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Genetic Interrelations of Two Andromonoecious Types of Maize, Dwarf and Anther Ear

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GENETIC INTERRELATIONS OF TWO ANDROMONOECIOUS TYPES OF MAIZE, DWARF AND ANTHER EAR[1]

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TABLE OF CONTENTS

INTRODUCTION 203
Characteristics of the dwarf and anther-ear types 204
Inheritance of the dwarf type 210
Inheritance of the anther-ear type 212
Genetic interrelations of the dwarf and anther-ear types 212
Variability in stature of dwarf and anther-ear types 218
Rudimentary stamens in dwarf and anther-ear types 224
SUMMARY 225
LITERATURE CITED 226
APPENDIX—TABLES 227

INTRODUCTION

Attention was called by MONTGOMERY (1906) to the occasional appearance of perfect flowers in the staminate inflorescence of maize and similar cases were reported by KEMPTON (1913). MONTGOMERY (1911) described with illustrations a true-breeding type of semi-dwarf dent maize, the ears of which were perfect-flowered. Perfect-flowered maize was described and illustrated also by BLARINGHEM (1908, pp. 180-183). EAST and HAYES (1911, pp. 13, 14) noted and illustrated a perfect-flowered sweet corn. WEATHERWAX (1916, 1917) showed that typically pistillate flowers of maize exhibit in microscopic sections the rudiments of stamens and that staminate flowers show rudiments of pistils.

The senior author of this paper (EMERSON 1911, pp. 82-87; 1912) described and illustrated dwarf and semi-dwarf andromonoecious maize types and showed that they are inherited as simple recessives to monoecious forms of normal height. Later work has shown that two genetically distinct types, now known as "dwarf" and "anther ear," were confused in these accounts. It was noted in one of them (EMERSON 1911) that the andromonoecious forms of unrelated stocks differed much in height, but

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the differences were thought to be due to growth factors modifying the height of dwarfs as multiple factors are assumed to differentiate normal races of diverse heights.

CHARACTERISTICS OF THE DWARF AND ANTHER-EAR TYPES

Perhaps the most nearly unique feature of both dwarf and anther ear is the presence of stamens throughout their ears (figures 1 and 2). Sometimes one flower of the spikelet has three well developed stamens and the other flower more or less rudimentary ones but in other cases both flowers have fully developed stamens. Since the terminal inflorescences of dwarf and anther-ear plants have staminate flowers only, the types are andromonoecious. Exceptions to this condition, that is, dwarf and anther-ear plants without ear stamens or with rudimentary ones only, have been observed and are discussed in a later section of this account.

The ears of both dwarf and anther ear generally end in thick unbranched tassel-like spikes having staminate flowers only. Anther-ear plants in which the ear is represented by only a few seeds at the base of these club-like staminate-flowered spikes are common, and one plant was found that lacked even these few seeds and that was therefore wholly staminate-flowered. Some stocks of both dwarf and anther ear, on the contrary, have no tassel-like appendages to their ears. In any case the ears are short and relatively thick (figure 1).

The tassels of dwarf plants are compact and little branched, often quite unbranched. The smaller forms of the anther-ear type have tassels that are very similar to those of dwarfs in both compactness and branching while the taller forms usually have tassels that are more slender and more branched than those of dwarfs but rarely so much so as those of normal plants (figures 3 and 4). Our early cultures of dwarfs shed little or no pollen, due apparently to failure of the glumes to open normally. Pollen collected from anthers that had been removed from the tassel proved to be functional. Two dwarf plants found in a culture grown in 1913 shed pollen abundantly. By selection in later cultures of dwarfs descended mostly from these two plants, dwarf strains have been obtained that shed pollen fairly well.

The dwarf type is further characterized by very short culms, ordinarily not more than one-fourth the length of the culms of related normal plants (figure 3). Anther-ear plants also are usually considerably shorter than normals. There are, however, marked differences between different stocks of anther ear with respect to height, some being definitely semi-dwarf and some only slightly shorter than related normal plants (figures 3 and 4).

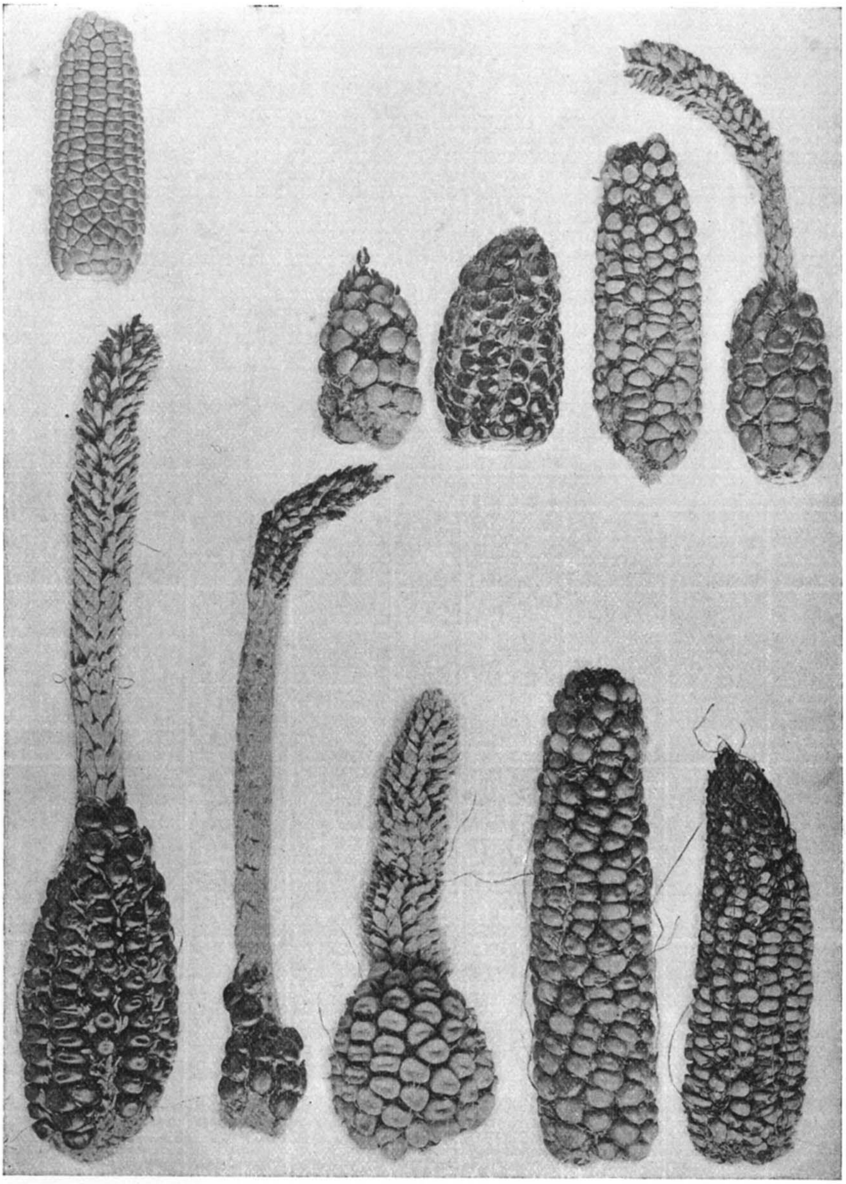

FIGURE 1.—Representative ear types. Below, five anther ear; above, right, four dwarf; above, left, one Tom Thumb.

The possible significance of this variation in height is considered in a later section of this paper. The differences in height are apparent even in the seedling stage (figure 5), though the taller forms of anther-ear seedlings are not always greatly different from normals.

The leaves of dwarf plants are characteristically short and broad. The first seedling leaves are not only shorter but actually broader than those of normal plants and the leaves of mature dwarf plants, though very short, are often quite as broad as those of normal plants. The leaves of most anther-ear plants also are relatively short and broad, being in this respect as a rule intermediate between those of dwarf and those of normal plants. The leaves of the taller anther-ear stocks are often not very different from those of normal plants.

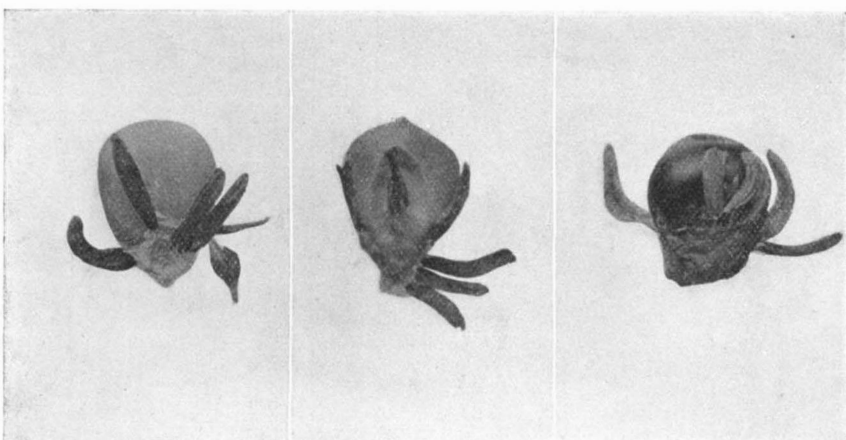

FIGURE 2—Seeds of anther ear and dwarf with stamens attached.

The low stature of dwarf and of anther-ear plants is due to shorter internodes than those of normal plants. In number of internodes these types are not characteristically different. In contrast to this condition of dwarf and anther ear, the low stature of such varieties as Tom Thumb pop is due to the small number of internodes, not merely to short ones (figure 4). Tom Thumb is normal not only in lacking ear stamens (figure 1) but in the relative length, breadth and thickness of its parts. Its ears, tassels, culms and leaves are like those of normal tall plants except that they are proportionately smaller in all dimensions. Dwarf and anther ear, on the other hand, are dwarfed in all longitudinal dimensions but not correspondingly so in diameter of parts.

A type of extreme dwarfness, known as "dwarf anther ear," the double recessive of dwarf and anther ear, as its name indicates, has appeared in certain crosses discussed in a later part of this account (figures 3, 5 and 6). This type is much smaller even than the type called "dwarf." It is char-

FIGURE 3.—Mature plants of normal, anther ear, dwarf, and dwarf anther ear.

acterized by an excessive shortening of all longitudinal dimensions. The length of culm, including the tassel, is often not over 12 centimeters. Its largest leaves are not far from 12 centimeters long and 6 centimeters broad. Since the plant usually has several tillers which spread out almost on the ground, it sometimes has a total spread of branches and leaves of

FIGURE 4.—Mature plants of dwarf, small anther ear, larger anther ear, very small normal Tom Thumb, and tall normal.

two and a half times its height. The tassel is a short, compact, unbranched spike. The anthers do not shed pollen normally. No adequate test has

FIGURE 5.—Seedlings of normal, anther ear, dwarf, and dwarf anther ear.

been made to determine whether or not the pollen is functional. No fertile ear shoots have been observed on any of these plants.

INHERITANCE OF THE DWARF TYPE

That the dwarf type is inherited as a simple recessive to normal has been reported previously by the senior author (EMERSON 1911, 1912). Since in these accounts the anther-ear type was confused with the dwarf type, it seems wise to present here such evidence as is necessary to show the mode of inheritance of the true dwarf type in crosses between dwarf and normal.

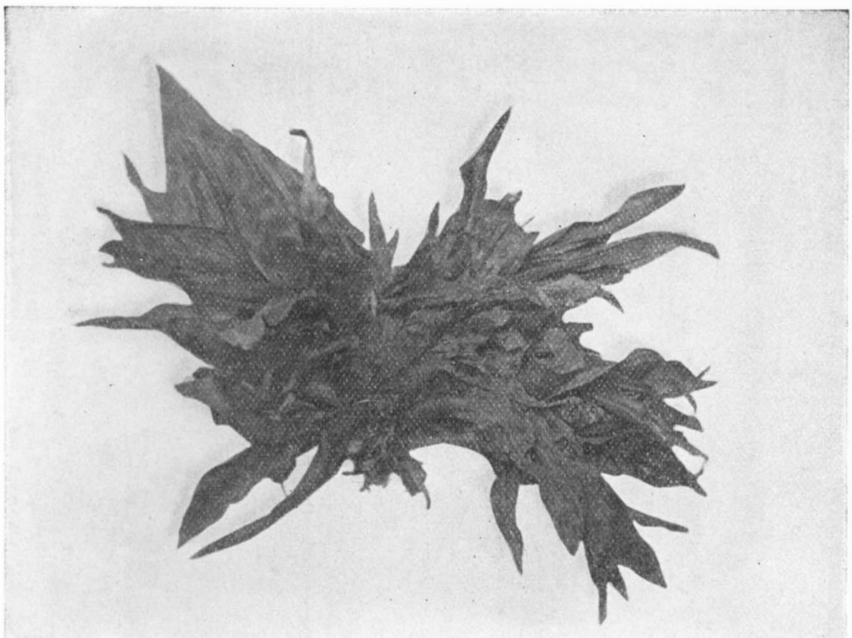

FIGURE 6.—Mature plant of dwarf anther ear.

Our records show that nineteen direct crosses of dwarf with normal resulted in 272 F_1 plants, all of which were normal. From selfed normal plants heterozygous for dwarf, fifty-four F_2 progenies with a total of 2932 individuals were grown. Of these F_2's thirty progenies were grown from seed planted in the field (table 7, group 1; see appendix). They resulted in 1095 normal and 231 dwarf plants. The deviation from a 3 : 1 ratio is 100.5 ± 10.6. The odds against such a deviation being due to chance are almost inconceivably great. The longitudinal axis of germinating seedlings of dwarf is relatively as short as that of mature plants.

Part of these F_2 cultures were grown at Lincoln, Nebraska, where it is customary to plant maize seeds about ten centimeters deep. The other cultures were grown at Ithaca, N. Y., from plantings not over three or four centimeters deep but in sticky clay soil. It seems obvious that under neither of these conditions could dwarf be expected to germinate well.

Fourteen other F_2 cultures (table 7, group 2) were germinated in light soil in greenhouse flats from seed planted about two centimeters deep. These cultures contained 436 normals and 138 dwarfs, a deviation from the 3 : 1 ratio of 5.5 ± 7.0. These two lots of F_2's were closely related, all having come from a single lot a few generations before, so that there can be little doubt that the same type is concerned in both. More decisive evidence, however, is afforded by the behavior of ten other F_2 cultures (table 7, group 3), each of which was planted both in the field and in the greenhouse. Of the field-grown lots, 277 were normal and 60 dwarf, a deviation from the 3 : 1 ratio of 24.3 ± 5.4, which should not occur by chance more than once in somewhat over 400 trials. Of the lots germinated in the greenhouse, there were 510 normals and 185 dwarfs, an excess of dwarfs over expectation of 11.3 ± 7.7, or such a deviation as might occur by chance about once in three trials.

F_1 plants of this cross, back-crossed with dwarfs, yielded eight progenies (table 8) with 331 normals and 354 dwarfs, a deviation from the expected equality of 11.5 ± 8.8, or such as might occur by chance almost twice in five trials. All but one of these eight progenies were germinated in the greenhouse.

Some of the F_2 normals remained constant in F_3 and others again threw dwarfs. Normals of the segregating F_3 progenies should theoretically be equivalent to F_2's. In all, seven F_3 and equivalent F_4 progenies (table 9, group 1) gave none but normal plants, a total of 208. Fifteen F_3 and F_4 progenies (table 9, group 2) gave 484 normals and 120 dwarfs, a deviation from the 3 : 1 relation of 31.0 ± 7.2, or such as might occur by chance only once in about 270 trials. All but three of the fifteen progenies were grown in the field. It is expected that one in three F_2 and equivalent F_3 normal plants will breed true. The seven true-breeding and fifteen segregating progenies is a close approach to this expectation.

Five F_2 and F_3 dwarfs bred true in the next generation (table 9, group 3) having produced a total of 56 dwarfs and one normal, the latter doubtless due to accidental pollination.

It is to be concluded, therefore, that dwarf, *d d*, behaves as a simple Mendelian recessive to normal, *D D*.

INHERITANCE OF THE ANTHER-EAR TYPE

That anther ear, like dwarf, is a simple Mendelian recessive to normal is shown by the data now to be presented. Eighteen F_1 progenies of crosses between anther ear and normal resulted in 485 normal plants. From such heterozygous normal plants, twenty-seven F_2 progenies with a total of 1151 individuals were grown. Of these, twelve progenies grown in the field (table 10, group 1) had 455 normal and 108 anther-ear plants, a deviation from a 3 : 1 ratio of 32.8 ± 6.9, or such as would be expected to occur by chance not more than once in about 750 trials. Since anther ear is less vigorous than normal, it seems probable that this deficiency of anther ear was due to the failure of some plants to survive under field conditions. Thirteen F_2 progenies germinated in the greenhouse (table 10, group 2) contained 320 normal and 128 anther-ear plants, a deviation of 16.0 ± 6.2 from a 3 : 1 ratio. Such a deviation might be expected to occur by chance once in about twelve such trials. Two progenies (table 10, group 3) were grown in both the field and greenhouse. Of the field-grown plants there were 53 normal and 8 anther ear and of the greenhouse-grown ones 55 normal and 24 anther ear. The deviations from a 3 : 1 relation are 7.3 ± 2.3 and 4.3 ± 2.6, or such as might occur by chance about once in thirty and once in four trials, respectively.

Four normal plants of F_2 bred true in F_3 (table 11, group 1), three of them having produced a total of 272 normal plants from self-pollination and one of them 12 normals from a back-cross with anther ear. Seven F_2 normals and one F_3 equivalent to an F_2 (table 11, group 2) produced 393 normal and 110 anther-ear plants, a deviation from the 3 : 1 ratio of 15.8 ± 6.6, or such as might occur by chance about once in nine trials. The deficiency of anther ear is probably due to the fact that all but one of these cultures were field-grown.

Three F_2 anther-ear plants (table 11, group 3) produced 36 anther-ear and 2 normal plants in F_3. The normals are doubtless to be accounted for by accidental pollination, so that the conclusion that anther-ear plants breed true seems justifiable.

On the whole, therefore, anther ear, $a_n\ a_n$, can be said to behave in inheritance as a simple recessive to normal, $A_n\ A_n$.

GENETIC INTERRELATIONS OF THE DWARF AND ANTHER-EAR TYPES

In the foregoing account, it has been assumed that dwarf and anther ear are genetically different types. The evidence upon which this assumption is based is presented here. It has been stated previously that the two types were confused in the earlier papers of the senior author. Both types exhibit so much variation in stature and have so many characters in common,—stamens in the ears, relatively short culms, leaves, tassels and ears, and recessiveness to normal,—that this confusion was perhaps not unnatural in the early stages of the work.

Crosses of dwarf, d, with anther ear, a_n, have resulted in plants that were normal in all respects, including relatively long culms and leaves, slender much-branched tassels, and ears without stamens or with mere rudiments of stamens. Six such crosses (table 12) gave F_1 progenies totaling 83 normal plants. In addition normal plants heterozygous for dwarf, crossed with normals heterozygous for anther ear, resulted in 21 normal plants.

The F_2 progenies of the cross dwarf × anther ear, $D\ d\ A_n\ a_n$, are recorded in group 1 of table 13. A cross of a normal, $D\ D\ A_n\ A_n$, with an anther ear that is heterozygous for dwarf, $D\ d\ a_n\ a_n$, should give two F_1 genotypes, $D\ D\ A_n\ a_n$ and $D\ d\ A_n\ a_n$. Similarly a cross of a normal with a dwarf that is heterozygous for anther ear, $d\ d\ A_n\ a_n$, should give two genotypes, $D\ d\ A_n\ A_n$ and $D\ d\ A_n\ a_n$. The double heterozygotes, in case of each of these crosses, are equivalent to F_1's of the cross normal × dwarf anther ear and should give the same results in F_2 as F_1's of the cross dwarf × anther ear. Two such F_2 progenies are recorded in group 2 of table 13, the first being a cross of normal with anther ear and the second a cross of normal with dwarf.

The eight F_2 progenies had a total of 752 individuals distributed as shown below to the four types, normal, dwarf, anther ear, and dwarf anther ear. There is about one chance in thirteen that the deviations from the 9 : 3 : 3 : 1 relation, expected on the basis of two independent factor pairs, may be due to errors of random sampling, P equaling 0.076. The comparison follows:

	Normal	*Dwarf*	*Anther ear*	*Dwarf anther ear*	*Total*
Observed	446	139	136	31	752
Calculated	*423*	*141*	*141*	*47*	*752*
Difference	+23	−2	−5	−16	0

The deficiency of dwarf anther ear is doubtless due to the extremely small size of this type, which makes it incapable of germinating or of surviving under field conditions. Since both dwarf and anther ear are ordinarily deficient in field cultures, the much smaller double recessive could hardly be expected to survive in the field. The apparent excess of normals is probably due to the deficiencies of the other three types. That this explanation of the rather poor fit of the observed with the theoretical distributions is correct is made highly probable by the comparisons given below. Of the eight F_2 progenies, two were grown in the field only, three in the greenhouse only, and three in both the field and the greenhouse. Of the field-grown lots the deviations from the calculated frequencies are so great that they would not be expected to occur by chance more than about once in over twelve thousand trials, P equaling 0.000,085. With the greenhouse-grown lots, on the other hand, there is so close a fit between the observed and the theoretical frequency distributions that no value of P is to be found in published probability tables, χ^2 equaling 0.65. (When $\chi^2 = 1$ and $n' = 4$, $P = 0.80$.) The comparisons follow:

	Normal	*Dwarf*	*Anther ear*	*Dwarf anther ear*	*Total*
Field cultures					
Observed.......	182	43	49	1	275
Calculated......	*155*	*52*	*52*	*17*	*276*
Difference......	+27	−9	−3	−16	−1
Greenhouse cultures					
Observed.......	264	96	87	30	477
Calculated......	*268*	*89*	*89*	*30*	*476*
Difference......	−4	+7	−2	0	+1

Three F_1 normals back-crossed with anther ear gave 157 normals and 93 anther ears (table 14, group 1). Numerical equality of these two classes is to be expected on the basis of independent inheritance of the complementary factor pairs *D d* and A_n a_n. The deviation from expectation is 32.0 ± 5.3. This extreme deficiency of anther ear must be explained by the fact that all these cultures were field-grown, mostly under unfavorable conditions.

Five F_1 normals of the cross of dwarf with anther ear were back-crossed with dwarf and gave 274 normal and 204 dwarf plants (table 14, group 2). The deviation from equality is 35.0 ± 7.4, which, while less than that found in the case of anther ear from back-crosses of F_1 with anther ear, is so great that appeal must be made here also to the difficulties to which dwarf is subjected under unfavorable field conditions.

The F_2 results of the cross dwarf × anther ear reported above, particularly the greenhouse-grown cultures, leave little doubt that *D d* and A_n a_n are independent complementary factor pairs. The crucial evidence, however, must be sought in the F_3 behavior of the several F_2 types. On the basis of the hypothesis under test, the F_2 types should behave as follows:

F_2 types		F_3 behavior			
Phenotype	Genotype	Normal	Dwarf	Anther ear	Dwarf anther ear
9 normal	1 $D\ D\ A_n\ A_n$	1			
	2 $D\ d\ A_n\ A_n$	3	1		
	2 $D\ D\ A_n\ a_n$	3		1	
	4 $D\ d\ A_n\ a_n$	9	3	3	1
3 dwarf	1 $d\ d\ A_n\ A_n$		1		
	2 $d\ d\ A_n\ a_n$		3		1
3 anther ear	1 $D\ D\ a_n\ a_n$			1	
	2 $D\ d\ a_n\ a_n$			3	1
1 dwarf anther ear	1 $d\ d\ a_n\ a_n$				1

Twenty-four F_2 normals were tested in F_3 (table 15). Plantings of most of the F_3 progenies (culture numbers S48-S90) were made in the greenhouse, and duplicate plantings were made in the field under unusually adverse soil conditions, part of them (S126-S166) in 1918 and part (9618-9642) in 1919. It was hardly to be expected that the weaker types would appear in field plantings in numbers close to the theoretical ones. The field and greenhouse plantings are recorded together in table 15.

Of the twenty-four F_2 normals tested, two (table 15, group 1) remained constant, $D\ D\ A_n\ A_n$, in F_3, having produced 290 normal plants and no other types.

Five F_2 normals, $D\ d\ A_n\ A_n$, (group 2) produced 374 normals and 86 dwarfs, a deviation from the 3 : 1 relation of 29.0 ± 6.3. Such a deviation could occur by chance not more than once in over five hundred trials. Of these 460 F_3's, the 173 grown in the greenhouse consisted of 120 normals and 53 dwarfs, an excess over expectation of 9.8 ± 3.8 dwarfs, a deviation that might occur by chance about once in thirteen trials.

Three F_2 normals, $D\ D\ A_n\ a_n$, (group 3) produced 249 normals and 61 anther ears in F_3, a deviation from the 3 : 1 relation of 16.5 ± 5.1, or such as might occur by chance not more than three times in one hundred trials. Of these 310 F_3's, the 132 greenhouse-grown plants consisted of 98 normal and 34 anther-ear plants, a deviation of only 1.0 ± 3.4 from the 3 : 1 ratio.

Fourteen F_2 normals, $D\ d\ A_n\ a_n$, (table 15, group 4) produced in F_3 the three types, normal, dwarf and anther ear, and six of them produced dwarf anther ear in addition. In a total of 1174 F_3 plants, the four types, in the order given above, appeared in the numbers 774 : 174 : 215 : 11.

The departures from expectation are so extreme that no value of P is to be found in published tables, χ^2 equaling 84. (When $\chi^2 = 30$ and $n' = 4$, $P = 0.000,001$). Of these 1174 F_3 plants, 594 that were germinated in the greenhouse exhibited the four types in the numbers 330 : 105 : 148 : 11. Even in case of these greenhouse-grown seedlings, there is not more than one chance in a million that the observed deviations from expectation could be due to errors of random sampling. The great deficiency in the very weak double recessive, dwarf anther ear, is responsible more than anything else for the poor fit. All the plants of this type that appeared were in greenhouse cultures but apparently they were too weak to complete their germination even under greenhouse conditions. The only other marked difference between observed and calculated frequencies in these greenhouse cultures occurred in the anther-ear class, but here there was an excess over expectation. It is not particularly difficult to separate the smaller types of anther ear from normal even in the seedling stage, but the taller anther-ear stocks cannot always be distinguished until the flowering stage. It seems possible that the recorded excess of anther ear in these lots may have come in part from errors in classification.

Notwithstanding the poor fit of observed with calculated frequencies in some cases, the F_2 normals of the cross of dwarf with anther ear exhibited in general the F_3 behavior expected of them in accordance with the hypothesis that $D\ d$ and $A_n\ a_n$ are complementary independently inherited factor pairs. Of the twenty-four F_2 normals tested, the four types of F_3 behavior, were exhibited in the relation of 2 : 5 : 3 : 14, while the theoretical relation for twenty-four individuals is 2.7 : 5.3 : 5.3 : 10.7. There is slightly better than an even chance that deviations such as this might occur through errors of random sampling.

Two F_2 dwarfs were tested by their F_3 behavior, both in greenhouse plantings. One of these, $d\ d\ A_n\ A_n$, (table 15, group 5) bred true, having produced 51 dwarf plants, and one, $d\ d\ A_n\ a_n$, threw 17 dwarfs and 6 dwarf anther ears, as nearly a 3 : 1 ratio as is possible with a total of 23 plants. Theoretically, one out of three F_2 dwarfs should breed true and two throw dwarfs and dwarf anther ears.

No F_2 anther ear was tested in F_3. It is obviously impossible to test dwarf anther ear, since no plant of that type has ever produced seeds.

It has been shown (table 14) that F_1 normals of the cross dwarf × anther ear back-crossed with anther ear throw only normal and anther ear in the next generation. Of such normals, half, $D\ D\ A_n\ a_n$, should again throw normal and anther ear, and half, $D\ d\ A_n\ a_n$, should throw all four types. Records of twenty-one such tests are given in table 16. Eleven normals threw normal and anther ear (table 16, group 1) in the relation of 252 : 63, a deviation from 3 : 1 of 15.8 ± 5.2. Only one of these progenies was germinated in the greenhouse and this consisted of 73 normal and 24 anther ear, deviation 0.3 ± 2.9. The other ten normals tested (group 2) gave a total of 257 plants distributed to the four types in the relation of 186 : 26 : 43 : 2. This extreme departure from the expected 9 : 3 : 3 : 1 relation is doubtless due to the fact that all but one of the cultures were field-grown. This one showed the four types in the relation of 10 : 3 : 3 : 2, a very close fit to expectation, χ^2 equaling 0.83. Of the 21 normals tested, 11 gave the one type of behavior and 10 the other, where equality was expected.

Nine anther-ear plants of these same back-crosses (table 8) were tested by their F_3 behavior. Four bred true, $D\ D\ a_n\ a_n$, with a total of 57 anther-ear plants (table 16, group 3) and five, $D\ d\ a_n\ a_n$, produced anther ear and dwarf anther ear only (group 4) in the relation of 127 : 37, a deviation from 3 : 1 of 4.0 ± 3.7. All these lots were grown in the greenhouse. Since half of the anther-ear plants tested are expected theoretically to breed true and half to throw the two types observed, the results are in the closest possible accord with expectation.

F_1 normal plants of the cross dwarf × anther ear back-crossed with dwarf (table 14), it will be recalled, threw normals and dwarfs only. Thirteen of these normals were tested by their progenies. Half of such normals, $D\ d\ A_n\ A_n$, should throw normal and dwarf, and half, $D\ d\ A_n\ a_n$, should throw the four types. Seven of the thirteen (table 17, group 1) threw a total of 161 normal and 26 dwarf, a deviation from 3 : 1 of 20.8 ± 4.0. The deficiency of dwarfs was doubtless due to the fact that all the cultures were field-grown. The other six normals that were tested (table 17, group 2) threw normal, dwarf, and anther ear in the relation of 115 : 10 : 19. The failure of dwarf anther ear to appear, as well as the extreme departure from the expected 9 : 3 : 3 : 1 relation, is ascribed to the field conditions under which all of these cultures were grown.

Three dwarfs from the same back-crosses (table 14) were tested by greenhouse progenies and found (table 17, group 3) to breed true, having produced a total of 173 dwarf plants. Half of them, $d\ d\ A_n\ A_n$, were expected to breed true and half, $d\ d\ A_n\ a_n$, to throw dwarf and dwarf anther-ear. While neither of these dwarfs threw dwarf anther-ear, it has been shown that some such dwarfs carry the a_n factor in a heterozygous condition, $d\ d\ A_n\ a_n$. Dwarfs of back-cross progenies when crossed with normals gave normals in F_1. One of these F_1 normals (table 13, group 2) threw the four types in F_2 with frequencies of 47 : 12 : 13 : 4. This behavior could have resulted only from a dwarf of the genotype $d\ d\ A_n\ a_n$.

By way of summary, it may be noted that all the genotypes theoretically possible on the assumption of two independently inherited factor pairs, $D\ d$ and $A_n\ a_n$, have been demonstrated in the cross of dwarf with anther ear. It is true that the observed frequency distributions of the several phenotypes have in many instances been far from the theoretical frequencies, but it has been shown conclusively, by growing cultures in both the field and the greenhouse, that these departures from expectation have been due to the failure of the weaker forms to germinate or to survive under field conditions. In a few cases, an excess of anther ear over expectation has been recorded with cultures germinated in the greenhouse, but this result is regarded as due mainly to the difficulty of separating anther ear from normal in the seedling stage.

VARIABILITY IN STATURE OF DWARF AND ANTHER-EAR TYPES

In the foregoing sections of this paper, repeated references have been made to the differences in height between different stocks of anther ear. Similar differences exist between diverse stocks of dwarf. Since all our stocks of dwarf and of anther ear came each from a single plant, it is of interest to consider the possible nature of these diversities.

The dwarf type ordinarily varies in height from about 30 to 60 centimeters as contrasted with heights of from about 120 to 200 centimeters for normal plants of the same cultures. Frequency distributions for height of plants of F_2 progenies of crosses of dwarfs with normals are given in table 1. In no case have the heights of dwarfs and of normals of the

TABLE 1

Heights of normal and dwarf plants of F_2 progenies of the cross dwarf × normal.

PEDIGREE CULTURE	HEIGHT OF PLANTS IN DECIMETERS																	
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean
396 Normal....										1	1	3	5	2	2	5	2		16.0
Dwarf.....	1	1																	3.5
7424 Normal....										2	3	7	5	6	7	4		2	15.6
Dwarf.....	11	23	12	3															4.1

same culture been observed to overlap. This sharp segregation in height is ascribed to the single factor pair $D\ d$. That other growth factors, and environmental influences as well, affect the height of dwarfs, much as they do the height of normal plants, is evident from crosses of dwarfs, $d\ d$, with normals $D\ D$, of very low stature, such as Tom Thumb pop.

It has been shown (EMERSON and EAST 1913) that, when a tall normal strain is crossed with Tom Thumb, the height of the F_1 plants is intermediate between the height of the parents, while the range in height of the F_2 plants extends practically to the extremes of both parents. An illustration of this behavior is given in table 2. Such behavior in F_2 is ordinarily interpreted on the basis of partially dominant multiple factors affecting growth. Obviously no single factor pair is alone concerned here, of the nature of *D d*, which is assumed to be responsible for the sharp segregation shown in table 1.

TABLE 2

Heights of parental, F_1, and F_2 plants of the cross tall dent × Tom Thumb pop.

PEDIGREE CULTURE	HEIGHT OF PLANTS IN DECIMETERS																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean
357 Tall dent...											2	1	2	6	2	4	3	3	20.9
508 Tom Thumb	2	6	5	2															8.5
509 F_1.........									1	3	5	7	4						17.5
510 F_2.........	2			2	8	6	25	26	29	30	32	28	22	6	4	1	2		15.9

When dwarf plants, *d d*, are crossed with normals, *D D*, of very low stature like Tom Thumb pop, both the normals and dwarfs differentiated by *D d* should be influenced by diverse partially dominant growth factors just as is true of the F_2 plants of crosses of tall normals with the small Tom Thumb. The results of such a cross are presented in table 3. For ready comparison, the dwarfs of culture 7424 (table 1) and Tom Thumb plants of culture 508 (table 2) are included. Neither of these cultures was grown during the same season as the F_1 and F_2 progenies of the cross of dwarf with Tom Thumb. It will be noted that the F_1 plants of this cross were taller than either parent. Evidently the dwarf parent of the cross brought into the combination partially dominant growth factors that

TABLE 3

Heights of Tom Thumb and dwarf plants and of F_1 and F_2 of the cross dwarf × Tom Thumb.

PEDIGREE CULTURE	HEIGHT OF PLANTS IN DECIMETERS																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Mean
508 Tom Thumb.							2	6	5	2								8.5
7424 Dwarf.......			11	23	12	13												4.1
10727 F_1 normal....											1	2		4	2	1	1	14.0
10728 F_2 normal....						1	4	3	4	4	6	14	13	12	2	4		11.6
F_2 dwarf.....	1	8	6															2.3

were not present in Tom Thumb. These together with the dominant factor D from Tom Thumb resulted in a height growth not greatly different from that of F_1 plants of crosses between Tom Thumb and tall normals. If this supposition is correct, the F_2 plants should exhibit a wide range of variation in height, some of the F_2 normals being taller than the normal Tom Thumb parent and some of the dwarfs being shorter than the dwarf parent. This expectation was strikingly realized. The F_2 normals ranged in height from that of Tom Thumb as ordinarily grown to nearly twice that height with a mean height considerably above that of Tom Thumb. The F_2 dwarfs did not show a great range in height, due perhaps to the small numbers involved, but their mean height was considerably below that of the usual height of dwarfs. While the ranges of heights of the F_2 normals and dwarfs did not overlap, they came close together. Moreover, the shortest F_2 normals were no taller than the tallest dwarfs of other cultures. Evidently the height of these F_2's was influenced by growth factors besides $D\ d$.

Anther-ear plants also are ordinarily shorter than normal plants of the same cultures. In some cultures anther ear is sharply differentiated from normal by its semi-dwarfness (table 4, culture 294), there being no overlapping of the height distributions of the two forms. In such cultures the principal factor pair for plant height differentiating normal from anther ear is $A_n\ a_n$. Since $a_n\ a_n$ does not exert so strong a dwarfing effect as does $d\ d$, there is less difference in height between normals and anther ears even of such a culture as 294 than there usually is between normals and dwarfs. In other cultures the anther-ear plants, while on the average shorter than normals, overlap them in height distributions so much that separation of the two forms must be based on characters other than height (table 4, cultures 298 and 7421).

TABLE 4

Heights of normal and anther-ear plants of F_2 progenies of the cross anther ear × normal.

PEDIGREE CULTURE	HEIGHT OF PLANTS IN DECIMETERS																	
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Mean
294 Normal.......								2	5	5	11	4	3	1	1			18.9
Anther ear....	1	5	1	1	1													10.6
298 Normal.......				1		1	3	4	6	8	8	8	8	3	1			18.6
Anther ear....	1	1			2	5	2	1	2	1								14.0
7421 Normal.......						1			4	1	3	13	9	9	5	4	2	21.1
Anther ear....					1	1		3	4	4	1	5	1	1				17.9

The cause or causes of overlapping in the height ranges of normal and anther-ear plants of some cultures and the sharp segregation in height of these two types in other cultures cannot be determined with certainty from the data now available. Certain possibilities, however, should be noted.

There may exist a series of allelomorphs instead of the single pair A_n a_n. The fact that all our anther-ear stocks came originally from a single plant makes this supposition improbable. Since, however, this plant was not self-pollinated, the suggestion is not an impossible one. Moreover, there is always the possibility of one or more mutations having occurred in one or both members of the A_n a_n pair since the original stock was obtained. If there exist an allelomorph of A_n a_n which has a less dwarfing effect than a_n, just as a_n has less effect than d, the anther-ear plants of some cultures might well be considerably taller than those of other cultures without any corresponding difference in height between the normal plants of the two lots.

A second possibility is that other growth factors may be linked with the A_n a_n pair. If multiple factors affecting height growth are distributed widely throughout the chromosome complex of maize, as seems probable, some of them must necessarily be linked with A_n a_n. Such linkage might well bring about overlapping of heights of normal with those of anther-ear plants in certain cultures and sharp segregation of heights in others, the result in any one culture depending on whether certain dominant or partially dominant growth factors entered the cross with A_n or with a_n. The effects of such linkage might of course be more or less masked by the presence in a heterozygous condition of other growth factors not linked with A_n a_n.

While it seems highly probable that some growth factors may be linked with A_n a_n, resort to this hypothesis is not essential to a plausible explanation of the data presented in table 4. It may well be that in such sharply segregating cultures as 294 few growth factors other than A_n a_n were heterozygous while in such overlapping cultures as 298 and 7421 numerous other growth factors were heterozygous. In case of the latter cultures, such normal plants as happened to receive few dominant or partially dominant growth factors would be expected to be relatively short in stature and such anther-ear plants as happened to receive many of these factors would be relatively tall, thus insuring an overlapping of the height distributions of the two types. If this hypothesis be true, both normal and anther-ear plants should exhibit greater variability in height in overlapping cultures than in sharply segregating ones. While the numbers of individuals involved were perhaps too few to afford conclusive evidence on this point, it is apparent that the overlapping cultures of table 4 were more variable than the sharply segregating culture.

As bearing further upon this suggestion of the possible effect of heterozygous growth factors in addition to A_n a_n, a cross of the very small normal race Tom Thumb with a stock of anther ear of relatively low stature may be cited. Unfortunately individual records of height of plants were not made for this cross, our records indicating merely the range of variation in height of the F_2 normals and anther ears. The F_1's of this cross, culture 1848, were normals of medium height such as result from crosses of Tom Thumb with a tall normal race. The ranges in height of the F_2 normals and anther ears are shown in table 5. For comparison the heights of anther-ear plants of culture 294 (table 4), of Tom Thumb plants of culture 508 (table 2), and of dwarf plants of culture 7424 (table 1) are included. The added cultures were not grown at the same time as the F_2 cultures and are not therefore wholly comparable with them.

TABLE 5

Range of heights of parent types and of F_2 normal and anther-ear plants of the cross anther ear × Tom Thumb, and of a culture of dwarf plants.

PEDIGREE CULTURE	HEIGHT OF PLANTS IN DECIMETERS													
	3	4	5	6	7	8	9	10	11	12	13	14	15	16
294 Anther ear (table 4)							←	—	—	—	→			
508 Tom Thumb (table 2)					←	—	—	→						
7424 Dwarf (table 1)	←	—	—	→										
8286 F_2 normal				←	—	—	—	—	—	—	—	—	—	→
F_2 anther ear			←	—	—	—	—	—	—	—	—	—	→	

It is evident from the height distributions shown in table 5 that an unusually large complex of growth factors besides A_n a_n were brought into this cross by Tom Thumb pop and the anther-ear parent. The anther-ear plants of F_2 ranged in height from above the usual height of the stock of anther ear used as one parent to much below the ordinary height of Tom Thumb and even to about the average height of ordinary dwarfs. The F_2 normals showed about the same range of heights but were on the whole slightly taller than the anther ears.

From the above it seems safe to conclude that the diverse heights of different anther-ear stocks, and of dwarfs as well, are in large measure due to the influence of growth factors other than A_n a_n and D d. The overlapping in height of anther-ear and normal plants of some F_2 cultures

TABLE 6

Heights of F_2 normal, anther ear, dwarf, and dwarf anther ear of the cross dwarf × anther ear and of a cross equivalent to normal × dwarf anther ear.

PEDIGREE CULTURE	HEIGHT OF PLANTS IN DECIMETERS																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Mean
7420 Normal												4	5	3	10	9	4	5	6							15.7
Anther ear									3	2	2	1	1	1		1										11.3
Dwarf			3	9	2	1																				4.1
Dwarf anther ear	1																									
10536 Normal												1		2	3	7	14	7	9	2	8	2	5	2	1	18.6
Anther ear									2		2		2	2	2	6	1		2	1						14.8
Dwarf		4	8	2	1																					
10735, 10736 Normal														1	2	3	5	3	5	6	3	3				18.4
Anther ear											2		1	1			1	2	2							15.6
Dwarf			3	3																						3.5
Dwarf anther ear	1																									

and the sharp height segregation of these types in other cultures appears to be due largely to the relative number of growth factors that happen to be in a heterozygous condition in the several cases. The linkage of certain growth factors with A_n a_n probably has an effect also. Whether allelomorphs of A_n a_n are involved cannot be determined from the data at hand, but that the pairs A_n a_n and D d, particularly the latter, play an important part in determining height of plant is evident. In no single F_2 culture as yet observed have dwarfs overlapped in height either normals or anther ears.

That dwarfs are distinctly smaller than the other two types, normal and anther ear, is particularly well shown in table 6 in which are presented data from F_2 cultures involving all these types together with a few plants of the double recessive dwarf anther ear. One of these cultures was an F_2 of a cross of normal with anther ear heterozygous for dwarf, equivalent to a cross of normal with dwarf anther ear, and the others were F_2's of the cross dwarf $\times$ anther ear (table 13). The normals in all cases were somewhat taller than the anther ears. This increase in height over the parent types, dwarf and anther ear, is doubtless due in the main to the interaction of the dominant factors D and A_n. The sharp segregation in height of dwarfs is in strong contrast with the overlapping of the heights of normal and anther ear. So few dwarf anther ears were measured that it cannot be determined from the data whether dwarf and dwarf anther ear ever overlap in height ranges as do normal and anther ear.

RUDIMENTARY STAMENS IN DWARF AND ANTHER-EAR TYPES

The original stocks of dwarf and of anther ear had well developed stamens throughout the ears. In 1915 in a culture consisting of normals and dwarfs, the ears of some of the dwarf plants were found to have only rudimentary stamens. Since other dwarfs of the same culture had well developed stamens, the character was evidently heterozygous in the stock. A dwarf with rudimentary ear stamens was crossed with an anther ear with normal ear stamens. The F_1 plants had no stamens in their ears or only a few very rudimentary ones such as are sometimes seen in normal stocks. The F_2 cultures of this cross (table 13) consisted of normal, dwarf, anther ear and dwarf anther ear. The latter had no ears and the normals were without ear stamens. Of the F_2 dwarfs and anther ears some had well formed ear stamens and others only rudimentary ones. The 64 dwarf and anther-ear plants were distributed among the four classes as follows:

	Stamens normal	*Stamens rudimentary*	*Total*
Dwarf	11	22	33
Anther ear	21	10	31
Total	32	32	64

While the number of individuals observed is too small for reliable indications, the frequency distribution noted above suggests that a factor for rudimentary stamens in this material may be linked with *d*. But no simple linkage relation of that kind would be expected to give the observed frequency distribution in an F_2 culture. If a factor for rudimentary stamens should be found to behave as a dominant in dwarf and as a recessive in anther ear, the observed F_2 frequencies should be fairly closely realized. Until the question is investigated more fully, no purpose is served by further speculation.

SUMMARY

Two andromonoecious types of maize, dwarf and anther ear, are described and compared with normal maize and with the double recessive, dwarf anther ear. Both types are characterized by the presence of stamens,—usually well developed but in some stocks rudimentary,—throughout the ear. These types have relatively short internodes and relatively short, broad leaves. The tassels are stout and relatively little branched. The ears of both types are short and comparatively thick and frequently end in unbranched tassel-like spikes. With respect to all these characters except perfect flowers the dwarf type is more extreme than the anther-ear type, the latter, in some stocks, approaching closely to the normal type of maize. Dwarf anther ear is an extremely dwarf type with very broad, short leaves and thick, unbranched tassels. No pollen is shed and no ear shoots have been produced by this type.

Both dwarf and anther ear are simple recessives to normal. Intercrosses of these two types give normal plants in F_1 and normals, dwarfs, anther ears, and dwarf anther ears in F_2 in approximately a 9 : 3 : 3 : 1 relation. Owing to failure of the more dwarf forms to germinate or to persist under field conditions, this numerical relation of the several types is approached closely only in greenhouse cultures. This F_2 behavior is interpreted on the basis of two independent factor pairs, $D\ d$ and $A_n\ a_n$. The hypothesis has been tested by the behavior in F_3 and later generations of the several types and by intercrosses between them.

Marked diversities have been observed in height of plants between different anther-ear stocks and to a less degree between different dwarf stocks. These diversities are ascribed to the influence of partially domi-

nant growth factors other than D d and A_n a_n, such as are assumed to differentiate tall and short races of normal maize.

Dwarf plants with rudimentary ear stamens crossed with anther-ear plants with fully developed stamens have given in F_2 both dwarf and anther ear with both rudimentary and well developed ear stamens. The numerical relation of these four types is not that expected on the basis either of independent inheritance or of any simple linkage relation.

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APPENDIX—TABLES

TABLE 7

F_2 progenies of the cross dwarf × normal.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_2 PLANTS			
	F_1	F_2	Field		Greenhouse	
			Normal	Dwarf	Normal	Dwarf
	164 – 4	396	22	2		
	1794– 3	2237	63	19		
	1799– 6	2226	15	3		
	9	2221, 2222	22	11		
	14	2225	16	3		
	28	2224	13	3		
	32	2220	15	5		
	37	2223	12	4		
	1914– 1	1946	37	6		
	2	1952	34	2		
	3	1948	37	3		
	4	1953	49	4		
	5	1947, 1949	70	7		
	8	1945	38	7		
	9	1944	41	3		
	10	1950	25	4		
1	11	1954	47	10		
	12	1951	36	1		
	2403– 1	2962–2966	34	7		
	2967– 2	6826, 6827	71	20		
	10	6830, 6831	38	9		
	11	6828, 6829	112	29		
	4257– 1	5539, 5540	41	16		
	2	5541, 5552	61	14		
	11	5536–5538	7	3		
	9613– 8	10728, 10729	67	15		
	9643– 6	10400	19	3		
	8	10401, 10731	23	7		
	A1400–4	10730	19	5		
	S7–4	7697	11	6		
	Total, 30 progenies		1095	231		

TABLE 7 (*continued*)

F_2 progenies of the cross dwarf × normal.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_2 PLANTS			
	F_1	F_2	Field		Greenhouse	
			Normal	Dwarf	Normal	Dwarf
2	1120— 1	1451			32	15
	2	1452			35	9
	3	1453			39	10
	4	1454			37	12
	3608—18	6780			18	4
	7351— 5	S220—S222			84	23
	7859— 1	S294, S295			39	13
	7867— 1	S289—S291			12	8
	2	S292, S293			15	5
	7869— 2	S298, S299			16	6
	7870— 1	S300			38	9
	7871— 1	S301, S302			30	9
	S6—2	7759, S200, S201			26	8
	6	7760, S202, S203			15	7
	Total, 14 progenies				436	138
3	3609—18	6779, 7408	15	1	30	13
	4257— 3	5535, 6784	62	10	73	27
	21	5543, 6740, 6783	48	19	75	18
	7417— 6	S217	13	5	67	29
	7	S218	6	0	27	8
	7440— 1	S190	30	3	26	12
	2	S191	25	11	37	12
	3	S192	35	1	37	13
	5	S195	32	7	35	13
	S7—7	7434, S189	11	3	103	40
	Total, 10 progenies		277	60	510	185
	Total, 54 progenies		1372	291	946	323

TABLE 8

F_2 progenies of the cross dwarf × normal, back-crossed with dwarf.

PEDIGREE NUMBERS		NUMBER OF F_2 PLANTS	
F_1 × dwarf	F_2	Normal	Dwarf
6785—1 × 6784—18	7429, 7430, S179	37	44
1 × 28	7431, 7432	63	60
S180—1 × S300—3	8857	14	16
S184—4 × S202—1	8858, 8859	89	98
8 × 1	8860—8863	51	46
S186—2 × S294—2	8855, 8856	17	22
S207—6 × A744—11	9643	8	4
S219—2 × S222—7	8865—8868	52	64
Total, 8 progenies		331	354

TABLE 9

F_3 and equivalent F_4 and F_5 progenies of the cross dwarf × normal.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_3, F_4 AND F_5 PLANTS Normal	Dwarf
1	F_2	F_3		
	1945–18	2423	13	
	2220–14	4208	30	
	6829– 9	7655–7657	25	
	F_3	F_4		
	5049–13	6913, 6914	11	
	37	6919–6921	78	
	5054–10	6745, 6872	41	
	5055– 2	6871, 7315	10	
	Total, 7 progenies		208	
2	F_2	F_3		
	1945–10	2308	8	3
	11	2305, 2306	16	7
	1946–34	2523, 2524	39	11
	1949–43	2535, 2536	12	13
	2966– 7	5049–5055	86	15
	6828–12	7658–7660	24	1
	F_3	F_4		
	5049–25	6816–6818	65	19
	5050– 1	6874	13	4
	6	6822–6824, 7058, 7059	79	12
	5052– 3	6833	18	6
	7	6825, 7202, 7323, 7442	43	4
	12	6832	21	11
	5053– 1	6875, 6911	37	9
	7660– 1	8536	8	3
	F_4	F_5		
	6832–31	7313, S181	15	2
	Total, 15 progenies		484	120
3	F_2	F		
	7429–18	S213, S214		4
	7760– 9	S206		5
	9643– 3	10402, 10732		12
	S189–50 × S217–27	9644		20
	F_3	F_4		
	5052– 5	S5	1	15
	Total, 5 progenies		1	56

TABLE 10

F_2 progenies of the cross anther ear × normal.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_2 PLANTS			
			Field		Greenhouse	
	F_1	F_2	Normal	Anther ear	Normal	Anther ear
1	19C −2	294−296	38	8		
	19E −2	297−299	59	15		
	419 −3	1019−1021	26	8		
	432 −1	1037	31	6		
	4	1040	146	30		
	2451−1	4089	8	2		
	3	4088	8	3		
	4078−9	6781, 6782	30	15		
	6786−1	7434, 7435				
		S279, S280	63	12		
	5	7436, 7437	12	4		
	7874−1	S282, S283	19	3		
	7875−1	S286	15	2		
	Total, 12 progenies		455	108		
2	792 −4	1439			12	5
	796 −3	1442			23	19
	799 −3	1443			29	9
	800 −2	1445			6	1
	801 −1	1446			32	13
	803 −1	1448			53	16
	2	1447			32	12
	824 −1	1438			36	14
	3	1462			23	7
	S272−2	9763			24	8
	S273−3	9764			29	17
	S275−3	9765			11	3
	S278−1	9766			10	4
	Total, 13 progenies				320	128
3	792 −2	1440, 1847	30	5	25	8
	800 −1	1444, 1764, 1843	23	3	30	16
	Total, 2 progenies		53	8	55	24
Total, 27 progenies			508	116	375	152

TABLE 11

F_3 and equivalent F_4 progenies of the cross anther ear × normal.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_3 PLANTS	
			Normal	Anther ear
1	F_2	F_3		
	295 −1	810−812, 1766	53	
	297 −3	816−820	105	
	1843−3	2241	114	
	7410−1 × 7436−7	S269	12	
	Total, 4 progenies		284	
2	294 − 1	805, 806	33	3
	296 − 2	814	17	5
	297 − 1	821−823, 1839	12	3
	1843− 5	2243	110	35
	11	2242	61	17
	12	2240	66	16
	1847−16	2244	69	21
	F_3	F_4		
	805 −3	1449	25	10
	Total, 8 progenies		393	110
3	294 −28	746, 784, 1123		7
	6781−22	7409		15
	6782−16	7410	2	14
	Total, 3 progenies		2	36

TABLE 13

F_2 progenies of the cross dwarf × anther ear and crosses equivalent to normal × dwarf anther ear.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_2 PLANTS							
			Field				Greenhouse			
	F_1	F_2	Normal	Dwarf	Anther ear	Dwarf anther ear	Normal	Dwarf	Anther ear	Dwarf anther ear
1	7407–1	S176					25	9	8	0
	5	10735, S177	20	5	8	1	18	11	9	6
	9	10736, S178	25	2	7	0	31	10	8	1
	7418–3	S174	31	4	6	0				
	6787–1	7420, S97	23	7	6	0	39	14	15	5
	S3–3	9754					104	40	34	14
	Total, 6 progenies		99	18	27	1	217	84	74	26
2	9161–5	10536	83	25	22	0				
	S224–2	9761					47	12	13	4
Total, 8 progenies			182	43	49	1	264	96	87	30

TABLE 12

F_1 progenies of the cross dwarf × anther ear.

PEDIGREE NUMBERS		NUMBER OF F_1 PLANTS NORMAL
P_1	F_1	
2451– 2 × 2440– 2	4084	2
5053– 3 × L188– 1	6787, 6788, S3, S4	29
6779–23 × 6781–22	7407	10
6781– 3 × 6831–14	7418, S175	35
6783–16 × 6781–18	7419	4
7409–14 × 7439–12	S276	3
Total, 6 progenies		83

TABLE 14

F_2 progenies of the cross dwarf × anther ear back-crossed with anther ear and with dwarf.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_2 PLANTS		
	F_1 × Anther ear	F_2	Normal	Anther ear	Dwarf
1	7418– 5 × 7409–7	S167, S168	54	31	
	13 × 7	S169	36	17	
	S4–5 × 6781–27	7421–7423, S98	67	45	
	Total, 3 progenies		157	93	
2	F_1 × dwarf				
	7418–11 × 7439–21	S91, S170, S171	45		16
	13 × 21	S92, S172, S173	128		85
	S4–1 × 6827–10	7427, 7428, S100	25		31
	S5–15 × S4–5	7424–7426, S99	26		30
	S175–15 × S200–2	8864	50		42
	Total, 5 progenies		274		204

TABLE 15

F_3 progenies of the cross dwarf × anther ear.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_3 PLANTS			
	F_2	F_3	Normal	Dwarf	Anther ear	Dwarf anther ear
1	7420–19	9624, S60, S136	155			
	54	9635, S81, S135	135			
	Total, 2 progenies		290			
2	7420– 5	9619, S51, S128	107	28		
	29	9628, S69, S145	53	18		
	33	9631, S74, S150	100	15		
	50	9633, S156	47	10		
	74	9640, S86, S163	67	15		
	Total, 5 progenies		374	86		
3	7420–15	9623, S57, S133	77		21	
	20	9625, S63, S139	90		28	
	35	9632, S77, S153	82		12	
	Total, 3 progenies		249		61	
4	7420– 2	9618, S48, S126	74	19	21	1
	6	9620, S52, S129	63	14	27	
	12	9622, S54, S130	63	19	18	
	21	9626, S64, S140	68	19	18	
	23	9627, S66, S142	20	6	10	
	30	9629, S70, S146	44	15	17	1
	32	9630, S71, S147	58	16	13	
	51	9634, S80, S157	67	16	16	2
	58	9636, S82, S159	75	10	11	
	61	9637, S83, S160	54	8	9	2
	62	9638, S84, S161	45	6	17	
	68	9639, S85, S162	44	7	11	2
	76	9641, S87, S164	41	12	14	
	77	9642, S88, S165	58	7	13	3
	Total, 14 progenies		774	174	215	11
5	7420–34	9757		51		
	S97–14	9775		17		6

TABLE 16

F_3 progenies of the cross dwarf × anther ear back-crossed with anther ear.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_3 PLANTS			
	F_2	F_3	Normal	Dwarf	Anther ear	Dwarf anther ear
1	7421–11	S242	11		2	
	20	S246	12		2	
	7422– 1	S247	24		3	
	3	S248	27		3	
	11	S251	22		5	
	12	S252	22		8	
	28	S255	18		7	
	32	S256	14		2	
	7423– 1	S257	23		5	
	33	S264	6		2	
	S98 – 4	9755	73		24	
	Total, 11 progenies		252		63	
2	7421–19	S245	19	1	5	
	7422– 5	S249	12	1	2	
	7	S250	17	1	2	
	26	S254	25	2	6	
	7423– 4	S258	24	4	4	
	5	S259	14	2	4	
	9	S260	25	6	3	
	18	S262	19	4	6	
	20	S263	21	2	8	
	S99 –10	9756	10	3	3	2
	Total, 10 progenies		186	26	43	2
3	7421–17	S104			9	
	21	S35, S105			13	
	7422– 6	9769, S36, S106			18	
	7423–32	9770, S47			17	
	Total, 4 progenies				57	
4	7422– 8	S37, S107			14	7
	10	S109			10	2
	16	S40, S95			52	17
	21	9768, S41, S112			37	6
	7423– 6	9771, S44			14	5
	Total, 5 progenies				127	37

TABLE 17

F_3 progenies of the cross dwarf × anther ear back-crossed with dwarf.

GROUP	PEDIGREE NUMBERS		NUMBER OF F_3 PLANTS			
	F_2	F_3	Normal	Dwarf	Anther ear	Dwarf anther ear
1	7424–13	S226	26	3		
	19	S228	24	5		
	7426– 1	S231	29	3		
	6	S233	10	3		
	7427– 2	S235	20	7		
	7428– 4	S238	30	3		
	8	S240	22	2		
	Total, 7 progenies		161	26		
2	7425– 4	S230	19	2	2	
	7426– 3	S232	16	2	3	
	8	S234	10	0	2	
	7427– 7	S236	23	1	3	
	7428– 6	S239	25	2	4	
	9	S241	22	3	5	
	Total, 6 progenies		115	10	19	0
3	7427–12	9772, S208		29		
	21	9773, S209, S210		56		
	7428–19	9774, S212		88		
	Total, 3 progenies			173		