed normally, while Concho is skewed toward the tall side. The F_1 and backcross have curves which are somewhat less than normal; while the F_2 and F_3 are more normal, but flatter. The peak of the F_3 has shifted one class to the right of the F_2 populations.

The greenhouse-grown populations are shown in Figures 5 and 6. There is a wider spread between the parents than was observed in the field. The F_1 population is clearly intermediate, as well as the peaks of the F_2 and F_3.

Peduncle length

Figures 7 and 8 represent the frequency distributions of populations grown in the field. The parent and F_1 curve is near normal, but the F_2 and F_3 curves appear slightly skewed toward the short side. The peaks of the backcrosses are near the mid-point of the F_1 and the parent

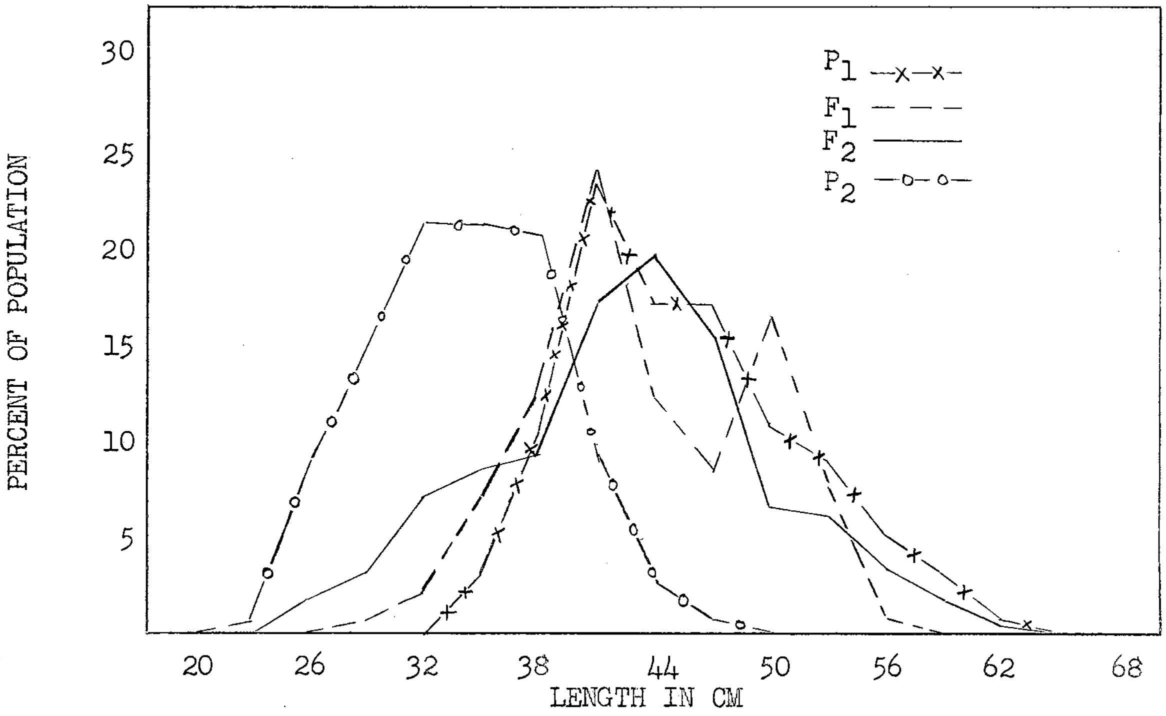

Fig. 3.—Culm length (less peduncle) distribution of Concho (P_1), F_1, F_2 and Stw. 554382-2 (P_2) grown in the field.

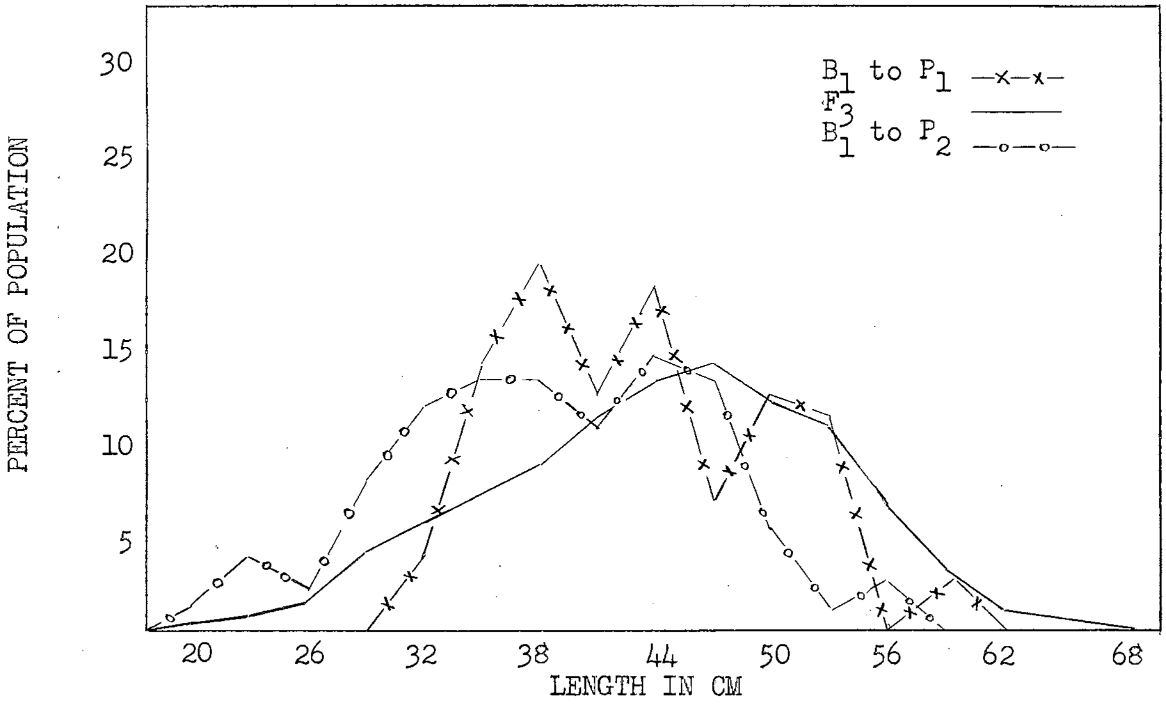

Fig. 4.—Culm length (less peduncle) distribution of B_1 to Concho, F_3 and B_1 to Stw. 554382-2 grown in the field.

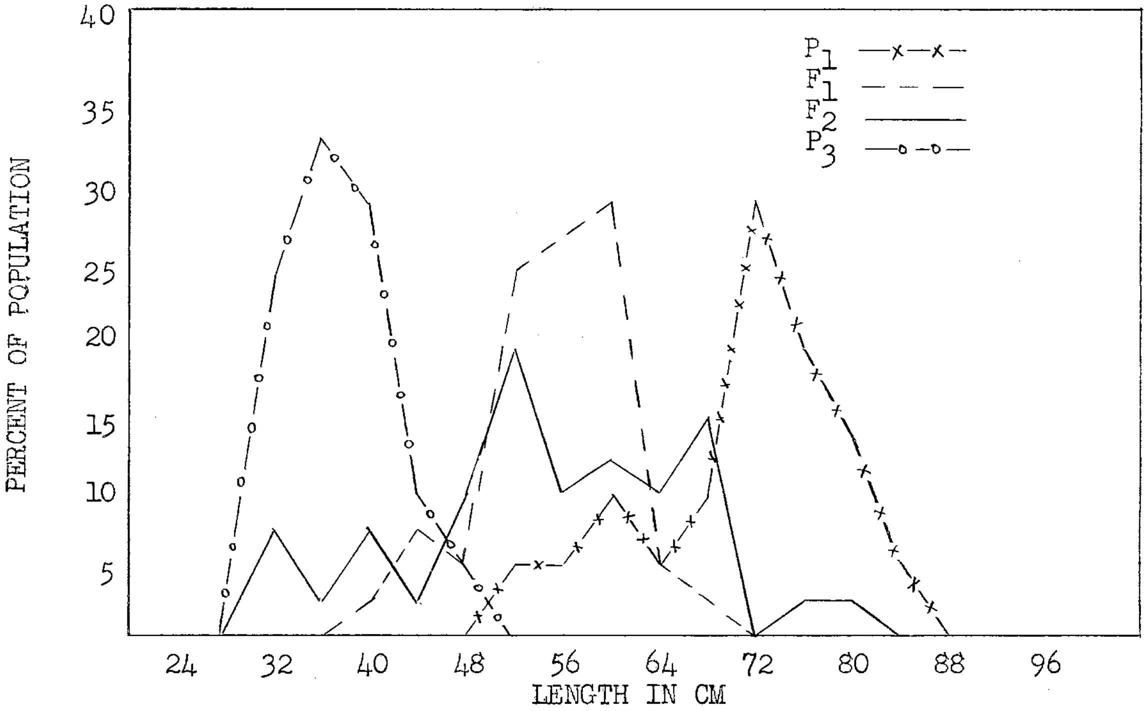

Fig. 5.—Culm length (less peduncle) distribution of Concho (P_1), F_1, F_2 and Stw. 554387-20 (P_3) grown in the greenhouse.

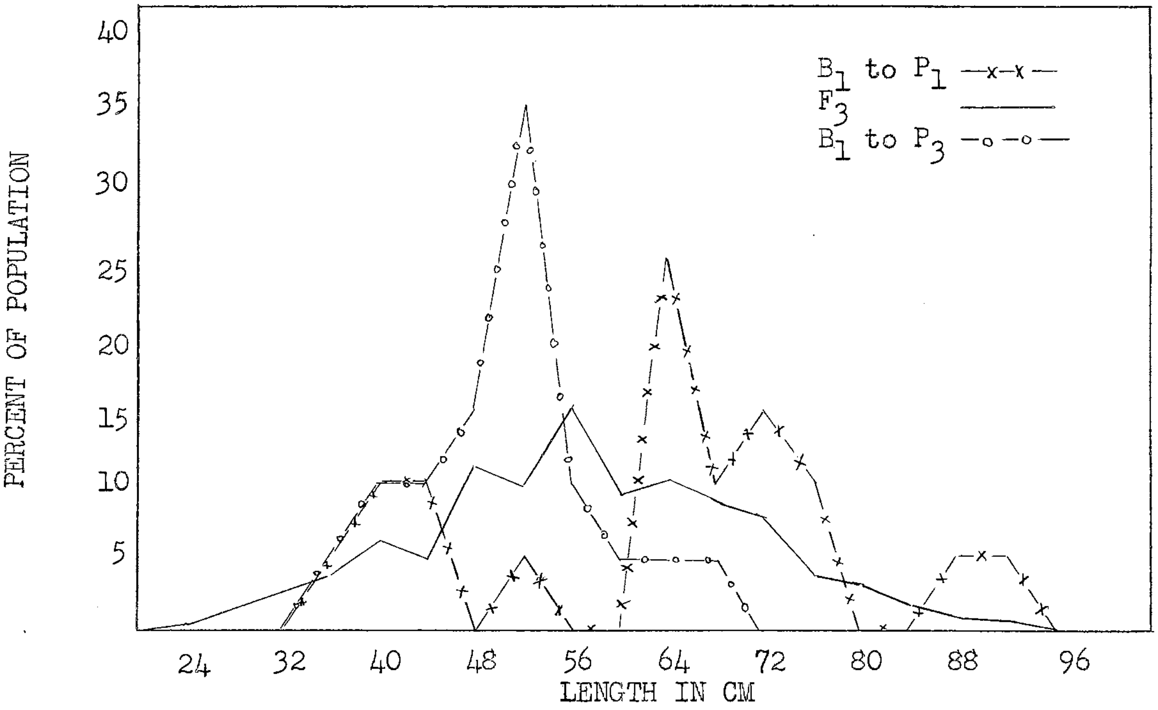

Fig. 6.—Culm length (less peduncle) distribution of B_1 to Concho, F_3 and B_1 to Stw. 554387-20 grown in the greenhouse.

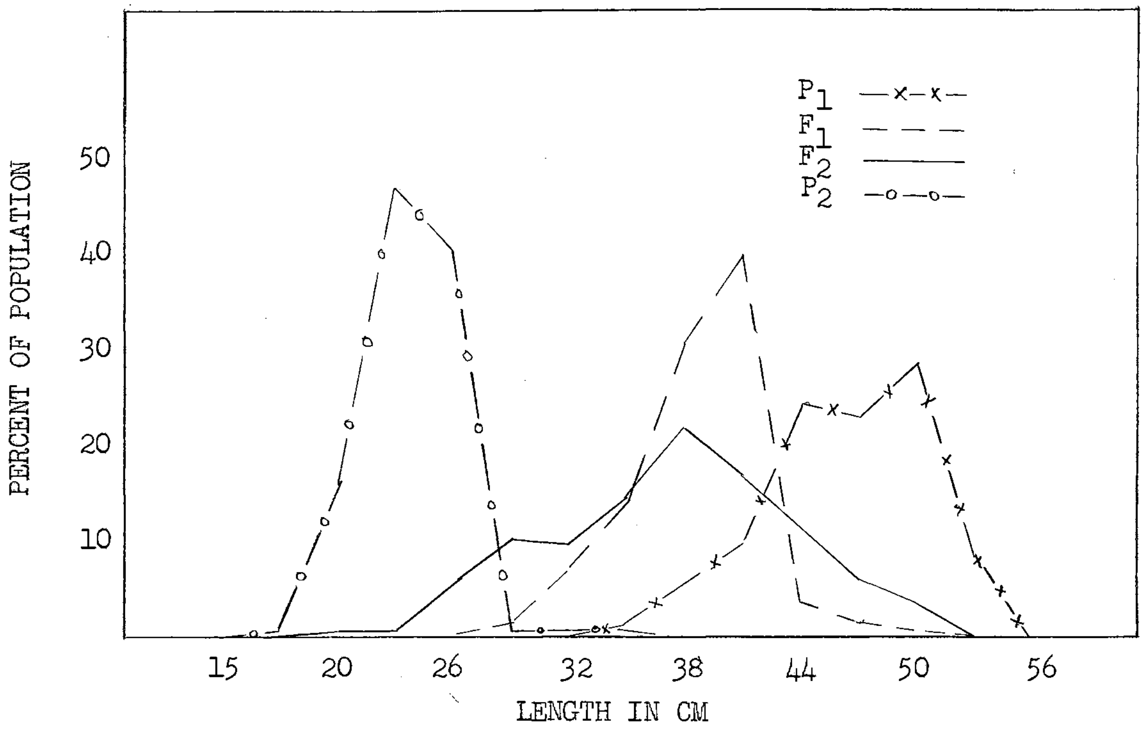

Fig. 7.—Peduncle length distribution of Concho (P_1), F_1, F_2 and Stw. 554382-2 (P_2) grown in the field.

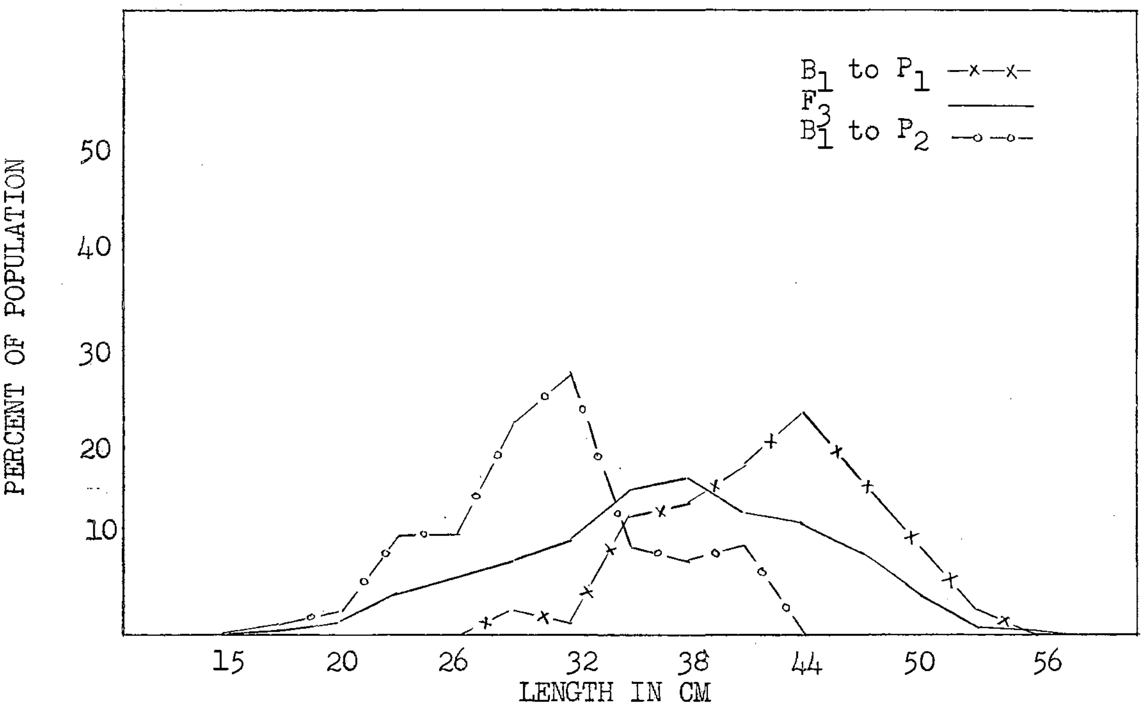

Fig. 8.—Peduncle length distribution of B_1 to Concho, F_3 and B_1 to Stw. 554382-2 grown in the field.

to which they are most closely related.

The populations grown in the greenhouse are shown in Figures 9 and 10. The parents are not spread apart as far as the field-grown populations. For culm length, the reverse of this situation was observed. The backcrosses and the F_2 population have very irregular curves, while the F_3 is skewed a great amount toward the short side. Interaction of genotype with environment is apparent.

Head length

The frequency distributions for head length is represented in Figures 11 and 12 for the field-grown material. These curves are very unusual, in that they are so very normal in distribution as well as having peaks which show the relationship of each population to one another. It is also immediately noticeable that relative length are reversed. Concho has the shorter head, while the semi-dwarf has the longer.

The greenhouse-grown populations are presented in Figures 13 and 14. The greenhouse curves are unusual for another reason. The frequency distributions are very abnormal, with the greater part of the parent distribution falling in exactly the same place. A 23 cm head is recorded for the extremely long side of the distribution (See "Experimental Methods" for explanation of head length measurements).

Total height

Figures 15 and 16 represent frequency distributions for the populations grown in the field. Except for the tails of the F_1 and Concho (low side) the distributions are near normal, with the peak of the F_1

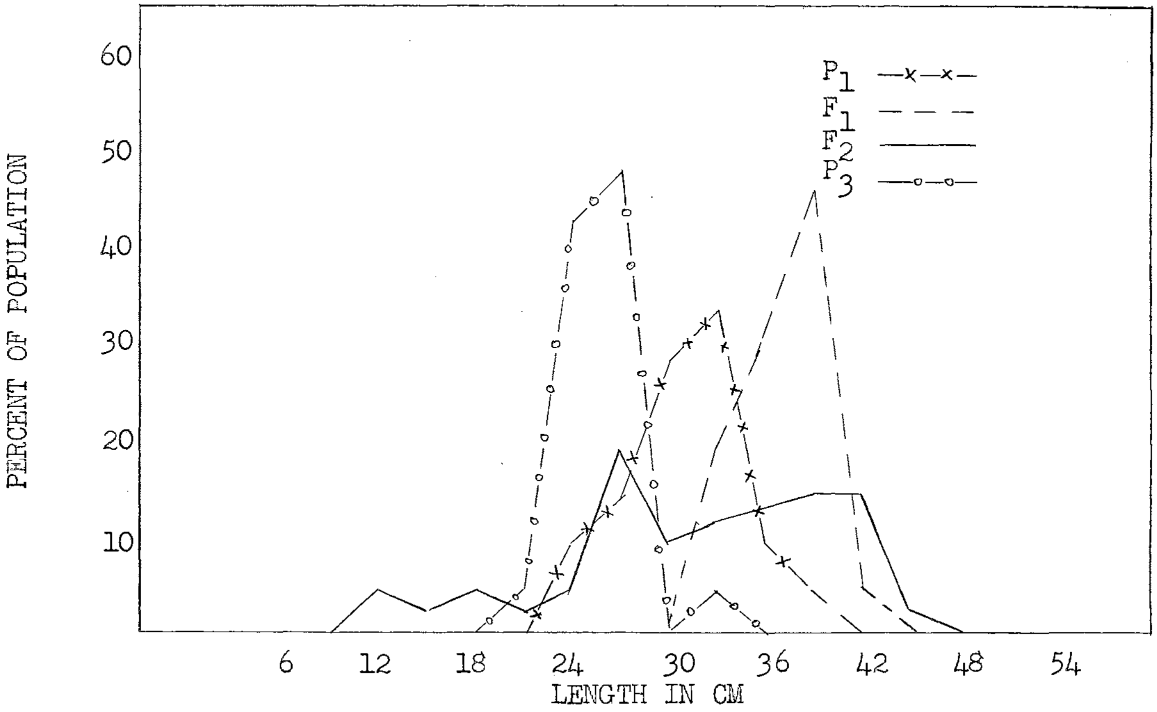

Fig. 9.—Peduncle length distribution of Concho (P_1), F_1, F_2 and Stw. 554387-20 (P_3) grown in the greenhouse.

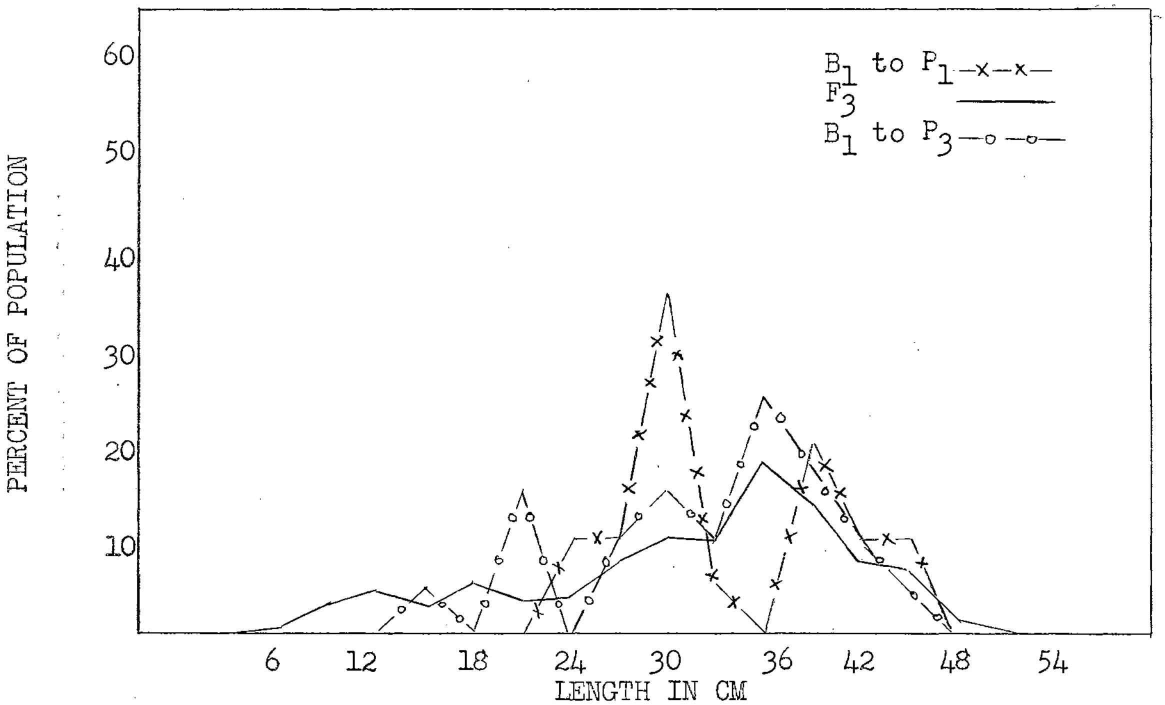

Fig. 10.—Peduncle length distribution of B_1 to Concho, F_3 and B_1 to Stw. 554387-20 grown in the greenhouse.

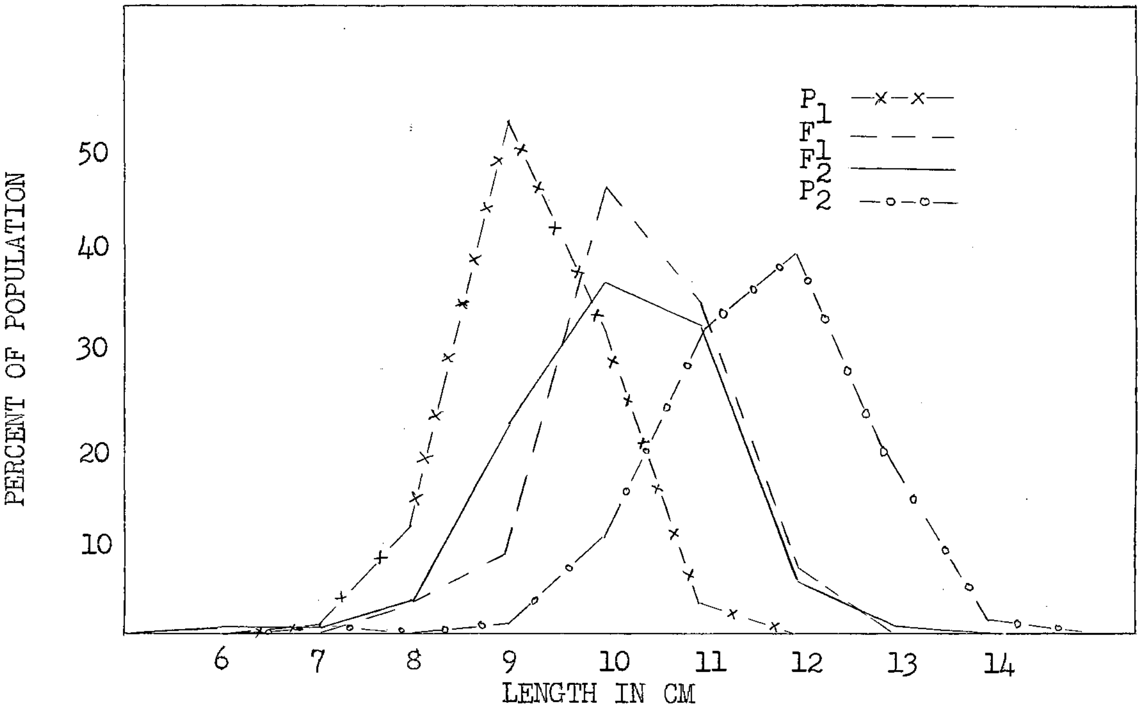

Fig. 11.—Head length distribution of Concho (P_1), F_1, F_2 and Stw. 554382-2 (P_2) grown in the field.

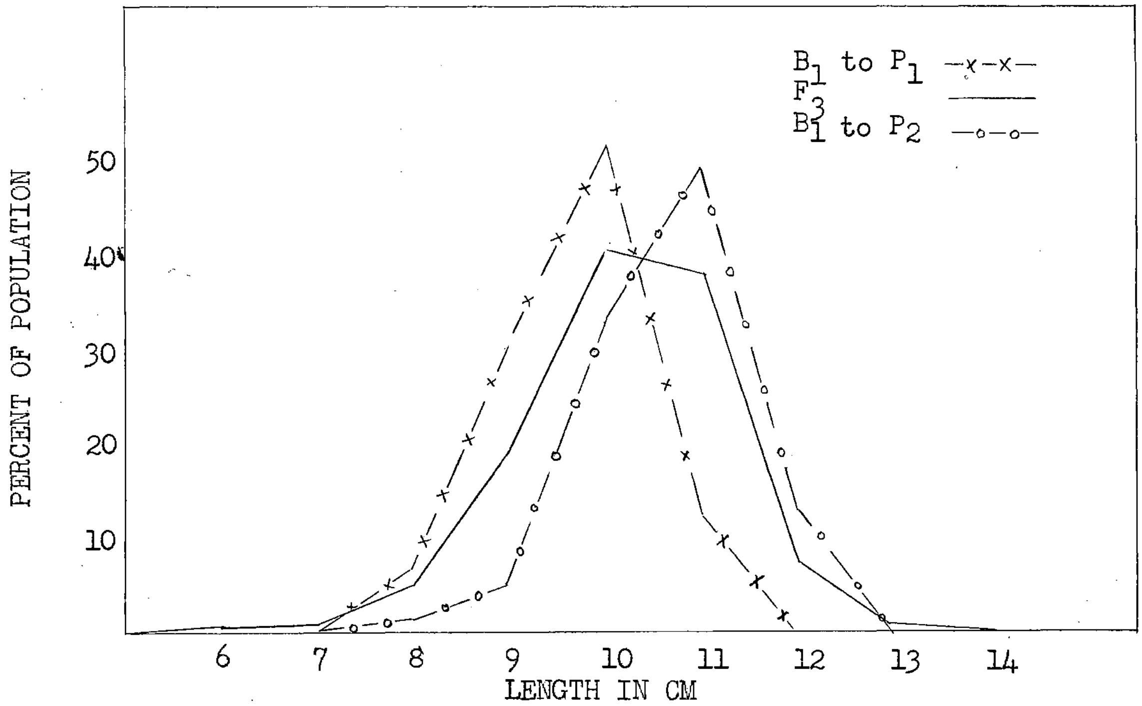

Fig. 12.—Head length distribution of B_1 to Concho, F_3 and B_1 to Stw. 554382-2 grown in the field.

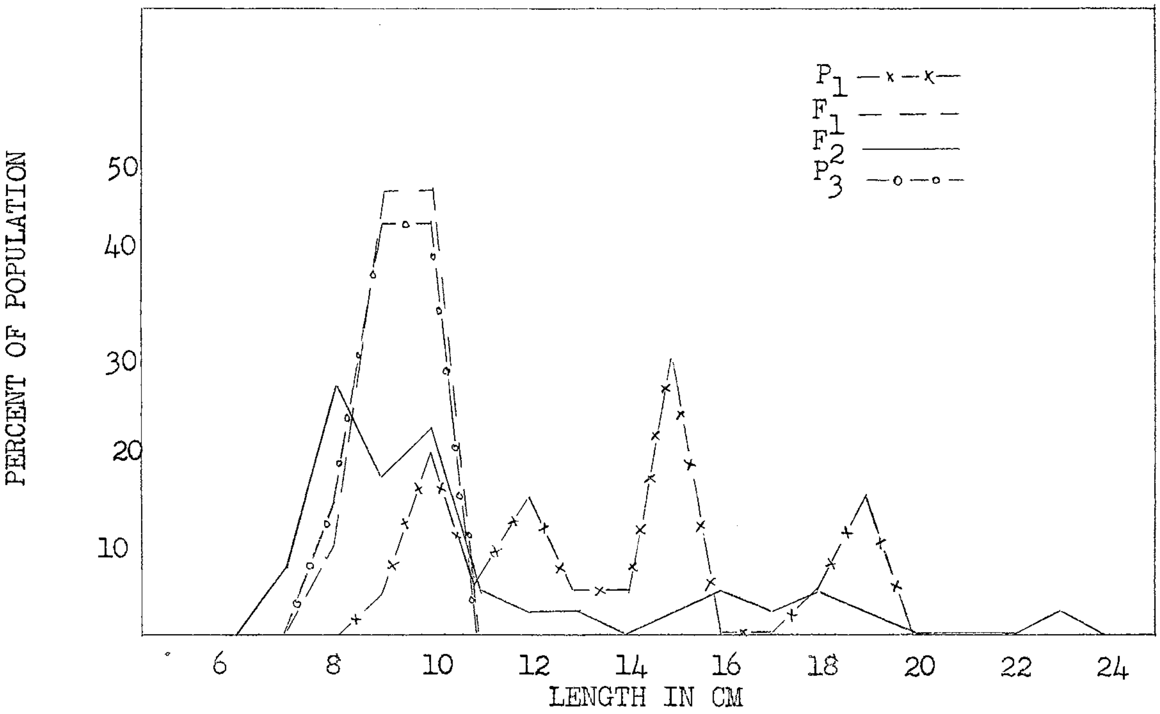

Fig. 13.—Head length distribution of Concho (P_1), F_1, F_2 and Stw. 554387-20 (P_3) grown in the greenhouse.

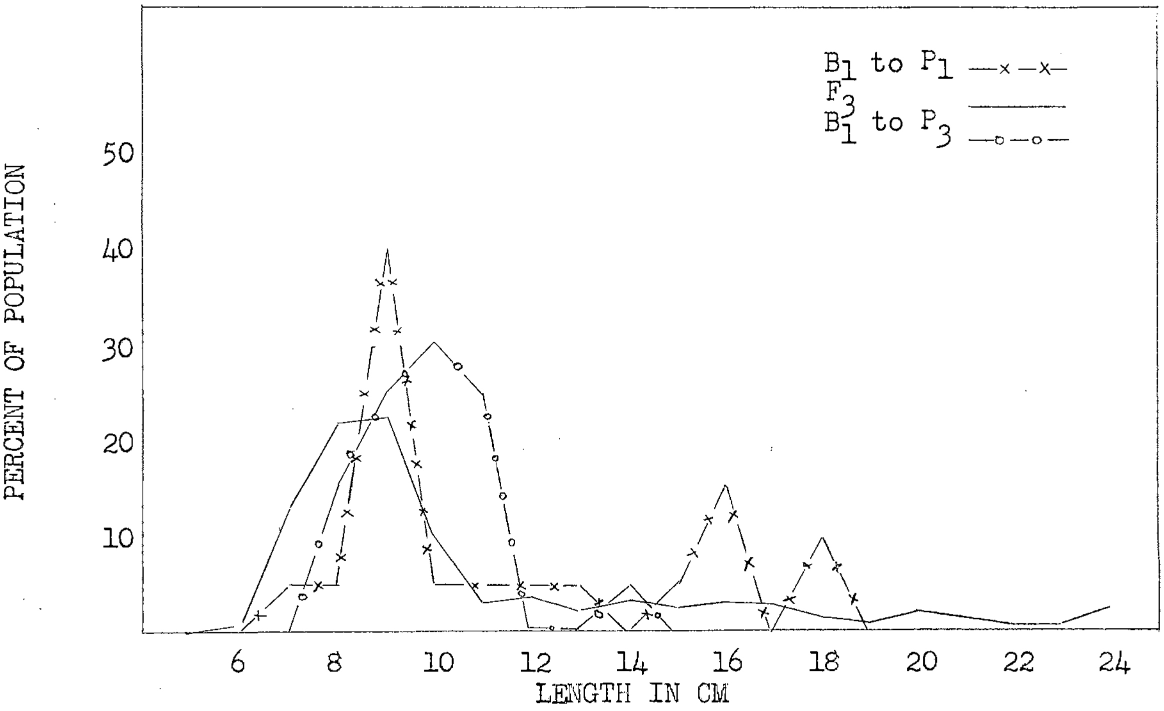

Fig. 14.—Head length distribution of B_1 to Concho, F_3 and B_1 to Stw. 554387-20 grown in the greenhouse.

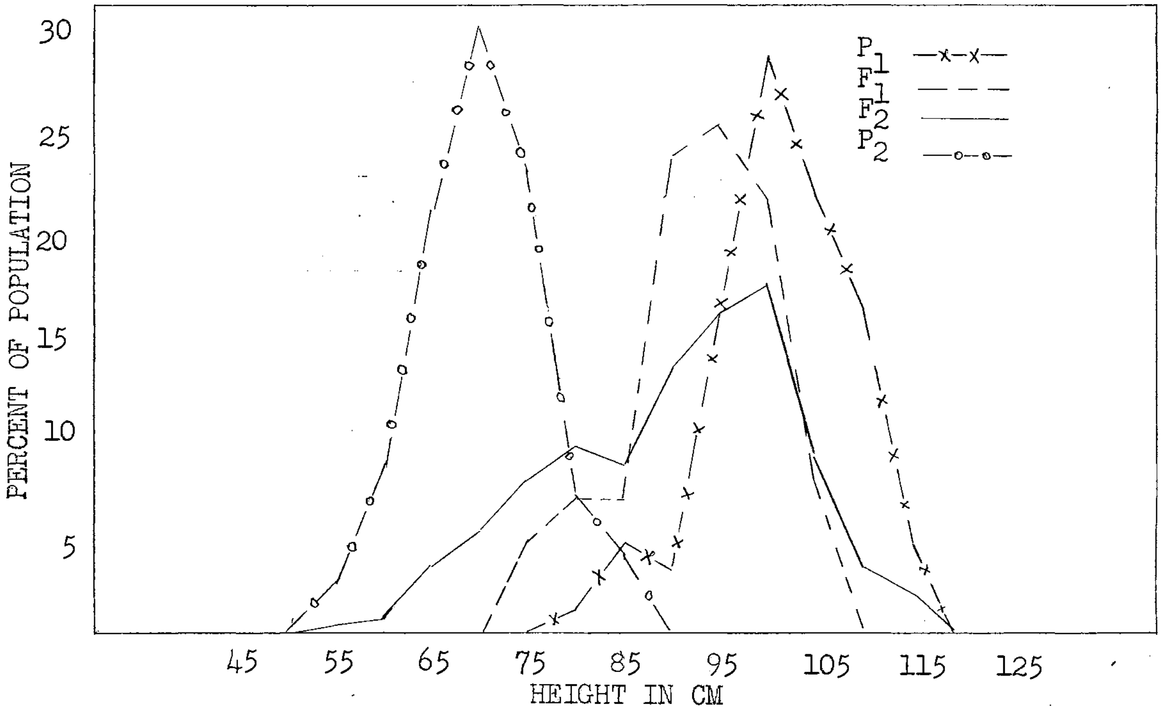

Fig. 15.—Total height distribution of Concho (P_1), F_1, F_2 and Stw. 554382-2 (P_2) grown in the field.

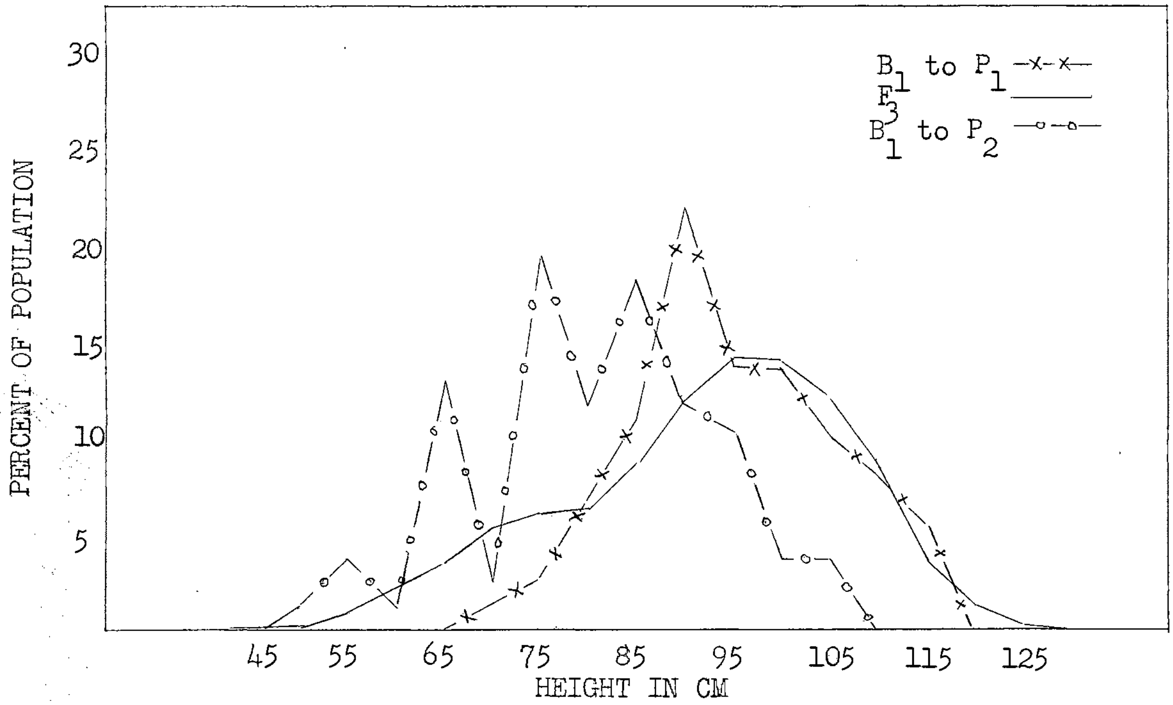

Fig. 16.—Total height distribution of B_1 to Concho, F_3 and B_1 to Stw. 554382-2 grown in the field.

closer to the tall side of the distribution. The F_2 curve shows a drop at the 85 cm class, and at first glance it would appear that the curve is bimodal due to genetic cause. This is not believed to be the case, because the Concho parent and the F_1 both have this characteristic drop near this class. The backcross to the semi-dwarf curve is very irregular, while the backcross to Concho is more nearly normal. The F_3 population shows signs of being skewed toward the low side.

To determine which lines were true breeding in the F_3 generation, frequency distributions were determined for 100 lines grown in the field. Table 6 records the distribution of 20 or less plants per line, depending upon emergence. These 100 lines represent all of the F_2 plants grown in the greenhouse in 1956-57, with the exception of one plant which was not grown because of a lack of space. Using both height and the frequency spread as a basis of classification, only 2 semi-dwarf lines appear to breed true for height. These are lines 207 and 308, the 2 shortest plants classified in the F_2 generation. Only the semi-dwarf side of the F_3 frequency distributions was classified as true breeding or segregating.

The greenhouse-grown populations are presented in Figures 17 and 18. Population size was not large enough here to permit a very normal distribution. Again the peak of the F_1 is toward the tall side of the curve, while the backcrosses are very irregular and have widely separated peaks. The F_3 curve is unusually flat. The F_3 population includes 19 plants picked at random from the field nursery grown in 1956-57. Table 7 records the individual frequency distribution for the 19 lines grown in the greenhouse in 1957-58. An examination of lines shows that no semi-dwarf lines were included in the random sample. All

Table 6.--Plant height frequency distribution of individual F_3 lines grown in the field and ranked according to F_2 plant height.

Line No.	Height of 1957 F_2 Plant	Total number of plants in classes[1]															
		45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
207	49	-	-	5	7	7	1	-	-	-	-	-	-	-	-	-	-
308	50	-	-	4	6	8	2	-	-	-	-	-	-	-	-	-	-
204	54	-	2	2	3	5	4	2	1	1	-	-	-	-	-	-	-
222	54	-	1	1	1	5	4	3	-	1	3	-	-	1	-	-	-
206	55	-	1	2	5	5	2	2	-	3	-	-	-	-	-	-	-
235	58	-	-	1	1	3	-	6	2	2	4	-	1	-	-	-	-
261	58	-	-	-	-	-	-	3	6	7	4	-	-	-	-	-	-
248	59	-	-	-	2	7	7	3	-	1	-	-	-	-	-	-	-
226	60	-	1	-	1	4	4	4	4	2	-	-	-	-	-	-	-
251	60	-	-	-	-	-	-	1	3	6	4	2	3	-	-	-	-
283	60	-	1	-	-	4	3	2	1	4	2	-	1	-	-	-	-
290	60	2	2	2	4	2	2	-	2	1	-	-	-	-	-	-	-
241	62	-	-	-	-	-	-	-	1	4	6	6	3	-	-	-	-
264	62	-	1	2	2	3	2	3	2	1	3	-	-	-	-	-	-

Table 6.--Continued

Line No.	Height of 1957 F_2 Plant	Total number of plants in classes[1]															
		45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
309	62	-	-	2	1	3	1	2	4	2	1	1	1	-	-	-	-
310	62	-	-	2	2	2	3	8	1	1	1	-	-	-	-	-	-
253	63	-	-	-	-	1	1	5	6	6	1	-	-	-	-	-	-
278	63	-	-	1	1	2	4	2	3	3	3	-	-	1	-	-	-
279	63	-	-	1	-	2	1	1	6	3	3	1	1	1	-	-	-
301	63	-	-	2	2	2	1	6	2	-	2	2	-	-	-	-	-
227	64	-	2	-	-	-	4	1	1	1	2	4	1	-	-	-	-
238	64	2	2	2	2	5	4	2	-	-	1	-	-	-	-	-	-
273	64	-	-	1	5	2	3	6	2	1	-	-	-	-	-	-	-
299	64	-	2	1	2	2	4	1	2	1	2	1	-	-	-	-	-
218	65	1	-	-	3	2	1	-	1	-	6	1	2	-	-	-	-
271	65	-	1	-	-	1	5	-	2	4	1	3	1	2	-	-	-
303	65	-	-	1	-	-	2	3	1	4	5	3	1	-	-	-	-
250	66	-	-	-	-	-	-	-	-	-	2	4	7	4	3	-	-

Table 6.--Continued

Line No.	Height of 1957 F_2 Plant	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
280	66	-	1	-	-	-	1	3	2	2	3	2	-	4	2	-	-
306	66	-	-	-	-	1	1	2	1	3	1	2	6	1	1	-	-
221	67	-	1	-	-	2	5	2	1	4	1	3	-	-	-	-	-
255	67	-	-	1	-	3	-	3	1	-	3	6	2	1	-	-	-
216	68	-	-	-	-	-	-	2	3	6	6	2	1	-	-	-	-
254	68	-	-	-	-	-	1	-	3	6	1	4	3	2	-	-	-
266	68	-	-	1	1	2	3	1	3	1	3	1	1	1	1	-	-
208	69	-	-	-	-	1	-	1	1	4	1	7	3	-	-	-	-
223	69	-	1	-	-	2	2	1	3	2	5	2	-	-	-	1	-
224	69	-	-	-	-	-	-	-	4	3	9	4	-	-	-	-	-
274	69	-	-	-	-	-	1	-	2	3	3	2	6	2	1	-	-
201	70	-	-	-	-	-	1	3	3	10	3	-	-	-	-	-	-
263	70	-	-	-	-	-	-	-	1	9	1	6	2	1	-	-	-
270	70	-	-	-	-	-	-	1	1	1	-	1	4	7	4	1	-
232	71	-	-	-	-	-	-	-	1	-	2	3	3	5	4	1	1

Table 6.--Continued

Line No.	Height of 1957 F_2 Plant	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
234	71	-	-	1	-	1	1	5	1	2	3	4	1	1	-	-	-
242	71	-	-	-	-	-	1	1	2	5	5	3	3	-	-	-	-
228	72	-	-	-	-	-	-	2	2	3	4	2	-	4	3	-	-
205	73	-	-	-	-	-	-	2	1	2	-	6	4	2	3	-	-
236	73	-	-	-	-	-	-	-	1	2	6	2	4	3	2	-	-
260	73	-	-	1	-	-	-	2	4	8	2	3	-	-	-	-	-
277	73	-	-	-	-	-	-	-	1	3	3	4	7	1	1	-	-
212	74	-	-	-	-	-	-	1	1	1	6	4	6	1	-	-	-
291	74	-	-	-	-	1	-	7	1	2	2	2	1	2	-	-	-
298	74	-	-	-	-	-	-	-	1	-	-	5	6	6	1	1	-
304	74	-	-	-	-	-	-	-	-	-	6	6	5	2	1	-	-
243	75	-	-	2	2	-	1	1	2	3	4	2	1	1	-	-	-
244	75	-	-	-	-	1	-	-	2	6	7	2	2	-	-	-	-
247	75	-	-	-	-	-	1	-	2	1	6	3	4	2	-	-	-
258	75	-	-	-	-	-	-	-	1	1	3	6	6	2	1	-	-

Table 6.--Continued

Line No.	Height of 1957 F_2 Plant[2]	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
267	75	-	-	-	-	-	-	-	2	5	3	5	1	4	-	-	-
286	75	-	-	-	-	1	-	-	2	2	3	3	2	2	1	1	1
288	75	-	-	1	2	2	3	5	1	4	1	1	-	-	-	-	-
311	75	-	-	-	-	-	-	-	1	-	4	6	4	4	-	1	-
257	76	-	-	-	-	-	-	-	1	2	1	3	6	6	1	-	-
305	76	-	-	-	2	3	5	5	4	-	-	-	-	-	-	-	-
233	77	-	-	-	-	-	1	-	2	5	3	7	2	-	-	-	-
252	77	-	-	-	-	-	-	-	2	1	2	2	6	5	1	-	1
282	77	-	-	-	-	-	-	-	1	1	2	8	5	1	1	-	-
209	78	-	-	-	-	-	-	-	1	5	4	4	4	-	-	-	-
214	78	-	-	-	-	-	-	-	1	2	1	4	6	4	1	1	-
268	78	-	-	-	-	-	-	-	3	3	3	4	5	2	-	-	-
269	78	-	-	-	-	-	1	1	1	2	3	6	3	2	1	-	-
300	78	-	-	-	-	1	-	2	1	2	3	4	4	1	2	-	-
203	79	-	-	-	1	-	1	2	-	3	1	5	3	3	-	-	1

Table 6.--Continued

Line No.	Height of 1957 F_2 Plant	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
275	79	-	-	-	-	-	-	1	-	2	2	5	4	4	2	-	-
287	79	-	-	-	-	-	1	-	1	3	3	5	3	2	2	-	-
296	79	-	-	-	-	-	-	-	-	4	1	2	7	6	-	-	-
307	79	-	-	-	-	-	-	1	2	3	2	4	3	2	3	-	-
211	80	-	-	-	-	-	-	-	1	2	3	5	5	1	2	1	-
213	80	-	-	-	-	-	-	-	-	-	1	2	8	4	2	1	-
217	80	-	-	-	-	-	-	1	1	5	6	6	1	-	-	-	-
259	80	-	-	-	-	-	-	-	-	3	6	2	6	2	-	1	-
265	80	-	-	-	-	-	1	2	4	3	-	1	3	2	3	-	-
272	80	-	-	-	-	-	-	-	-	3	4	6	2	4	1	-	-
284	80	-	-	-	-	-	-	-	-	1	1	1	4	3	8	2	-
231	81	-	-	-	-	-	-	-	2	1	3	5	3	5	-	1	-
245	81	-	-	1	1	2	3	1	2	1	2	7	-	-	-	-	-
256	81	-	-	-	-	-	-	1	1	2	-	4	10	1	1	-	-
292	81	-	-	-	-	-	1	2	2	2	2	2	7	1	1	-	-

Table 6.--Concluded

Line No.	Height of 1957 F_2 Plant	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
295	81	-	-	-	-	-	-	-	-	-	-	3	4	5	5	3	-
276	82	-	-	-	-	-	-	-	1	-	5	9	4	1	-	-	-
281	82	-	-	-	-	-	-	-	3	1	3	1	3	5	3	1	-
219	83	-	-	-	-	-	-	-	-	-	2	4	5	5	3	1	-
240	83	-	-	-	-	-	-	-	-	1	1	1	2	7	4	2	2
220	84	-	-	-	-	-	-	-	-	3	2	3	5	1	3	1	1
246	84	-	-	-	-	-	-	1	1	3	4	3	4	2	2	-	-
239	85	-	-	-	-	-	-	1	-	-	5	1	4	7	1	1	-
237	86	-	-	-	-	1	-	2	-	1	3	5	5	3	-	-	-
202	87	-	-	-	-	-	2	4	-	1	-	4	2	3	2	-	-
293	89	-	-	-	-	-	1	-	1	1	3	3	2	4	4	-	-
215	100	-	-	-	-	-	-	-	-	-	1	2	4	6	1	3	2

/1 Classes are designated by upper limits in centimeters and are inclusive.

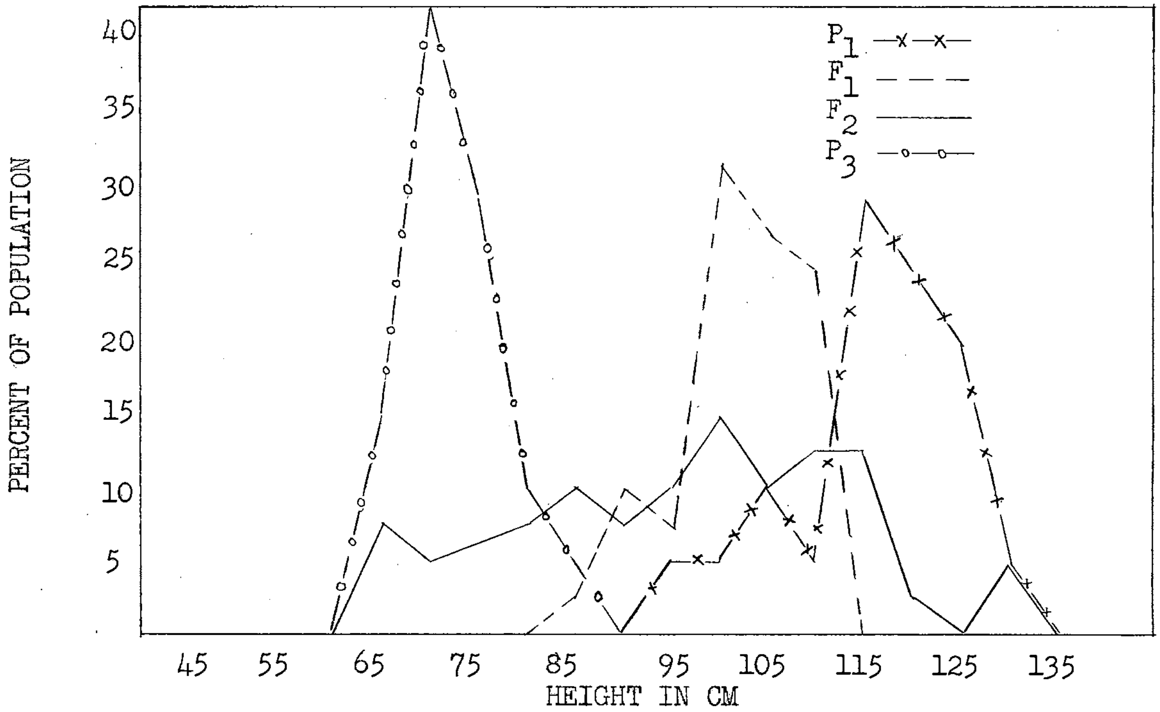

Fig. 17.—Total height distribution of Concho (P_1), F_1, F_2 and Stw. 554387-20 (P_3) grown in the greenhouse.

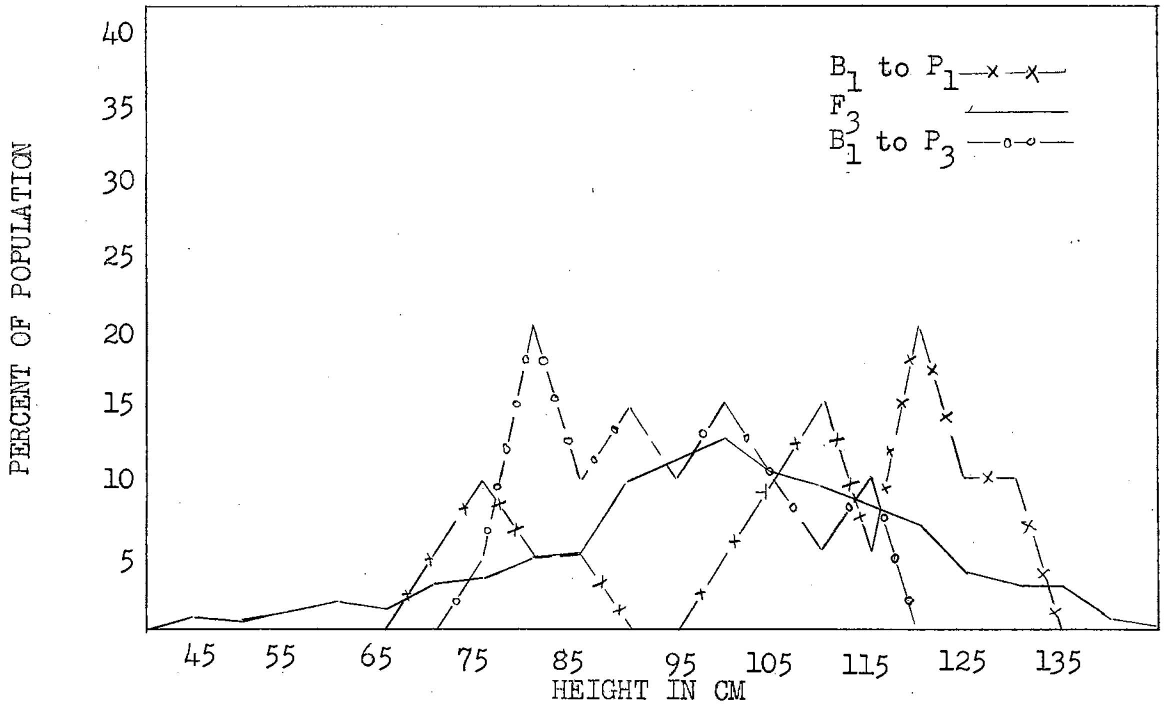

Fig. 18.—Total height distribution of B_1 to Concho, F_3 and B_1 to Stw. 554387-20 grown in the greenhouse.

Table 7.--Plant height frequency distribution of individual F_3 lines grown in the greenhouse and ranked according to F_2 plant height.

Line No.	Height of 1957 F_2 Plant[2]	Total number of plants in classes[1]																				
		44	49	54	59	64	69	74	79	84	89	94	99	104	109	114	119	124	129	134	139	144
140	71	1	2	2	3	1	1	1	1	5	-	1	1	2	-	-	-	-	-	-	-	-
091	80	1	-	1	1	-	3	3	3	2	2	2	3	-	-	-	-	-	-	-	-	-
288	80	-	-	-	-	-	-	1	3	3	3	3	3	4	1	-	-	-	-	-	-	-
232	85	-	-	-	1	-	1	1	2	1	2	1	4	1	3	1	1	-	-	1	1	-
208	85	-	-	-	2	1	1	2	2	1	3	4	2	-	2	-	1	-	-	-	-	-
117	88	-	-	-	-	-	-	1	2	2	4	2	3	3	2	-	1	-	-	-	-	-
170	90	1	-	-	1	-	-	3	2	1	-	2	3	1	2	2	1	1	1	-	-	-
058	91	-	-	-	-	-	-	-	-	-	3	5	4	6	3	-	-	-	-	-	-	-
067	93	-	-	-	-	-	-	-	1	1	6	3	1	2	2	3	-	2	-	-	-	-
064	94	-	-	-	-	-	1	2	-	1	3	2	2	2	5	-	3	-	-	-	-	-
093	94	-	-	-	-	-	1	2	2	-	2	4	4	3	3	-	-	-	-	-	-	-
165	94	-	-	-	-	-	-	-	-	-	1	1	1	2	5	1	1	4	2	3	-	-
226	94	-	-	-	-	-	-	1	-	-	1	3	2	6	-	6	1	1	-	-	-	-
056	100	-	-	-	-	-	-	-	-	1	-	3	3	3	2	2	5	-	1	1	-	-

Table 7.—Concluded

Line No.	Height of 1957 F_2 Plant	44	49	54	59	64	69	74	79	84	89	94	99	104	109	114	119	124	129	134	139	144
144	100	-	-	-	-	-	-	-	-	-	1	2	3	4	3	4	-	3	-	1	-	-
294	100	-	-	-	-	-	-	-	-	-	-	4	3	4	3	4	2	-	1	-	-	-
156	101	-	-	-	-	-	-	-	-	-	-	1	1	1	4	2	5	2	3	1	-	1
223	107	-	-	-	-	-	-	1	-	-	2	2	1	1	2	4	1	3	2	1	1	-
257	109	-	-	-	-	-	-	-	-	-	1	1	4	2	-	1	3	5	1	3	-	-

/1 Classes are designated by upper limits in centimeters and are inclusive.

of the shorter lines appear to be segregating.

Effective factor analysis

The genetic analysis of a quantitative character is not complete without some estimate of the number of factors operating in the cross for the character under study. Various methods have been used to estimate the number of factors operating, such as heritability estimates, diallel analysis, and the partitioning method of genetic analysis. Other attempts have been made to group classes into frequencies and study ratios, usually with little success. The material under study seems adaptable to an "effective factor" analysis, discussed by Mather (23), for several reasons. The P_1, B_1 to P_1, F_1, F_2, B_1 to P_2 and P_2 populations are all available, and were grown in a completely randomized experiment. Further, indications are that the inheritance of height is not overly complex if the populations can be partitioned for genotypes.

The theory behind an effective factor analysis, as explained by Powers (29), assumes that frequency distributions of specific genotypes, expressed as percentages, are the same as those populations used in estimating the number of effective factors. This, of course, is assumed to be true within limits of random sampling. Further, frequency distribution classes, within the populations under consideration, may contain only 1 genotype. By dividing the frequency distribution of 1 population with the frequency distribution of another and multiplying by 100, a percent estimate of the frequency of occurrence of the genotypes desired is obtained.

The plant height data for the field grown material was submitted to this test to determine the number of effective factors which were differentiating the parents. Table 8 shows percentages obtained between frequency distribution classes of designated populations for plant height. Calculations are based on at least 10 observations for each class and are computed from App. Tables 1-8. Estimates of number of effective factors are determined by how close the percentage estimates are to the expected. Expected percentages for a 1, 2 and 3 effective factor model are shown in Table 9, assuming no dominance and that factors which are decreasing plant height entered the cross from the semi-dwarf, and factors tending to increase plant height entered the cross from Concho.

Estimates in column $\frac{B_1 \text{ to } P_2}{F_1b}$ and in the $\frac{B_1 \text{ to } P_2}{P_2}$ column of Table 8 seem to be fluctuating around a common percentage of near 50%. Estimates in column $\frac{F_2b}{P_2}$ appear to be fluctuating around 25% to 30%, while estimates in column $\frac{F_2b}{B_1 \text{ to } P_2}$ range from 52.8% to 93.9%. A comparison of the percentages obtained (Table 8) with the percentages expected (Table 9) shows that the one factor hypothesis fits more closely the actual partitioned percentages.

Since the shorter or the semi-dwarf side of the frequencies was partitioned in Table 8, the taller side of the frequencies is presented in Table 10. If there is no dominance for height, the same results should be obtained as that for the shorter side of the frequencies. An examination of Table 10 shows that nearly all of the estimates are higher. In other words, there is evidence of partial dominance for plant height, but the effects are small. This test is very sensitive to change in frequencies, and random sampling has a large effect on percentages if sample number is low, or where there is high

Table 8.--Percentages obtained between distribution classes and designated populations of at least 10 observations of plant height.

Distribution Classes	Percentages			
	B_1 to P_2	B_1 to P_2	F_2b	F_2b
	F_1b	P_2	P_2	B_1 to P_2
1	31.7	58.0	19.0	55.9
2	36.4	34.0	24.7	52.8
3	55.7	46.8	39.5	57.5
4	79.3	55.3	----	55.1
5	----	71.5	----	64.2
6	----	----	----	93.9

Table 9.--Theoretical percentages for plant height based on different effective factor pairs isodirectionally distributed.

No. of factor pairs	Percentages*			
	B_1 to P_2	B_1 to P_2	F_2	F_2
	F_1	P_2	P_2	B_1 to P_2
1	50.0	50.0	25.0	50.0
2	25.0	25.0	6.25	25.0
3	12.5	12.5	1.56	12.5

* Percentages are the same for both semi-dwarf and tall side of distribution.

Table 10.--Percentages obtained between distribution classes and designated populations based on at least 10 observations of plant height in the class.

Distribution Classes	Percentages			
	B_1 to P_1	B_1 to P_1	F_2b	F_2b
	F_1b	P_1	P_1	B_1 to P_1
1	123.0	64.0	29.9	45.8
2	103.1	65.3	46.5	80.1
3	82.9	57.4	50.4	83.1
4	76.8	61.9	79.7	77.7
5	91.1	89.1	----	94.9

interaction with environmental factors.

If plant height is controlled by one major effective factor, it remains to be explained why no more than 2 true breeding semi-dwarf lines were recovered in 100 F_3 lines. One major effective factor does not account for all of the genetic variability of plant height, but seems to account for a major portion of it. In Table 6 are shown a number of lines which have a low mean height, but have 1 or 2 taller types. There may be minor genes also affecting plant height, and this would cause these short-statured types to throw intermediate types. Another fact which may bear on this is that a genotype-environment interaction may cause a genetically short plant to be taller than usual under a given condition, although this would seem unlikely.

Association of Characters

Correlations of components of height

Means and standard deviations of all characters correlated in both field and greenhouse are found in Tables 11 and 12. Correlation coefficients for culm length (less peduncle), peduncle length, head length and total height for the parent lines grown in the field are found in Table 13. The correlation coefficients of 0.803 and 0.921 for Concho and Stw. 554382-2, respectively, are highly significant between height of plant and culm length. This is to be expected. The correlation of 0.620 and 0.655, Concho and Stw. 554382-2 respectively, between peduncle length and plant height are less, but still significant at the 1% level. It is interesting to note that the mean of the peduncle length for Concho is 45.5 cm while that for culm length (less peduncle) is 44.6 (Table 4), yet the correlation of peduncle length with height is lower

Table 11.--Means and standard deviations of characters measured on 9 populations grown in the field, 1957-58.

	Height	Heading Date	Culm[/1] Length	Peduncle Length	Head Length	Spikelet Number	Node No.
Concho	99.7 ± 7.26	11.1±1.51	44.6±5.77	45.4±4.06	9.6 ±0.68	21.3 ±0.82	3.6 ±0.48
B_1 to Concho . .	93.4±10.24	9.1±3.40	42.1±6.63	41.2±5.28	10.0±0.73	21.1±1.54	3.7 ±0.45
F_1a	91.4 ± 6.79	8.4±1.70	42.5±5.47	38.1±3.28	10.7 ±0.74	21.3 ±0.79	3.8 ±0.44
F_1b	90.9 ± 7.42	7.8±1.55	42.8±5.46	37.3 ±3.20	10.7±0.79	21.5±0.82	3.8 ±0.41
F_2a	89.4±11.88	9.0±3.38	42.3 ±6.65	36.3±6.40	10.6 ±1.01	21.5±1.65	3.8 ±0.42
F_2b	87.5±12.71	8.8±3.46	40.9 ±7.65	36.0±6.26	10.4±0.95	20.9±1.52	3.7±0.50
F_3	89.9±14.63	9.7±4.16	43.4 ±8.59	36.0 ±7.50	10.5 ±1.02	21.3 ±1.84	3.8±0.45
B_1 to Stw 554382-2	78.5 ±12.46	10.1±1.70	37.6±7.97	29.7±5.60	11.1±0.78	21.4 ±1.04	3.7 ±0.44
Stw. 554382-2. .	68.2 ± 6.28	11.9±1.50	33.1±4.72	23.0 ±2.18	12.0±0.93	22.0±0.85	3.8 ±0.44

[/1] Culm length, less peduncle.

Table 12.--Means and standard deviations of characters measured on 8 populations grown in the greenhouse, 1957-58.

	Height	Culm Length Less Peduncle	Peduncle Length	Head Length	Spikelet Number
Concho.	113.8 ± 9.53	69.8 ± 8.87	30.0 ±3.34	13.9 ±2.78	24.5 ±1.55
B_1 to Concho. . . .	104.3 ±14.26	61.5 ±13.17	30.7 ±7.19	12.0 ±3.24	24.8 ±2.97
F_1a	99.3 ± 4.64	53.1 ± 4.59	36.3 ±2.20	9.8 ±0.42	24.2 ±1.05
F_1b	100.8 ± 4.60	55.0 ± 4.93	35.4 ±1.82	9.8 ±0.43	24.5 ±1.33
F_2c	95.1 ±16.83	53.0 ±11.98	30.3 ±8.82	11.8 ±4.85	24.0 ±2.41
F_3	97.7 ±18.03	55.8 ±13.15	30.2 ±9.83	11.6 ±5.04	23.7 ±2.98
B_1 to Stw 554387-20	92.1 ± 9.36	48.9 ± 6.58	33.0 ±4.91	10.2 ±1.36	25.2 ±1.82
Stw. 554387-20. . .	70.6 ± 3.82	36.0 ± 3.32	24.9 ±2.54	9.6 ±0.52	25.1 ±1.39

Table 12.--Concluded

	Seed Weight	Tiller Number	Heading Date	Ripening Date	Node No.
Concho	8.6±1.29	7.5±1.74	59.8 ± 6.74	37.2 ±3.90	5.0±0.45
B_1 to Concho . . .	8.7±2.75	6.5±1.53	46.3±14.30	27.7 ± 9.51	4.6±0.72
F_1a.	10.2±1.89	6.8±1.04	31.6 ± 2.08	19.3± 1.84	4.0±0.00
F_1b.	10.0± 1.64	6.0±1.23	33.0 ± 2.98	19.1 ± 2.17	4.0±0.22
F_2c.	8.9±2.22	6.2±1.42	40.3 ±18.27	24.3±13.63	4.4±0.78
F_3	8.4±2.48	6.5±1.78	46.5 ±20.91	27.9±14.15	4.6±0.85
B_1 to Stw 554387-20	9.7±2.10	6.4±1.54	34.6 ± 8.34	22.1± 6.63	4.3±0.45
Stw 554387-20 . .	7.1±1.24	6.1±1.08	33.7 ± 2.38	23.5 ± 2.17	4.2±0.40

Table 13.--Correlation coefficients for parent progenies grown in the field, 1957-58.

Concho

	Height	Heading Date	Culm[1] Length	Peduncle Length	Head Length	Spikelet Number	Node No.
Height		-0.254**	0.803**	0.620**	0.061	-0.006	0.352**
Heading Date	-0.463**		0.078	-0.483**	-0.525**	0.034	0.232**
Culm Length[1]	0.921**	-0.083		0.041	-0.227**	-0.020	0.616**
Peduncle L.	0.655**	-0.290**	0.336**		0.268**	-0.070	-0.207*
Head Length	0.550**	-0.481**	0.386**	0.351**		0.556**	-0.267**
Spikelet No.	0.171*	-0.580**	0.143	0.025	0.413**		-0.033
Node Number	0.581**	-0.085	0.664**	0.130	0.281**	0.147	

Stw. 554382-2

[1] Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

than is the culm length with height. Head length of Stw. 554382-2 is found to be highly correlated with height, while the correlation coefficient for Concho between these two characters was not significant. Head length with peduncle length, as well as with culm length, are both highly correlated in Stw. 554382-2. Although head length with peduncle is also highly correlated in Concho, a highly significant negative correlation was found between head length and culm length. A highly significant correlation coefficient of 0.336 is recorded for peduncle length and culm length for Stw. 554382-2, while a correlation of only 0.041 is recorded for Concho.

Correlation coefficients for the components of height for the greenhouse-grown parent populations are found in Table 14. Due to a reduced number of observations, much higher correlation coefficients were needed to be significant. Total height and culm length (less peduncle) were still found to be highly correlated in both parents. No significant correlations were found between height and peduncle or peduncle and culm length in either parent. Head length and height were highly significantly correlated in Stw. 554382-2, while not significantly correlated in Concho. As mentioned earlier, some of the plants had very abnormal head development which resulted in very long heads and short peduncles. This is reflected in Concho by the significant negative correlation of head length and peduncle length.

The correlation coefficients for reciprocal F_1 generations grown in the field are presented in Table 15. Assuming there are no maternal affects, the F_1 generations should give similar correlation coefficients, since they are of the same genotype. Only sample size would reduce the efficiencies of the correlation coefficients. Correlations

Table 14.--Correlation coefficients for parent progenies grown in the greenhouse, 1957-58.

	Height	Seed Weight	Tiller Number	Heading Date	Ripening Date	Culm[1] Length	Peduncle Length	Head Length	Spikelet Number	Node No.
					Concho					
Height		-0.066	-0.564*	-0.138	-0.182	0.949**	-0.012	0.365	0.007	0.233
Seed Weight	0.111		0.542*	-0.468	-0.321	0.002	0.024	-0.273	-0.256	-0.466
Tiller No.	-0.293	0.248		0.013	0.090	-0.571	0.210	-0.351	-0.440	-0.131
Heading Date	0.130	0.548*	0.331		0.940**	-0.286	0.016	0.431	0.269	0.285
Ripening Date	0.018	-0.008	0.061	0.470		-0.301	-0.009	0.346	0.305	0.224
Culm Length[1]	0.732**	0.336	0.118	0.451	0.046		-0.221	0.284	-0.067	0.207
Peduncle L.	0.420	-0.221	-0.537*	-0.315	0.016	-0.299		-0.545*	0.173	-0.016
Head Length	0.624**	-0.076	-0.469	-0.183	-0.269	0.504	0.087		0.024	0.114
Spikelet No.	-0.110	-0.464	-0.116	0.093	0.071	-0.050	-0.132	0.209		-0.023
Node Number	0.313	0.048	0.204	-0.042	-0.119	0.553**	-0.345	0.320	-0.100	
					Stw. 554387-20					

[1] Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Table 15.--Correlation coefficients for reciprocal F_1 generations grown in the field, 1957-58.

	Height	Heading Date	Culm[/1] Length	Peduncle Length	Head Length	Spikelet Number	Node No.
(Concho X Stw. 554382-2) F_1c							
Height		-0.003	0.880**	0.557**	0.190	0.341*	0.365**
Heading Date	-0.528**		0.141	-0.125	-0.539**	0.046	0.098
Culm Length[/1]	0.887**	-0.310**		0.112	0.189	0.397**	0.540**
Peduncle L.	0.700**	-0.555**	0.306**		-0.141	-0.058	-0.189
Head Length	0.512**	-0.591**	0.288*	0.457**		0.469**	0.211
Spikelet No.	0.129	0.025	0.084	0.054	0.428**		0.282*
Node Number	0.405**	-0.318**	0.535**	0.003	0.155	0.036	
(Stw. 554382-2 X Concho) F_1d							

[/1] Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

are based on 56 observations for the F_1c and 73 observations in the F_1d population. The correlation of height and head length, as well as, peduncle length and head length in F_1c is not significant, while both indicate highly significant correlations in the F_1d. In no case is there a significant correlation in the F_1c population and a non-significant correlation in the F_1d population. The reverse is not the case. This would seem to indicate that sample size is playing a much larger role than was previously expected. Fortunately, the F_2 and F_3 populations are much larger.

Correlation coefficients of reciprocal F_1 generations grown in the greenhouse are presented in Table 16. Only one significant correlation was found among all components of height characters. This was a highly significant correlation of height and culm length (less peduncle). Sample size was evidently too small to detect other differences, if they were present.

Table 17 gives the correlation coefficients for 2 F_2 generations grown in the field. Correlation coefficients for the component characters, culm length (less peduncle), peduncle length and head length with height, as well as all other possible combinations, are all highly significantly correlated; except one which is significant at the 5% level. The trend in correlations is the same for both populations. This would indicate that the coefficients are reliable. Factors affecting plant height would appear to be affecting the components of height in the same direction.

Correlation coefficients for the F_2 generation grown in the greenhouse are found in Table 18. Coefficients of 0.947 and 0.578 are recorded between height and culm length and height and peduncle length.

Table 16.--Correlation coefficients for reciprocal F_1 generations grown in the greenhouse, 1957-58.

(Stw. 554387-20 X Concho) F_1a

	Height	Seed Weight	Tiller Number	Heading Date	Ripening Date	Culm/1 Length	Peduncle Length	Head Length	Spikelet Number	Node No.
Height		0.049	0.046	0.106	0.017	0.883**	0.338	-0.435	0.130	----
Seed Weight	-0.360		0.624**	-0.076	-0.068	0.111	-0.112	-0.022	-0.025	----
Tiller No.	-0.462	0.667**		-0.029	-0.054	0.145	-0.170	-0.136	0.007	----
Heading Date	0.316	-0.402	-0.319		0.486*	0.291	-0.243	-0.399	0.235	----
Ripening Date	0.240	-0.200	-0.315	0.805**		0.128	-0.149	-0.356	0.061	----
Culm Length/1	0.916**	-0.299	-0.342	0.181	0.177		-0.131	-0.396	0.190	----
Peduncle L.	0.027	-0.027	-0.163	0.235	0.070	-0.366		-0.293	-0.181	----
Head Length	0.033	-0.288	-0.291	0.232	0.114	-0.196	0.412		0.326	----
Spikelet No.	0.139	-0.431	-0.005	0.475	0.192	0.021	0.183	0.581*		----
Node Number	0.301	-0.244	-0.326	0.000	-0.067	0.265	0.020	0.143	0.055	

(Concho X Stw. 554387-20) F_1b

/1 Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Table 17.--Correlation coefficients of 2 generations of F_2 grown in the field, 1957-58.

(Concho X Stw. 554382-2) $F_{2}a$

	Height	Heading Date	Culm[/1] Length	Peduncle Length	Head Length	Spikelet Number	Node No.
Height		-0.226*	0.881**	0.877**	0.384**	0.089	0.160
Heading Date	-0.160		-0.081	-0.329**	-0.063	0.503**	0.084
Culm Length[/1]	0.911**	0.009		0.557**	0.231*	0.111	0.390**
Peduncle L.	0.852**	-0.328**	0.568**		0.311**	-0.031	-0.093
Head Length	0.427**	-0.044	0.389	0.235*		0.498**	-0.115
Spikelet No.	0.109	0.570**	0.224*	-0.123	0.463**		0.024
Node Number	0.478**	0.023	0.666**	0.121	0.265**	0.253**	

(Concho X Stw. 554382-2) $F_{2}b$

[/1] Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Table 18.--Correlation coefficients for F_2 and F_3 generations grown in the greenhouse, 1957-58.

(Stw. 554387-20 X Concho) $F_{2}c$

	Height	Seed Weight	Tiller Number	Heading Date	Ripening Date	Culm Length[1]	Peduncle Length	Head Length	Spikelet Number	Node No.
Height		0.591*	-0.024	-0.184	-0.292	0.947**	0.578*	0.072	0.062	0.122
Seed Weight	0.523**		0.363*	-0.021	-0.090	0.526**	0.365*	0.082	0.273	0.065
Tiller No.	0.070	0.380**		0.162	0.170	-0.002	-0.113	0.114	0.341*	0.133
Heading Date	-0.272**	-0.488**	0.072		0.972**	-0.030	-0.770**	0.851**	0.301	0.830**
Ripening Date	-0.271**	-0.471**	0.077	0.982**		-0.140	-0.804**	0.805**	0.325*	0.766**
Culm Length[1]	0.923**	0.384**	0.091	-0.026	-0.029		0.339*	0.194	0.037	0.295
Peduncle L.	0.547**	0.506**	-0.029	-0.810**	-0.810**	0.242**		-0.667**	-0.123	-0.625**
Head Length	0.097	-0.123*	0.065	0.675**	0.687**	0.216**	-0.626**		0.350*	0.840**
Spikelet No.	0.028	-0.023	0.082	0.460**	0.491**	0.088	-0.271**	0.400**		0.256
Node Number	0.034	-0.287**	0.093	0.790**	0.772**	0.313**	-0.695**	0.660**	0.326**	

(Stw. 554387-20 X Concho) F_3

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[1] Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Both are highly significant. A significant correlation was not found between height and head length. A highly significant negative correlation between head length and peduncle is recorded, again detecting the abnormal relationship between the peduncle and head length in the greenhouse.

The correlation coefficients for both backcross populations grown in the field are reported in Table 19. The relationships of positive correlations between peduncle, culm length and height are the same for the 9 populations grown in the field. The head length correlation with height, however, is significant in only the B_1 to Concho population.

Greenhouse-grown backcross population coefficients are shown in Table 20. Culm length in both backcrosses and peduncle length in the B_1 to Stw. 554387-20 population are highly correlated with height. Neither backcross has significant correlations of culm length and peduncle length, while only the B_1 to Concho has a significant negative correlation of peduncle length and head length.

Correlation coefficients for the F_3 population grown in the field are recorded in Table 21. The total number of plants measured in the field totaled 1,958. If small associations of the component characters are present, this number of observations should permit detection. All three components of height were found to be highly positively correlated in all combinations.

The correlation coefficients for the greenhouse grown F_3 population is found in Table 18. The total number of plants measured was 399. Height with both culm length and peduncle are again found to be highly significantly correlated. Only head length with height was not found to be significantly correlated. Head length and peduncle are highly significantly negatively correlated.

Table 19.--Correlation coefficients for backcross generations grown in the field, 1957-58.

B_1 to Concho

	Height	Heading Date	Culm/1 Length	Peduncle Length	Head Length	Spikelet Number	Node No.
Height		-0.079	0.881**	0.796**	0.240*	0.048	0.381**
Heading Date	-0.357**		0.147	-0.367**	0.133	0.794**	0.298*
Culm Length/1	0.939**	-0.174		0.423**	0.161	0.204	0.551**
Peduncle L.	0.870**	-0.504**	0.655**		0.111	-0.236*	0.000
Head Length	0.213	-0.267**	0.151	0.112		0.463**	0.300*
Spikelet No.	0.242*	0.251**	0.307**	0.052	0.379**		0.329*
Node Number	0.434**	0.038	0.527**	0.213	0.131	0.261*	

B_1 to Stw. 554382-2

/1 Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Table 20.--Correlation coefficients for backcross generations grown in the greenhouse, 1957-58.

B_1 to Concho

	Height	Seed Weight	Tiller Number	Heading Date	Ripening Date	Culm/1 Length	Peduncle Length	Head Length	Spikelet Number	Node No.
Height		0.628**	0.291	-0.125	-0.229	0.931**	0.262	0.040	0.209	0.113
Seed Weight	0.253		0.544*	-0.098	-0.180	0.650**	0.036	0.084	-0.030	0.222
Tiller No.	-0.335	0.543*		0.280	0.276	0.389	-0.308	0.416	0.072	0.587*
Heading Date	-0.446	0.272	0.121		0.970**	0.041	-0.719**	0.873**	0.810**	0.805**
Ripening Date	-0.595*	0.317	0.119	0.915**		-0.063	-0.713**	0.826**	0.733**	0.805**
Culm Length/1	0.890**	0.171	-0.268	-0.210	-0.348		-0.076	0.214	0.288	0.344
Peduncle L.	0.731**	0.305	-0.247	-0.779**	-0.807**	0.370		-0.761**	-0.473	-0.741**
Head Length	-0.117	0.126	-0.047	0.764**	0.515*	-0.083	-0.395		0.775**	0.754**
Spikelet No.	0.158	0.063	0.210	0.577*	0.343	0.184	-0.165	0.724**		0.564*
Node Number	-0.158	0.182	0.158	0.711**	0.550*	0.125	-0.598*	0.451	0.545*	

B_1 to Stw. 554387-20

/1 Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Table 21.—Correlation coefficients of the F_3 generation grown in the field, 1957-58.

	Height	Heading Date	Culm[/1] Length	Peduncle Length	Head Length	Spikelet Number	Node No.
			(Concho X Stw. 554382-2) F_3				
Height		-0.167**	0.907**	0.871**	0.305**	0.084**	0.350**
Heading Date			0.019	-0.367**	0.147**	0.681**	0.234**
Culm Length[/1]				0.590**	0.245**	0.199**	0.529**
Peduncle L.					0.177**	-0.126**	0.051
Head Length						0.450**	0.193**
Spikelet No.							0.268**
Node Number							

[/1] Culm length, less peduncle.

* Significant at 5% level.

** Significant at 1% level.

Correlation coefficients for the component characters of culm length (less peduncle), peduncle length and head length with total height in general are all positively correlated when only the field correlations are considered. This would indicate several possibilities of the genetic relationships between these characters. The correlation coefficients obtained would tendto discount the possibility that different factors are controlling the elongation of peduncle and the remaining portion of the culm, or if different factors are controlling the elongation of each, they are very closely linked. If both characters were controlled by independently inherited pairs of genes, no correlation between these two components would be expected, except that which is contributed by environment.

Height and other characters

Only three characters other than the component of height characters were measured in the field. These include heading date, spikelet number and the above-ground node number. Without exception, a negative correlation coefficient was found between heading date and height for all 9 populations (Tables 13, 15, 17, 19, 21). Only the F_1c, B_1 to Concho and F_2b have correlations which are not significant. Taller plants, on the average, headed earlier than shorter plants in this material. This relationship is not the same as reported by Clark (3) and Clark and Hooker (4).

Spikelet number was not found to be very highly correlated with height in the 9 populations grown in the field. Five of the populations had correlations which were not significant, while the F_1c, B_1 to Stw. 554382-2 and Stw. 554382-2 populations had significant correlations at the 5% level. Only the F_3 was significant at the 1% level.

Above-ground node number was found to be highly significantly correlated with plant height in all 9 populations, except for the F_2a population. In other words, although node number is fairly stable for parental lines, the small amount of variation of a larger or smaller number of nodes is directly related to increased or decreased height of the plants.

In addition to the component of height characters measured in the greenhouse, measurements were also made on seed weight, tiller number, heading date, ripening date, spikelet number and above-ground node number. No significant correlations were recorded for seed weight and height in the parental or F_1 populations (Tables 14 and 16). Significant and highly significant correlations, however, were found in the segregating generations. The B_1 to Concho and the F_3 populations both show highly significant positive correlations of height and seed weight, while the F_2c correlation coefficients for these 2 characters is significant at the 5% level. These findings are different from those reported by Mekasha (24), if seed weight is assumed to be a reliable measure of yield.

Of the 8 populations grown in the greenhouse, tiller number was not found to be significantly correlated with height, except in the Concho population, where a negative significant correlation was recorded. The heading date correlation with height in the greenhouse followed the same trend as was recorded for the field-grown populations. Only the F_1 populations and Stw. 554387-20 populations have positive correlation coefficients. The F_1's are not significant, while Stw. 554387-20 is significant. The remaining 5 populations have negative correlations of height and maturity, with the F_3 population coefficients recorded as being highly significant.

Ripening date was found to be significantly correlated with height in the B_1 to Stw. 554387-20 population and highly correlated in the F_3 population. Otherwise, the remaining 6 populations had no significant correlations.

No significant correlation coefficients were recorded for the characters, spikelet number, and above-ground node number with height in the 8 populations grown in the greenhouse.

Other character associations

Head length and spikelet number correlations are shown in Tables 13, 15, 17, 19, and 21 for the 9 populations grown in the field. Without exception, these characters are significantly highly positively correlated. Since indications are that height and number of above-ground nodes are positively correlated, and height and heading date are negatively correlated, it is reasonable to assume that heading date and above-ground node number would also be negatively correlated. An examination of Tables 13, 15, 17, 19, and 21 shows that this apparently is not the case. All correlations between heading date and spikelet number are positive except for 2. The correlation coefficient of -0.085 is recorded for Stw. 554382-2, while a highly significant negative coefficient is recorded for the F_1d population.

Several character associations are of interest in the greenhouse material (Tables 14, 16, 18, 20). Ripening date was found to be very highly correlated with heading date in Concho, while the correlation coefficients of heading and ripening date for Stw. 554387-20 was not significant. One explanation of this difference between varieties is that during the ripening period, a very different type of ripening was observed to occur in the semi-dwarf line and segregating populations. Heads and culms of some plants retained their green color until the seeds had nearly completed drying. This may have caused non-significant correlation of heading date and maturity in the semi-dwarf line.

Tiller number was not found to be correlated with most characters studied, considering all the populations, although correlations with seed weight were found in all populations but the semi-dwarf.

SUMMARY

A study of the inheritance of semi-dwarfism was carried out during the crop years 1957 and 1958. Along with the inheritance study, a study was made of the association of certain plant characters in the segregating and parental populations by use of correlation coefficients.

The parental, F_1, F_2, F_3 and backcross generations of a semi-dwarf X tall cross were grown in both field and greenhouse in a randomized complete block design.

Studies in 1956-57 showed that internode number in the semi-dwarf lines did not differ from the internode number in the tall line.

An analysis of means of the component characters, culm length (less peduncle), peduncle length, and head length along with total height, revealed that in general the mean of any population agreed closely with the expected, assuming partial dominance. Factors controlling plant height were found to cumulate additively.

Frequency distributions are presented for the components of plant height. The peak of the F_1 distributions for total height in the field was shifted toward the tall parent. The peak of the F_3 distribution appears to be shifted one class to the tall side, while skewness is toward the short side.

An effective factor analysis of plant height of the field-grown material gives evidence of plant height being controlled by one major effective factor. Other minor modifying genes are also thought to be contributing to plant height.

Correlation studies of component characters of height show all 3 to be positively correlated with one another, as well as with total height.

Height of plant was found to be negatively correlated with heading date under field conditions.

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APPENDIX

TABLE OF CONTENTS

App. Table 1.--Culm length (less peduncle) frequency distribution of 9 populations grown in the field.

Population[2]	Total number of plants in classes[1]																	Total number of plants
	20	23	26	29	32	35	38	41	44	47	50	53	56	59	62	65	68	
Concho.	-	-	-	-	-	5	16	35	26	26	16	12	8	5	1	-	-	150
B_1 to Concho.	-	-	-	-	3	10	14	9	13	5	9	8	-	2	-	-	-	73
F_1c	-	-	-	1	1	5	6	15	8	6	10	4	-	-	-	-	-	56
F_1d	-	-	-	-	2	4	10	16	8	18	8	6	1	-	-	-	-	73
F_2a	-	-	1	1	6	10	10	23	19	21	8	7	3	2	1	-	-	112
F_2b	-	-	3	6	10	9	11	16	25	14	7	7	4	2	-	-	-	114
F_3	7	18	29	79	109	140	168	217	256	270	232	208	130	65	20	9	1	1958
B_1 to Stw 554387-20 .	1	3	2	6	9	10	10	8	11	10	4	1	2	-	-	-	-	77
Stw 554387-20	-	1	13	22	32	32	31	14	4	1	-	-	-	-	-	-	-	150

[1] Classes are designated by upper limits in centimeters and are inclusive.

[2] See Table 2 for C.I., selection, or cross number.

App. Table 2.--Culm length (less peduncle) frequency distribution of 8 populations grown in greenhouse.

Population[2]	Total number of plants in classes[1]																			Total number of plants
	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96	
Concho.	-	-	-	-	-	-	-	1	1	2	1	2	6	4	3	1	-	-	-	21
B_1 to Concho. . . .	-	-	-	1	2	2	-	1	-	-	5	2	3	2	-	-	1	1	-	20
F_1a	-	-	-	-	1	2	2	5	2	9	-	-	-	-	-	-	-	-	-	21
F_1b	-	-	-	-	-	1	-	5	9	3	2	1	-	-	-	-	-	-	-	21
F_2c	-	-	3	1	3	2	4	8	4	5	4	6	-	1	1	-	-	-	-	42
F_3	2	6	8	15	24	19	44	39	59	36	40	35	30	15	13	7	4	2	1	399
B_1 to Stw 554387-20	-	-	-	1	2	2	3	7	2	1	1	1	-	-	-	-	-	-	-	20
Stw 554387-20 . . .	-	-	5	7	6	2	1	-	-	-	-	-	-	-	-	-	-	-	-	21

[1] Classes are designated by upper limits in centimeters and are inclusive.

[2] See Table 2 for C.I., selection, or cross number.

App. Table 3.--Peduncle length frequency distribution of 9 populations grown in the field.

Population[2]	Total number of plants in classes[1]															Total number of plants
	15	17	20	23	26	29	32	35	38	41	44	47	50	53	56	
Concho.	-	-	-	-	-	-	-	2	8	15	36	34	42	13	-	150
B_1 to Concho.	-	-	-	-	-	2	1	9	10	13	17	12	7	2	-	73
F_1c	-	-	-	-	-	-	4	7	15	26	1	2	1	-	-	56
F_1d	-	-	-	-	-	2	5	11	26	25	4	-	-	-	-	73
F_2a	-	-	1	-	8	11	11	13	26	20	11	6	5	-	-	112
F_2b	-	-	1	2	5	12	11	19	23	18	14	7	2	-	-	114
F_3	2	6	27	88	119	155	195	296	323	247	227	171	80	17	5	1958
B_1 to Stw 554382-2. . . .	-	1	2	8	8	17	21	7	6	7	-	-	-	-	-	77
Stw 554382-2.	-	1	16	70	60	1	1	1	-	-	-	-	-	-	-	150

[1] Classes are designated by upper limits in centimeters and are inclusive.

[2] See Table 2 for C.I., selection, or cross number.

App. Table 4.--Peduncle length frequency distribution of 8 populations grown in the greenhouse.

Population[2]	Total number of plants in classes[1]																Total number of plants
	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	
Concho.	-	-	-	-	-	-	2	3	6	7	2	1	-	-	-	-	21
B_1 to Concho.	-	-	-	1	-	3	-	2	3	2	5	1	2	1	-	-	20
F_1a	-	-	-	-	-	-	-	-	-	3	7	9	2	-	-	-	21
F_1b	-	-	-	-	-	-	-	-	-	5	6	10	-	-	-	-	21
F_2c	-	-	2	1	2	1	2	8	4	5	4	6	6	1	-	-	43
F_3	3	13	19	12	22	14	15	31	40	39	72	54	31	27	6	1	399
B_1 to Stw 554387-20	-	-	-	-	-	-	2	2	7	1	-	4	2	2	-	-	20
Stw 554387-20	-	-	-	-	-	1	9	10	-	1	-	-	-	-	-	-	21

[1] Classes are designated by upper limits in centimeters and are inclusive.

[2] See Table 2 for C.I., selection, or cross number.

App. Table 5.—Head length frequency distribution of 9 populations grown in the field.

Population/2	Total number of plant in classes/1									Total number of plants
	6	7	8	9	10	11	12	13	14	
Concho.	-	1	17	80	47	5	-	-	-	150
B_1 to Concho.	-	-	5	22	37	9	-	-	-	73
F_1c	-	-	1	5	28	20	2	-	-	56
F_1d	-	-	3	6	32	25	7	-	-	73
F_2a	1	1	2	19	35	47	6	1	-	112
F_2b	-	1	5	30	47	25	6	-	-	114
F_3	3	16	93	372	776	533	153	10	2	1958
B_1 to Stw 554387-20 . . .	-	-	1	4	25	37	10	-	-	77
Stw 554387-20	-	1	-	1	15	47	59	25	2	150

/1 Classes are designated by upper limits in centimeters and are inclusive.

/2 See Table 2 for C.I., selection, or cross number.

App. Table 6.--Head length frequency distribution of 8 populations grown in the greenhouse.

Population[2]	Total number of plants in classes[1]																			Total number of plants
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Over 23	
Concho	-	-	-	1	4	1	3	1	1	6	-	-	1	3	-	-	-	-	-	21
B_1 to Concho . . .	-	1	1	8	1	1	1	1	-	1	3	-	2	-	-	-	-	-	-	20
F_1a.	-	-	2	9	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21
F_1b.	-	-	2	10	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21
F_2c.	-	3	11	7	9	2	1	1	-	1	2	1	2	1	-	-	-	1	-	42
F_3	3	52	87	88	40	12	15	9	12	10	13	12	7	5	9	7	3	4	11	399
B_1 to Stw 554387-20. . . .	-	-	3	5	6	5	-	-	1	-	-	-	-	-	-	-	-	-	-	20
Stw 554387-20. . .	-	-	3	9	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21

[1] Classes are designated by upper limits in centimeters and are inclusive.

[2] See Table 2 for C.I., selection, or cross number.

App. Table 7.--Plant height frequency distribution of 9 populations grown in the field.

Populations/2	Total number of plants in classes/1																	Total number of plants
	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	
Concho.	-	-	-	-	-	-	-	2	7	5	25	45	34	25	7	-	-	150
B_1 to Concho.	-	-	-	-	-	1	2	5	8	16	10	10	11	6	4	-	-	73
F_1c	-	-	-	-	-	-	2	3	6	14	14	13	4	-	-	-	-	56
F_1d	-	-	-	-	-	-	4	6	3	18	20	16	6	-	-	-	-	73
F_2a	-	-	-	1	4	4	7	12	10	15	24	17	12	2	4	-	-	112
F_2b	-	-	1	1	4	8	11	10	10	16	14	24	8	6	1	-	-	114
F_3	2	4	20	44	69	101	120	126	170	237	279	275	241	168	71	25	6	1958
B_1 to Stw 554382-2. .	-	1	3	1	10	2	15	9	14	9	8	3	3	-	-	-	-	77
Stw 554382-2.	-	-	4	13	33	47	36	11	6	-	-	-	-	-	-	-	-	150

/1 Classes are designated by upper limits in centimeters and are inclusive.

/2 See Table 2 for C.I., selection, or cross number.

App. Table 8.--Plant height frequency distribution of 8 populations grown in the greenhouse.

Population[2]	Total number of plants in classes[1]																				Total number of plants
	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	
Concho.	-	-	-	-	-	-	-	-	-	-	1	1	2	1	6	5	4	1	-	-	21
B_1 to Concho. .	-	-	-	-	-	1	2	1	1	-	-	1	2	3	1	4	2	2	-	-	20
F_1a	-	-	-	-	-	-	-	-	1	3	2	4	6	5	-	-	-	-	-	-	21
F_1b	-	-	-	-	-	-	-	-	-	1	1	9	5	5	-	-	-	-	-	-	21
F_2c	-	-	-	-	3	2	-	3	4	3	4	6	4	5	5	1	-	2	-	-	42
F_3	3	2	4	7	5	12	14	19	20	39	45	50	43	38	33	28	15	10	10	2	399
B_1 to Stw 554387-20 . .	-	-	-	-	-	-	1	4	2	3	2	3	2	1	2	-	-	-	-	-	20
Stw 554387-20 .	-	-	-	-	3	9	6	2	1	-	-	-	-	-	-	-	-	-	-	-	21

[1] Classes are designated by upper limits in centimeters and are inclusive.

[2] See Table 2 for C.I., selection, or cross number.

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