THE EFFECTS OF MASS SELECTION FOR SEED SIZE IN HEXAPLOID TRITICALE

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Ian S. Ogilvie

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Mature Spike of Hexaploid Triticale

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ABSTRACT

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Three lines and two F3 segregating populations of hexaploid triticale (X *Triticosecale* Wittmack) were subjected to two cycles of ambidirectional mass selection for seed characteristics on the basis of size and density. No advance due to selection was observed in two contrasting environments. As neither seed size nor density were consistently correlated with plot yield, mass selection for these seed characteristics was ineffective in changing the yield of the populations studied. However, in seven crosses, plants resulting from large F2 seeds, selected on an individual F1 plant basis, outperformed those from small seeds. Similar selection in an advanced line yielded no significant differences. It is argued that the few genes which control seed size in these populations become fixed in the homozygous condition by the F3 generation, rendering further selection ineffective. This, coupled with a certain amount of outcrossing in triticale, suggests that mass selection techniques, suitable for wheat or other completely self-pollinated plants, would be ineffective in present early generations of hexaploid triticale, unless the techniques are modified, because of differences in the breeding system.

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INTRODUCTION

Selection for seed size and its effect on seed yield in triticale lines and segregating populations

Importance of selection from large populations

Large populations of the early segregating generations are required to recover all possible favourable recombinants, when working with characters controlled by a large number of genes, such as yield. Shebeski (1967) has calculated that in the F2 of a cross differing by 21 gene pairs (assuming only one gene difference on each chromosome of hexaploid wheat or triticale) only 0.237% of the plants would contain all the favourable alleles in either the homozygous or heterozygous condition. As environmental conditions would probably affect phenotypic expression of various genotypes, a much smaller proportion of the most favourable genotypes would exhibit superior phenotypes. This would necessitate using even larger F2 populations,than theoretically expected, to ensure a fair chance of selecting the desirable genotype.

Yield components and selection efficiency

To make selection for yield easier to manage, various characters associated with it have been used as its predictors. These characters, considered to be parts of yield, are known as its components and are thought to be under the control of a simpler genetic system. For crop plants in which the harvested seed is the economic product, the major components of seed yield are: (1) the number of plants harvested in a given unit area, (2) the average number of fertile or seed-bearing inflorescences per plant, (3) the average number of seeds per inflorescence and (4) the average weight of the individual seed (Langer, 1967).

All these yield components have been used in plant breeding programmes; however, some of them may be highly affected by environmental conditions and whether phenotypic selection actually indicates superior genotypes may, in many cases, be questionable.

To effectively deal with the large populations necessary for selection of the individuals with the largest possible number of genes for improved yield, a rapid method of handling must be used. The first three yield components depend on an extensive system of recording and labelling which would preclude the handling of a sufficiently large population to achieve significant improvement of the specific yield component.

Selection for seed size and yield improvement

Selection for seed size on a phenotypic basis could be achieved rather easily on a mass scale which would enable the use of mechanical methods and the rapid screening of reasonably large populations. A number of researchers have recorded evidence that seed size is positively correlated with seed yield in a number of cereal and other crops (see Literature Review). When different seed sizes of an inbred line are selected, the size differences should be due only to environmental differences or other factors such as the position of the seed in the inflorescence. When selecting from segregating populations, however, there will be both a genetic and an environmental component of seed size, and selection for a specific seed size should shift the mean seed size of the progeny towards the mean of the selected individuals with a corresponding shift in associated yield characters.

Problems in triticale breeding

The pedigree method and mass selection techniques for seed size selection, as a component of seed yield, have been widely used with positive results in hexaploid wheat and many other crop plants. However, for the object of this triticale investigation, some of the problems encountered are different from those associated with hexaploid wheat or any of the other more important cereal crops.

Hexaploid triticale has its origin from amphidiploids produced by colchicine or other chromosome doubling treatments of crosses between tetraploid wheats of various species (Triticum sp.), which are all naturally inbreeding, and diploid rye (Secale cereale L.) which is a naturally outcrossing species. The combination of an outcrossing species and a naturally inbreeding species in a new artificially synthesized hybrid appears to have created a number of problems which must be overcome before the new species can compete economically with established varieties of the traditional cereals. Many of the present triticale lines have very low fertility and produce varying amounts of shrivelled seed, especially in the early segregating generations. In this specific area, the problem of low fertility has been further complicated by the high susceptibility of most triticale lines to infection by ergot (Claviceps purpurea (Fr.) Tul.). Most florets which do not form seed are then infected by the fungal spores and produce a fungal body (sclerotium) in the place of the seed. Many seeds which do form are also infected by fungal spores at an early stage, with, in most cases, the embryo and much of the endosperm being destroyed by fungal growth.

These problems complicate the simple mechanical selection or separation of triticale lines on the basis of seed size as compared with hexaploid wheat or other cytologically stable crops. When there is a high degree of sterility on a given spike, only a few seeds may form. The possibility exists then that all the available nutrients could be translocated into these few seeds, resulting in much larger seeds than would be the case when the available nutrients are distributed to the much larger number of growing kernels in a highly fertile spike. Shrivelled, twisted seeds may be retained in the same class as large sound, plump seed when a bulk population is passed through a set of seed screens or sieves. These shrivelled seeds will have a much lower density than normal seeds, and will have a much lower weight and lower endosperm reserves for the nutrition of the developing embryo during germination and early development. Some method is therefore needed to compensate for this variation in seed density or weight in the mechanical separation on a size basis for most segregating triticale populations.

Because of these problems, mass selection screening techniques which have been used for increasing seed size and yield in other cereal crops may not be directly applicable to triticale breeding. Modifications therefore may have to be made to these methods to achieve any effective improvements.

Seed size selection in triticale

Some of the larger seeded lines of triticale have generally higher seed quality and indications of good yield combined with certain undesirable agronomic characters such as excessive plant height. An effective breeding programme should combine the reasonably good seed quality and large seed size of these lines with the short straw length of the semi-dwarf lines which have smaller seeds, a high degree of seed shrivelling and rather poor fertility.

When triticale lines of diverse origin and type are crossed there is some difficulty in obtaining sufficient amounts of seed from which to obtain, through mechanical separation, at least three different seed classes for a replicated yield trial. A preliminary experiment was first undertaken on F2 seed, using visiual selection for seed size and its effects on single plant and plot yields. Eventually two segregating populations of F2 plants were obtained from the winter nurseries growing at Ciudad Obregon, Sonora (Mexico), which gave sufficient F3 bulk seed for a replicated yield trial. Additionally, three advanced lines which differed widely in genetic origin and seed size were obtained. These five populations were subjected to two cycles of mass selection for seed size and were grown at two contrasting environments with a view to ascertaining: (1) the effectiveness of mechanical mass selection for seed size in segregating (F3 and F4) and pure triticale lines, (2) the correlated response, if any, of yield to selection for larger seed size and (3) the effect, in any, of the type of environment on the magnitude of the selection response.

This series of selection experiments, along with some growth studies of embryos cultured from seeds of various sizes from the lines and populations used in the F3 bulk selection experiments should give some definite information on the effectiveness of mass selection for seed size in increasing the yield of hexaploid triticale.

LITERATURE REVIEW

Genetic segregation in self-pollinated plants

When selecting for a quantitative character such as seed yield, in which a large number of genes may control its expression, large populations need to be evaluated. Shebeski (1967) has calculated that in a cross differing by 21 genes (one for each chromosome pair for hexaploid wheat or triticale) only 0.238% of all plants in the F2 generation would have all favourable genes in either the homozygous or heterozygous condition and that this would decrease to 0.0052% in the F3 and 0.00057% in the F4 generation. The difficulty of handling such large numbers of plants in order to obtain the most favourable possible genotype obviously makes it impossible to use the conventional pedigree system. This necessitates the use of certain screening techniques to eliminate obviously inferior genotypes and increase the possibility of selecting superior genotypes at the earliest possible generation.

Yield components as indicators of yield

Yield, in any crop where the seed is the desired economic product, may be resolved into four main components: (1) the number of plants per unit area, (2) the number of inflorescences or heads per plant, (3) the number of seeds per head and (4) the average weight per seed (Lander, 1967). All of these components can be used as a selection index in breeding for total seed yield, but it is necessary to choose one which can be used for populations consisting of many thousands of plants.

The first three components all require a process of observation and recording which would limit the size of populations which could be handled by a given amount of labour, while seed weight or size can be effectively handled by mechanical means and the populations separated into a range of classes from which positive or negative selection can be made.

The effectiveness of seed size as a component of yield, its effect on development of vegetative and reproductive structures of the plants, the heritability of seed size and the contribution of the embryo and the nutrient reserves in the seed are all factors which must be taken into consideration when attempting to initiate a programme of mass selection for seed size to improve yield. The accompanying review of previous investigations in a wide variety of economic plants, with a more detailed examination of similar work in cereals, has been done in order to apply these results to the present investigation of mass selection for seed size in hexaploid triticale.

Forage grasses

Rogler (1954), working with six depths of seeding and six seed sizes in crested wheatgrass (*Agropyron cristatum* L.), found a significant correlation between seed weight and emergence from depths greater than five centimetres. Leaf development was also greater for the larger seed sizes.

Kneebone and Cremer (1955) found that large seed size was associated with seedling vigour in five native American range grass species (*Buchloe dactyloides* (Nutt.) Engelm., *Bouteloua curtipendula* (Michx.) Torr., *Andropogon hallii* Hack., *Sorghastrum nutans* (L.) Nash. and

Panicum virgatum L.) but that germination was decreased in smaller seeds only in Panicum virgatum L. Kneebone (1956) made single plant selections in Andropogon hallii Hack. and found a correlation of 0.88 between seed weight and percentage stand. One cycle of selection in Bouteloua curtipendula (Michx.) Torr. for seedling vigour resulted in increased seed size and more vigourous progeny.

Thomas (1966), studying populations of perennial ryegrass (Lolium perenne L.), found that seed weight was positively correlated with seedling vigour (within a population) but that these correlations decrease with age. Arnott (1975) found that seedlings from large seeds of S24 perennial ryegrass produced longer and heavier roots, as well as having longer coleoptiles which enabled them to emerge from greater depths.

Trupp and Coulson (1971) found that early seedling vigour was correlated with seed size in smooth bromegrass (Bromus inermis Leyss.). This correlation decreased with time but was still evident 93 days after seeding.

Forage legumes

Twamley (1971) found that there was no negative correlation between seed size and seed yield in Lotus corniculatus L. (birdsfoot trefoil). Conje and Carlson (1973) reported that seedling dry weight and length were positively correlated with seed size in F1 plants of a cross between two diverse strains of birdsfoot trefoil. Twamley (1974) made three cycles of selection for seedling size and vigour in lines of birdsfoot trefoil in which an increase of seedling weight by 40% also resulted in a seed weight increase of 36%. Carleton and Cooper (1972) found that correlation of average seed size of a clone with its seedling vigour was significant in birdsfoot trefoil, not significant in alfalfa (*Medicago sativa* L.) and approached significance in sainfoin (*Onobrychis sativa* Lam.).

Townsend (1972) found large and medium seeds to be significantly superior to small seeds for emergence in *Astragalus cicer* L. but not significantly greater for *Astragalus falcatus* Lam.

Haskins and Gorz (1975) selected small, medium and large seeds in two lines of sweet clover (*Melilotus alba* Desr.). Increased seed size improved both seed emergence and dry matter production.

Grain legumes

Fehr and Probst (1971) found that for 10 different strains of soybeans (*Glycine max* Mer.) at 14 locations, yield, height and seed size were all positively correlated with the size of the seed sown. Fontes (1971) showed that plants grown from large seed had higher yield, greater height, fewer barren plants and were better competitors than those from small seed of the same two varieties. Singh, Tripathi and Negi (1972) demonstrated that plants from large seeds of three soybean varieties produced more dry matter than those from small seeds but that seed yield and yield components were not affected by seed size. Lal, Mehta and Nigam (1973) found that small and medium seeded varieties of soybeans were superior in emergence and seed yield than large seeded ones. Johnson and Luedders (1974) showed no effect of seed size on emergence or seed yield.

Coffelt and Hammons (1973) graded groundnut (*Arachis hypogea* L.) seeds by 1/64 inch intervals from 22/64 to 14/64 inches and found that an excess of albino seedlings were produced by the small seed sizes but that the defect 'sterile brachytic' was inherited independently of seed size. Seed yields were lower for the smaller seeds (less than 15/64 inches). Sivasubramanian and Ramakrishnan (1974) noted the superiority in field emergence and dry matter production to 90 days of plants originating from large groundnut seed over those from small and shrivelled seeds and attributed this to the increased amounts of proteins and amino acids stored in the cotyledons.

Meuhlbauer (1973) noted that seed weight was negatively correlated with yield in 45 cultivars of lentil (*Lens esculenta* Moench.) Muehlbauer (1975) stated that there is a negative association between seed size and yield in lentils and that extensive backcrossing would be needed to increase the yield in large seeded cultivars.

Singh and Singh (1972) reported that the main yield contributing factors in field peas (*Pisum sativum* L.) were seeds per pod, branches per plant and seed size.

Pinthus , Bar-Am and Muhasen (1973) isolated large and small seeded lines from one cultivar of chick peas (*Cicer arietinum* L.). Bulks from the large seeded line produced higher yields and those from the small seeded line lower yields than the original cultivar.

Hamblin (1975), in a competition study of seven varieties of beans (*Phaseolus vulgaris* L.), found that large seeded high yielding lines would tend to be eliminated in mixtures with lower yielding small seeded types which produce a larger number of seeds per plant if the mixtures were maintained as bulks.

Miscellaneous economic plants

Gorina (1971) stated that selection by seed size in buckwheat

(Fagopyrum esculentum Moench.) increased the yield of the progeny by 8-12%, with the greatest increase in medium sized lines.

Harper and Obeid (1967) found that seedlings from small flax (Linum usitatissimum L.) seeds emerge fastest from one centimetre sowings and those from large seeds at six centimetres in depth. Large seeds had a competitive disadvantage in mixtures.

Dabral and Holker (1971) reported that capsule length and 1000 seed weight were correlated with yield in sesame (Sesamum indicum L.)

Ahmed and Zuberi (1973) found that in four varieties of rapeseed (Brassica campestris L.), large seeds (100 seeds = 56-63 mg) produced higher seed yields per plant, more fruits per plant, larger fruits and heavier seeds than small seeds (100 seeds = 23-29 mg) but had fewer seeds per fruit.

Kubka, Hortynski and Hulewicz (1974) reported that the correlation between the seed weight of a mother plant in radish (Raphanus sativus L.) with the root yield of its progeny was high and significant.

MacLachlan (1972) separated sugar beet (Beta vulgaris L.) seeds into six sizes from 7/64 inches to 12/64 inches and found that a yield increase of 0.4 tons of roots per acre without any effect of sugar percentage was obtained for each 1/64 inch increase in seed size. Scott, Harper, Wood and Jaggard (1974) reported that increasing sugar beet seed size caused a progressively greater percentage of emergence and root/ shoot ratio.

Halsey (1971) found significantly greater yields of mature green and marketable size tomatoes (Lycopersicum esculentum Mill.) from plantings of heavy seed over those from light and unsized seed.

Cochran (1973) reported that large and medium seeds of the pepper (Capsicum annuum L.) "Truhard Perfection" emerged two days earlier than small seeds and had sufficient growth for transplanting while those from small seeds were not ready at 75 days.

El Zahab, Abo and Zahran (1974) tested four different seed sizes in three varieties of cotton (Gossypium hirsutum L.). Large seeds produced plants with 37% more dry matter than those from small seeds and 12% more than those from unselected bulks at 71 days but the yield of seed cotton did not differ between seed sizes.

Griffin (1972) graded a half-sib seed lot of Monterrey pine (Pinus radiata D. Don) into large and small seeds. The seedlings from large seeds were 18% taller and had a 45% greater dry weight at 32 weeks than those from small seeds.

Tropical cereals

Abdullah and Vanderlip (1972) reported that large (over 10/64 inches) and medium (10/64 to 9/64 inches) seeds of sorghum (Sorghum vulgare Pers.) taken from a hybrid grown at nine different locations were similar and superior to small (less than 9/64 inches) seeds in all tests of seedling vigour and field establishment but that grain yield did not differ significantly between seed sizes.

Gubbels (1974) found that seed size was positively correlated with the emergence of the first five seedlings and with green weight of maize (Zea mays L.) genotypes planted at low temperatures. Hunter and Kannenberg (1972) reported that there was no difference in grain yield or in days to 50% emergence in maize seeds within a line between those with a 100 seed weight of 39 g and those of 23 g. Sevov and Mitev (1974) found a direct positive correlation between the size of the seed and the yield of the plants grown from them in popcorn.

Herrmann (1969) classified 20 different cultivars of rice (*Oryza sativa* L.) by seed size and found that increased seed size improved the germination and early development of the rice plant independent of the geographical origin of the cultivar or environmental conditions.

Oats (*Avena sativa* L.)

Frey and Wiggins (1956) tested seeds of various test weights from four oat varieties. The dry weight of the seedlings was correlated with the test weight of the seed from which they were grown, but the difference disappeared at maturity. However, low test weight samples did not produce as high grain yields as those from high test weights, indicating a lower grain/straw ratio. Kernels from plants grown from the low test weight seed were lower in 100 kernel weight than those grown from high test weight seed in three of the four varieties. Murphy and Frey (1962) found that seed width was more closely correlated with seed weight than was seed length. Heritability was 51.1% for length, 35.1% for width and 36% for weight. Bowman and Rothman (1967) reported no significant difference in yield between eight different test weights ranging from 28.3 to 46.3 kg/hl in the winter oat variety "Victorgrain 48-93". Frey and Huang (1969) found that the relationship between yield and 100 seed weight was curvilinear. Maximum yields were recorded from lines with a 100 seed weight of 2.75 to 3.10 g.

Barley (*Hordeum vulgare* L.)

Kaufman and McFadden (1960) reported higher yields of plants grown from larger seeds due to a higher number of heads produced per plant. Dermirlicakmak, Kaufman and Johnson (1963) found that lower rates of seeding produced higher 1000 kernel weights within a variety. There was no effect of seed size on emergence, but increased tillering produced higher yields from large seeds, although tillering capacity alone was a poor indicator of yield. Kaufman and McFadden (1963) reported greater tiller numbers for large seeds over medium, bulk and small in four different varieties. Kaufman and Guitard (1967) found that large seeds produced superior seedling growth and leaf size for the first two leaves than small seeds (one half the size of the large seeds) but that results were inconsistent for subsequent growth. McDaniel (1969) reported that heavy seeds contained a greater initial quantity of mitochondrial protein than the light seeds and therefore produced seedlings with a greater energy production potential, resulting in faster growth. Rasmusson and Cannell (1970) found that heads per plant was the most effective index for selection for yield but that selection for high kernel weight was also effective. Malhotra and Jain (1972), in analysing 30 strains of barley, found that yield was positively associated with 1000 kernel weight and seeds per spike.

Wheat (Triticum aestivum L.)

Waldron (1941) found that within spring wheat varieties, heavy seeds (40.0 mg per seed) outyielded light seeds (26.6 mg per seed) by 12% when equal numbers of seed were planted per row and by 10% when equal weights of seed were planted per row. Marchetti (1948) reported contrasting results with large (24,900 grains per kg) and medium (31,600 grains per kg) seeds of the Italian wheat variety "Libero." Medium seeds sown at 154 kg/ha (equal seed number) and at 195 kg/ha (equal seed weight) outyielded large seeds sown at 195 kg/ha in both cases by 18%.

Quisenberry and Reitz (1967) reported that seed weight has been found to be under monogenic control in some crosses and in others by two to four genes. Heritability estimates ranged from 0.370 to 0.693. Sharma and Knott (1964) estimated that four genes controlled seed size differences in the cross between the spring wheat varieties "Selkirk" (large) and "Chagot" (small). Heritability was high with estimates of 0.370 to 0.695. Selection in the F2 indicated that the higher estimate was correct.

Bremner, Eckersall and Scott (1963) found that small embryos in the variety "Cappelle" had a higher initial growth rate than large embryos due to a larger scutellum/embryo ratio. Larger seeds were found to produce larger seedlings due to larger endosperm reserves and especially a larger source of magnesium. Embryo size had no significant effects when endosperm was equalised.

Fasoulas (1963) reported that large seeds produced plants with greater numbers of seminal roots, longer first three leaves, earlier tillering and heading, greater number of spikes per plant and spikelets per spike and higher yields of grain and straw. Larger embryos were also found to be superior than small embryos and varieties with large embryos were found to have a greater competitive advantage in mixtures. MacKey (1973) stated that seminal roots are deeper and more efficient per unit of weight than crown roots but that high seminal root number is not automatically associated with large embryo size. Seed size influences shoot and root development equally. Both are reduced by dwarfing genes.

Fonseca and Patterson (1968) reported that yield in a seven parent diallel was correlated with kernel weight. Borojevic and Cupina (1969) found a positive correlation between 1000 grain weight and yield in quintals per hectare of 0.771 and with yield in grams per plant of 0.524 for nine Central European wheat varieties. Austenson and Walton (1970) reported that the size of the individual seed accounted for 2.5-4.5% of the variation in yield of spring wheat plants of three different varieties. Goydani and Singh (1971) found that plants from small seeds (1000 grains = 20-29 g) of four varieties produced low yields due to a decrease in germination, low numbers of fertile tillers per plant and a low survival to harvest.

Khadi (1971) found transgressive segregation for both small and large seed size in six wheat crosses. Heritability for kernel weight was 70%. Knott and Talukdar (1971) reported a negative correlation between high seed weight and kernels per plot and a positive correlation between seed weight and yield.

Karamalishoev (1972) reported a positive correlation between seed size and root penetration in two wheat cultivars. Kir'yan and Dashevs'skii (1972) found the highest number and growth of embryonic roots in wheat was from the largest seeds and that it was also affected by the location of the ear, being highest for those from the middle of the ear.

Bagnara, Poukhalski and Rossi (1972), in crosses of four mutant lines and two cultivars of durum wheat (*Triticum durum* Desf.) reported that dominant alleles are more frequent than recessive and act mainly to increase kernel size. Small seed size was recessive in one variety and semi-dominant in another line. There was a positive association between culm length and kernel weight in some crosses.

Derera and Bhatt (1972,1973) compared mass selection for seed size in four varieties and three segregating F2 bulks as compared with unselected controls in all populations. Large seed selections in the heterogeneous bulks showed higher 100 kernel weight, grains per ear and yield per plot than the controls, while the small seed selections were in all cases lower. There were no significant differences between either size and controls for three of the four varieties, with only a significant difference (decrease) for small seeds in one variety. Selection appeared to be for genetic differences in size for the segregating bulks and for non-genetic differences in the varieties.

Dasgupta and Austenson (1973), in testing 83 seed samples of the variety "Manitou" at three different locations, determined that 1000 kernel weight was the only character associated with yield at all three stations.

Chebib, Helgason and Kaltsikes (1973) tested small, large and unselected bulk seeds of a pure line and a segregating population at three different row spacings. Wide plant spacing was the main cause of intraplot variance. The effect of genotype did not approach the 5% significance level for any of the 11 yield components. It was concluded that sorting seeds into equal sizes would increase the effectiveness of single plant selection by 10% while decreasing spacings from 15 cm to 5 cm would increase it by 51%.

Bhatt and Derera (1973) found that phenotypes from large seed selections produced highly significant increases in mean tiller number and grain yield per plant in two of three crosses. Quality factors were independent of seed size. Roy (1973) planted large and small seeds of two varieties in both pure and mixed (size) stands at spacings of 1.7 cm X 3.0 cm. In mixed stands the large seeds gave higher yields per plant than the small seeds, but the yield per plant from small seed plants was higher in pure stands.

Kikot (1973) attributed decreases in yield from small seeds compared with large and unselected bulks to decreases in tillering and 1000 grain weight. They also had reduced germination and vigour. Randhawa, Anand and Jolly (1974) reported an average yield increase of 16.4% for large seeds over small and 7.4% over bulk in the dwarf wheat "Kalyansona" at seed rates of 40,60, 80 and 100 kg/ha.

Kir'yan (1974) reported that the number of seminal roots depended on the cultivar and on seed size. In winter wheat, 80% of the seedlings from large seeds had four to five roots while only 45% of those from medium seedlings had four to five roots.

Rye (Secale cereale L.)

Vageler (1927) reported that plot yield in Petkuser rye increased with the size of the seed used, but that there was no relation between the size of the kernels used for seed and those of the harvest. Kuvarin (1974) noted that small defective seeds were over half aneuploids in a tetraploid rye population. Selection of only plants containing none of these defective seeds reduced aneuploids in this population from 13.67% to 6.81%. Pfahler (1974) found that early seedling growth as measured by coleoptile length was not closely associated with vigour expressed at later stages of growth.

Miscellaneous cereals

Kiesselbach (1924) presented data on sized seed of several varieties of spring wheat, winter wheat and oats grown over several seasons. Upon space planting, small seeds gave rise to plants which yielded 19% less than those originating from small seed, but this difference decreased to less than 10% at optimum rates of seeding. It was concluded that sizing within a variety was not practical for commercial production

Guitard, Newman and Hoyt (1961) found that 1000 kernel weight was not highly affected by different seeding rates in wheat and barley. Tillering was of little use in selection for yield, and most progress was made in selecting heads with the highest 1000 kernel weight and maximum number of kernels.

Landenmark (1972) reported on the germination of sized samples of oats, barley and spring wheat over two years. When all seed was of good quality, in the first year, there was no significant difference in germination between seed sizes. The second year showed poorer seed quality and large sizes showed higher germination than medium, with both being significantly higher than small sizes. Koval'chuk (1973) found that the decrease in germination and viability during long storage was greater in small seeds than in large seeds of wheat and barley.

Triticale (X *Triticosecale* Wittmack)

Bishnoi and Sapra (1975) reported that in three hexaploid triticales, large seeds (greater than 7½/64 inches) gave 51% higher field stand, 62% more seedling dry weight and 37% higher grain yield than small (less than 6/64 inches) seeds.

Kaltsikes and Larter (1970) found the percentage of aneuploids ranged from three to nine times in shrivelled seeds as in plump seeds of three cultivars of hexaploid triticale but only slightly higher in a fourth. Reitz (1970) reported that seeds set in the higher part of the spikelet were often only half the size of those set at the base in hexaploid triticale. Tsuchiya (1972) found that the percentage of euploid plants was higher from large seeds in five of six hexaploid triticale strains. Kaltsikes (1974) reported that 1000 grain weight was positively correlated with yield while width of flag leaf was negatively correlated with yield in a 5 X 5 F3 diallel of hexaploid triticale lines.

Weimarck (1975) found that the percentage of euploid plants from large smooth seeds with a 1000 kernel weight of over 55 g was double that of smaller seeds in the octoploid triticale cultivar "Kagawa."

General trend of seed size selection

The various investigations on selection for increased seed size (Table 1) have generally shown an increase in the yield of seed from the selected individuals, as well as other desired economic characters. Even in cross-pollinated species, selection for large seed size has usually had the effect of increasing seedling characters, such as vigour, although the weight of seed produced was not increased to the same degree as in self-pollinated species.

Although seed yield and vegetative characters such as an increase in early seedling growth have generally been associated with large seed size, there have been some exceptions. The investigations on lentils (*Lens esculenta* Moench.) have demonstrated a negative correlation between seed size and seed yield (Muehlbauer, 1974, 1975). Other species

TABLE 1. Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection: Positive	None	Negative	Author	Breeding System	Authority
<u>Grasses</u>							
Lolium perenne	Seedling weight	+			Arnott (1975)	cross	Allard (1966)
	Early seedling development	+			Thomas (1966)		
Bromus inermis	Early seedling development	+			Trupp & Carlson (1974)	cross	Allard (1966)
	Seed,forage yield		0				
Agropyron cristatum	Early seedling	+			Rogler (1954)	cross	Hughes *et al.* (1951)
Andropogon hallii	Seedling vigour	+			Kneebone & Cremer (1955,1956)	cross	
	% stand	+					
Bouteloua curtipendula	Seedling vigour	+			Kneebone & Cremer (1955,1956)	cross	Hughes *et al.* (1951)
Buchloe dactyloides	Seedling vigour	+			Kneebone & Cremer (1955,1956)	cross	Allard (1966)
Panicum virgatum	Seedling vigour	+			Kneebone & Cremer (1955,1956)	cross	Hughes *et al.* (1951)
Sorghastrum nutans	Seedling vigour	+			Kneebone & Cremer (1955,1956)	cross	

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection: Positive	None	Negative	Author	Breeding System	Authority
Forage Legumes							
Astragalus cicer	Seed emergence	+			Townsend (1972)	cross	Scheetz et al. (1971)
Astragalus falcatus	Seed emergence		0		Townsend (1972)	cross	
Lotus corniculatus	Seedling vigour	+			Twamley (1974)	cross	Allard (1966)
	Seedling vigour	+			Carleton & Cooper (1972)		
	Seedling weight	+			Conje & Carlson (1973)		
	Seed yield		0		Twamley (1971)		
Medicago sativa	Seedling vigour		0		Carleton & Cooper (1972)	cross	Brauer (1969)
Melilotus alba	Dry matter production	+			Haskins & Gorz (1975)	cross	Brauer (1969)
Onobrychis sativa	Seedling vigour		0		Carleton & Cooper (1972)	cross	
Grain Legumes							
Arachis hypogea	Seed yield	+			Coffelt & Hammons (1973)	self	Brauer (1969)
	Field emergence Dry matter production	+ +			Sivasubramanian & Ramakrishnan (1974)		

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection: Positive	None	Negative	Author	Breeding System	Authority
Grain Legumes							
Glycine max	Yield,height,seed size	+			Fehr & Probst (1971)	self	Allard (1966)
	Dry matter,seed yield		0		Singh et al.(1972)		
	Seed yield, emergence		0		Johnson & Luedders (1974)		
	Seed yield, emergence			-	Lal et al. (1973)		
Lens esculenta	Seed yield			-	Muehlbauer (1974, 1975)	self	Arnon (1972)
Cicer arietinum	Seed yield	+			Pinthus et al. (1973)	self	Brauer (1969)
Pisum sativum	Seed yield	+			Singh & Singh (1972)	self	Brauer (1969)
Phaseolus vulgaris	Seed yield	+			Hamblin (1975)	self	Brauer (1969)
Miscellaneous species							
Fagopyrum esculentum	Seed yield	+			Gorina (1971)	cross	Brauer (1969)
Sesamum indicum	Seed yield	+			Dabral & Holker (1971)	self	Brauer (1969)
Brassica campestris	Seed yield/plant	+			Ahmed & Zuberi (1973)	cross	Williams (1964)

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection			Author	Breeding System	Authority
		Positive	None	Negative			
<u>Miscellaneous species</u>							
Raphanus sativus	Progeny root yield	+			Kubka <u>et al</u>.(1973)	cross	Allard (1966)
Beta vulgaris	Root yield	+			MacLachlan (1972)	cross	Brauer (1969)
	Emergence	+			Harper <u>et al</u>(1974)		
	Root/shoot ratio	+					
Lycopersicum esculentum	Mature fruit yield	+			Halsey (1971)	self	Allard (1966)
Capsicum annuum	Seedling growth	+			Cochran (1973)	self	Allard (1966)
Gossypium hirsutum	Dry matter	+			El Zahab <u>et al</u>. (1974)	self	Allard (1966)
	Seed cotton yield		0				
Pinus radiata	Seedling height and weight	+			Griffin (1972)	cross	Brauer (1969)
<u>Tropical cereals</u>							
Sorghum vulgare	Seedling vigour	+			Abdullah & Vanderlip (1972)	self	Allard (1966)
	Grain yield		0				
Zea mays	Emergence, green weight	+			Gubbels (1974)	cross	Allard (1966)
	Days to 50% emergence, grain yield		0		Hunter & Kannenberg (1972)		

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection: Positive	None	Negative	Author	Breeding System	Authority
<u>Tropical Cereals</u>							
Zea mays	Individual plant yield	+			Sevov & Mitev (1974)	cross	Allard (1966)
Oryza sativa	Germination, early seedling development	+			Herrmann (1969)	self	Allard (1966)
<u>Temperate Cereals</u>							
Avena sativa	Seed yield	+			Frey & Wiggins (1956)	self	Allard (1966)
	Seed yield	+			Murphy & Frey (1962)		
	Seed yield	+			Bowman & Rothman (1967)		
	Seed yield	+ (curvilinear)			Frey & Huang (1969)		
Hordeum vulgare	Seed yield	+			Kaufman & McFadden (1960)	self	Allard (1966)
	Seed emergence		0		Dermirlicakmak & al (1963)		
	Seed yield	+			Dermirlicakmak & al (1963)		
	Tillering	+			Dermirlicakmak & al (1963)		
	Tillering	+			Kaufman & McFadden (1963)		

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection: Positive	None	Negative	Author	Breeding System	Authority
<u>Temperate Cereals</u>							
Hordeum vulgare	Seed yield	+			Rasmusson & Cannell (1970)	self	Allard (1966)
	Seed yield	+			Malhotra & Jain (1972)		
Triticum aestivum	Seed yield	+			Waldron (1941)	self	Allard (1966)
	Seed yield			-	Marchetti (1950)		
	Grain and straw yield	+			Fasoulas (1963)		
	Grain yield	+			Fonseca & Patterson (1968)		
	Yield/unit area	+			Borojevic & Cupina (1969)		
	Plant survival	+			Goydani & Singh (1971)		
	Germination	+			Goydani & Singh (1971)		
	Tillers/plant	+			Goydani & Singh (1971)		
	Seed yield	+			Knott & Talukdar (1971)		
	Root penetration	+			Karamalishoev (1972)		

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection Positive	None	Negative	Author	Breeding System	Authority
<u>Temperate Cereals</u>							
Triticum aestivum	Plot yield	+			Derera & Bhatt (1972,1973)	self	Allard (1966)
	Grains/ear	+			Derera & Bhatt (1972,1973)		
	Tiller number	+			Bhatt & Derera (1973)		
	Grain yield/plant	+			Bhatt & Derera (1973)		
	Individual plant yield (mixed stands)	+			Roy (1973)		
	Individual plant yield (pure stands)			-	Roy (1973)		
	Grain yield	+			Kikot (1973)		
	Grain yield	+			Randhawa & al (1972)		
	Number of seminal roots	+			Kir'yan (1974)		
	Number of seminal roots		0		MacKey (1974)		

TABLE 1. (Continued) Response to Increased Seed Size Selection in Various Economic Plants

Species	Character	Response to Increased Seed Size Selection Positive	None	Negative	Author	Breeding System	Authority
Temperate Cereals							
Secale cereale	Plot yield	+			Vageler (1927)	cross	Allard (1926)
	Seed size from harvested plots		0		Vageler (1927)		
Various Cereals							
Triticum aestivum and Avena sativa	Plot yield	+			Kiesselbach (1924)	self	Allard (1966)
Triticum aestivum, Avena sativa and Hordeum vulgare	Seed germination	+			Landenmark	self	Allard (1966)
Triticum aestivum and Hordeum vulgare	Seed viability in long storage	+			Loval'chuk (1973)	self	Allard (1966)
X Triticosecale	Field stand	+			Bishnoi & Sapra (1975)	$\pm$self	Yeung & Larter (1973)
	Grain yield	+			Bishnoi & Sapra (1975)		
	Seed yield	+			Kaltsikes (1974)		

such as soybeans (Glycine max Mer.) have shown wide variations within the species, with both positive and negative associations between seed size and seed yield for different genotypes (Fehr and Probst, 1971:Lal, Mehta and Nigam, 1973).

Investigations in the cereal crops have generally demonstrated increased seed yields when selection has been made for increased seed size. An exception has been the oat selection of Frey and Huang (1969), where a curvilinear response was obtained, with the highest yields being recorded for lines selected which have an intermediate seed size. All references to selection for seed size in wheat showed seed size to be positively correlated with seed yield and yield components with the exception of the work of Marchetti (1950) for size selection within one variety. The limited investigations in rye (Secale cereale L.) have not shown increased seed size from the progeny of large seed size selections (Vageler, 1926). The fact that rye is the only cross-pollinated cereal of the temperate small grains would in all probability decrease the efficiency of selection where only the female parent was selected, pollination being completely at random.

The investigations on triticale have indicated that seed weight is positively correlated with seed yield (Kaltsikes, 1974) and some advantages in yield in preliminary field experiments have been demonstrated for the selection of large seed sizes within segregating populations (Bishnoi and Sapra, 1975). The heritability of seed size within the specific triticale population and the genetic background of the triticale lines used in the specific cross would have an important effect on the advance obtained from seed size selection. From the results of previous investigators, it would appear that selection for large seed should improve seed yield in triticale, provided that modifications in technique are made to prevent uncontrolled outcrossing and provided sufficiently large populations are available so that a high degree of selection intensity can be applied.

MATERIALS AND METHODS

Visual seed size selection of F2 seed from crosses of lines differing in seed size and other characters

A preliminary investigation on selection at the F2 seed level was undertaken in order to determine if selection for seed size in segregating hexaploid triticale populations was an effective method of increasing grain yield. As only F3 and later generations were available from already existing segregating populations, in which the parental lines did not differ as much in seed size as desired, a series of crosses were made between lines with widely differing seed sizes and other characters.

The following lines were used as parents:

Line	Characters	Average 100 seed weight
6531	Large seed, excellent seed quality, tall straw	7.100 g
6A405	Large seed, fair seed quality, tall straw	5.995 "
ITSN73	Medium seed, good seed quality, medium height	4.820 "
6TA204*	Small seed, poor seed quality, dwarf	3.400 "
ITSN52	Small seed, fair seed quality, medium height	3.200 "

Crosses were made among all the selected lines, but many failed to produce any seed due to ergot infection and other causes. All F1 seed was harvested and each seed was planted in a four inch plastic pot. Each F1 plant provided 200-300 seeds for selection on the basis of seed size.

* All references to 6TA204 refer to the EMS dwarf mutant of this line.

In order to avoid any effects caused by seed shrivelling, only plump full seeds were selected. The 10 largest and 10 smallest seeds were then selected by visual means from the progeny of each F1 plant. This was also done for a number of different plants of the line 6531 which was used as an advanced line control.

To obtain the average weight of the large and small F2 seeds selected from each F1 plant, each selected lot of 10 large and 10 small seeds was weighed separately. The large and small selected seeds from each F1 plants were sown in plots consisting of paired 2.5 metre rows for the progeny of each F1 plant (Figure 1). This was a selection intensity of approximately 5% of the population for both the large and the small seed class. Data were recorded on germination and survival to harvest. Each plant surviving to harvest was pulled, tagged and recorded for agronomic characteristics which would give an estimate of fertility. All plants were individually threshed and their yield of grain was recorded.

A number of paired progeny rows were discarded due to the loss of all plants in a row. The remaining paired rows for F2 progeny and controls were analysed by the paired t-test.

<u>Mass selection for seed size in F3 and F4 material</u>

Because of positive indications from selection in the F2 and insufficient seed for yield trials at the F2 generation, a series of replicated yield trials were set up for mass selection over two cycles or generations of selection. Selection was made in the F3 and F4 generations in two segregating populations, with a similar two cycles of selection in three advanced lines serving as controls. The two

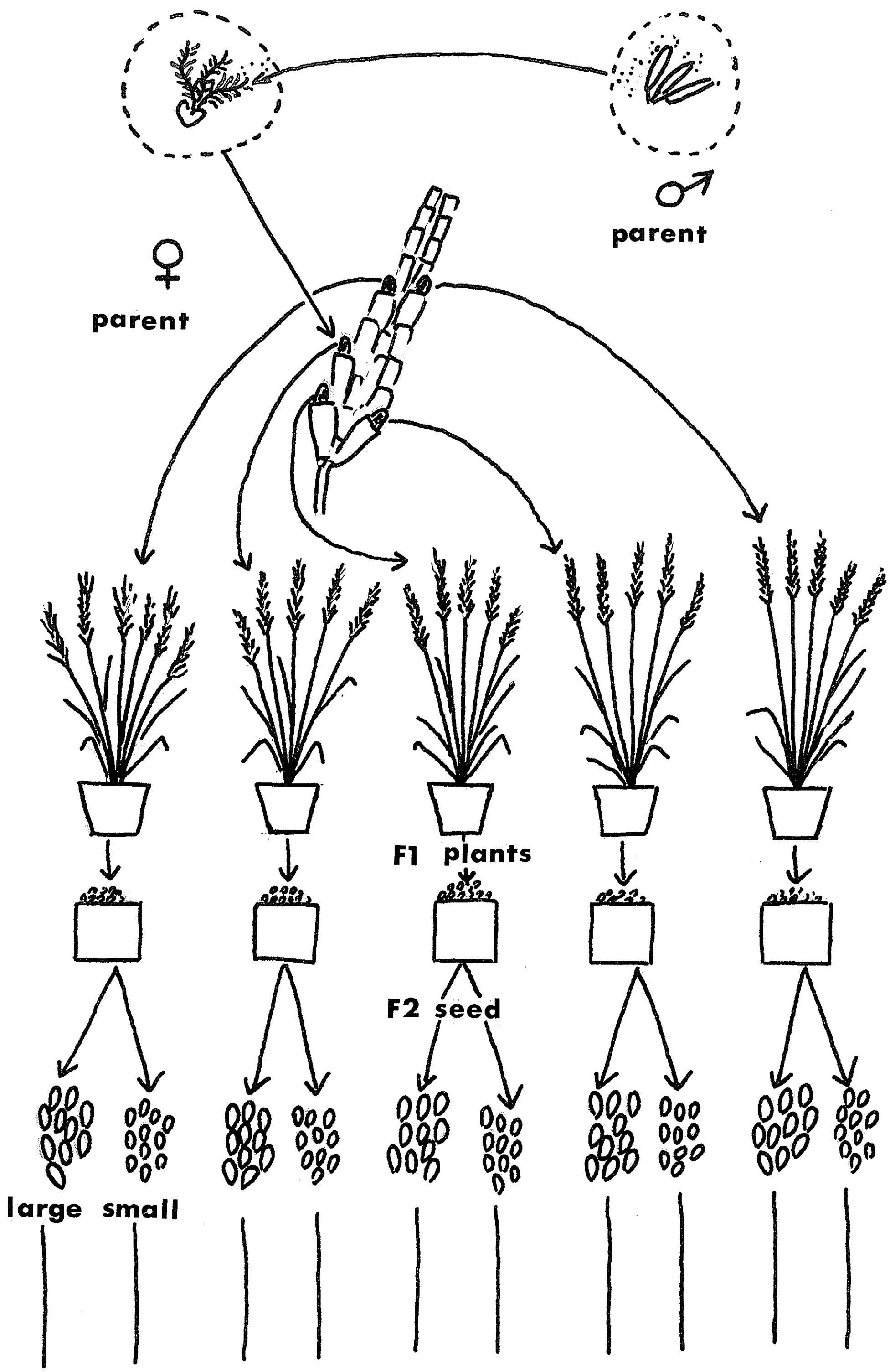


Figure 1. Experimental design: paired progeny rows of F2 plants

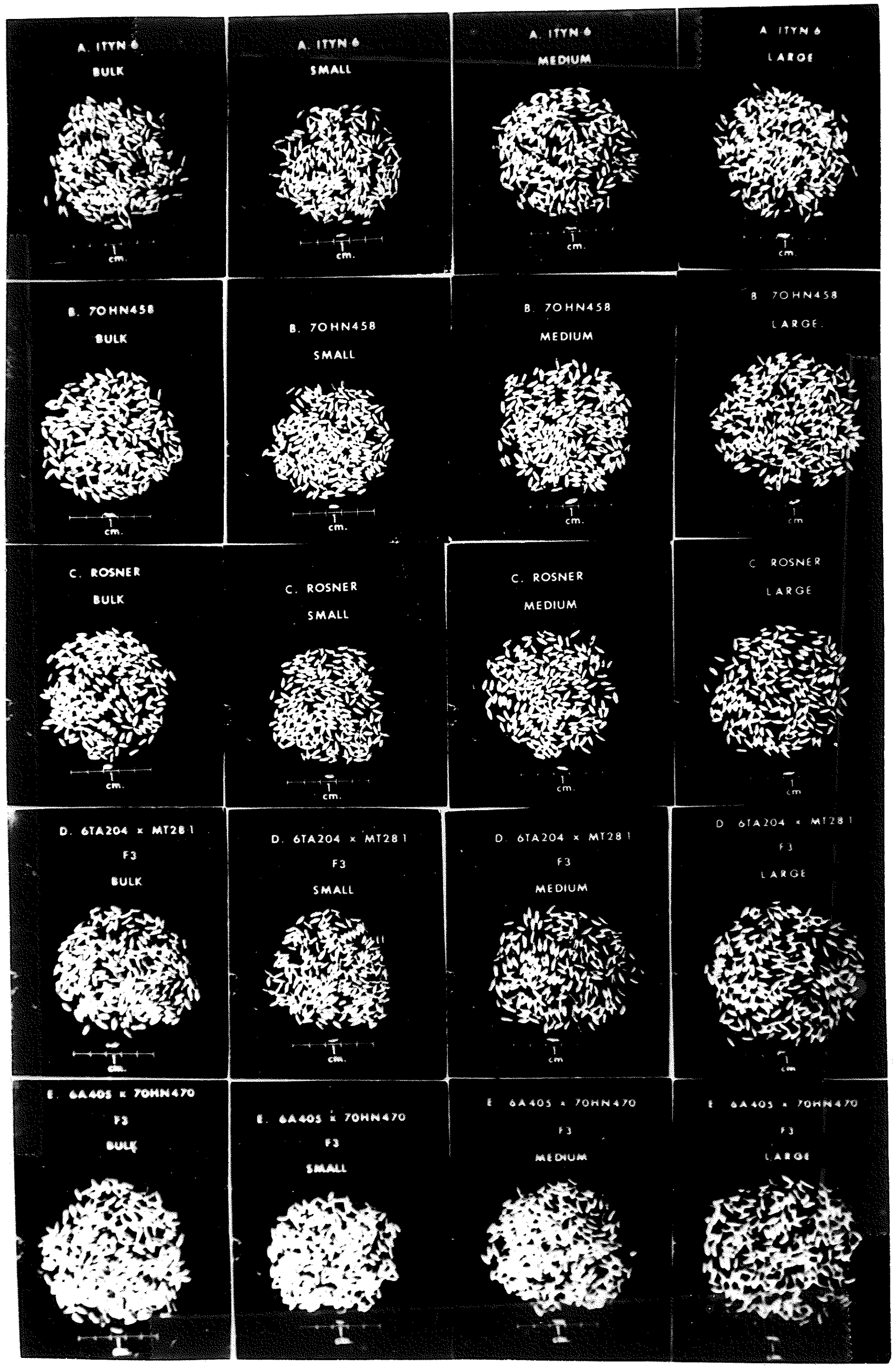


Plate I. Seed Size Selections in Three Advanced Lines and Two Segregating Populations.

segregating populations were chosen on the basis of sufficient seed availability for a four replicate trial at each of two locations and the fact that two of the parental lines had also been used in the production of crosses which had been selected at the F2 level. The advanced lines were selected on the basis of contrasting seed size and differences in other agronomic characteristics.

The selected material used was as follows:

Advanced lines

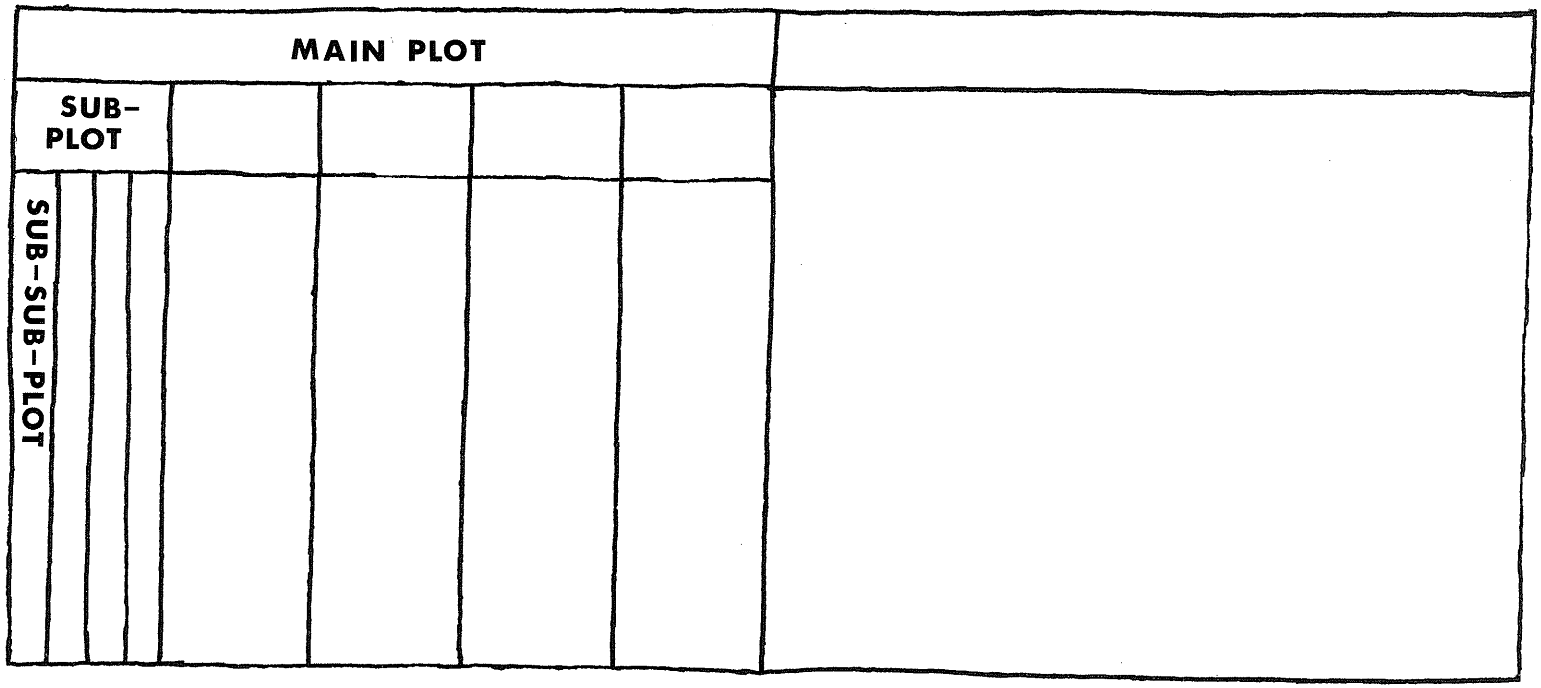
1. ITYN-6 (1972): small seeded line, wrinkled seeds
2. 70HN458 (Armadillo): medium sized seeds, good quality, short straw
3. Rosner: medium to large seeds, taller straw

Segregating populations (F3 and F4)

A.	6TA204 dwarf small shrivelled seed	X	MT28-1 medium height small to medium seed
B.	6A405 tall large seed	X	70HN470 short straw medium sized seed

Seed bulks of all populations and lines were separated by the use of standard seed sieves into portions of small, medium and large seed sizes. Large seeds were those retained by a 10/64 inch standard seed sieve. Medium seeds were all those which passed through the 10/64 inch sieve but were retained by a 9/64 inch sieve, while small seeds were classed as all those which passed through the 9/64 inch sieve. Unselected bulk seed was used as a control with all five groups (See Plate I for comparative seed sizes of all groups used). All this material which was selected from the original source of seed (F3 material in the case of the two segregating populations) was designated 'Cycle 1.' All material of the first cycle of selection was grown in a preliminary four replicate yield trial. From the material harvested from the preliminary yield trial, a further cycle of selection was carried out for each size in each of the five different groups- i.e. the harvested plots from large seed origin again subjected to selection for size and the large seeds retained and planted as the second cycle of selection. This second cycle of selection was designated 'Cycle 2' (F4 in the case of the segregating material). In the second year both cycles of selection were planted together in replicated yield trials at two locations (Figure 2).

The main section of this investigation consists of a series of four replicate yield trials in a split-split plot experimental design. The main plot consisted of the cycle of selection for a specified seed size (first or second cycle of selection). The sub-plot in all of this series of experiments consisted of the variety (advanced line or segregating population) and the sub-sub-plot of the selected seed size. All sub-plots were randomised within main plots and all sub-sub-plots were randomised within sub-plots. The basic unit (sub-sub-plot) consisted of a three row 5.5 metre plot adjusted by seeding rate (based on laboratory seed germination tests of all material for all sizes separately) to produce a theoretical number of 165 plants per plot, 55 plants per row with an average spacing of 10 cm between plants. The experimental design is illustrated in Figure 3. This design was used at two different locations: (1) University of Manitoba Point Field- a sheltered location on the University Fort Garry Campus located in a bend of the Red River which could be considered an optimum environment for cereal crops and (2) West Field- an open location about 4 km west of the University



Sub-plots randomized within main plots and sub-sub-plots randomized within sub-plots

Figure 2. Experimental design: split-split-plot

Main plots: 2 selection cycles or seed densities

Sub-plots: 5 varieties (3 advanced lines and 2 segregating populations)

Sub-sub-plots: 4 seed sizes

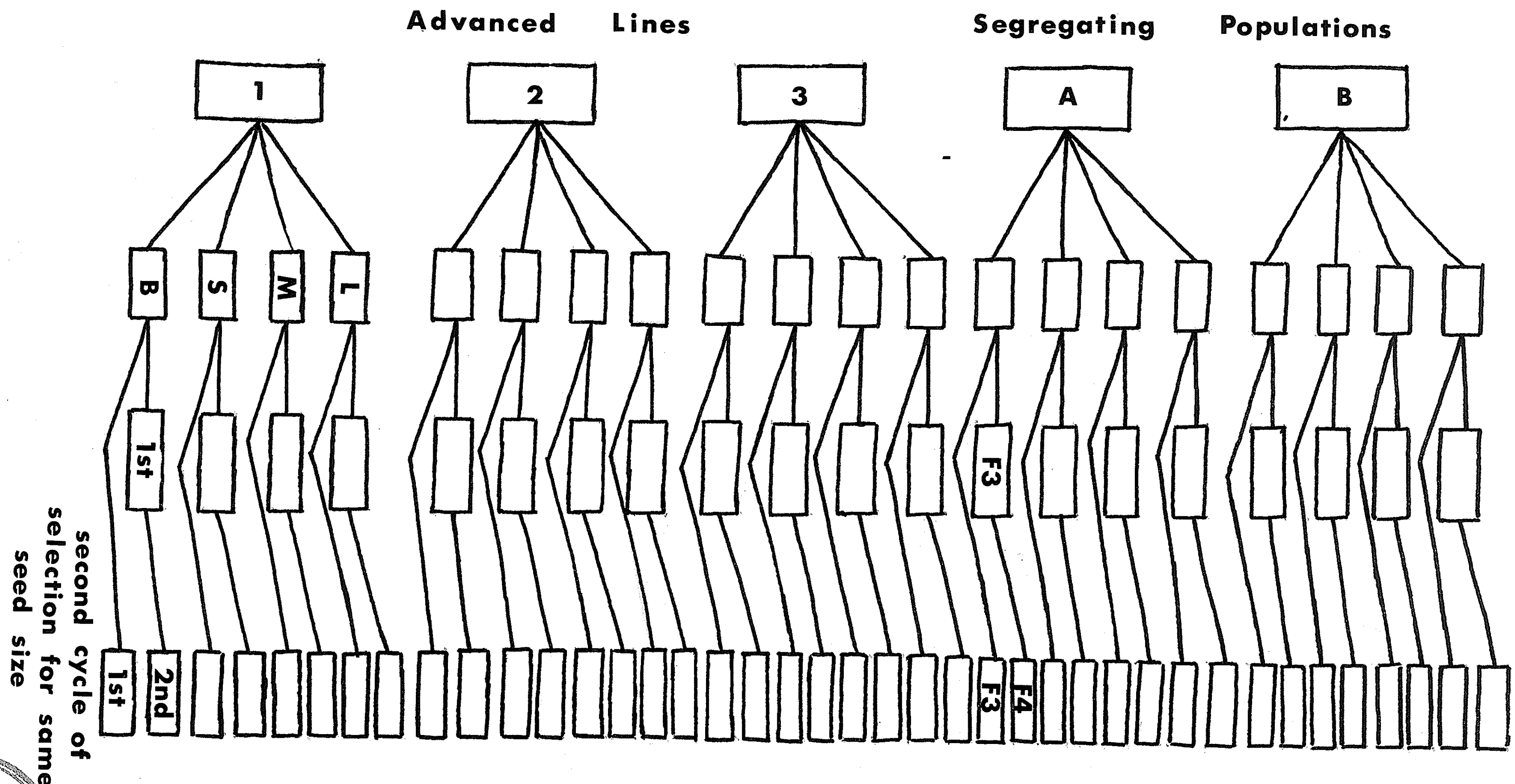


Figure 3. Experimental design. Two cycles of selection

Seed size: B = bulk S = small M = medium L = large which could be considered an average environment for cereal crops. Both locations were on heavy Red River clay soil.

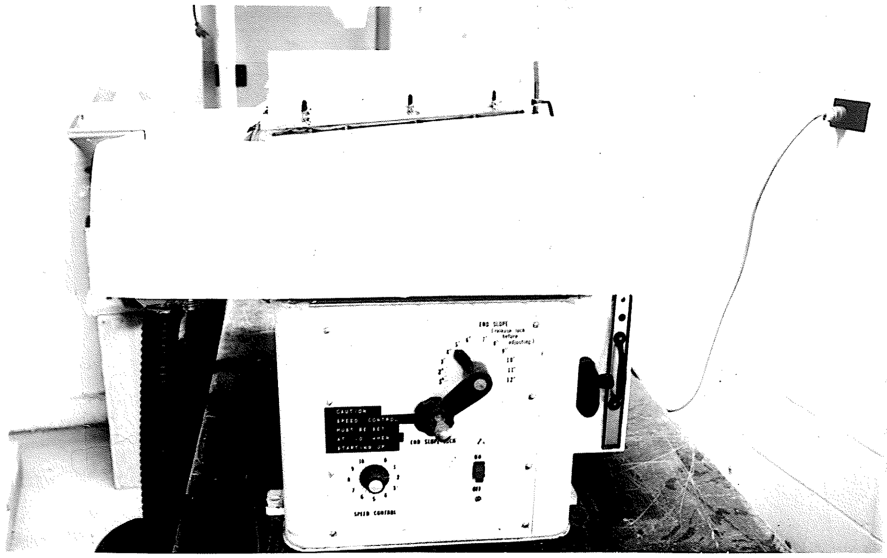
All plots were sown with a modified three-row John Deere horticultural plot type seeder. Seedling emergence was recorded for each plot. At harvest, the total number of plants growing in each plot was recorded. From each plot, 10 plants were selected at random and tagged to provide a random sample of individual plant yield and measurements of plant height and other agronomic characteristics (from which an estimate or indication of fertility could be determined) after the remaining plants had been harvested to provide the yield of grain per plot.

Seed separation on the basis of gravity

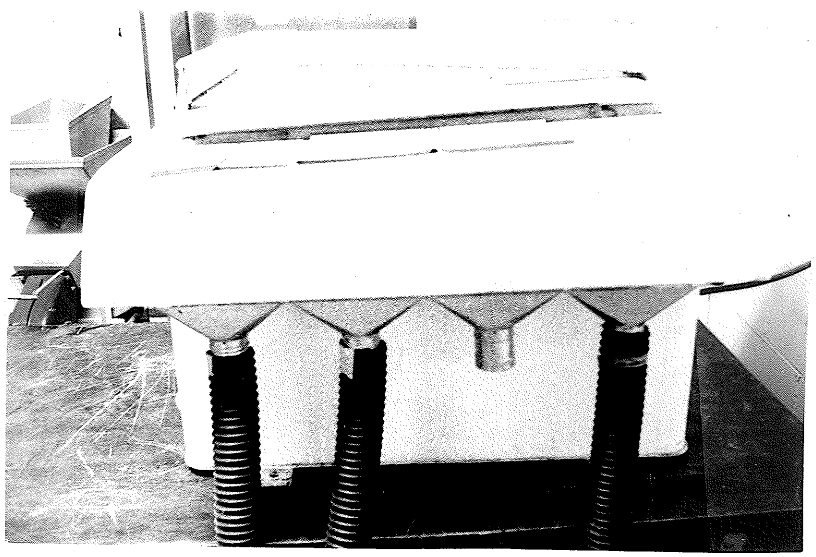
In order to obtain some estimate of the effects of specific gravity or density on the yield and other characters of plants grown from seeds of various sizes and origins, a "Kipp-Kelly" specific gravity separator, Model V-1358 (See Plate II), was used. The machine was adjusted so that approximately one half of a seed sample (unselected bulk of Rosner was used as a control) separated into a 'high density' fraction and half into a 'low density' fraction (machine setting was a speed of 3.5 on the speed setting, an air vent setting of 7.0 and an angle of elevation of 7).

All seed sizes of all the lines and populations (previously described in 'mass selection for seed size') were run over the specific gravity separator at the indicated setting for separation into 'high' and 'low' density fractions.

A four replicate yield trial with seed density as the main plot, variety or population as the sub-plot and seed size as the sub-sub-plot



a. Controls for Machine Speed, Elevation and Fan Speed



Light Fraction Heavy or Dense Fraction

b. Separation Table of Machine

Plate II. Specific Gravity Separator

was set up under similar conditions of germination testing and field conditions as the mechanical mass selection cycle experiment. The design is illustrated in Figure 4. Data recorded and analysis were similar to that of the previous experiment on two cycles of selection for seed size.

Relation of seed size, embryo size and plant development

Whether the relationship between seed size and yield is due to the initial size of the embryo or to the size of the nutrient reserves in the endosperm has been an important point of discussion (See Literature Review). In order to try to separate the effects of embryo size and endosperm size from different sized seed, an embryo culture experiment was set up to equalise the effect of nutrient reserves from seed of different size classes.

Seed from the three advanced lines and two segregating populations described earlier, which had been mechanically mass selected for small, medium and large seed sizes, was used. All seeds were uniformly soaked for five hours in sterile distilled water, disinfected and prepared for dissection in a sterile room under a "Wild" dissecting microscope. Prior to the actual dissection of each individual embryo, each seed was measured for length and width by means of a calibrated micrometer eyepiece on the dissecting microscope. Immediately on dissection, the length and width of each embryo and the length of the scutellum were also measured with the micrometer.

After dissection, each embryo was placed on a slanted surface of "Nitsch" orchid agar in a 100 ml screw cap vial (equal measured amounts of agar in each vial). Each vial with embryo was sealed and then incub-

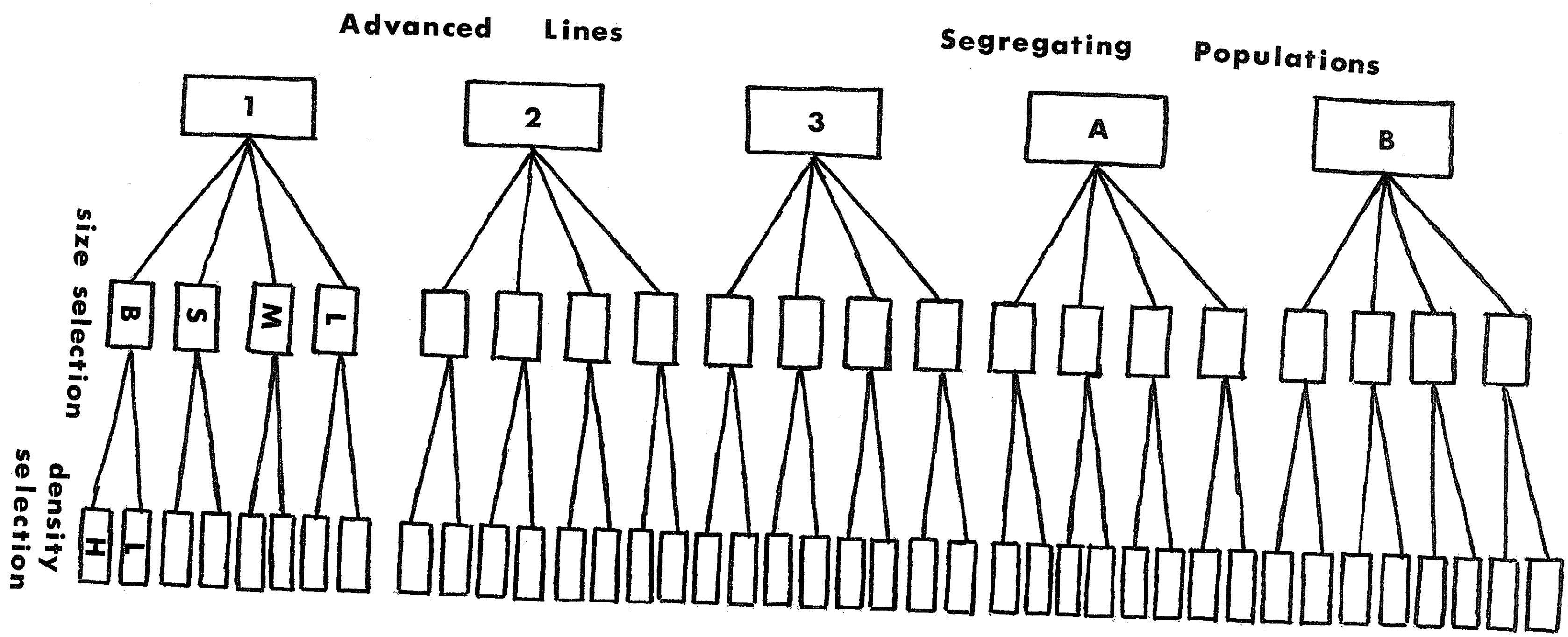


Figure 4. Selection for seed size at high and low seed density

Seed size: B = bulk S = small M = medium L = large

Seed density: H = high L = low

ated under a bank of three fluorescent tubes for 10 days with 24 hour per day lighting. Approximately 50 embryos were dissected from each size of each variety or population in order to obtain sufficient seedlings for further measurements of growth after any losses due to failure of growth or contamination.

After 10 days of growth on the nutrient agar media, all developing plants were removed from the vials, agar was washed off the roots and the numbers and measurements of shoots (leaves) and roots were recorded. All normally developed plants were then transplanted to a standard potting mixture of two parts loam, one part peat moss and one part sand in individually labelled four inch plastic pots. The transplanted seedlings were then grown in the greenhouse at approximately 20° C. with supplemental lighting to provide 16 hours of daylight.

All plants surviving were harvested at 13 weeks from the beginning of culture. Each plant was tagged and all soil washed from the roots. All tagged harvested plants were air dried for a period of 90 days at 20 C. Each plant was then separated into head, leaf, stem and root material and weighed. All mature plant part weights were then recorded for correlation with initial seed and embryo measurements.

RESULTS

Visual selection for seed size in F2 populations

Comparison of large and small F2 seeds

The grain yield and agronomic characteristics for plants originating from the 10 largest seeds (L) and the 10 smallest seeds (S) for progeny of each cross are presented in Table 2. The paired row t test for significance betweeen paired large and small seed rows from each progeny group is presented for each cross.

The F2 progeny of the cross 6531 X 6A405 showed higher values for plant survival and spikelets per spike for plants from large seeds. Average plant grain yield for plants from large seeds was 148% of that from small seeds while average plot yield for plants from large seed was 166.5% of that from small seeds. Plant height, tillers per plant, fertile tillers per plant and seeds per spike were higher for plants from small seed. Most values did not show statistical significance, with significant differences only shown for the superiority of the individual plant yields from plants originating from large seeds (P=0.05), although plot yield also approached a significant difference (P=0.063) in favour of plants from large seeds.

The F2 progeny of ITSN73 X 6TA204 exhibited higher values for plants grown from large seeds for all characteristics than for those grown from small seeds. The plants grown from large seeds were significantly higher for plant survival (P=0.05) and spikelets per spike (P=0.05)

TABLE 2. Agronomic Characteristics of Plants Grown from Large and Small F2 Seeds from a Number of Crosses

Cross	Number of Paired Progeny Rows	Seed Size	Average Seed Weight (g)	Plant Survival	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Plant Yield (g)	Plot Yield (g)
6531	6	L	0.0766	5.5	71.0	7.4	3.9	23.1	9.5	5.18	31.96
X		S	0.0490	4.7	71.6	8.1	4.2	21.9	12.5	3.50	19.19
6A405		t test		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.05	0.063
ITSN73	5	L	0.0584	5.8	66.1	12.3	5.2	22.7	22.3	5.58	32.58
X		S	0.0326	3.6	57.1	7.9	4.0	20.0	19.2	3.23	12.10
6TA204		t test		0.05	N.S.	N.S.	N.S.	0.05	N.S.	N.S.	0.07
ITSN52	4	L	0.0563	5.0	59.3	7.7	4.5	19.4	25.0	3.33	17.24
X		S	0.0333	3.8	51.8	4.1	2.1	17.5	26.4	2.00	7.33
6531		t test		N.S.	N.S.	0.05	0.05	N.S.	N.S.	0.05	0.05
6531	6	L	0.0598	7.0	77.2	12.5	9.7	21.2	32.7	11.74	85.15
X		S	0.0345	3.7	69.1	11.0	7.6	18.8	24.3	7.18	26.55
ITSN73		t test		0.05	N.S.	N.S.	N.S.	N.S.	0.05	0.05	0.01
Above	8	L	0.0604	7.0	74.8	12.2	9.2	21.0	31.9	10.72	77.20
with		S	0.0345	4.1	69.1	10.3	6.7	19.2	23.9	7.09	29.33
Reciprocals		t test		0.01	N.S.	N.S.	N.S.	N.S.	0.01	0.05	0.01
ITSN52	11	L	0.0495	6.2	61.5	14.9	10.6	21.2	29.5	9.80	58.35
X		S	0.0270	4.9	59.7	10.8	7.2	20.5	20.9	7.00	40.11
6TA204		t test		0.077	N.S.	0.01	0.01	N.S.	0.05	0.082	N.S.
6531	11	L	0.0668	4.1	92.9	14.3	11.2	23.4	50.9	17.97	75.89
(Selfs)		S	0.0352	4.9	94.6	16.4	12.7	23.3	51.6	19.89	105.29
		t test		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

and approached the 5% level for plot yield (P=0.07)

The F2 progeny of ITSN52 X 6531 had all characters higher for plants originating from large seeds, with significance shown for tillers per plant (P=0.05), fertile tillers per plant (P=0.05), average plant yield (P=0.05) and plot yield (P=0.05).

In F2 progeny of 6531 X ITSN73, plants from large seeds were higher for all characters, with significance shown for plant survival (P=0.05), seeds per spike (P=0.05), average plant yield (P=0.05) and plot yield (P=0.01). Average plant yield for plants originating from large seed was 163.5% of that of those from small seed, while plot yield for plants from large seed was 324.5% that of those from small seed. With the reciprocal cross included, values were higher from plants originating from large seeds for all characteristics, with statistical significant higher values shown for plant survival (P=0.01), seeds per spike (P=0.01), average plant yield (P=0.05) and average plant yield (P=0.01). Average plant yield from large seed origin plants was 140% of that from small seeds and plot yield was 263.2% for large seed origin plants over those from small seeds.

With F2 plants from ITSN52 X 6TA204 there were higher values for plants grown from large seeds for all characters, with significance shown for tillers per plant (P=0.01), fertile tillers per plant (P=0.01), and seeds per spike (P=0.05). Plant survival (P=0.077) and average plant yield (P=0.082) approached the 5% level of significance. Average plant yield for plants from large seed was 140% of that from small seed plants while average plot yield for large seed plants was 145.5% of that for small seed plants.

The progeny from different plants of line 6531 did not show any consistent trend. Plants from large seeds were below those from small seeds for all characters except spikelets per spike. However, none of these differences was significant or closely approached significant levels. Average plant yield for plants from large seeds was 90.3% of that from small seeds, while plot yield for plants from large seeds was 72% of that from small seeds.

Correlation of seed weight with agronomic characteristics

Correlations were run between the average seed weight for each plot (single row- large or small seed) and the agronomic characteristics of the plants grown from them (Table 3).

Seed weight in the F2 progeny of 6531 X 6A405 was not significantly correlated with any of the agronomic characteristics measured.

The F2 progeny of ITSN73 X 6TA204 showed significant correlations between seed weight and plant survival (P=0.01), tillers per plant (P=0.01), average plant yield (P=0.05) and plot yield (P=0.01).

For the F2 progeny from ITSN52 X 6531, there were significant correlations of seed weight with tillers per plant (P=0.01), fertile tillers per plant (P=0.01) and plot yield (P=0.05).

With F2 progeny of 6531 X ITSN73 there was significant correlation between seed weight and plant survival (P=0.01), spikelets per spike (P=0.05), seeds per spike (P=0.01), average plant yield (P=0.01) and plot yield (P=0.01). When combined with the reciprocal cross there were significant correlations between seed weight and plant survival (P=0.01), seeds per spike (P=0.01), plant yield (P=0.05) and plot yield (P=0.01)

The F2 progeny of ITSN52 X 6TA204 showed significant correlation

TABLE 3. Correlation Coefficients (x 100) of Average Initial Seed Weight with Various Agronomic Characteristics in F2 Plants of a Number of Different Crosses

Cross or Line	Number of Plots (Equal number of) Large and Small	Plant Survival	Plant Height (cm)	Tillers/Plant	Fertile Tillers/Plant	Spikelets/Spike	Seeds/Spike	Plant Yield (g)	Plot Yield (g)
6531 X 6A405	12	7	- 1	-19	- 5	55	-16	26	23
ITSN73 X 6TA204	10	71**	44	72**	39	51	17	59*	74**
ITSN52 X 6531	8	43	51	88**	93**	44	- 8	60	66
6531 X ITSN73	12	63**	49	33	40	57*	71**	72**	77**
6531 X ITSN73 and reciprocal	16	59**	36	34	40	49	64**	58*	68**
ITSN52 X 6TA204	22	30	18	58**	50*	27	39	36	26
6531 (selfs)	22	-21	-21	-38	-28	4	3	-10	-21

* significant at 0.05 level

** significant at 0.01 level

of seed weight with tillers per plant (P=0.01) and fertile tillers per plant (P=0.05).

The progeny of individual plants of line 6531 showed no significant correlation between seed weight and any of the selected agronomic characteristics. Correlation coefficients were lower than in any of the segregating populations for most characters and showed negative values for all characters except spikelets per spike and seeds per spike.

The effect of mass selection for seed size in three advanced lines and two segregating populations

Preliminary selection cycle

Advanced lines

Regarding plot yield of the small and large seeded selections, generally all three lines reacted in a similar manner (Table 4). Thus all small seeded selections showed a reduction in yield over the control, ITYN-6 and 70HN458 being significant at the 1% level, whereas all three lines had highly significant positive responses (P=0.01) in the large seeded selections. On the other hand, the medium selections indicated that the three lines responded differently. ITYN-6 had a non-significant negative value while 70HN458 and Rosner had positive values (P=0.01).

The number of plants per plot showed no differences among the small seeded selections and the controls. Medium selections showed no response in ITYN-6, while increases were shown for 70HN458 (P=0.05) and Rosner (P=0.01). Similar trends were demonstrated for large selections with no difference for ITYN-6 and increases for 70HN458 and Rosner (P=0.01).

Average plant height for small seed selections was reduced in ITYN-6 (P=0.01) and 70HN458 (P=0.05), with no difference in Rosner. In

TABLE 4. The Effect of Selection for Seed Size on Several Agronomic Characteristics in Three Advanced Lines of Hexaploid Triticale- Preliminary Selection- Point Field

Line and Size Comparison	Plot Yield (g)	Plants/ Plot	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
1. ITYN-6								
Bulk	661.0	93.5	88.95	8.93	7.30	17.6	50.4	9.16
S - B	- 69.0**	- 4.3	- 2.00**	-0.63	-0.80*	- 0.3	- 4.4**	-0.57
M - B	- 10.0	4.0	- 0.60	-0.83*	-1.13**	- 0.7**	- 3.1*	-1.07*
L - B	91.0**	2.3	- 0.06	0.13	-0.33	0.2	- 0.3	-0.56
2. 70HN458								
Bulk	601.0	89.8	86.75	8.90	7.18	17.5	46.3	8.46
S - B	- 72.3**	- 3.3	- 1.35*	-0.58	-0.53	0.5*	- 3.3**	-0.48
M - B	86.3**	5.3*	1.25*	-0.98*	-0.63*	0.5*	- 3.3**	-0.09
L - B	156.3**	13.3**	1.00	-0.58	-0.43	0.5*	1.2	0.21
3. Rosner								
Bulk	577.0	79.5	94.50	10.45	9.03	19.5	57.7	11.78
S - B	- 5.8	4.5	- 0.73	-0.95*	-0.98**	0.6*	- 2.6*	-2.38**
M - B	132.5**	11.3**	0.95*	-1.35**	-1.25**	1.0**	- 5.3**	-1.33**
L - B	93.0**	22.8**	- 1.60*	-0.70	-0.68*	- 0.6*	- 2.2	-1.29**
LSD (P=0.05)	34.2	4.6	1.25	0.77	0.62	0.4	2.5	0.91
LSD (P=0.01)	45.4	6.1	1.66	1.02	0.82	0.7	3.3	1.21

medium selections there was an increase for 70HN458 (P=0.05), with no significant change for the other two lines. There was a differing response in large selections, a decrease being present in Rosner (P=0.05), but no difference in the first two lines.

The number of tillers per plant in small seed selections did not change significantly in the first two lines while there was a decrease (P=0.05) in Rosner. A similar response was found in all three lines for medium seed selections, with decreases in ITYN-6 (P=0.05), 70HN458 (P=0.05) and Rosner (P=0.01). All three lines showed a similar response in the large seed selections, with no differences from the controls.

There were differences in response for the number of fertile tillers for small seed selections, with decreases being shown in ITYN-6 (P=0.05) and Rosner (P=0.01), but not in 70HN458. All lines showed a decrease for medium size selections, at the 1% level for ITYN-6 and Rosner, and at the 5% level for 70HN458. In the large seed selections, there was a similar trend in the first two lines, which showed no change, while there was a decrease (P=0.05) for Rosner.

Selection for small seed size increased (P=0.05) the number of spikelets per spike in both 70HN458 and Rosner, with no change for ITYN-6. Medium seed selections showed an increase for 70HN458 (P=0.05) and Rosner (P=0.01) and a decrease (P=0.01) for ITYN-6. Large seeded selections showed a contrasting response, with an increase for 70HN458 (P=0.05), a decrease for Rosner (P=0.05), and no significant difference for ITYN-6.

Small seed size selections demonstrated decreases from bulk controls in ITYN-6 (P=0.01), 70HN458 (P=0.01) and Rosner (P=0.05) for the number of seeds per primary spike. A similar trend was shown for the medium selections, with decreases in ITYN-6 (P=0.05), 70HN458 (P=0.01) and Rosner (P=0.01). There were no significant differences from unselected bulk controls for large seed selections in any of the three lines.

For the average yield of the 10 plants selected from each plot, selection for small seeds produced no significant difference from unselected bulks for ITYN-6 or 70HN458, while there was a decrease for Rosner (P=0.01). Medium seed size selections demonstrated decreases in both ITYN-6 (P=0.05) and Rosner (P=0.01), while there was no change for 70HN458. Large seed selections showed a similar trend for ITYN-6 and 70HN458, which did not show any significant differences, while Rosner had a decrease (P=0.05).

Segregating populations

For the first cycle of selection (Table 5), the two segregating F3 populations responded in a similar manner for average plot yields, with decreases for small (P=0.01) and medium (P=0.01) and an increase for large (P=0.05) seed selections.

The number of plants per plot showed a decrease (P=0.01) for both populations in the small seed selections but differed for medium size selections, with decreases (P=0.01) in population B (6A405 X 70HN458), but no significant difference for population A (6TA204 X MT28-1). Neither population demonstrated significant differences from the bulk seed for large seed selections.

Average plant height exhibited similar trends in both populations, with no difference in small seed selections and increases (P=0.01) for medium seed selections. There were increases in large seed selections for populations A (P=0.01) and B (P=0.05).

A differing response was shown for tillers per plant in small size selections, with increases (P=0.01) in A and no significant difference

TABLE 5. The Effect of Selection for Seed Size on Several Agronomic Characteristics in Two Segregating Populations (F3) of Hexaploid Triticale: Preliminary Selection- Point Field

Size Comparison Population	Plot Yield (g)	Plants/ Plot	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
A. 6TA204 X MT28-1								
Bulk	509.8	87.8	82.40	9.23	7.83	21.9	50.4	8.92
S - B	- 74.0**	- 8.8**	1.10	2.30**	1.35**	- 0.8**	- 2.0	3.07
M - B	- 50.3**	1.5	3.90**	1.65**	0.48	1.0**	- 5.3**	0.10
L - B	40.0*	- 2.3	2.98**	1.15**	1.00**	- 0.5	- 6.5**	0.81
B. 6A405 X 70HN470								
Bulk	348.5	89.8	80.78	10.50	8.90	19.9	29.6	6.83
S - B	-177.5**	-27.5**	0.03	0.48	0.30	- 0.5	4.1	-0.34
M - B	- 77.8**	-14.5**	2.60**	1.40**	0.63*	1.0**	3.2*	1.36**
L - B	34.5*	3.5	1.35*	1.63**	0.65*	- 1.5**	- 1.8	-0.42
LSD (P=0.05)	34.2	4.6	1.25	0.77	0.62	0.4	2.5	0.91
LSD (P=0.01)	45.4	6.1	1.66	1.02	0.82	0.7	3.3	1.21

in B. Both populations showed increases (P=0.01) for medium and large size selections.

Fertile tillers per plant differed for small seed selections, with increases (P=0.01) in A and no significant differences in B. Medium sizes demonstrated a different trend, with increases in B (P=0.05) and no significant difference in A. Both populations showed an increase for large seed selections, that for A (P=0.01) being greater than that for B (P=0.05).

Spikelets per spike showed similar trends for both populations, with decreases in A (P=0.01) and B (P=0.05) for small seed sizes. A similar increase (P=0.01) was shown for both populations for medium seed size selections. Decreases were demonstrated for both A (P=0.05) and B (P=0.01) for large seed size selections.

Seeds per spike showed opposite trends for the two populations. Small seed size selections demonstrated no difference for A and an increase (P=0.01) for B. Medium sizes exhibited a decrease (P=0.01) for A and an increase (P=0.05) for B. Large sizes demonstrated a decrease for A (P=0.01) and no significant difference from bulk controls in B.

Average plant yield for the selected plants showed differences between the two populations. Population A exhibited an increase (P=0.01) in small seed selections while there was no significant difference for B. Medium size selections demonstrated no difference for A and an increase (P=0.01) for B, while large seed selections showed no significant difference for either population.

Correlation of plot yields with agronomic characters

The advanced lines showed different trends with respect to the

TABLE 6. Correlation of Plot Yields with Agronomic Characteristics in Hexaploid Triticale- All Seed Sizes: Preliminary Cycle of Selection (Coefficients x 100)

		Advanced Lines		Segregating Populations	
	ITYN-6	70HN458	Rosner	6TA204 X MT28-1 F3	6A405 X 70HN470 F3
1. Plants/plot	15	74**	61**	67**	74**
2. Plant height (cm)	41	5	-26	16	-21
3. Tillers/plant	23	-11	-21	15	13
4. Fertile Tillers/plant	12	- 4	-15	10	-19
5. Spikelets/ Primary spike	39	15	4	-17	-58*
6. Seeds/ Primary spike	35	6	- 5	52*	-49*
7. Average Selected Plant yield (g)	39	14	- 3	15	-13

* significant at 0.05 level

** significant at 0.01 level

TABLE 7. Advanced Lines: Two Cycles of Selection- Point Field

Line and Size Comparison	Cycle	Plot Yield	Plants/ Plot	Seed Emergence	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
ITYN-6										
Bulk	1	571.0	104.8	118.3	67.05	5.63	4.95	17.3	32.5	5.07
	2	501.0	101.3	117.0	66.82	5.48	4.98	17.5	39.8	6.48
S - B	1	- 54.0**	- 0.3	0.8	0.03	0.15	0.08	0.4	5.1**	1.30**
	2	- 29.3	17.5	18.5	-0.10	0.43	0.10	0.6**	-5.3**	-0.63*
M - B	1	- 4.0	0.8	2.5	1.50*	0.13	0.10	0.7**	5.4**	1.09**
	2	- 50.0**	- 2.0	0.0	-1.32	-0.13	-0.13	0.3	-3.0*	-0.70
L - B	1	- 11.8	- 2.5	- 1.3	0.43	0.85**	0.65**	0.1	5.3**	1.57**
	2	77.5**	9.5*	8.5*	-0.02	0.13	-0.03	-0.3	-6.1**	-1.17**
70HN458										
Bulk	1	604.5	96.8	109.0	69.23	6.42	5.43	18.4	43.9	7.32
	2	576.8	99.5	115.3	67.73	6.23	5.50	18.2	40.9	7.21
S - B	1	- 34.5*	- 1.0	5.3	1.40*	-0.50	-0.18	-0.4	- 7.5**	-1.04**
	2	- 57.5**	- 4.3	- 3.8	-0.78	-1.08**	-1.03**	-0.4	- 0.7	-1.55**
M - B	1	68.8**	11.8**	19.3**	-0.10	-0.73**	-0.28	-0.5*	- 3.5*	-1.40**
	2	7.0	- 7.5	- 8.8*	0.83	-0.18	0.23	-0.6*	- 1.2	-0.32
L - B	1	116.5**	13.8**	17.5**	1.88**	0.23	0.58*	-0.5*	- 4.3**	-0.52
	2	114.0**	13.8**	14.5**	-0.58	-0.03	0.18	-0.6**	- 1.3	-1.01**
Rosner										
Bulk	1	694.0	104.2	121.3	69.73	6.58	6.13	19.3	50.0	8.00
	2	625.3	91.3	108.5	70.80	6.23	5.60	20.4	42.6	7.38
S - B	1	-192.0**	-11.0**	-14.5**	-0.30	-0.20	-0.20	0.1	- 0.9	-0.61*
	2	-175.0**	-18.0	-19.5**	-1.43	1.38**	1.28**	-1.4**	-4.6	1.76**
M - B	1	26.5	12.0**	9.0*	1.83*	0.83*	0.63**	0.9**	3.6**	1.34**
	2	103.5**	17.3**	16.5**	-0.70	-0.13	-0.05	-0.7**	-5.7**	-0.04
L - B	1	- 91.0**	3.0	- 1.5	2.13**	0.70**	0.25	0.3	-0.4	0.10
	2	76.0**	42.8**	43.0**	-0.48	-0.03	0.23	-0.7**	-5.4**	-0.11
LSD (P=0.05)		34.3	7.8	8.2	1.40	0.51	0.44	0.5	2.6	0.60
LSD (P=0.01)		45.4	10.4	10.8	1.86	0.66	0.59	0.6	3.5	0.79

for Rosner (P=0.01). Large seed selections again showed differing responses. For the first cycle there was no change for ITYN-6, an increase for 70HN458 (P=0.01), and a decrease for Rosner (P=0.01), while the second cycle showed increases for all three lines (P=0.01), with the greatest increase in 70HN458.

The number of plants per plot demonstrated similar trends with decreases in ITYN-6 and Rosner from the first to the second cycle for unselected bulks. Small seed selections showed a similar trend for ITYN-6 and 70HN458 for the first cycle, with no change from the bulk, Rosner exhibiting a significant decrease (P=0.01), while during the second cycle there was an increase for ITYN-6 (P=0.01), no change for 70HN458 and a decrease for Rosner (P=0.01). Medium seed selections demonstrated no change in the first cycle for ITYN-6 and an increase for 70HN458 (P=0.01) and Rosner (P=0.01), while the second cycle showed no change for ITYN-6 or 70HN458 and an increase for Rosner (P=0.01). Large seed selections produced no change in the first cycle for ITYN-6 or Rosner and an increase in 70HN458 (P=0.01), while the second cycle showed increases in ITYN-6 (P=0.05), 70HN458 (P=0.05) and Rosner (P=0.01). Seed emergence showed similar differences to those exhibited for final number of plants per plot.

Average plant height in small seed selections was not different from bulk selections in ITYN-6 or Rosner, but showed a decrease in 70HN458 (P=0.05) in the first cycle, while for the second cycle there was no change in the first two lines and a decrease in Rosner (P=0.05). Medium selections produced increases in the first cycle for ITYN-6 (P=0.05) and Rosner (P=0.05), while there was no effect in any line in the second cycle. Large selections demonstrated increases for 70HN458

(P=0.01) and Rosner (P=0.01) for the first cycle but no effect on any line for the second cycle.

Small seed selections in the first cycle produced a decrease in 70HN458 (P=0.05), while in the second cycle there was a decrease for 70HN458 (P=0.01) and an increase for Rosner (P=0.01) for the number of tillers per plant. Medium seed selections demonstrated a decrease in 70HN458 (P=0.01) and an increase in Rosner (P=0.05) for the first cycle and no significant change in the second cycle for any line. Large seed selections exhibited an increase for ITYN-6 (P=0.01) and Rosner (P=0.01) in the first cycle cycle and no change in the second cycle for any line.

Fertile tillers per plant in small seed selections were not different from bulk in the first cycle for any line while the second cycle produced a decrease in 70HN458 (P=0.01) and an increase in Rosner (P=0.01). Medium size seed selections did not show any differences for either cycle in ITYN-6 or 70HN458 but there was an increase in Rosner (P=0.01) in the first cycle. Large selections produced increases over bulk in ITYN-6 (P=0.01) and 70HN458 (P=0.05) for the first cycle but no differences for any of the lines in the second cycle.

Spikelets per spike in small seed selections showed no change in any of the three lines in the first cycle, an increase for ITYN-6 (P=0.01) and a decrease for Rosner (P=0.01) in the second cycle. Medium sized seed demonstrated increases for ITYN-6 (P=0.01) and Rosner (P=0.01) and a decrease for 70HN458 (P=0.05) in the first cycle, with decreases for 70HN458 (P=0.05) and Rosner (P=0.01) in the second cycle. Large seed selections demonstrated a decrease in 70HN458 (P=0.05) in the first cycle and for Rosner (P=0.01) in the second cycle.

Seeds per spike in small seed selections were higher than bulk (P=0.01) for ITYN-6 and lower (P=0.01) in 70HN458 in the first cycle of selection and were lower for ITYN-6 (P=0.01) and Rosner (P=0.01) in the second cycle. Medium selections produced increases in ITYN-6 (P=0.01) and Rosner (P=0.01) and a decrease in 70HN458 (P=0.05) for the first cycle and decreases for ITYN-6 (P=0.05) and Rosner (P=0.01) in the second cycle. Large selections showed an increase in ITYN-6 (P=0.01) and a decrease in 70HN458 (P=0.01) in the first selection cycle, with decreases for ITYN-6 (P=0.01) and Rosner (P=0.01) in the second cycle.

Average plant yield in small seed selections increased in the first cycle for ITYN-6 (P=0.01) and decreased in 70HN458 (P=0.01) and Rosner (P=0.05), while in the second cycle there were decreases in ITYN-6 (P=0.05) and 70HN458 (P=0.01) with an increase in Rosner (P=0.01). Medium seed sizes in the first cycle showed increases in ITYN-6 (P=0.01) and Rosner (P=0.01) and a decrease in 70HN458 (P=0.01), while there was a decrease in ITYN-6 (P=0.05) in the second cycle. Large size selections had an increased yield in ITYN-6 (P=0.01) in the first cycle, while the second cycle showed decreases in ITYN-6 (P=0.01) and 70HN458 (P=0.01).

Segregating populations at Point Field

Plot yields (Table 8) in bulk selections increased in cycle 2 over cycle 1 in population A (6TA204 X MT28-1) while there was no change in population B (6A405 X 70HN470). Small seed selections showed a decrease compared with bulks for both A and B (P=0.01) in the first cycle, while in the second cycle only A had a decrease (P=0.01). Medium seed selections in the first cycle were lower in B (P=0.01), but in the second cycle produced increases in both A and B (P=0.01). Large seed showed an increase for A (P=0.05) at the first cycle, but a decrease for B (P=0.01), while

TABLE 8. Segregating Populations: Two Cycles of Selection- Point Field Effect of Selection on Agronomic Characteristics

Line and Size Comparison	Cycle	Plot Yield (g)	Plants/ Plot	Seed Emergence	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
6TA204 X MT28-1										
Bulk	1	345.5	108.8	123.8	63.43	6.35	4.68	21.5	30.3	4.83
	2	422.5	110.8	126.5	60.75	6.53	4.85	20.2	28.5	5.35
S - B	1	- 49.8**	- 6.3	- 9.3*	-1.75*	-1.00**	-1.18**	-0.6**	-4.0**	-1.28**
	2	-110.8**	-23.0**	-23.5**	1.03	0.60*	0.08	0.8**	7.7**	0.89**
M - B	1	23.5	-13.5**	-13.8**	-0.70	1.28**	0.80**	0.0	-1.5	0.31
	2	62.0**	2.3	0.8	6.65**	0.13	0.30	1.5**	5.6**	-0.03
L - B	1	37.8*	6.0	7.5	-2.73**	-0.38	-1.15**	-1.3**	0.7	0.12
	2	- 34.3*	- 3.3	- 2.2	5.53**	0.23	0.05	2.6**	4.3**	-0.20
6A405 X 70HN470										
Bulk	1	363.3	121.0	138.5	63.40	5.80	4.38	20.1	28.5	4.33
	2	360.3	95.0	108.5	67.15	6.63	5.45	20.0	37.4	5.60
S - B	1	-100.3**	-22.0**	-24.5**	-4.55**	-0.23	-0.15	-1.6**	-1.8	0.39
	2	8.5	1.5	4.3	-5.43**	-0.65*	-0.60**	-0.4	-8.0**	-0.68*
M - B	1	- 79.5**	-11.5**	-12.5**	-1.63*	-0.15	-0.58*	0.2	5.9**	-1.13**
	2	42.0**	22.3**	23.3**	-3.08**	0.48	0.25	-0.4	-5.7**	0.13
L - B	1	- 49.0**	-13.5**	-14.3**	3.40**	1.50**	1.10**	0.3	0.9	-0.53
	2	28.0	21.0**	23.5**	-3.08**	-0.28	-0.90**	0.2	-4.5**	-0.19
LSD (P=0.05)		34.3	7.8	8.2	1.40	0.51	0.44	0.5	2.6	0.60
LSD (P=0.01)		45.4	10.4	10.8	1.86	0.66	0.59	0.6	3.5	0.79

at the second cycle there was an decrease for A (P=0.05), but no significant change for B.

Plants per plot and seed emergence demonstrated similar trends. Small seed selections at the first selection cycle produced only a slight decrease for A (P=0.05 for seed emergence, no significance for plants per plot) with a large decrease for B (P=0.01), while at the second cycle this was reversed with a large decrease for A (P=0.01) and no significant change for B. Medium selections showed a decrease for both populations (P=0.01) at the first cycle, while at the second cycle there was no change for A and an increase for B (P=0.01). Large seed selections produced no significant change for either cycle in A, while with B there was a decrease in the first cycle (P=0.01) and an increase (P=0.01) in the second.

Average plant height in unselected bulks decreased from the first to the second cycle in A and increased in B. In small seed size selections there was a decrease in height compared with bulks in the first cycle for both A (P=0.05) and B (P=0.01), while the second cycle produced no significant change in A but a decrease (P=0.01) in B. Medium selections did not change in A for the first cyle of selection and there was a decrease in B (P=0.05), while the second cycle showed an increase in A (P=0.01) and a decrease in B (P=0.01). Large seed selections demonstrated opposing trends for the two populations as the first cycle showed a decrease for A (P=0.01) and an increase for B (P=0.01), while the reverse occurred in the second cycle.

Tillers per plant in the small seed selections showed a decrease from bulk in A (P=0.01) but no change in B for the first cycle, while the

TABLE 9. Correlation Coefficients (x 100) of Plot Yields with Agronomic Characteristics- Point Field: Two Cycles of Selection All Seed Sizes Combined

	Advanced Lines						Segregating Populations			
	ITYN-6		70HN458		Rosner		6TA204 X MT28-1		6A405 X 70HN470	
Cycle of Selection	1	2	1	2	1	2	1 F3	2 F4	1 F3	2 F4
1. Plants/plot	57*	69**	83**	60**	60**	60**	52*	60**	50*	60**
2. Seed Emergence	52*	68**	81**	68**	65**	64**	55*	58*	42	58*
3. Plant Height (cm)	46	80**	65**	82**	49*	71**	27	19	10	43
4. Tillers/ Plant	6	32	66**	68**	47	-24	-11	0	15	32
5. Fertile Tillers/ Plant	9	43	72**	18	54*	3	- 2	26	8	24
6. Spikelets/ Primary Spike	41	54*	71**	37	-12	20	-38	- 4	- 8	52*
7. Seeds/ Primary Spike	23	10	44	16	66**	57**	23	11	- 6	18
8. Selected Plant Yield (g)	23	41	71**	28	72**	34	57*	33	- 8	51*

* significant at 0.05 level

** significant at 0.01 level

the first cycle of 70HN458 (P=0.01) and in the first cycle of Rosner (P=0.05) for fertile tillers only. Selected plant yield was significantly correlated with plot yield in the first cycle of 70HN458 (P=0.01) and Rosner (P=0.01).

There were fewer significant correlations between agronomic characters and plot yield in the two segregating populations. Plot yield was significantly correlated with numbers of plants per plot in the first cycle for both populations (P=0.05), and also in the second cycle for both populations (P=0.01). Seed emergence showed significant correlation with plot yield in both cycles in population A (P=0.05), and for only the second cycle for population B (P=0.05).

No other agronomic characters showed any significant correlation with yield with the exception of average plant yield for the first cycle in population A (P=0.05).

Effect of two cycles of selection

There was a general decrease in plot yield from the first cycle to the second cycle in the three advanced lines (Table 10), although this decline was not present in large seed selection for ITYN-6 and Rosner. The two segregating populations generally showed an increase for the second cycle (F4) over the first (F3). However, none of these differences showed significance for the level of cycle (main plot in the split-split-plot experimental design).

There was no consistent trend for agronomic characters. A significant increase in seed emergence and plants per plot was present for the second cycle of selection for large seed in Rosner (P=0.05). Plant height and seeds per spike generally decreased in the second cycle of

TABLE 10. Agronomic Characteristics in Hexaploid Triticale-Difference of Second Cycle over First Cycle of Selection-Advanced Lines: Point Field

Line and Size	Plot Yield (g)	Plants/ Plot	Seed Emergence	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
1. ITYN-6									
Bulk	- 70.0	- 3.5	- 1.3	-0.23	-0.15	0.03	0.2	7.2	1.41
Small	- 45.3	14.3	14.3	0.35	0.13	-0.05	0.4	-3.2	-0.53
Medium	-124.0	- 6.3	- 3.8	-3.05	-0.40	-0.20	-0.2	-1.2	-0.38
Large	19.3	8.5	8.5	-0.68	-0.88	-0.60	-0.2	-4.2	-1.32
2. 70HN458									
Bulk	- 27.8	2.8	6.3	-1.50	-2.85**	0.08	-0.2	-3.0	-0.12
Small	- 50.8	- 0.5	- 2.8	-0.88	0.78	-0.78	-0.2	3.8	-0.63
Medium	- 89.5	-16.5	-21.8	-0.58	0.35	0.58	-0.3	-0.8	0.96
Large	- 30.3	2.8	2.8	-3.95	-0.45	-0.33	-0.3	0.0	-0.61
3. Rosner									
Bulk	- 68.8	-13.0	-13.3	1.08	-0.35	-0.53	1.1	-7.4	-0.59
Small	- 51.8	-20.0	-20.0	-0.05	1.03	0.95	-0.4	-2.0	1.78
Medium	8.3	- 3.3	- 5.3	-1.45	-1.30	-1.20	-0.6	-5.3	-1.96
Large	98.3	32.8*	31.8*	-1.53	-1.08	-0.55	0.1	-1.6	-0.79
LSD (P=0.05)	214.4	26.9	28.6	5.87	1.84	1.79	1.5	9.7	3.00
LSD (P=0.01)	284.4	35.7	37.9	7.78	2.45	2.38	1.9	12.9	3.98

TABLE 10. (Continued) Agronomic Characteristics in Hexaploid Triticale- Difference of Second Cycle over First Cycle of Selection- Segregating Populations: Point Field

Population and Size	Plot Yield (g)	Plants/ Plot	Seed Emergence	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
A. 6TA204 X MT28-1									
Bulk	77.0	2.0	- 2.8	-2.68	0.18	0.18	-1.4	- 1.8	0.51
Small	16.0	-14.8	-11.5	0.10	1.78	1.43	0.0	10.1*	2.68
Medium	162.5	17.8	17.3	4.69	-0.98	-0.33	0.1	5.4	0.18
Large	5.0	- 7.3	- 7.0	5.58	0.78	1.38	2.5**	1.8	0.20
B. 6A405 X 70HN470									
Bulk	- 3.0	-26.0	-30.0*	3.75	0.83	1.08	-0.1	8.8	1.28
Small	105.8	- 2.5	- 1.3	2.85	0.40	0.63	1.2	2.6	0.22
Medium	118.5	7.8	5.8	2.30	1.45	1.90*	-0.7	9.1	2.54
Large	74.0	8.5	8.8	2.73	-0.95	-0.93	-0.2	5.3	0.56
LSD (P=0.05)	214.4	26.9	28.6	5.87	1.84	1.79	1.5	9.7	3.00
LSD (P=0.01)	284.4	35.7	37.9	7.78	2.45	2.38	1.9	12.9	3.98

selection for advanced lines and increased for the segregating populations. There was a significant decrease in the number of tillers per plant for the second cycle of the bulk of 70HN458 (P=0.01). There were increases in the number of fertile tillers per plant for the second cycle of selection for medium seed size in population B (P=0.05) and in the number of seeds per spike in the second cycle of selection for small seed size in A (P=0.05). The number of spikelets per spike was significantly larger in the second cycle of selection for large seeds in A (P=0.01)..

Advanced lines at West Field

Plot yields for small seed selections in the first cycle of selection (Table 11) were less than the bulks in ITYN-6 (P=0.01) and Rosner (P=0.01), while in the second cycle there was a greater decrease for ITYN-6 (P=0.01) and a decrease in 70HN458 (P=0.01), with no significant change in Rosner. Medium selections showed an increase for 70HN458 (P=0.01) and Rosner (P=0.01) in the first cycle, with increases in ITYN-6 (P=0.01) and Rosner (P=0.05) and a decrease for 70HN458 (P=0.05) for the second. Large seed size selections produced increases in 70HN458 (P=0.01) and Rosner (P=0.01) in the first cycle and for ITYN-6 (P=0.05) and Rosner (P=0.05) for the second.

Plots grown from unselected bulk seed showed increases in the number of seeds emerging and the final number of plants per plot from the first to the second selection cycle for ITYN-6 and Rosner, and a corresponding decrease in 70HN458. Plants per plot and seed emergence in small seed selections were higher in ITYN-6 (P=0.01) and lower in 70HN458 (P=0.01) in the first cycle of selection, while the reverse response was shown in the second cycle. Medium size seeds were higher

TABLE 11. Advanced Lines: Two Cycles of Selection- West Field
Effect of Selection on Agronomic Characteristics

Line and Size Comparison	Cycle	Plot Yield (g)	Plants/ Plot	Seed Emergence	Plant Height (cm)	Tillers/ Plant	Fertile Tillers/ Plant	Spikelets/ Spike	Seeds/ Spike	Selected Plant Yield (g)
ITYN-6										
Bulk	1	511.3	100.3	110.3	67.45	7.60	6.73	17.3	33.6	6.76
	2	508.3	109.3	119.3	63.70	6.15	5.40	16.8	31.1	5.16
S - B	1	- 50.8**	8.3**	8.3**	-1.23	-1.10**	-0.98	0.0	-0.7	-1.16**
	2	-147.5**	-13.0**	-13.0**	0.65	0.43*	0.13	0.1	1.2	0.17
M - B	1	3.5	7.8**	7.8**	-3.76**	-0.98**	-1.00**	0.3	0.2	-1.16**
	2	93.8**	- 1.3	- 1.3	1.38	1.08**	0.60**	0.8**	2.7**	0.82**
L - B	1	- 12.5	3.3	3.3	-2.73**	-0.93**	-0.88**	-0.1	1.0	-0.59**
	2	81.0*	2.3	2.3	2.20**	0.28	0.10	0.2	1.1	0.36
70HN458										
Bulk	1	497.5	113.8	123.8	63.03	6.60	5.60	17.6	36.5	6.19
	2	526.0	91.0	101.0	63.55	6.45	5.73	17.1	34.9	5.92
S - B	1	- 29.3	- 12.3**	- 12.3**	-0.88	-0.20	-0.10	-0.4**	-0.6	-0.49*
	2	- 86.0**	11.5**	11.5**	-1.48*	-0.23	-0.38*	0.1	-0.3	-0.39
M - B	1	86.0**	6.3*	6.3*	1.00	-0.28	-0.35*	0.0	0.2	-0.40
	2	- 39.3*	3.8	3.8	0.23	-0.33	-0.33*	0.2	1.6*	0.09
L - B	1	110.8**	- 2.3	- 2.3	1.33	-0.83**	-0.33*	-0.3*	-1.3	-0.60**
	2	21.8	18.0**	18.0**	-0.50	0.08	-0.08	0.9**	1.7*	0.18
Rosner										
Bulk	1	506.0	97.5	107.5	74.58	7.28	7.00	19.1	39.4	6.87
	2	535.3	111.5	121.5	74.83	7.05	6.73	19.4	39.8	6.20
S - B	1	- 81.0**	- 2.3	- 2.3	1.13	0.15	0.13	-0.2	1.0	0.22
	2	- 19.3	- 1.5	- 1.5	3.38**	0.48	0.63**	-0.1	2.2**	1.89**
M - B	1	72.3**	11.8**	11.8**	1.63*	-0.60**	-0.35*	0.3*	2.9**	0.19
	2	36.6*	- 0.5	- 0.5	4.78**	0.20	0.48**	0.2	1.3	1.28**
L - B	1	150.0**	15.5**	15.5**	3.75**	-0.48**	-0.25	0.1	1.4	0.25
	2	41.8*	0.5	0.5	1.53*	0.80**	0.70**	0.1	-0.1	1.32**
LSD (P=0.05)		36.6	4.8	4.9	1.44	0.34	0.31	0.3	1.5	0.43
LSD (P=0.01)		48.6	6.4	6.5	1.91	0.45	0.41	0.4	2.0	0.56

at the first cycle for ITYN-6 (P=0.01), 70HN458 (P=0.05) and Rosner (P=0.01), while none of the lines were significantly different from the bulks at the second cycle. Large size selections did not differ from the bulks for either cycle in ITYN-6, but were higher only in the second cycle for 70HN458 (P=0.01) and in the first cycle for Rosner (P=0.01).

Average plant height for small seed selections showed no significant differences from the bulks for any of the three lines in the first cycle, while in the second cycle there was a decrease in 70HN458 (P=0.05) and an increase in Rosner (P=0.01). Medium selections had a decrease in ITYN-6 (P=0.01) and an increase for Rosner (P=0.05) in the first cycle, while in the second cycle the only change was an increase for Rosner (P=0.01). For large seed selections in the first cycle there was a decrease in ITYN-6 (P=0.01) and an increase for Rosner (P=0.01), while in the second cycle there was an increase in ITYN-6 (P=0.01) and Rosner (P=0.05).

There was a decrease in the number of tillers per plant for bulks in the second cycle of selection as compared with the first for ITYN-6. Tillers per plant in small seed selections at the first cycle only showed a change in ITYN-6, being lower (P=0.01) than bulks, while at the second cycle there were increases in ITYN-6 (P=0.05) and Rosner (P=0.01). Medium selections showed decreases for ITYN-6 (P=0.01) and Rosner (P=0.01) in the first cycle, while there was an increase for ITYN-6 (P=0.01) in the second cycle. With large seed selections there was a decrease in all three lines (P=0.01) at the first cycle, while the only change at the second cycle was an increase in Rosner (P=0.01).

There was a decrease in the number of fertile tillers per plant in bulks of ITYN-6 from the first to second cycle, with little change in the other two lines. Fertile tillers per plant in small seed selections were lower for ITYN-6 (P=0.01) at the first cycle, and higher for Rosner (P=0.01) and lower for 70HN458 (P=0.05) at the second cycle. Medium selections were lower at the first cycle for ITYN-6 (P=0.01), 70HN458 (P=0.05) and Rosner (P=0.05), while at the second cycle there were increases in ITYN-6 (P=0.01) and Rosner (P=0.05) and decreases in 70HN458 (P=0.05). Large seed sizes showed decreases in ITYN-6 (P=0.01) and 70HN458 (P=0.05) at the first cycle, while at the second cycle there was an increase for Rosner (P=0.01).

Spikelets per spike in small seed selections at the first cycle were lower in 70HN458 (P=0.01), while none of the lines showed any change from the bulks at the second cycle. Medium seed selections demonstrated an increase for Rosner (P=0.05) in the first cycle and for ITYN-6 (P=0.01) at the second cycle. Large selections showed a decrease for 70HN458 (P=0.05) in the first cycle and an increase (P=0.01) in the second cycle.

Seeds per spike in small selections only showed a change for Rosner, where there was an increase (P=0.01) in the second cycle. In medium seed size selections, there was an increase for Rosner (P=0.01) in the first cycle and for ITYN-6 (P=0.01) and 70HN458 (P=0.05) in the second cycle. Large seed sizes only demonstrated change in 70HN458, with an increase (P=0.05) in the second cycle.

Average plant yield in bulk selections decreased greatly from the first to the second cycle in ITYN-6, with small decreases in the other two lines. Small size selections demonstrated decreases for ITYN-6 (P=0.01) and 70HN458 (P=0.05) in the first cycle and an increase for Rosner (P=0.01) in the second cycle. Medium size selections were lower in the first cycle for ITYN-6 (P=0.01) and greater in the second cycle for ITYN-6 (P=0.01) and Rosner (P=0.01). Large seed size selections showed decreases in the first cycle for ITYN-6 (P=0.01) and 70HN458 (P=0.01) and an increase in the second cycle for Rosner (P=0.01).

Segregating populations at West Field

Plot yield in bulk selections (Table 12) showed little change over the two cycles in A, but an increase in the second cycle for B. Small seed selections demonstrated a decrease for both A (P=0.01) and B (P=0.05) in the first cycle, but increases for both A (P=0.01) and B (P=0.05) in the second cycle. The medium seed size selections of A showed a decrease in the first selection cycle (P=0.05) and no significant change in the second, while those of B demonstrated a large increase over the bulks (P=0.01) in both cycles. Large seed sizes showed a decrease in the second cycle for A (P=0.05) and no change from the bulks in either cycle for B.

The bulk seeds showed increases in the number of seeds emerging and the number of plants per plot for the second cycle over the first in A, while there was a decrease in B. Small seed size selections demonstrated significant decreases for both populations (P=0.01) at both cycles of selection. Medium selections did not change for A but in B decreased in the first cycle (P=0.05) and increased in the second cycle (P=0.01). Large selections showed opposing trends, with increases for A (P=0.01) and decreases for B (P=0.01) in the first cycle and an increase for B in the second cycle (P=0.01).

Average plant height in bulks of both populations increases from the first to the second cycle. Small seed selections showed decreases