SEMINAL ROOT DEVELOPMENT AND ITS RELATIONSHIP TO CERTAIN OTHER CHARACTERISTICS IN MAIZE, WHEAT AND BARLEY

by

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ABSTRACT

The possible associations of seminal root number, maturity period, and other distinctive characteristics of varieties in wheat, barley and corn were studied. The F_2 and backcross progenies of one cross between dent and flint lines were also studied in corn.

Inbred lines of corn were found to differ in production of seminal roots; each group had distinctive characteristic in this respect. Positive association of seminal root number and maturity period was obtained in dent, flint and sweet lines, but in no case was the association close. In flint lines, seminal root number was negatively related to tiller number. Seminal root number was positively related to row number in dent lines, to ear height in flint and sweet lines and to cob length in pop lines. Maturity period, plant height and ear height were positively interrelated in all corn groups and in F_2 and backcross populations from a cross.

The varieties of barley and wheat studied differed significantly in production of seminal roots. In both barley and wheat seminal root number was independent of maturity period, yield, number of spikelets, spike length, height of plant and 1000-kernel weight.

In the segregating populations of one cross in corn, seminal root number and maturity were related positively, whereas these characters were negatively related to tiller number. Linkage of genes conditioning these characters was indicated. Seminal root number was independent of cob colour, degree of denting and ear row number.

Primary *vs.* secondary seminal root production was found to be controlled by one gene pair with major effect, but the presence of modifying genes was indicated.

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INTRODUCTION

Field selection to modify yield, maturity and similarly inherited characters of corn, barley, wheat and other crops is laborious and expensive. Any discovery which would simplify this operation would be of great value. The obvious utility of an easily observed morphological character that would serve as an index of yield or of other quantitative characters in these crops has inspired many workers to measure correlations between readily observable characters and those which are quantitative in nature. Special interest is therefore attached to the experiments of Smith and Walworth (26) who reported a rather close correlation between yield and number of seminal roots. The number of seminal roots is easily determined and has the further advantage of being a seedling character, thus making it possible to test a large number of progenies at any time in the year. Mangelsdorf and Goodsel (13) found, in corn, that number of seminal roots was independent of length, diameter, number of rows and degree of denting of the ears. They also showed that date of silking, height of plant, height of ear, number of tillers and yield were independent of seminal root number. Recently, however, Ebert (4) reported in corn a high degree of association between maturity and number of seminal roots. Any evidence that early strains can be detected by counting seminal roots is considered worth investigating.

The primary purpose of this investigation was to determine the consistency of association between seminal root numbers and maturity among a number of inbred lines of maize widely divergent in morphology and origin. Information on the association of other characters of maize was also obtained, emphasizing those involving seminal root numbers. Similar investigations were carried out on a smaller scale in wheat and barley.

LITERATURE REVIEW

The root system in corn (9), as well as in other crops, consists of seminal roots and permanent roots. The initials of seminal roots are present in the embryo and are often called temporary roots or seed roots. These consist of a radicle, or primary seminal root, and a variable number of secondary seminal roots which arise adventitiously at the base of the first internode of the stem just above the scutellar node. The radicle is always present except when killed by some injury. This may be the only seminal root, or there may be one to several secondary seminal roots in various varieties or lines of corn.

Seminal roots form such a small part of the total root system of a plant that they are of greatest importance during early growth of the seedling before the adventitious or permanent roots of higher internodes have become established (8, 9).

Collins (2) was probably one of the first investigators to recognise that some varieties of corn have only one seminal root. He reported that the Pueblo variety of maize developed a large, single radicle that rapidly descended to moist sub-soil, supplied water and nutrients during the critical seedling stage, and played a part throughout the entire life period of the plant.

In wheat, according to Percival (17) and Robbins (19) upon germination of the seed, the primary seminal root takes the lead. Pairs of lateral roots often appear on either side of the primary root. These laterals originate from the hypocotyl. A sixth root sometimes arises at a point near the base of the plumule and behind the epiblast. Rarely a third pair of rootlets may appear above the second pair.

Sallans (20) showed that the first 3 seminal roots were as valuable in sustaining growth as crown roots; but the second pair and the sixth root were found to be less valuable in this respect. Seminal roots, under some circumstances, maintain the growth of wheat plants to maturity or until permanent roots develop (12). Weaver and Zink (29) reported that the seminal roots of smaller cereals were not temporary. In forage grasses studied by these workers, seminal roots were alive as absorbing organs for 3.5 to 4 months. Pavlychenko (16) stated that seminal roots in several annual grasses in arid zones functioned through the entire growing season. Hunt (7) had shown that seminal roots functioned for rather long periods after germination, and were necessary for successful establishment of seedlings. Weaver et al. (30) concluded after numerous investigations on seminal roots of cereal crops that seminal roots remain alive until the time of harvest. Krassovosky (11) showed that seminal roots were not stimulated in growth and activity by removing the crown roots, in water culture studies. Consequently dry soil conditions, during the late seedling period may favour the progressive development of the first root system. However that may be, seminal root penetration is known to reach well into sub-soil even with good crown roots according to Simmonds (23).

Locke and Clark (12) reported that seminal roots maintained the growth of wheat plants till maturity during a period of drought which prevents penetration of permanent roots. Gliemeroth et al. (5) found that seminal roots maintained wheat plants from flowering to maturity. Even a higher respiration quotient in seminal roots than that in crown roots was observed by these workers.

Robbins (19) reported that dent corn produced 4 seminal roots, and sweet and flint types only one. Wiggans (31) observed that corn produced seminal roots over a range of 1 to 13. He found 4 temporary roots in dent and pop types in a greater percentages of cases than any other number. In flint corn he found only one temporary root in more cases than any other number. Weaver (28) reported 3 seminal roots in the M.35 variety of corn. Smith and Walworth (26) noted 1 to 10 seminal roots in 8 dent varieties. They also noted the difference in average number of seminal roots ranged from 3.08 to 3.55. They concluded that the kernels of an individual ear showed a wide range of variation and that individual ears possessed a characteristic tendency in this respect. Mangelsdorf and Goodsel (13) observed, in Surecropper corn, that the average number of seminal roots varied with position of seed on the ear; i.e. seeds borne at the base or middle of the ear had higher seminal root numbers than those borne at the tip. These differences were statistically significant. They also noted that higher average numbers of seminal roots were produced at 30°C-34°C than at 24.5°C to 28°C or at 36°C, and observed that seminal root number varied with moisture, light, oxygen and inbreeding. Siemens (22) found that flint strains and Michigan pop usually produced no secondary seminal roots. Sixty percent of sweet and ninety percent of dent strains produced secondary seminal roots. The dent varieties produced 3 secondary seminal roots more often than any other number. Kiesselbach (9) found only one seminal root in flint varieties and 1 to 7 in dent corn. Ebert (4) classified inbreds and hybrids into 2 groups according to seminal root production; those with only a primary root and others forming additional seminal roots.

Wiggans (31) observed 5 seminal roots in a number of wheat types studied. Walworth and Smith (27) found 2 seminal roots in some wheat varieties studied, and 4 in other types. Simmonds (23, 24) reported that the total seminal roots of wheat rarely exceeded 6. Manner (14) observed that wheat plants having one seminal root had a low rate of survival and reduced yield compared with those having more seminal roots.

Robbins (19) found five to eight seminal roots in both wheat and barley. Walworth and Smith (27) observed that barley had a tendency towards a higher number of seminal roots than was found in either wheat or oats. They found 7 as a maximum and 3 as a minimum in barley. In sorghum only one seminal root was observed by Sieglinger (21). In the Alpha variety of barley 9 seminal roots were found as a maximum number by Merry (15). The average number of seminal roots varied from 5.4 in 6-rowed barley to 8.9 in the 2-rowed Alpha, as shown by Pope (18). He also observed that within the species the seminal root number ranged from 5.6 to 8.9 and a natural hybrid of barley produced 6.8 roots, almost identical to that of the *H. vulgare* (L) parent from which it had been derived. Hansel (6) found a minimum of 5 seminal roots and a maximum of 7 in a number of barley varieties. He also noted that 2-rowed varieties had slightly but significantly higher values than 6-rowed ones, and spring barley had a higher number of seminal roots than winter barley. Skripeinskii (25) reported 5 seminal roots in wheat and 5.9 to 6.7 in winter and spring barley respectively.

A high correlation between number of seminal roots per ear and grain yield of progeny plants of corn was observed by Smith and Walworth (26). Collins (3) called attention to the fact that the above correlation was meaningless since inter- and intra-class correlations were confused. Smith accepted the criticism but pointed out that the results were still suggestive of a slight relationship between seminal roots and yield. He noted that there was a tendency for the progenies of the high seminal-root seedlings to forge ahead of the low seminal-root group. Mangelsdorf and Goodsel (13) found in corn that number of seminal roots was independent of length, diameter, number of rows and degree of denting of the ears. They also showed that date of silking, height of plant, height of ear, number of tillers and yield were independent of seminal root number. These workers found a positive significant correlation between seminal root numbers and vigour of seedlings of corn after transplanting them from blotters but the correlation did not hold when the seed was planted directly in soil. Ebert (4) reported in corn a high degree of association between maturity and number of seminal roots.

Pope (18) reported in barley that there was no association between seminal root number and density of spike, colour of seed, adherance of lemma, palea or lemma-tip and malting quality. He also found that area of absorptive surface of the scutellum was not correlated with seminal root number.

Hansel (6) found that there was no correlation of spread nor winter-hardiness with seminal root number in wheat.

MATERIALS AND METHODS

Inbred Lines and Varieties

Inbred lines of corn consisting of four distinct groups with a wide range of maturity represented within each group were obtained from widely separated research institutions in North America. The four groups represented were the types in general commercial use, flint, dent, sweet and pop. The lines within each were chosen with a view to obtaining the greatest possible range in morphological characteristics such as plant height, ear height, row number, etc. as well as maturity. The sources from which the inbred lines were received are given in Table 1. Two of the flint stock used, Saskatchewan White flint and Howe's Alberta flint and one pop stock, Carnival, are not inbred lines but closely selected varieties.

F_2 seeds of a cross S.W.F. x B.14 together with back cross seeds of the same cross, viz. S.W.F x B.14^2, were available for study of seedling root development and other characters. S.W.F. (Saskatchewan Whiteflint) is an early flint line with a low seminal root number and B.14 is late dent line with high seminal root number.

Pure seed of 15 representative barley varieties to provide a wide range of maturity, colour of kernels, spike length and number of spikelets were obtained. These 15 types consisted of two different species, viz. 2-rowed barley (H. distichon L.) and 6-rowed (H. vulgare L.). These varieties were available at the University of Manitoba.

Similarly 18 wheat varieties, both from T. durum and T. aestivum were secured with a wide range of maturity, height, spike density, length of spike and grain colour. These varieties were supplied by the Canada Department of Agriculture, Research Branch, Winnipeg.

Determination of Seminal Root Development

Kernels of inbred lines of corn were germinated in galvanised iron trays with dimensions of 20" x 10" x 2". The medium for germination was vermiculite. This medium was chosen after a pilot experiment with three kinds of media, i.e. blotters in petri plates, a mixture of sand and peat, and vermiculite. The medium had no apparent effect on seminal root development, but vermiculite was found most convenient.

The groups of corn, dent, flint, sweet and pop, were each handled as an experiment for determination of seminal root numbers. The tests were carried out in five randomised replications, using 20 kernels for a plot, based on Mangelsdorf's (13) conclusion that 20 seeds were sufficient for this purpose. Seedling roots were counted after 5 days. Ebert (4) found 5 days enough for the emergence of seminal roots. The number of seminal roots for each kernel was recorded in all replications and the average number of seminal roots for 20 kernels from each plot was taken for statistical analysis.

Using a similar technique, 15 barley and 18 wheat varieties were germinated in 3 replications. The average number of seminal roots on 30 kernels was taken as a plot for statistical analysis.

F_2 and back cross seeds were germinated in the same manner as inbred lines but the seedlings were serially numbered and the seminal root count for each was recorded. These seedlings were transplanted in jiffy pots in sand, peat and soil mixed in proportion of 1:1:5 respectively. Transplanting of seedlings was done after keeping them in the greenhouse for a week. The spacing in the field for F_2 plants was 2 feet with rows 3 feet apart and for backcross plants was 1 foot between plants and 3 feet between rows. In all 587 F_2 and 1083 backcross seedlings were transplanted. The stand of these seedling was normal and survival percentage was 94. There was a scattered attack of cutworms in the early stage of growth, and affected plants were excluded from observation.

Plan of Field Study

Inbred lines of corn consisting of 36 of dent, 23 of flint, 17 of sweet and 7 of pop types were grouped by type and laid out in 2 randomised replications using a single row of 10 feet for each plot. The seeds were planted 1 foot apart with 3 feet between rows. Similarly 18 wheat varieties were drilled in 3 randomised replications of single row plots 10 feet long with 1 foot spacing between rows. Two hundred kernels were planted per row. A row of winter rye was sown between wheat rows to minimize inter-varietal competition. In the same way, 15 barley varieties were also planted. Here about 225 kernels were used per row. The stand of these crops was good.

Procedure in Collecting Field Data

Date of silking in each plant of corn excluding border plants was recorded as that when the first silk protruded from the ear shoot. Similarly the date of pollen shedding was recorded. The silking dates in F_2 and backcross plants and in inbred lines were observed daily. Some plants, selected over a period of time to give a wide range in maturity, were self-pollinated in the F_2's and backcross progenies. Two ears in each inbred line were also self-pollinated for confirmation of seminal root number in the next generation. Characters such as plant height, ear height, tillers, row number, degree of denting, and cob colour were recorded when plants were ripened in the F_2 population only. Plant height, ear height and tiller number were recorded on 5 plants of each of the inbred lines. Moisture content of the ears was determined by taking 3 ears from each inbred line and determining the percent moisture lost on drying. From the same cobs, provided they had fully ripened kernels, ear characters such as row number, cob length and cob width were recorded.

In wheat and barley, strains were recorded as in flower when emergence of heads from 90 percent of plants was visible. The initial date as well as the completion of flowering was noted. The ripening period was recorded when the strains were ready for harvesting. The plant characters such as height of plant, number of spikelets, spike length, laxity of spike, glume colour, glume pubescence, awn colour and awn length were recorded from the main tiller. Total grain weight per plot, 1000 kernel weight, and grain colour were also recorded for each variety. The analysis of variance was applied to determine the statistical significance of differences in seminal root number among inbred lines of the various groups of corn, and among the varieties in each of wheat and barley.

Association of Characters

Data collected on inbred lines, F_2 and the backcross in corn were used to test for association between seminal root number with each of maturity, plant height, ear height, tillers, etc., by working out total, partial and multiple correlations. Chi-square tests were applied to detect the inter-relationship between seminal roots, tillers, cob colour and row number in F_2 progenies. Similarly the associations between maturity period and other characters were worked out. The F_2 data on number of seminal roots were used to interpret the number of genes conditioning the expression of seminal roots. For this purpose tests of goodness of fit and independence were made by means of the chi-square. A probability value greater than 0.05 was regarded as indicating a satisfactory fit. The data collected in plant characters and numbers of seminal roots in wheat and barley varieties was used to see if any correlation existed between seminal root number and maturity and other characters. Fifty randomly chosen F_3 progenies were germinated and the number of seminal roots counted on 40 kernels in each progeny to test agreement with the findings in F_2.

Table 1

Source and Station Number of Inbred Lines from Different Morphological Groups of Corn

Institution from which obtained	Lines by Types and Station Number			
	Number of lines of type			
	Dent	Flint	Sweet	Pop
1. University of Missouri Columbia, Missouri	6 (H.28, C.I.21E, M.O.22, M.O.1W, M.O.11 and H.30)	-	-	-
2. Purdue Agric. Exp. Stn. Lafayette, Indiana	5 (O.H.43E, O.H.51A, W.F.9, H.60, and H.59)	-	-	-
3. Institute of Agriculture St. Paul, Minnesota	8 (A.427, O.5420, B.14, W.22, M.14, A.401, A.498 and A.116)		3 (S.4, S.8 and S.43)	6 (C.1-29, C.6-29, P.18, P.40, P.1, and P.5)
4. Wisconsin Agricultural Research Station, Madison, Wisconsin	1 (W. D.)	-	-	-
Spooner, Wisconsin	-	5 (W.333, W.563, W.597, W.627 and 15)	-	-
5. Macdonald College, Quebec	-	3 (Q.572, Q.573 and Q.703)	-	-

(Continued)

Table 1 (Continued)

Institution from which obtained	Lines by Types and Station Number — Number of lines of type: Dent	Flint	Sweet	Pop
6. Canada Department of Agriculture	8 (V.3, 152, C.H.159, C.H. 157, C.H.9, C.H.39, C.H. 3 and C.H.25)	15 (M.7, 38, M.6, C.O.4, C.O.12, C.O. 23, C.O.24, C.O.38, C.O. 41, C.O.45, C.O.46, C.O. 47, C.O.48, Howe's Alberta flint, and S.W.F.)	14 (W.E.7, Seneca, C.27, Filar sunshine, I.5125, P.39, F.7735, W.3647, W.3670, Simonet, V.577, D.37A, G.115, I.453)	1 Carnival
7. University of Manitoba	8 (59-124, 382, K.Far, 59-120, 59-38, 59-49, 59-36, and K.D.54)			
Total	36	23	17	7

RESULTS AND DISCUSSION

Seminal Root Number in Inbred Lines of Corn

Average number of seminal roots and maturity period of each of 36 dent inbred lines are presented in Table 2. The greatest range of seminal root numbers was 1 to 10 for the whole group with the average numbers ranging from 1.13 to 4.39. There was not a single line which produced only primary roots. This finding is in complete agreement with that of Siemens (22) and Smith et al (26) with respect to dent strains. The range in maturity among the dent lines investigated was substantially large, i.e. 68 to 124 days (planting to silking).

The data on average and range of seminal root numbers and maturity period for flint, sweet and pop inbred lines are listed in Tables 3, 4 and 5 respectively. Out of the 23 flint inbred lines studied, 9 had only primary roots. The average number of seminal roots ranged from 1.00 to 5.15 with the maximum range of 1 to 8 for the whole group. In sweet inbred lines the average number ranged from 1.00 to 4.73 with a maximum of 9 roots. Three lines in this group had only primary seminal roots. Among pop inbred lines the maximum range was 1 to 4 seminal roots with the average number ranging from 1.00 to 1.94. This group produced the lowest number of seminal roots per line. This finding is in agreement with that of Siemens (22) but not with that of Wiggans (31), who reported more secondary seminal roots for pop lines than for other types. In flint and sweet lines the highest average was greater than that of dent and pop lines.

Statistical analysis showed that in each group, the difference in seminal root number among lines was significant at the 1 percent level. The highest range of seminal roots (1-10) was observed in dent lines and the lowest range (1-4) in pop lines while sweet and flint groups were intermediate in this respect. It was further observed that each morphological group produced a characteristic number of seminal roots. For example, in dent lines the tendency was towards high seminal root numbers and production of secondary seminal roots in every line. Some of the lines in each of the other groups produced no secondary seminal roots. In pop lines seminal roots had a preponderance of seeds with primary root only and this was characteristic of these lines irrespective of their maturity period. A high proportion of the flint lines produced primary seminal roots only. Although the latest flint lines were characterised by high seminal root numbers, those with low seminal root numbers involved a wide maturity range.

Table 2

Number of Seminal Roots and Maturity Period in Inbred Lines of Dent Corn

Serial Number	Name of Inbred Lines	Average Number of Seminal Roots	Range in Seminal Roots	Days for Silking
1.	W.D.	4.29	1-7	68.7
2.	382	1.13	1-3	69.1
3.	59-49	1.16	1-3	69.2
4.	152	2.64	2-6	70.4
5.	V.3	4.39	1-10	70.6
6.	59-36	3.03	1-5	70.6
7.	59-120	1.53	1-7	71.9
8.	K.Fa[illegible]	1.58	1-5	72.5
9.	59-38	4.01	2-9	72.6
10.	K.D.54	2.77	1-5	72.6
11.	A.498	2.40	1-8	74.4
12.	59-124	3.79	2-9	77.2
13.	A.116	2.29	1-7	78.5
14.	CH 39	3.95	3-8	85.3
15.	CH 3	3.17	1-8	85.5
16.	OH 51 A	2.89	1-4	85.7
17.	CH 159	3.12	2-7	86.5
18.	CH 157	3.04	3-8	87.1
19.	M.14	2.70	1-6	87.3
20.	CH 9	4.36	3-9	88.6
21.	A 427	2.99	1-4	88.6
22.	O.S.420	3.15	1-7	88.9
23.	OH 43 E	2.55	1-10	89.3
24.	W. 22	2.58	1-10	90.0
25.	A.401	2.72	1-4	90.6
26.	W.F.9	2.95	1-5	91.8
27.	B.14	3.90	2-6	96.0
28.	H.30	2.83	1-4	96.5
29.	M.O. 11	2.74	1-5	98.1
30.	H.28	2.93	1-6	100.8
31.	H.60	2.66	1-5	101.1
32.	M.O. 1 W	2.48	1-7	101.6
33.	CH 25	2.99	1-6	102.0
34.	C.I. 21 E	3.03	1-7	104.1
35.	H. 59	2.22	1-4	117.1
36.	M.O. 22	2.91	2-6	124.1
Average		2.89		
L.S.D. at 5%		0.283		

Table 3

Number of Seminal Roots and Maturity Period in Inbred Lines of Flint Corn

Serial Number	Name of Inbred Line	Average Number of Seminal Roots	Range in Seminal Roots	Days for Silking
1.	Howe's Alta.Flint	1.00	1-1	46.7
2.	Sask.White Flint	1.06	1-4	53.5
3.	C.O.38	1.00	1-1	63.0
4.	C.O.23	2.21	1-3	63.1
5.	C.O.48	1.24	1-2	63.9
6.	M. 7	2.27	1-5	65.5
7.	C.O.41	1.00	1-1	67.4
8.	C.O.12	1.00	1-1	67.7
9.	C.O.46	2.64	1-3	68.2
10.	C.O.47	2.11	1-4	69.1
11.	Q.573	1.00	1-1	70.7
12.	Q.572	1.30	1-3	71.0
13.	C.O.24	5.15	1-6	71.6
14.	C.O.4	1.00	1-1	72.1
15.	C.O.45	1.68	1-3	72.1
16.	W.597	3.08	3-4	73.1
17.	38	1.00	1-1	73.7
18.	15	1.00	1-1	75.9
19.	W.627	3.01	1-8	76.7
20.	M.6	1.00	1-1	77.4
21.	W.333	5.08	1-6	78.9
22.	Q.573	4.50	1-6	81.7
23.	W.563	4.16	3-5	89.0
Mean		2.11		
L.S.D. at 5%		0.158		

Table 4

Number of Seminal Roots and Maturity Period in Inbred Lines of Sweet Corn

Serial Number	Name of Inbred Line	Average Number of Seminal Roots	Range in Seminal Roots	Days for Silking
1.	F.7735	1.01	1-2	54.4
2.	Simonet	1.05	1-2	61.8
3.	Seneca 60	1.00	1-1	64.5
4.	P. 39	1.84	1-4	65.0
5.	Filer Sunshine	1.01	1-2	68.2
6.	I.5125	2.33	1-5	72.2
7.	S.43	1.00	1-1	72.2
8.	S.8	2.45	1-3	73.8
9.	W.3670	1.86	1-3	73.9
10.	C.27	1.36	1-3	75.6
11.	S.4	1.00	1-1	76.1
12.	W.C.7	2.10	1-3	77.6
13.	V.577	1.04	1-2	78.5
14.	W.3647	1.26	1-4	81.2
15.	I.453	2.70	1-4	85.5
16.	D.37A	4.73	1-9	86.1
17.	G.115	2.65	1-3	87.7
Mean		1.79		
L.S.D. at 5%		0.186		

Table 5

Number of Seminal Roots and Maturity Period in Inbred Lines of Pop Corn

Serial Number	Name of Inbred Line	Average Number of Seminal Roots	Range in Seminal Roots	Days for Silking
1.	Carnival	1.82	1-4	62.6
2.	P.18	1.00	1-1	80.7
3.	C.1-29	1.00	1-1	80.8
4.	P.40	1.00	1-1	83.8
5.	C.6-29	1.13	1-3	85.2
6.	P.1	1.94	1-3	88.9
7.	P.5	1.14	1-3	90.4
Mean		1.29		
L.S.D. at 5%		0.138		

Association of Seminal Root Number with Maturity and Other Characters in Inbred Lines of Corn

Total correlation coefficients for 7 characters; seminal root number, days to maturity, plant height, ear height, cob length, row number and tillers were calculated in all combinations and are presented in Table 6 for the dent lines. Based on total correlation all the associations with seminal roots were small, although that with row number exceeded the five percent level of significance. The maturity period was associated positively with plant height, ear height and cob length as revealed by total correlation coefficients which were significant at the one percent level. Ear height and seminal root numbers were each related to row number based on total correlation coefficients. The relation between seminal root and ear height as revealed by the partial coefficient of correlation might be due to the influence of row number to a large extent (Table 7). The other associations of seminal root number and each of maturity, plant height, cob length based on the partial coefficients of correlation was due to the influence of the other characters held constant in each case. But the association between seminal root and row number in the dent group was direct and stronger on the basis of both partial and total correlation coefficients. These results suggest that selection in heterozygous populations of seedlings with high seminal root numbers would tend to produce lines with late maturity, higher plant, long cob and high ear row number. However, the associations were moderate, and with regard to maturity and seminal root numbers, were characterized by large deviations from the trend at both ends of the maturity scale (Table 2).

Tables 8 and 9 list the total and partial coefficients of correlation between seven characters of the flint lines studied. The seminal root number gave significant total correlation coefficients with maturity period, ear height and tillers. The first two of these associations were positive, the last negative. This indicates that as seminal root numbers increase the maturity is prolonged, the ear height increases and tiller numbers decrease. Maturity period gave significant correlation coefficients with plant height, ear height, tiller number and row number showing that early lines tend to have short stature with low ear placement, low row number and abundant tillers. There was an association between row number and each of tillers and ear height based on the total correlation coefficients. When the effect of other characters was held constant, the partial coefficient of correlation between seminal root number and maturity period became smaller and not significant, revealing that this relation was influenced by other characters. Based on partial coefficient of correlation, the relation between seminal root number and each of ear height and tillers was found to be direct and not influenced by other characters held constant. The multiple correlation coefficient of seminal roots on other characters was low and not significant.

The total and partial correlation coefficients for sweet inbred lines are presented in Tables 10 and 11 respectively. The total correlation coefficient between seminal root number and maturity period and ear height were positive and significant at the 5 percent level. In other words, the lines with few seminal roots tended to be early maturing with low ear placement. Maturity period was positively associated with ear and plant height. The total correlation coefficients were significant at the one percent level. This shows that late maturing lines tended to be tall with high placement of ears and *vice versa*. The association between seminal root number and each of maturity period and ear height was influenced by other characters as revealed by the partial correlation coefficients. The multiple coefficient of correlation of seminal root number on other characters was .746 and was not significant.

Table 12 shows the total correlation coefficients in pop lines. Unlike the results with other morphological groups the seminal root number was negatively associated with maturity, plant height, ear height, tillers and row number though the coefficients were not significant. Cob length was positively associated with seminal root number and the correlation coefficient was significant at the one percent level. In other words, long cobs were produced by lines having numerous seminal roots. The three characters maturity period, plant height and ear height were found to be rather closely interrelated on the basis of total correlation coefficients. These findings differ from those of Mangelsdorf (13) who reported no association of seminal root number with most of the morphological characters.

Table 6

Total Correlation Coefficients among Seven Characters of Thirty-Six Inbred Lines of Dent Corn

	Maturity	Plant Height	Ear Height	Tillers	Cob Length	Row Number
Seminal roots	+.052	+.194	+.051	−.173	−.277	+.384*
Maturity		+.762**	+.770**	−.021	+.675**	+.322
Plant Height			+.836**	−.140	+.091	+.211
Ear Height				−.023	−.034	+.326*
Tillers					+.191	−.145
Cob Length						+.029

* Exceeds .325; significant value of r at 5% level.
** Exceeds .418; significant value of r at 1% level.

Table 7

Partial and Multiple Correlation Coefficients for Seminal Roots on Other Characteristics of Thirty-Six Inbred Lines of Dent Corn

Characters Correlated	Total Correlation	Characters Eliminated	Partial Correlation Coefficients
Seminal roots on maturity	+.052	Plant height, ear height, tillers, cob length and row number	+.655**
Seminal roots on plant height	+.194	Maturity, ear height, tillers, cob length and row number	+.520**
Seminal roots on ear height	+.051	Maturity, plant height, tillers, cob length and row number	+.455*
Seminal roots on tillers	-.173	Maturity, plant height, ear height, cob length and row number	-.141
Seminal roots on cob length	-.277	Maturity, plant height, ear height, tillers and row number	+.439*
Seminal roots on row number	+.384*	Maturity, plant height, ear height, tillers and cob length	+.474**

* Exceeds .355; significant value of r at 5% level
** Exceeds .456; significant value of r at 1% level.

Multiple Correlation

R. Seminal roots on maturity, plant height, ear height, tillers, cob length and row number +.370
* Exceeds .579; significant value of r at 5% level
** Exceeds .648; significant value of r at 1% level.

Table 8

Total Correlation Coefficients among Seven Characters of Twenty-Three Flint Inbred Lines of Corn

	Maturity	Plant Height	Ear Height	Cob Length	Tillers	Row Number
Seminal Roots	+.520*	+.369	+.475*	+.018	-.488*	+.388
Maturity		+.555**	+.762**	+.007	-.441*	+.689**
Plant Height			+.544*	+.309	-.176	+.194
Ear Height				+.346	-.380	+.599**
Cob Length					+.081	+.085
Tillers						-.444*

* Exceeds .413; significant value of r at 5% level

** Exceeds .526; significant value of r at 1% level.

Table 9

Partial and Multiple Correlation Coefficients for Seminal Roots on Other Characters of Twenty-Three Inbred Lines of Flint Corn

Characters Correlated	Total Correlation Coefficients	Characters eliminated	Partial Correlation Coefficients
Seminal roots on maturity	+.520*	Plant height, ear height, tillers, cob length and row number	+.102
Seminal roots on plant height	+.369	Maturity, ear height, tillers, cob length and row number	+.210
Seminal roots on ear height	+.475*	Maturity, plant height, tillers, cob length and row number	+.526*
Seminal roots on tillers	-.488*	Maturity, plant height, ear height, cob length and row number	-.746**
Seminal roots on cob length	+.018	Maturity, plant height, ear height, tillers, and row number	-.067
Seminal roots on row number	+.388	Maturity, plant height, ear height, tillers and cob length	+.335

* Exceeds .468; significant value of r at 5% level
** Exceeds .590; significant value of r at 1% level.

Multiple Correlation Coefficients

R. Seminal roots on maturity, plant height, ear height, tillers, cob length and row number .319
* Exceeds .698; significant value of r at 5% level
** Exceeds .769; significant value of r at 1% level.

Table 10

Total Correlation Coefficients among Seven Characters of Seventeen Inbred Lines of Sweet Corn

	Maturity	Plant Height	Ear Height	Cob Length	Tillers	Row Number
Seminal roots	+.588*	+.408	+.538*	+.343	+.028	+.115
Maturity		+.731**	+.747**	+.237	+.134	-.061
Plant Height			+.822**	+.265	+.101	+.141
Ear Height				+.143	+.031	+.199
Tillers				-.097		-.321
Cob Length						-.369

* Exceeds .482; significant value of r at 5% level
** Exceeds .606; significant value of r at 1% level

Table 11

Partial and Multiple Correlation Coefficients among Seven Characters of Seventeen Inbred Lines of Sweet Corn

Characters Correlated	Total Correlation	Characters Eliminated	Partial Correlation
Seminal roots on maturity	+.588*	Plant height, ear height, tillers, cob length and row number	+.428
Seminal roots on plant height	+.408	Maturity, ear height, tillers, cob length and row number	+.345
Seminal roots on ear height	+.538	Maturity, plant height, tillers, cob length and row number	+.288
Seminal roots on tillers	+.343	Maturity, plant height, ear height, cob length and row number	+.394
Seminal roots on cob length	+.028	Maturity, plant height, ear height, tillers and row number	+.182
Seminal roots on row number	+.115	Maturity, plant height, ear height, tillers and cob length	+.338

* Exceeds .576; significant value of r at 5% level
** Exceeds .708; significant value of r at 1% level.

Multiple Correlation

R. Seminal roots on maturity, plant height, ear height, tillers, cob length and row number .746
* Exceeds .812; significant value of r at 5% level
** Exceeds .874; significant value of r at 1% level.

Table 12

Total Correlation Coefficients among Seven Characters of Seven Inbred Lines of Pop Corn

	Maturity	Plant Height	Ear Height	Cob Length	Tillers	Row Number
Seminal roots	-.307	-.388	-.209	+.924**	-.205	-.631
Maturity		+.896**	+.905**	-.227	-.184	+.023
Plant Height			+.847*	-.289	+.247	+.212
Ear Height				-.268	-.026	+.212
Tillers				-.278		+.576
Cob Length						-.690

* Exceeds .754; significant value of r at 5% level

** Edceeds .874; significant value of r at 1% level.

Seminal Root Number in Barley and Wheat

Average number and range of seminal roots and the maturity period for each of 15 barley varieties are shown in Table 13. Varieties varied in average seminal root number from 5.27 in Titan to 6.64 in Herta, with a group average of 5.87. Six-rowed barley varieties had 5.27 to 6.10 seminal roots while two-rowed varieties gave 5.73 to 6.64 seminal roots. The minimum number of seminal roots was 3 and the maximum number 9.

The number of seminal roots and maturity period for the eighteen varieties of wheat studied are presented in Table 14. The average seminal root number ranged from 4.14 in the Nugget variety to 5.12 in Garnet. The general mean for all the varieties was 4.64. This observation is close to that of Skripeinskii (25) who reported an average of 5 seminal (germinal) roots per seedling in both spring and winter wheat varieties. The minimum number of seminal roots produced was 1 and the maximum 7. *Triticum aestivum* produced slightly lower average numbers of seminal roots than *T. durum*.

The difference in seminal root numbers within barley and within wheat varieties was significant at the 1 percent level. In the groups of varieties studied seminal roots in barley were more numerous than in wheat. This is in agreement with the results obtained by Walworth and Smith (27). The minimum number of seminal roots produced among the barley varieties was 3-5 while it was 1-3 in the wheat varieties.

Table 13

Number of Seminal Roots and Maturity Period in Barley Varieties

Serial Number	Name of Varieties	Average Number of Seminal Roots	Range of Seminal Roots	Maturity Period in days
1.	C.I. 4817	6.01	4-7	72.3
2.	Olli	6.07	3-8	72.7
3.	Gateway	5.90	3-8	72.7
4.	5332	5.90	3-8	73.3
5.	Colsess	5.86	3-8	75.7
6.	Traill	5.44	4-7	77.0
7.	Jet	6.18	5-8	78.0
8.	O.A.C. 21	5.62	4-8	78.0
9.	Parkland	5.63	4-7	78.3
10.	Wolfe	5.35	4-7	78.7
11.	Titan	5.27	4-7	79.0
12.	Husky	6.10	3-7	80.0
13.	Herta	6.64	5-8	83.7
14.	Sanalta	5.73	4-8	84.7
15.	Canadian Thorpe	6.31	4-9	87.3
Mean		5.87		
L.S.D.		0.360		

	Av.No.of Sem.Rts.
Six Rowed strains (11)	5.74
Two rowed strains (4)	6.22

	Av.No.of Sem.Rts.
(Early (5)	5.95
(Medium Early (5)	5.64
(Late (5)	6.01

Table 14

Number of Seminal Roots and Maturity Period in Wheat Varieties

Serial Number	Name of Varieties	Average Number of Seminal Roots	Range of Seminal Roots	Maturity period in days
1.	Garnet	5.12	3-7	79.6
2.	Heiti	4.30	1-6	85.6
3.	Saunders	4.63	2-6	86.0
4.	Selkirk	4.19	3-6	86.0
5.	Pembina	4.42	3-5	86.3
6.	Nugget	4.14	1-6	86.3
7.	Lee	4.79	2-6	86.6
8.	Redman	4.77	3-7	86.6
9.	Thatcher	4.59	3-6	86.6
10.	Lee x Kenya	4.22	2-6	86.6
11.	Fr. x Mac	4.42	2-6	87.6
12.	Ramsay	4.46	2-6	88.6
13.	D.T. 219	4.68	1-6	89.6
14.	D.T. 161	5.03	3-7	91.0
15.	Stewart	4.53	2-6	91.0
16.	Mindum	4.80	1-6	91.0
17.	Golden Ball	5.08	3-6	93.3
18.	Frontana	4.61	3-6	95.3
Average		4.64		
L.S.D.		0.480		

		Av.No.of Sem.Rts.
T. aestivum	(10)	4.58
T. durum	(8)	4.67

		Av.No.of Sem.Rts.
(Early	(6)	4.47
(Medium Early	(6)	4.54
(Late	(6)	4.79

Association of Seminal Roots with Other Characters in Barley and Wheat

Total correlation coefficients among seminal root number, maturity period, height, number of spikelets, spike length, laxity of spike, 1000 kernel weight and grain yield in barley varieties were calculated in all combinations and are presented in Table 15. Total correlation coefficients of seminal root number with maturity period, number of spikelets and spike length were positively associated but these values were low and not significant. Early barley varieties had slightly higher numbers of seminal roots than mid-early ones, but lower than late ones (Table 13). The total correlation coefficient of seminal root number and spike length was +.506 which was close to the 5 percent significance level (+.514). The association of seminal root number with grain yield, number of spikelets, laxity of spikes, 1000 kernel weight and height gave negative correlation coefficients which were not significant. However, significant positive total correlation coefficients were obtained between maturity period and each of weight per 1000 kernels, and spike length. This means that late plants tend to have long spikes and large grains and <u>vice versa</u>. Grain yield was positively associated with number of spikelets, reaching the 1 percent level of significance. Spikelet number was therefore a much more important yield component in this group of varieties than was the other direct component measured, i.e. weight per 1000 kernels. Seminal root number showed no significant association with any of the characters studied in barley and hence would not be expected to have any value as an index in selection.

In Table 16 are presented total correlation coefficients among eight characters of the wheat varieties and calculated in all possible combinations. The association of seminal root number with all other characters except 1000 kernel weight was positive though these values were very low and not significant. The total correlation coefficient between seminal root number and height of plants was +.402 which approached the 5 percent level of significance (+.468). This means that tall varieties produce more seminal roots and vice versa. Grain yield, unlike in barley, was positively associated with seminal root number although it was low and not significant. In wheat, maturity period was positively and significantly associated with number of spikelets. In other words, late types of wheat have more spikelets and vice versa. These results show that seminal roots are of little or no value as an index of selection for the characters studied in a breeding programme in wheat.

Table 15

Total Correlation Coefficients among Eight Characters of Fifteen Barley Varieties

	Maturity	Height	Number of Spikelets	Spike Length	Laxity of Spike	1000 K. Weight	Yield
Seminal roots	+.233	-.072	-.478	+.506	-.125	-.008	-.205
Maturity		-.126	-.527*	+.690**	-.228	+.802**	-.091
Height			+.604*	+.284	+.517*	-.162	+.302
Number of spikelets				-.408	+.279	-.572*	+.672**
Spike length					+.247	+.459	-.120
Laxity of spike						-.233	+.116
1000K. weight							-.210

* Exceeds .514; significant value of r at 5% level
** Exceeds .641; significant value of r at 1% level.

Table 16

Total Correlation Coefficients among Eight Characters of Eighteen Wheat Varieties

	Maturity	Height	Number of Spikelets	Spike Length	Laxity of Spike	1000 K. Weight	Yield
Seminal roots	+.046	+.402	+.057	+.152	+.073	-.002	+.196
Maturity		+.299	+.561*	-.152	-.435	+.073	-.227
Height			+.389	+.117	-.101	+.019	+.274
Number of spikelets				+.450	+.120	+.019	+.001
Spike length					+.906**	-.748**	+.206
Laxity of spike						-.599**	+.288
1000K. weight							-.430

* Exceeds .468; significant value of r at 5% level

** Exceeds .590; significant value of r at 1% level;

Association of Seminal Root Number with Maturity and Other Characters in F_2 Progeny of S.W.F. x B.14 in Corn

The correlation coefficients among maturity, plant height, ear height, tillers and seminal root number for the F_2 plants of S.W.F. x B.14 in corn were calculated in all combinations and are presented in Table 17. Seminal root number was positively associated with maturity, the total correlation coefficient, though low, (.243), was significant at the one percent level. This shows that late plants tended to have high seminal root numbers and *vice versa*. Plant height, ear height and tillers were negatively correlated with seminal root number, but the total correlation coefficients were not significant except between seminal roots and tillers which gave a low coefficient of correlation significant at the 5 percent level. Correlation coefficients of maturity period with other characters were significant at the one percent level; in a positive direction with height of plant and ear but negatively with number of tillers. In this case, therefore, early maturity, low plant and ear height and abundant tillering were associated.

When the effect of other characters, i.e. plant height, ear height and tillers, was removed the partial correlation coefficient between seminal root number and maturity increased slightly and was significant at the 1 percent level, (Table 18). This shows that the association between seminal root number and maturity was strengthened by holding the other characters constant. The partial coefficient of correlation between tillers and seminal root number was lower and not significant when the other characters were held constant (Table 18). This shows that the association between these characters viz. seminal root number and tillers was indirect, i.e. due to the influence of other characters. Based on the partial coefficient of correlation, the relation between maturity period and each of plant height, and tillers was strong and direct (Table 19). Maturity period, plant height and ear height were found to be closely interrelated as revealed by the total correlation coefficients. This sort of association was found in all the morphological groups such as dent, flint, sweet and pop, as stated in preceding pages.

The multiple correlation coefficient of seminal root number on other characters was .287 (Table 19), and significant at the one percent level. This means that 8 percent of the variability in seminal root number was accounted for by its association with the characters, maturity period, plant height, ear height and tillers. Similarly the multiple correlation coefficient of maturity period on other characters was .483 (Table 19) and was significant at the one percent level. This suggests that 23 percent of variability in maturity period was accounted for by its association with the characters, seminal root number, plant height, ear height and tillers.

The association among the characters seminal root number, cob colour, row number and degree of denting in the F_2 population was determined by applying Chi-square tests for independence (Table 20). Based on this criterion, there was no association between seminal root number and each of cob colour, row number and degree of denting. This finding is in agreement with that of Mangelsdorf (13). The three characters cob colour, degree of denting and row number were found to be interrelated based on the Chi-square test for independence. This means that an association was found of white cob colour with low row number; deep denting with red colour cob; and high row number with deep denting.

Table 17

Total Correlation Coefficients among Five Characters of F_2 (S.W.F. x B.14)

	Seminal Roots	Maturity	Plant Height	Ear Height
Maturity	+.243**			
Plant Height	-.027	+.375**		
Ear Height	-.075	+.274**	+.742**	
Tillers	-.097*	-.138**	+.138**	+.152**

* Exceeds .088; significant value of r at 5% level
** Exceeds .115; significant value of r at 1% level.

Table 18

Partial Correlation Coefficients of Seminal Roots on Other Characters in F_2 (S.W.F. x B.14)

Character Correlated	Total Correlation	Characters Eliminated	Partial Correlation
Seminal root vs Maturity	+.243**	Plant height, ear height, tillers	+.262**
Seminal root vs Plant height	-.027	Maturity, ear height, tillers	-.030
Seminal root vs Ear height	-.075	Maturity, plant height, tillers	-.079
Seminal root vs Tillers	-.097*	Maturity, plant height, ear height	-.034

* Exceeds .088; significant value of r at 5% level
** Exceeds .115; significant value of r at 1% level

Table 19

Partial and Multiple Correlation Coefficients of Maturity on Other Characters in F_2 (S.W.F. x B.14)

Character Correlated	Total Correlation Coefficient	Characters Eliminated	Partial Correlation Coefficient
Maturity on seminal roots	+.243**	Plant height, ear height, tillers	+.262**
Maturity on plant height	+.375**	Seminal roots, ear height, tillers	+.275**
Maturity on ear height	+.274**	Seminal roots, plant height, tillers	+.029
Maturity on tillers	-.138**	Seminal roots, plant height, ear height	-.190**

* Exceeds .088; significant value of r at 5% level
** Exceeds .115; significant value of r at 1% level

Multiple Correlation Coefficients

R seminal roots on maturity, plant height, ear height, tillers	+.287**
R Maturity on seminal roots, plant height, ear height, tillers	+.483**

* Exceeds .137; significant value of r at 5% level
** Exceeds .162; significant value of r at 1% level

Table 20

Chi-Square Test for Independence among Four Characters in F_2 (S.W.F. x B.14)

Character Pair	Degrees of Freedom	Observed Chi-Square	Chi-Square at 5 Percent	Calculated Coeff. of Contingency	Contingency from Table
S.roots *vs* Cob colour	2	2.303	5.99	.004	.011
" " Row number	4	3.678	9.49	-	-
" " Denting	5	5.204	11.07	-	-
Cob colour *vs* Row Number	3	8.528	7.82	.016	.015
" " Denting	5	23.54	11.07	.045	.021
Row number *vs* Denting	12	101.70	21.03	.098	.020

Association of Seminal Root Number with Other Characters in Backcross Population in S.W.F. x B^2_{14} in Corn

Total correlation coefficients on seminal root number, maturity period, plant height, ear height and tillers were calculated in all combinations and are presented in Table 21. The seminal root number was positively associated with maturity period, total correlation coefficient between these characters was very low (.0786) and significant at the 5 percent level. Other characters, plant height, ear height and tillers, were negatively correlated with seminal root number and not significant. Total correlation coefficients between maturity period and each of plant height and ear height were positive and significant at the 1 percent level (Table 21). Tillers were negatively associated with maturity period and the total correlation coefficient was significant at the 1 percent level.

The partial correlation coefficient between seminal root number and maturity period was higher and significant when the effects of the other 3 characters were eliminated (Table 22). This indicates a slight or no influence of other characters held constant. Similar results were obtained in the case of F_2 data. These relationships suggest the possible feasability of using seminal root number as a criterion of selection for early plants from a cross of the types studied. The relationship between seminal root number and each of plant height, ear height and tillers on the basis of partial correlation coefficient was positive and not significant. This indicates that the association showed by the total correlation coefficient was due to the influence of other characters. The partial correlation coefficients with maturity period and plant and ear height were significant and positive when the effect of other characters was eliminated (Table 23). This suggests the relation of plant height and ear height with maturity period was direct and strong, indicating that late plants tend to have tall stature and high ear placement. This kind of relation was found in all groups of inbred lines and among the F_2 progenies. Maturity period and tillers were associated negatively when the effects of other characters were removed. The partial coefficient of correlation was significant at the 1 percent level. This indicates that early plants tend to produce abundant tillers or vice versa.

The multiple correlation coefficient of seminal root number on other characters was low (.1063) and not significant at the 5 percent level (Table 23). The multiple correlation coefficient of maturity period on other characters was .420 and significant at the one percent level, indicating that 17.6 percent variability in maturity period was accounted for by its association with the other characters studied (Table 23).

Table 21

Total Correlation Coefficients among Five Characters of Backcross (S.W.F.xB14^2)

	Seminal Root	Maturity	Plant Height	Ear Height
Maturity	+.0786*			
Plant height	-.0006	+.1302**		
Ear height	-.0482	+.1825**	+.3097**	
Tillers	-.0362	-.3662**	-.0008	-.0194

* Exceeds .075; significant value of r at 5% level
** Exceeds .098; significant value of r at 1% level.

Table 22

Partial Correlation Coefficients of Seminal Roots on Other Characters in Backcross (S.W.F.xB.14[2])

Characters Correlated	Total Correlation	Characters Eliminated	Partial Correlation
Seminal root vs maturity	+.0786*	Plant height, ear height, tillers	+.0801*
Seminal root vs plant height	-.0006	Maturity, ear height, tillers	+.0083
Seminal root vs ear height	-.0482	Maturity, plant height, tillers	+.0610
Seminal root vs tillers	-.062	Maturity, plant height, ear height	+.0127

* Exceeds .075; significant value of r at 5% level
** Exceeds .096; significant value of r at 1% level.

Table 23

Partial and Multiple Correlation Coefficients of Maturity on Other Characters in Backcross (S.W.F. x B.14[2])

Characters Correlated	Total Correlation Coefficients	Characters Eliminated	Partial Correlation Coefficients
Maturity on seminal roots	+.0786*	Plant height, ear height, tillers	+.0801*
Maturity on plant height	+.1302**	Seminal roots, ear height, tillers	+.0862*
Maturity on ear height	+.1825**	Seminal roots, plant height, tillers	+.1442**
Maturity on tillers	-.3662**	Seminal roots, plant height, ear height	-.3690**

* Exceeds .075; significant value of r at 5% level
** Exceeds .096; significant value of r at 1% level.

Multiple Correlation Coefficients

R. Seminal roots on maturity, plant height, ear height, tillers +.1063
R. Maturity on seminal roots, plant height, ear height, tillers +.4200**

* Exceeds .117; significant value of r at 5% level
** Exceeds .139; significant value of r at 1% level.

Inheritance of Seminal Root Number in the Cross S.W.F. x B.14

Seeds of the F_2 generation (from F_1 ears) of the cross of S.W.F. x B.14 were germinated and classified into two phenotypic groups, those with a primary seminal root only and those having secondary seminal roots. The data are presented in Table 24. Here, 587 seeds from five families classified in this manner showed a satisfactory fit to a 3:1 ratio. Family 4 did not show a satisfactory fit. According to the chi-square test for heterogeneity, the data approached 0.05 probability level for homogeneity.

The backcross (S.W.F. x $B.14^2$) data on primary and secondary seminal roots are presented in Table 26. Out of 1062 seeds studied, 237 had only primary roots and 825 had secondary seminal roots. Based on the monofactorial hypothesis suggested by the F_2 progenies, all the back cross progenies (seeds) should give secondary seminal roots since B.14, the high seminal-root producing parent, was used in the backcross. Contrary to the above hypothesis, 237 progeny had only primary roots.

The seeds of 50 F_2 selfed progenies taken at random were germinated in their F_3 generation for the observation of primary and secondary seminal roots. The F_3 data are presented in Table 25. Eleven families with only primary roots in the F_2 generation gave 362 seeds with primary and 78 seeds with secondary seminal roots. Thirty-nine families with secondary seminal roots in the F_2 generation had 678 seeds with primary seminal roots and 882 seeds with secondary seminal roots. If one gene controls the production of seminal roots all the F_3 progenies should give primary roots in all 440 seeds coming from 11 families, from the group presumed to be recessive in F_2.

Table 24

Summary of Data from the F_2 Generation showing the Segregation for Primary *versus* Secondary Seminal Roots in the Cross S.W.F. x B.14

Progeny	Total	Phenotypes		Chi-square 3:1	Probability
		Primary Seminal Roots	Secondary Seminal Roots		
4	77	30	47	8.004	.01
5	104	26	78	0.000	
5C	65	18	47	0.251	.50-.70
6	235	56	179	1.717	.10-.20
26	106	32	74	1.521	.20-.30
Total	587	162	425	2.11	.10-.20

Chi-square for heterogeneity - 9.382
P. value for heterogeneity - .05-.10

Table 25

Summary of Data from the F_3 Generation showing the Segregation for Primary *versus* Secondary Seminal Roots in the Cross S.W.F. x B.14

Phenotypic Class of F_2 Family	Number of F_2 Families	F_3 Phenotypes		
		Primary Seminal Roots	Secondary Seminal Roots	Total
Primary seminal roots	11	362	78	440
Secondary seminal roots	39	678	882	1560

Table 26

Summary of Data from the Backcross Generation showing the Segregation for Primary and Secondary Seminal Roots in the Cross S.W.F. x B.14[2]

Total Backcross Progeny	Phenotypes	
	Primary Seminal Roots	Secondary Seminal Roots
1062	237	825

GENERAL DISCUSSION

Seminal Root Number

Production of seminal roots among the inbred lines of corn in each of the morphological groups dent, flint, sweet and pop was an inherent character having certain characteristic features, in each group. The difference in seminal root number among inbred lines within each group was significant at the one percent level. Dent lines had 10 seminal roots as the maximum number with every line having secondary seminal roots, while pop lines had a preponderance of seeds with primary roots only (Tables 2 and 5). The pop group had the lowest average number of seminal roots while sweet and flint lines were intermediate in this respect. The range in maturity of the corn inbred lines studied was fairly representative of adaption regions within North-temperate zone, but representative stocks from tropical regions or the Southern hemisphere were not included in this study due to the limitation of climatic conditions at the place of investigation. The corn material used was representative of adapted commercial types of the area sampled.

The data pertaining to seminal root number were close to those found in the literature (26 and 9) except for those of Wiggans (31) who reported 1 to 13 seminal roots in corn. Some of the variations observed in production of seminal roots in certain lines of dent and flint groups may have resulted from them having been derived from hybrids between flint and dent lines or varieties. Some lines in these groups were known to have such progenitors, and others may have had. Observations of Anderson and Brown (1) in corn suggest that modern dent varieties of corn originated from hybridization between Northern flint and southern dent types.

In barley and wheat, the range of maturity was sufficiently large to be fairly representative of varieties in the temperate region. The difference in seminal root number among strains of barley as well as wheat was significant at the 1 percent level. This shows that seminal root production is a varietal characteristic. All the barley varieties in this investigation had secondary seminal roots irrespective of origin and maturity period. Two-rowed barley types had higher number of seminal roots than those in 6 rowed ones. In this case, out of 4 two-rowed types 3 were very late. The higher number of seminal roots found in these types may be due to their late maturity. But there was no relation between maturity period and seminal root number (Table 15). Although some workers (6) have reported that two-rowed barley had higher seminal root numbers than six-rowed type, here, in this case there was an unequal number of strains in each category and the number in each was not large.

Association of Seminal Root Number and Other Characters

Examination of correlation coefficients among the different morphological groups of corn reveals that they were small and not consistent. For instance, seminal root numbers and maturity were related positively in dent, flint and sweet groups, but negatively in pop lines. Cob length and seminal root number were related in dent and pop lines but not in flint and sweet lines.

Seminal root numbers were related to the morphological grouping used, as revealed by the Chi-square test for independence (Table 27). This shows that certain proportion of lines in each group produced low or high numbers of seminal roots.

The interrelation among the characters maturity period, plant height and ear height was found to be universal in all groups of corn and hybrid progeny. This shows that early plants tend to have short plants and low-placed ears and vice versa. This kind of association may be accounted for by physiological activity of plants. Prolonged period of growth generally tends to produce more nodes or increased length of nodes and thus late plants tend to be tall with highly-placed ears (10).

In the flint group, tillers were related negatively to seminal root number and maturity period. Maturity period and seminal root numbers in turn were related to each other positively. This relation is suggestive of a tendency for late maturity plants with numerous seminal roots to produce few tillers. This sort of relationship was also observed in the F_2 progeny of cross S.W.F. x B.14. This indicates a possible linkage between genes conditioning maturity period, seminal root number and a low tiller number. However, the correlation coefficients were low, and new combinations of these characters would be expected in a substantial portion of segregating populations of this type.

In breeding programmes with the objective of combining all desirable traits from a late parent with numerous seminal roots and earliness from a second parent which had a low seminal root number, (similar to the situation found in the cross of S.W.F. x B.14), seminal roots would help to eliminate a number of plants in early generations. A backcrossing programme could be easily planned in such a situation and seminal root counts should be helpful in selecting early plants to effect successive backcrosses.

Inheritance of Seminal Root Number

The F_2 data on the phenotypic classes primary and secondary seminal roots provide evidence for inheritance of seminal root number on a single factor basis.

Examination of backcross progeny revealed that the monofactorial hypothesis observed in F_2 did not agree with these data (Table 26). Similarly eleven F_3 progenies belonging to the recessive class (producing only primary roots) in F_2 gave 362 seedlings having only primary roots and 78 seedlings with secondary seminal roots (Table 25). On a monofactorial basis, these 11 families should yield all seedlings having only primary roots. But the S.W.F. parent itself had 6 percent of seedlings with secondary seminal roots. On this basis, 26 seeds are expected to give secondary seminal roots, but the 78 seedlings of this phenotype observed exceed these expectations. The F_2 data were examined on the basis of 2 genes conditioning seminal root production and the chi-square did not fit a 13:3 ratio. On the basis of above findings it is assumed that the seminal root number is governed by one gene with major effect and many with minor effects.

Table 27

Chi-square Test for Independence between Seminal Root Number and Four Morphological Groups of Corn

Number of seminal roots (Average)	Number of Lines in each Morphological Group				
	Dent	Flint	Sweet	Pop	Total
1 - 1.9	4	13	11	7	35
2 - 2.9	19	4	5	-	28
3 - 3.9	9	2	-	-	11
4 - 4.9	4	2	1	-	7
5 - 5.9	-	2	-	-	2
Total	36	23	17	7	83

Character Pair	Degrees of Freedom	Observed Chi-square	Chi-square at 5% level
Seminal root number *vs* Morphological groups:	12	38.67	21.03

SUMMARY AND CONCLUSIONS

The primary objective of this study was to determine possible associations of seminal root number, maturity period, and other distinctive characteristics of varieties in wheat, barley and corn. Varieties in each crop were chosen to give a wide range in maturity and other characters. Inbred lines were used, representing the morphological groups dent, flint, sweet and pop. The F_2 and backcross progeny of one cross between an early flint line and a late dent line were studied in a similar manner.

Corn inbred lines differed widely in numbers of seminal roots. Each group had distinct characteristics in this respect. Dent lines had the highest number of seminal roots, pop lines the lowest number, while flint and sweet lines were intermediate. All of the lines sampled in the dent group produced some secondary seminal roots, whereas a number of lines in each of the other groups had only primary roots.

Positive association of seminal root number and maturity period was indicated in dent, flint and sweet lines of corn. Seminal root number was positively related to row number in dent lines, to ear height in flint and sweet lines, and to cob length in pop lines. A negative association of seminal root number and tiller number was observed among flint lines. Maturity period, plant height and ear height were interrelated in a positive direction. This relationship was found in all morphological groups and hybrid progenies.

The range in average seminal root number among barley varieties was from 5.27 to 6.64 with a maximum of nine. Two-rowed types had a slightly higher average number of seminal roots than six-rowed ones although the difference was not significant statistically. Wheat varieties had an average of 4.40 to 5.12 seminal roots with a maximum of 7 roots. *T. aestivum* varieties had slightly lower numbers of seminal roots than varieties of *T. durum* but the difference was not statistically significant. Barley had more seminal roots than wheat as an average of the varieties studied. All of the barley varieties produced some secondary seminal roots, while some strains of wheat had a small proportion of seeds which produced primary seminal roots only. There was no association between seminal root number and the other characters studied in either barley or wheat.

An association between seminal root number and maturity period was indicated in both the F_2 and backcross populations of S.W.F. x B.14. Tiller number was negatively related to seminal root number and maturity period. Seminal root number was indepehdent of each of cob colour, row number and degree of denting, but the latter three characters were related to each other.

Primary *vs.* secondary seminal root production in corn was found to be inherited on the basis of single gene pair with major effect, but the presence of modifying genes was indicated.

Results of the present investigation indicated the possible use of seminal root number in hybridization programme to reduce the size of population required in early generations on the basis of seminal root number. This would hold true only if the seminal root situation in the parents were known and then it is questionable if the association would be constant.

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