BASIS FOR SEED DENSITY AND SIZE DIFFERENCES OF PEARL MILLET [PENNISETUM AMERICANUM (L.) LEEKE]

by

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TO

THE MEMORY OF

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INTRODUCTION

Pearl millet (*Pennisetum americanum* (L.) Leeke) is consumed by millions of people in the semi-arid parts of Africa and Asia. It is the most widely grown of the millets but has received little attention compared to other agronomic crops. Garg, et al. (1973) and Mwageni (1978) reported that pearl millet has problems of poor seed vigor, and establishment.

Research has shown that seed density and size are positively related to stand establishment (Gardner, 1980). Schmidt (1921) found that heavy seeds germinated more rapidly than light seeds and that seedling emergence and growth were highly correlated with seed density. Lowe, et al. (1972) found that seedlings from large seeds grew faster, produced more tillers per plant and resulted in higher yields than those from small seeds.

The objectives of this study were to:

1. Confirm results of previous studies relative to the effects of seed size and seed density on establishment.
2. Determine effects of the seed density x size interaction on field establishment.
3. Explore the basis for seed density and seed size effects on establishment by attempting to relate density and size differences to variations in seed shape, seed color, seedling respiration, protein

content, seed starch appearance, relative embryo size, and other seed characteristics.

LITERATURE REVIEW

Seed Size

Lowe, et al. (1972) reported that seed size is a factor in seedling establishment and grain yield of wheat. Seedlings from large seeds grew faster, produced more tillers per plant, and produced higher yield than those from small seeds. Kaufmann and Guitard (1967) noted positive relationships among seed size, seedling vigor, and mature plant yield of two barley (*Hordeum vulgare* L.) cultivars. Lowe and Ries (1972 and 1973), Lowe, et al. (1972), and Ries and Everson (1973) observed that seedling vigor and final yield in wheat (*Triticum aestivum* L.) was associated with seed size and seed protein content. Muchena and Grogan (1977) reported that larger seeds of corn (*Zea mays* L.) have larger embryos and have the advantage of germinating earlier. Kiesselbach (1924), Kneebone and Cremer (1955), and Kauffman and Guitard (1967) noted that large seed of barley, small grain crops, and native grass species have more carbohydrate reserve for nourishment of the young plants than has small seed. Abdullahi and Vanderlip (1972) noted that germination and field establishment in sorghum (*Sorghum bicolor* L. Moench.) were related to seed size and source. Demirlicakmak, et al. (1963) noted that there was a positive correlation between seed size or seed weight and grain yield of barley.

Erickson (1946) found that seedling emergence from small alfalfa (Medicago sativa L.) seed was less than that from large seed. Moore (1943) noted that percent emergence of crimson clover (Trifolium incarnatum L.) seedlings from intermediate-sized seed was higher than that from the largest seed as well as that from the smallest seed. Black (1956) reported that germination percentage of subterranean clover (Trifolium subterraneum L.) was uniform among different seed-sized groups but that early growth was proportional to seed size because of the stored reserves in the seed. Beveridge and Wilsie (1959) observed that seeding large seed of alfalfa did not produce a greater number of plants than seeding average-sized seed but that greater seedling vigor resulted from the large seeds. Smith and Camper (1975) reported that large soybean (Glycine max) seeds produced plants that were taller at early stages of growth. Gardner (1980) reported that small seeds of pearl millet were not only low in emergence but also produced mature plants with lower grain yields and head numbers.

Kneebone and Cremer (1955) noted that seedlings from large seeds of buffalograss (Buchloe dactyloides Engelm), indiangrass (Sorghastrum nutans (L.) Nash), sand bluestem (Andropogon hallii Hack), sideoates grama (Bouteloua curtipendula (Michx.) Torro), and switchgrass (Panicum virgatum L.) had more rapid emergence and faster growth than seedlings from small seeds. In switchgrass germination percentage was 77.5 for large seed and 27.5 for small seeds. Zavitz (1908) reported that plants from large seeds of rape (Brassica napus var.) outyielded plants from small seeds by 40 percent.

Seed Density and Weight

Gardner (1980) reported that low density seeds of pearl millet were low in seedling vigor. Sung and Delouche (1962) observed that emergence percent, germination rate, and germination percent were related to seed density in rice (*Oryza sativa* L.) seed. Oelke, et al. (1969) also concluded that larger and more vigorous seedlings resulted from high-density rice seeds. Finfrock (1959) concluded that seed density of rice should be considered as a criterion of seed quality and germination. Whitcomb (1936), Oexemann (1942), Rogler (1954), Switzer (1958), and Slobodyanik (1961) observed a close relationship between seed density and seed quality in various kinds of seed. Eugenio (1970) reported that rice seeds with high density had a higher germination than those of low density and that low-density seeds produced seedlings with shorter roots. Tseng and Lin (1962) reported that high-density rice seeds produced more vigorous seedlings and higher yields. Inouye and Ito (1969) reported a close correlation between seed weight and plumule elongation in rice. Garg, et al. (1973) reported that pearl millet seed weight showed a significant and negative correlation with size and relative density. Thomas (1966) reported that tiller number at the sixth-leaf stage was positively correlated with seed weight of *Lolium perenne*.

Schmidt (1921) working with crimson clover, found that 86.6 percent of heavy seed germinated while only 53.3 percent of light seed germinated. He noted also that the heavy seeds germinated more rapidly than the light seeds. Beverige and Wilsie (1959) reported that alfalfa seed of high specific gravity had higher germination because of the chemical composition and morphology of the seed. They reported that loss of food reserves during respiration lowered the specific gravity of the seed without necessarily reducing seed size. Smith and Werker (1968), in a breeding study, noted that high seed density of soybean was associated with high protein content. Vaughan (1960, 1962) and Vaughan and Delouche (1968) reported that high-density seeds of red (*Trifolium pratense* L.), white (*T. repens* L.), and crimson clover (*T. incarnatum* L.) gave good germination. Cummings (1914), Schmidt (1921), and Fikry (1936) reported that high density seeds of crimson clover, wheat and radish (*Raphanus sativus Linn*) produced plants superior in dry weight, number of fruit, and yield. Allen and Donnelly (1965) noted that seedling vigor and dry matter yield of *Vicia* were greater in lines having heavier seeds.

Clark (1904) noted that grape (*Vitis vinifera*, Linn) seeds of high specific gravity maintained viability longer and that those of intermediate and high specific gravity had higher germination than seeds of low specific gravity. Bartee and Kreig (1974) noted that seeds high in density have more organic and inorganic materials available to the seedlings regardless of seed size. They found also that, in cultivars of upland cotton, proportion of the total seed weight attributable to the embryo increased from 50 percent to 65 percent as seed density increased. Tupper, et al. (1970) reported that seed density and seed weight were related to rate of germination in cotton seed. Pawlowski (1963) reported that seed density of safflower (Carthamus tinctorius L.) was highly correlated with oil content. Wilkes (1969) reported that high-density seeds of cotton gave higher field emergence and higher yields in the field. Muhtarov (1962) reported that high-density, acid-delinted cotton seeds had a higher germination percent and produced thicker stands and higher yields than the medium- and low-density seeds. MacDonald, et al. (1939) reported that heavy acid-delinted cotton seed produced plants which were higher in green weight and produced 19 percent more seed cotton than light seeds.

Seed Color

Athwal (1966) reported five pearl millet seed stocks with colors of purple, deep yellow, peachy amber, deep slate, and light slate. They noted the presence of white and brown seed types and the dominance of yellow to bluish green.

Eastman (1912) observed that differences in color of clover (*Trifolium* sp.) seed resulted from differences in maturity. Stewart and Carlson (1932) found that darker colored seed of alfalfa germinated more poorly than the lighter colored seed and that speed of germination of light green and light brown seed was more rapid than that of dark brown seed. Menke and Hillenmeyer (1888) reported that yellow seeds of clover germinated better and produced more vigorous seedlings than red seeds. Smith (1940) reported that, in clover, germination was higher with yellow than with purple seed.

Seed Protein

Ries and Everson (1973) reported that wheat seeds of high protein content produced vigorous seedlings. Lowe and Ries (1972, 1973) indicated that seed proteins of wheat may be a factor in seedling vigor. Seedlings grown from high-protein seeds were shown to be more advanced in morphological development than those from low-protein seeds. Lowe, et al. (1972) reported a positive relationship between seed-protein content and seedling growth and yield of wheat. Ries, et al. (1976) reported that protein content of winter wheat was related to seedling vigor. Gori (1979) noted that proteins and lipids were the main storage substances in the endosperm of *Pinus pinea* L.

Respiration

Copeland (1976) reported that heavy or high-density seeds produced vigorous seedlings due to a higher respiratory rate and a greater amount of energy (ATP) production. Woodstock and Grabe (1967) found a positive relationship between respiration rate of corn seed during the first 24 hours of germination and growth of the corn seedlings at 2 to 3 days. They reported that seedling growth and development were affected by the amount of reserves in the seed, the way they are mobilized, and the efficiency of metabolism. Woodstock (1966) observed that high germination in corn seeds did not mean that they were high in vigor. One seed lot with 91 percent germination was found to be low in seedling vigor in terms of field establishment.

Linko (1961) reported that glutamic acid decarboxylase activity (GADA) was related to seed germination, respiration, and seedling growth in wheat. He concluded that increased respiration in vigorous seeds was the result of metabolic changes which were associated with germination. Throneberry and Smith (1955) observed that activities of malic and alcohol dehydrogenases and cytochrome oxidase were highly correlated with germination percent of corn. Woodstock and Grabe (1967) also found that glutamic acid decarboxylase activity was positively correlated with seed germination and seedling growth of corn. Woodstock and Feeley (1965) reported that respiration in germinating corn seeds might indicate seed vigor. When different kinds of seeds such as corn (Woodstock and Grabe, 1967) sorghum, radish, and wheat (Woodstock and Justice, 1967) were subjected to various types of injury, differences in vigor were related to differences in respiration during the initial six hours of germination. These workers concluded that seeds which were high in vigor had high respiration rates, those intermediate in vigor had intermediate respiration rates, and seeds low in vigor had low respiration rates. Sittisroung (1970) reported that respiratory activity in rice seed decreased as the storage period increased. Delouche, et al. (1962) reported that dehydrogenase activity was closely associated with viability of seed. Grabe (1964, 1965) reported that GADA was highly correlated with seedling vigor of corn and oats.

MATERIALS AND METHODS

Plant Materials

Plant populations used were RMP 1, HMP 550, Serere 3A, and Senegal bulk (Senegal). Seed of each population was separated into high, medium, and low density fractions by a gravity table, at Mississippi State University. Each density fraction was then divided into three seed size fractions at Kansas State University as follows:

Large: Retained on a 7/64" round hole sieve

Medium: Passed by a 7/64" round hole sieve but retained on 6/64" round hole sieve

Small: Passed by a 6/64" round hole sieve

Seedburo sieves were used for these separations.

Field Experiment

Location and Soil

A field experiment was conducted at the Kansas State University Agronomy farm. The farm occupies the east half and northeast quarter of Section 1, Township 10S, Range 7 East and is located on old alluvial terraces that have dominantly silty clay loam surface soils (Bidwell, 1982).

Experimental Design

Experimental design was a split plot with three replications. Mainplot treatments were the four populations, and subplot treatments were the nine possible combinations of the three seed density and three seed size fractions, plus the original seed lot. Each plot consisted of two rows 6.1 m long and row spacing within and between plots was 76 cm.

Establishment

Planting was on Julian day 157 by means of a two-row vacuum planter. Each row of each plot received 110 seeds.

Furadan was incorporated into the soil at seeding for early chinchbug control. Sevin, as a liquid spray, was applied later, as necessary, for control after the early seedling stage. Weeds were not a major problem except for pigweed (*Amaranthus* sp.), puncture-vine (*Tribulus terrestris* L.), and crabgrass (*Digitaria sanguinalis* (L.) scop.) scattered over the plots. These were controlled by hand hoeing.

Observations

Emergence: This was the percent of seed that produced emerged seedlings. Seedlings were emerged on Julian day 161 and were counted on days 176 and 177, when they were in the 3-to-5 leaf stage. That was approximately 20 days after planting.

Seedling Vigor: Three seedlings in each row of each plot were selected randomly, and seedling heights (cm) were taken at the highest point of the extended foliage on Julian day 181. Measurements for the six seedlings of each plot were averaged to give a single vigor rating.

Days to Anthesis: The number of days from planting to anthesis was recorded as a measure of maturity for each plot.

Heads per Hectare: This was calculated from the total number of heads produced in each plot, as counted at time of grain harvest.

Head Weight: This was calculated as yield per hectare divided by heads per hectare.

Grain Yield: This was the amount of grain obtained per hectare, calculated from plot yield and adjusted to 12.5 percent moisture content.

Laboratory Determinations

Total Germination: Lots of 50 seeds were placed on moist filter paper in petri dishes and maintained in a germinator at 26.7° C for 7 days. Counts of germinated seeds were made each day beginning with the second day. A seed was considered germinated when it had produced both a plumule and a radicle. No germination was observed on the first day. Total germination at the end of 7 days was recorded.

Germination Index: The purpose of the germination index was to emphasize speed of germination. The index was calculated from the germination counts according to the following formula:

$$\text{Index} = \sum_{i=2}^{n} (n-i+1)Gi$$

where,

n = number of days to test (7)

i = day of germination count

Gi = germination for day of count

Seed Weight: This was the oven dry weight of fifty seeds in grams.

Average Seed Diameter: Fifty seeds were passed through a series of five dodder sieves arranged from top to bottom in descending order according to hole diameter. Hole diameters of sieves were: 3.51, 2.62, 2.01, 1.65, and 1.45 mm. All seeds passed the coarsest sieve while none passed the finest. Seeds retained on each sieve were counted and average seed diameter was calculated according to the following formula:

$$\text{Diameter} = \sum_{i=1}^{n} (SiDi)/50$$

where,

n = number of sieves

i = number of individual sieve in series

Si = number of seeds retained on sieve

Di = hole diameter of sieve (mm)

Seed Shape: Lots of 50 seeds were classified visually for seed shape, according to the following scale:

1. Long

2. Medium-long
3. Medium-round
4. Round

<u>Seed Color</u>: Lots of 50 seeds were classified visually for color according to the following rating system:

1. Mixture of tan (sienna) and light blue grey. Like a mixture of seeds from No. 2 and No. 4.
2. Tan with slight orange coloration.
3. Tan crown with germ end dark grey blue. Crown and germ ends sharply different.
4. Mixture of red-orange, dark grey, and tan grey green.
5. Consistent light grey color with little tan. Similar to No. 4 but lighter.

<u>Seed Starch Appearance</u>: Lots of 10 seeds were cut through the germ face with a razor blade to determine starch appearance. Halved seeds were observed under a 10X stereomicroscope, and starch appearance was rated according to the following scale:

0. 0- 20% chalky
1. 21- 40% chalky
2. 41- 60% chalky
3. 61- 80% chalky
4. 81-100% chalky

Observations for each lot of 10 seeds were averaged to give a single rating.

<u>Apparent Relative Embryo Size</u>: Seed halves used for determining seed starch appearance also were used for this

trial. Relative embryo size was estimated, under a 10X stereomicroscope, according to the following scale:

0. embryo constituted 1-10% of seed
1. embryo constituted 11-20% of seed
2. embryo constituted 21-30% of seed
3. embryo constituted 31-40% of seed
4. embryo constituted 41-50% of seed

Estimates for each lot of 10 seeds were averaged to give a single rating.

<u>Seed Density by Water Displacement</u>: Fifty grams of oven-dried (26.7° C) seed were placed in a 100 ml graduated cylinder containing 40 ml of water. Volume of seed was measured as the rise in the level of the water, and seed density was calculated according to the following formula:

$$\text{Seed density} = \frac{50\text{g}}{\text{Volume of seed in cm}^3}$$

<u>Seedling Respiration</u>: Lots of 50 seeds were placed in serum bottles to which had been added 5 ml of vermiculite and 5 ml of water. Serum bottles were covered with loose-fitting aluminum foil. Samples of gas were withdrawn from the bottles for determination of CO_2 content at intervals of 48, 72, 96, and 120 hours following introduction of seed. Ninety minutes before extraction of samples, bottles were stopped with rubber serum stoppers to give a final contained volume of 22.5 ml. Samples were 0.5 ml in volume and were extracted from the bottles in disposable glass syringes (Fig. 2).

Stoppers were removed from the bottles following each extraction. Carbon dioxide content of extracted gas samples was determined by means of a modified Carle 8501 thermal conductivity gas chromatograph with a 1.83 m column of Porapak S at 30° C and nitrogen carrier gas at a flow rate of 12 ml/min (Fig. 1). Respiration rate was calculated by means of the following equation:

$$\text{Respiration rate} = \frac{\text{Peak height of observation for } CO_2}{\text{(Standardization factor) (Stoppered time in hour}}$$

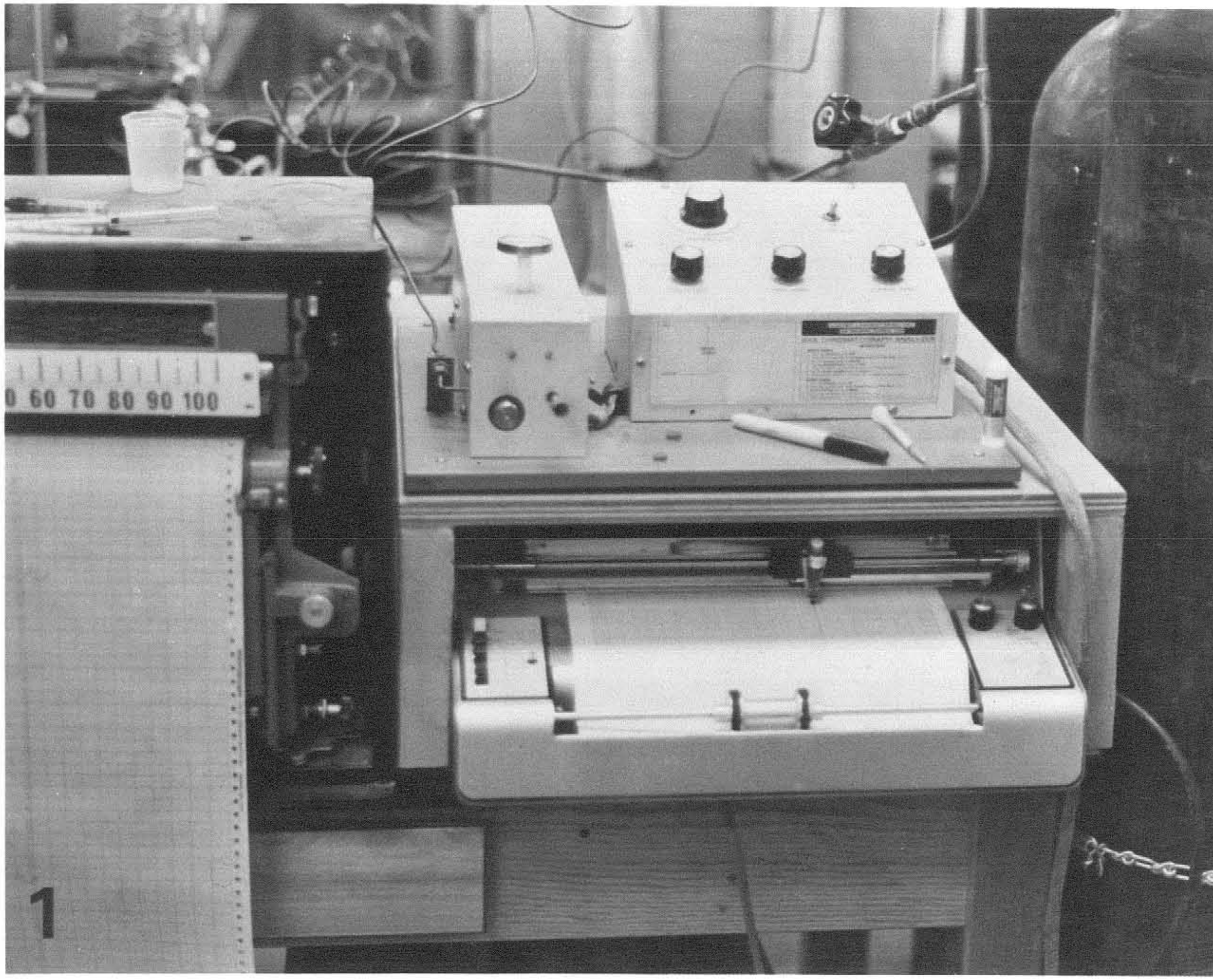
The standardization factor included corrections for the aliquot taken and the peak size per μ moles of CO_2 injected into the machine. Rates were expressed in two ways, viz.,

(a) as μ moles of CO_2 produced in 60 minutes by 50 seeds, and

(b) as μ moles of CO_2 produced in 60 minutes by 1 g of seed.

<u>Seed Protein</u>: Percent nitrogen of seed was determined by means of a spectrophotometric procedure (Technicon Industrial Systems, 1977) (Fig. 4). Protein content of seed was calculated as 6.25 times percent nitrogen.

<u>X-ray Observations</u>: Only HMP 550, Serere 3A and Senegal were used in these observations. Lots of 10 seeds were x-rayed by means of Hewlett Packard X-Ray Unit, Faxitron Series, Model 4380N. Seeds for x-raying were affixed to sheets of clear plastic with lead wire mesh, by means of Elmer's glue, with their germ faces upward. Samples were exposed to 20-22 kv



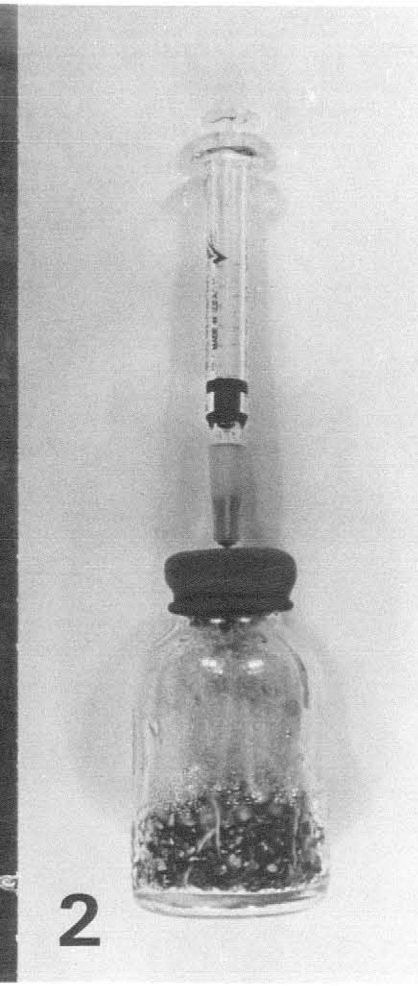


Fig. 1. A modified Carle 8501 thermal conductivity gas chromatograph used for determining seedling respiration.

Fig. 2. Serum bottle with disposable glass syringes and seedlings.

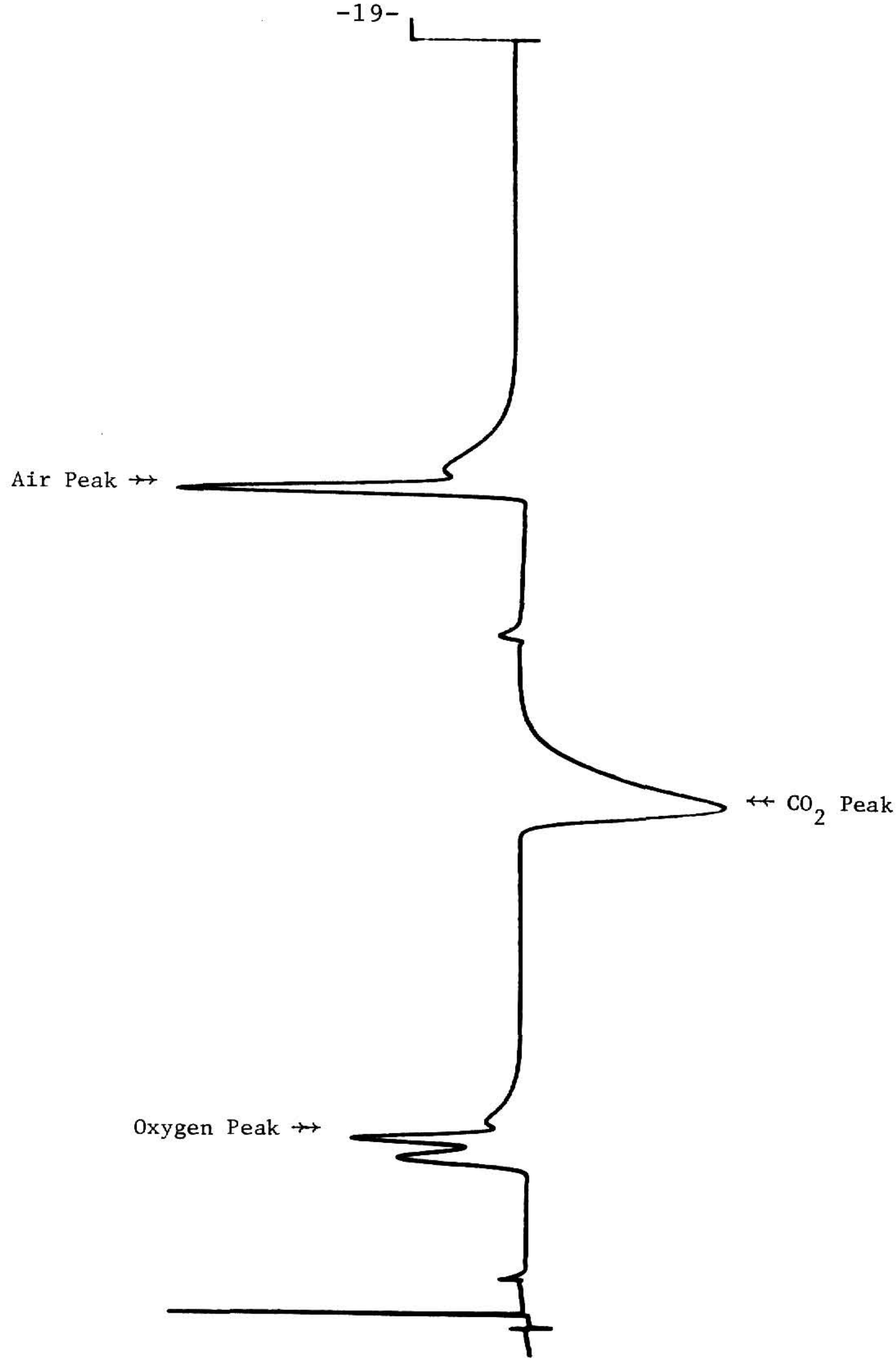


Fig. 3. CO_2 peak of seedling respiration of high-density, large seed of Senegal on 3rd day, as printed by gas chromatograph.

Fig. 4. Technicon Industrial Systems apparatus used for protein analysis.

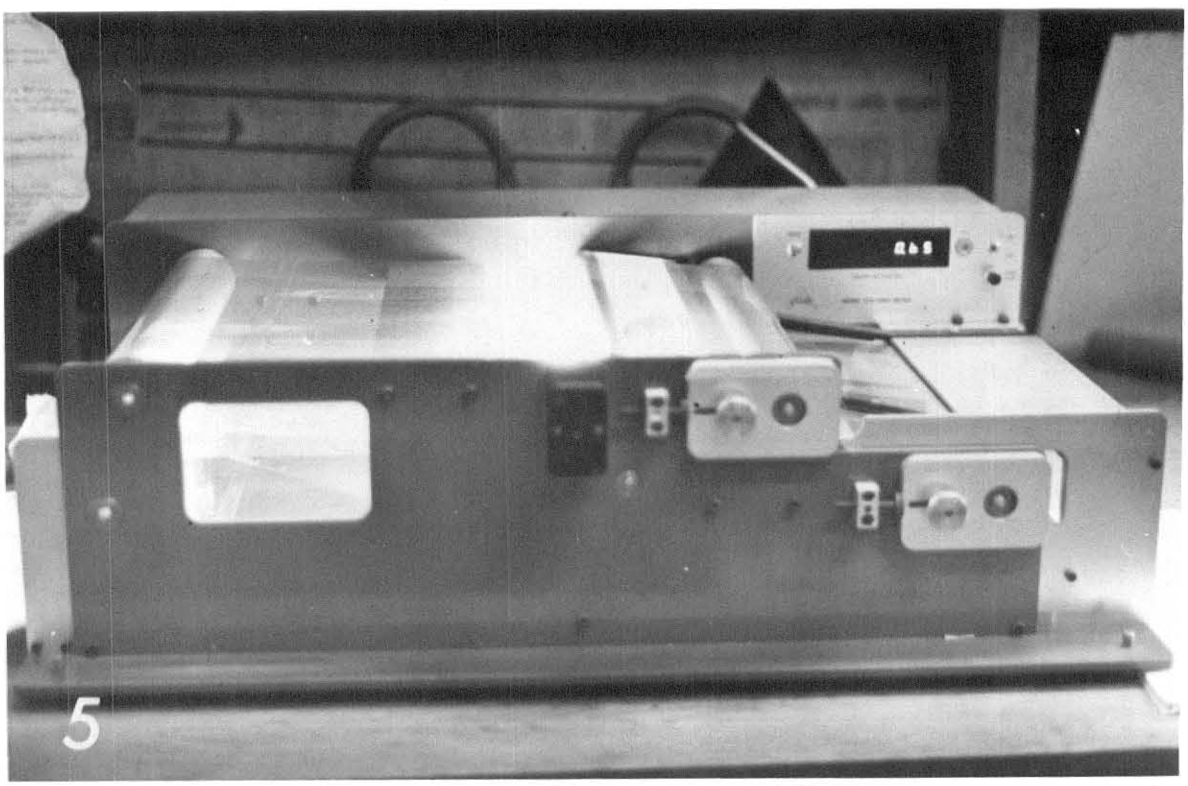


Fig. 5. Leaf area meter (model 3100) used for measuring embryo and seed areas.

for 1.9 minutes. Radiographs were made on Kodak industrial x-ray film, type M. Enlarged prints (10X) were prepared from the radiographs. Measurements of embryo length and embryo width, seed length, and seed width were made, from the prints, to the nearest mm.

Outlines of seeds and embryos were traced from the prints on sketch tissue paper. Tracings were cut out of the paper with a pair of scissors, and their areas were measured by means of a leaf area meter (Model 3100 area meter, Fig. 5). Areas of tracings were taken as representations of the cross-sectional areas of the embryos and seeds from which the tracings originated. Areas of the embryos and seeds were expressed in square centimeters. From the foregoing measurements, the following ratios were computed:

(a) embryo width/embryo length

(b) seed width/seed length

(c) embryo area/seed area.

Experimental Design: Experimental design for most of the laboratory experiments was split plot with 3 replications. The four populations were the main-plot treatments and the nine density x size combinations were subplot treatments. The original seed lots were not included in the analyses. Experiments on embryo length and width, seed length and width, embryo and seed areas, and the ratios employed a randomized complete block design with treatments consisting of all available combinations of population, seed density, and seed size.

In several analyses, missing cells necessitated the pooling of certain interactions. Pooled interactions have been presented as "Other interactions" in analysis-of-variance tables.

RESULTS

Field Study

Percent Emergence

Percent emergence was significantly affected by population, density, and the density x size interaction (Tables 1 and 3, Appendix Table 1). The density x size interaction was such that emergence was strongly affected by seed density at the lower ranges of seed size and essentially unaffected with large seed. Conversely, seed size significantly affected emergence when seed density was low but had no effect when density was high.

Seedling Vigor

Seedling vigor was significantly affected by population and density (Tables 1 and 2, Appendix Table 1). Seedlings from seeds of medium and high density were higher in vigor than those from seeds of low density.

Days to Anthesis

Days to anthesis were significantly affected by population, density, size, and the density x size interaction (Tables 1 and 3, Appendix Table 1). Generally, plants from seeds of low density and small size took longer to reach anthesis than plants from seeds of high density and large size. Size

Table 1. Effect of population on indicated variables.

Population	Variable				
	Percent emergence	Seedling vigor (cm)	Days to anthesis	Heads per hectare (000)	Head weight (g)
RMP 1	36.25	19.30	66.15	72	4.41
HMP 550	57.39	24.81	67.41	56	10.98
Serere 3A	65.77	25.11	58.22	81	9.42
Senegal	52.63	21.44	64.93	69	7.05
LSD(.05)	4.62	2.88	1.32	15	3.62

Table 2. Effect of seed density on indicated variables.

Seed density	Variable		
	Seedling vigor (cm)	Grain yield (kg/ha)	Head Weight (g)
Low	20.48	410.49	6.81
Medium	23.46	635.80	8.77
High	24.73	714.21	9.01
LSD(.05)	1.43	134.93	1.51

effects were significant only with seeds of low density. Density effects were significant with small and medium-sized seeds.

Heads per Hectare

Heads per hectare were significantly affected by population, density, and the density x size interaction (Tables 1 and 3, Appendix Table 1). The C.V. for this observation was high and may have obscured significance of other effects (Appendix Table 1). Seed size significantly affected heads per hectare when seed density was low while seed density affected heads per hectare at all seed sizes.

Head Weight

Head weight was significantly affected by population and density (Tables 1 and 2, Appendix Table 1). Size effects approached significance at the .05 level. The C.V. was high (Appendix Table 1), and other significant effects may have been obscured by the large amount of error in the measurements. Plants from medium and high density seeds had higher head weight than those from low density seeds.

Grain Yield

Grain yield was significantly affected by density, but the population x density x size interaction also was significant, making relationships difficult to interpret (Table 2, Appendix

Table 3. Effect of seed density and size on indicated variables.

Seed density	Variable and seed size								
	Percent emergence			Days to anthesis			Heads per hectare (000)		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Low	39.89	42.58	59.14	69.83	66.00	63.33	32	57	65
Medium	56.70	56.52	57.81	62.92	62.58	63.00	81	80	62
High	59.05	57.05	62.42	63.00	63.00	61.89	78	81	92
LSD(.05)†	5.83	5.83	5.83	2.66	2.66	2.66	19	19	19

† For comparing density means in the same or different size column.

Table 1). Plants from high and medium density seeds had higher grain yield than those from low density seeds. This analysis had a high C.V. which may have prevented identification of other significant effects (Appendix Table 1).

Laboratory Studies

Total Germination

Total germination was significantly affected by population, density, and the population x density interaction (Table 5, Appendix Table 2). The population x density interaction was such that, while germination tended to increase with seed density, differences were significant only in HMP 550.

Germination Index

Germination index was significantly affected by population, density, size, the density x size interaction, and the population x density interaction (Tables 4 and 5, Appendix Table 2). With large seed germination index tended to increase regularly with seed density. Seed-size effects were not significant with either low- or medium-density seed. With high density, however, the germination index was higher with large seed than with either small or medium-sized seed. With all populations germination index tended to increase with seed density, but differences between medium- and high-density seed were not significant. Differences were larger with HMP 550

Table 4. Effect of seed density and size on indicated variables.

Seed density	Germination index†			Average seed diameter (mm)			Seed Shape‡		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Low	220.00	213.75	222.33	1.87	2.11	2.41	4.0	3.5	4.0
Medium	259.92	252.50	247.89	1.92	2.10	2.33	2.8	3.0	3.3
High	244.67	249.25	265.89	1.95	2.08	2.45	3.5	3.3	2.7
LSD(.05)§	14.12	14.12	14.12	.04	.04	.04	.1	.1	.1

† See p. 14 for computation.

‡ Scale = 1 (elongate) - 4 (round).

§ For comparing density means in the same or different size column.

than with other populations.

Seed Weight

Seed weight was significantly affected by population, density, size, and the population x density interaction, but other interactions also were significant making relationships difficult to interpret (Table 5, Appendix Table 2). In all populations except HMP 550 seed weight increased with seed density. Seed weights for small, medium, and large seeds were .34g, .45g, and .58g respectively [L.S.D. (.05) = .03].

Average Seed Diameter

Seed diameter was significantly affected by population, seed density, seed size, the density x size interaction, and the population x density interaction. Other interactions also were significant, however, making relationships difficult to interpret (Tables 4 and 5, Appendix Table 2). Seed diameter increased with seed size at all densities. However, the effect of density on seed diameter varied across size classes. Seed diameter for small, medium, and large seeds was 1.92, 2.10, and 2.39 mm, respectively [L.S.D. (.05) = .02]. Seed diameter was significantly affected by seed density in Senegal but not in other populations. This analysis had a low C.V. (Appendix Table 2).

Table 5. Effect of population and seed density on indicated variables.

	Variable and seed density																			
	Total germination†				Germination index‡				Seed weight (g)				Average seed diameter (mm)				Seed shape§			
Population	Low	Medium	High	LSD(.05)	Low	Medium	High	LSD(.05)	Low	Medium	High	LSD(.05)	Low	Medium	High	LSD(.05)	Low	Medium	High	LSD(.05)
RMP 1	34.8	39.3	37.2	4.9	179.17	206.67	199.17	26.20	.26	.29	.34	.08	1.94	1.94	1.97	.08	4.0	4.0	4.0	.2
IMP 550	37.0	45.8	47.3	4.9	205.00	269.67	279.11	26.20	.46	.47	.46	.08	2.08	2.10	2.06	.08	3.0	2.3	2.7	.2
Serrere 3A	43.9	46.8	47.9	4.9	244.11	269.44	278.78	26.20	.53	.54	.60	.08	2.28	2.22	2.24	.08	3.7	2.4	2.7	.2
Senegal	41.7	45.2	41.3	4.9	221.33	254.22	233.78	26.20	.34	.38	.52	.08	2.03	2.08	2.20	.08	4.0	3.7	3.7	.2
LSD(.05)	5.2	5.2	5.2		35.92	35.92	35.92		.08	.08	.08		.08	.08	.08		.2	.2	.2	

† Number of seeds germinated out of 50.

‡ See p14 for computation.

§ Scale = 1 (elongate) - 4 (round).

Table 6. Seed color variation.†

Population and Replication	Low density			Medium density			High density		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
RMP 1									
1	2	5	-	2	2	-	1	1	-
2	2	5	-	2	2	-	1	1	-
3	2	5	-	2	2	-	1	1	-
HMP 550									
1	-	5	-	2	2	2	1	1	2
2	-	5	-	2	2	2	1	1	2
3	-	5	-	2	2	2	1	1	2
Serere 3A									
1	4	6	3	4	4	3	4	3	3
2	4	6	3	4	4	3	4	3	3
3	4	6	3	4	4	3	4	3	3
Senegal									
1	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
3	2	2	2	2	2	2	2	2	2

† See p.15 for color rating.

Seed Shape

Seed shape was significantly affected by population, density, size, the density x size interaction, and the population x density interaction. Other interactions also were significant making relationships difficult to interpret (Tables 4 and 5, Appendix Table 2).

Seed Color

Since there was no variation in any of population-density-size cells, experimental error was zero, and all differences were significant (Table 6). There were obviously interactions involving density, size, and population. RMP 1 and HMP 550 appeared to have the same seed colors although there were missing classes in both populations. There was a density x size interaction in RMP 1, HMP 550 and Serere 3A. Senegal had the same seed color of tan with slight orange coloration with all density and size classes.

Seed Starch Appearance

Seed starch appearance varied significantly with population, seed density, and seed size. The population x density and population x size interactions were significant (Tables 7 and 8, Appendix Table 3). High-density seed of all populations was more vitreous than low- and medium-density seed. Large seed of RMP 1 was more vitreous than seed of the small and medium-size classes.

Apparent Relative Embryo Size

Relative size of embryo varied significantly with population, seed density, and seed size. The population x density interaction approached significance at the .05 level (Table 7, Appendix Table 3). Relative embryo size for small, medium, and large seeds was 3.21, 3.24, and 3.54, respectively [L.S.D. (.05) = .15]. Relative embryo size for RMP 1, HMP 550, Serere 3A and Senegal was 3.19, 3.16, 3.32, and 3.58, respectively [L.S.D. (.05) = .23]. Relative embryo size for low, medium, and high density was 3.23, 3.26, and 3.47, respectively [L.S.D. (.05) = .15]. With seed of low and medium density Senegal had a higher relative size of embryo than HMP 550. With seed of high density, however, populations did not differ significantly in relative size of embryo.

Seed Density by Water Displacement

Seed density by water displacement was affected only marginally by density as determined by gravity-table separation (P = .0897; Appendix Table 4). Density by water displacement for seed of low, medium, and high gravity-separation density was 1.20, 1.28, 1.31 g/cm^3, respectively [L.S.D. (.10) = .04]. Water-displacement density was unaffected by population, seed size, or by any of the interactions among population, size, and density (Appendix Table 4). The C.V. for this analysis was low (Appendix Table 4).

Table 7. Effect of population and seed density on starch appearance and apparent relative embryo size.

	Starch appearance† seed density				Apparent relative embryo size‡ seed density			
Population	Low	Medium	High	LSD(.05)	Low	Medium	High	LSD(.05)
RMP 1	3.3	2.3	1.9	.5	3.1	3.2	3.3	.5
HMP 550	3.0	2.6	2.4	.5	3.0	3.0	3.5	.5
Serere 3A	3.2	2.9	2.8	.5	3.2	3.2	3.6	.5
Senegal	2.6	2.1	1.7	.5	3.6	3.6	3.5	.5
LSD(.05)§	.5	.5	.5		.6	.6	.6	

† Scale = 0 (0-20% chalky) - 4 (81-100% chalky)

‡ See p.16 for rating.

§ For comparing density means in the same population.

Table 8. Effect of population and seed size on starch appearance.†

	Seed size			
Population	Small	Medium	Large	LSD(.05)
RMP 1	2.5	2.7	1.9	.5
HMP 550	2.7	2.7	2.6	.5
Serere 3A	3.1	3.0	2.8	.5
Senegal	2.0	2.1	2.3	.5
LSD(.05)	.5	.5	.5	

† Scale = 0 (0-20% chalky) - 4 (81-100% chalky).

Table 9. Effect of population and seed size on seedling respiration per hour for 50 seeds and seedling respiration per hour per gram of seed.

	Average seedling respiration/hr (μ moles CO_2) seed size				Average seedling respiration/hr/g (μ moles CO_2) seed size			
Population	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)
RMP 1	8.86	10.87	11.59	3.66	24.14	25.31	26.96	7.76
HMP 550	10.10	15.73	11.93	3.66	23.16	28.80	18.41	7.76
Serere 3A	14.76	12.08	15.29	3.66	29.52	18.55	19.37	7.76
Senegal	11.91	12.99	16.33	3.66	30.55	24.25	26.63	7.76
LSD(.05)	6.52	6.52	6.52		12.65	12.65	12.65	

Seedling Respiration per Fifty Seeds per Hour

Appendix Table 7 summaries analysis-of-variance results for seedling respiration per 50 seeds averaged across days. Respiration was affected significantly by density, size, and the population x size interaction. Seedlings from seed of low, medium, and high density had respiration rates of 11.21, 12.92, and 13.72 μ moles/hour, respectively [L.S.D. (.05) = 1.25]. Following are results for individual populations with days treated separately. Coefficients of variability for these analyses were high (Appendix Tables 8, 9, 10, and 11) and the large amount of errors in the measurements may have obscured real effects other than those shown to be statistically significant.

RMP 1. Seedling respiration/hour was significantly affected only by day (Table 10, Appendix Table 8) and was highest on the fourth day. Day was not involved in any interactions.

HMP 550. Seedling respiration/hour was significantly affected by seed size, seed density, and day (Tables 11, 12, and 13, Appendix Table 9). Respiration rate was higher with medium-sized seed than with either small or large seed, but seedlings from high-density seed had a higher respiration rate than those from seed of low or medium density. Day was not involved in any interactions.

Serere 3A. Seedling respiration/hour was significantly affected only by day although size effects approached

Table 10. Effect of day on seedling respiration. RMP 1.

Day	Respiration/hr (μ moles CO_2)	Respiration/hr/g (μ moles CO_2)
2	5.92	14.48
3	10.64	26.39
4	12.88	32.21
5	11.00	27.11
LSD(.05)	1.82	4.69

Table 11. Effect of seed size on seedling respiration. HMP 550.

Seed size	Respiration/hr (μ moles CO_2)	Respiration/hr/g (μ moles CO_2)
Small	10.10	23.16
Medium	15.73	28.80
Large	11.93	16.45
LSD(.05)	2.48	5.07

significance at the .05 level (Table 14, Appendix Table 10). Seedlings of small, medium, and large seeds had a respiration rate of 14.76, 12.08, and 15.29 μ moles/hour respectively [L.S.D. (.05) = 3.56]. Respiration rate ranked highest on the fourth day. Day was not involved in any interactions.

Senegal. Seedling respiration/hour was significantly affected by seed size, seed density, day, and the size x density interaction. Day was not involved in any interactions (Tables 15 and 16, Appendix Table 11). Respiration rate ranked highest on the fourth day. With seed of low and medium density, seedlings from medium-sized and large seed had higher respiration rates than those from small seed. With high-density seed, all size effects were significant.

Seedling Respiration Per Gram Per Hour

Appendix Table 7 summarizes analysis-of-variance results for seedling respiration, per gram of seed, averaged across days. Respiration was affected significantly by only the population x size interaction, although seed density and density x size effects approached significance at the .05 level. Following are results for individual populations with days treated separately. Coefficients of variability for these analyses were high (Appendix Tables 8, 9, 10, and 11) and may have obscured real effects other than those shown to be statistically significant.

RMP 1. Seedling respiration/hour/gram was significantly

Table 12. Effect of seed density on seedling respiration. HMP 550.

Seed density	Respiration/hr (μ moles CO_2)	Respiration/hr/g (μ moles CO_2)
Low	8.84	19.18
Medium	13.17	23.64
High	13.54	24.11
LSD(.05)	2.48	4.69

Table 13. Effect of day on seedling respiration. HMP 550.

Day	Respiration/hr (μ moles CO_2)	Respiration/hr/g (μ moles CO_2)
2	6.66	11.96
3	13.78	25.76
4	15.49	27.89
5	15.68	28.02
LSD(.05)	2.80	5.14

affected only by day (Table 10, Appendix Table 8). Respiration rate was highest on the fourth day. There were no interactions involving day.

HMP 550. Seedling respiration/hour/gram was significantly affected by size, density, and day (Tables 11, 12, and 13, Appendix Table 9). There were no interactions involving day. Seedlings from medium-sized seed had higher respiration rates than those from either small or large seed. Seedlings from medium- and high-density seeds had higher respiration rates than those from low-density seeds. Respiration rate ranked highest on the fifth day.

Serere 3A. Seedling respiration/hour/gram was significantly affected only by day (Table 14, Appendix Table 10). Respiration rate was highest on the fourth day. There were no interactions involving day.

Senegal. Seedling respiration/hour/gram was significantly affected by size and day (Table 16, Appendix Table 11). Seedlings from small, medium, and large seeds had respiration rates of 30.55, 24.25, and 26.63 μ moles/hour/gram respectively [L.S.D. (.05) = 4.09]. There were no interactions involving day.

Seed Protein Analysis

Protein percent of seed was significantly affected by population, seed size, the density x size interaction, and the population x density interaction. Other interactions also

Table 14. Effect of day on seedling respiration. Serere 3A.

Day	Respiration/hr (μ moles CO_2)	Respiration/hr/g (μ moles CO_2)
2	8.28	11.58
3	14.23	20.37
4	17.48	24.46
5	16.21	22.46
LSD(.05)	3.56	4.70

Table 15. Effect of seed density and size on seedling respiration per hour for 50 seeds. Senegal.

	Respiration (μ moles CO_2) seed size		
Seed density	Small	Medium	Large
Low	9.33	13.87	12.54
Medium	10.28	14.76	13.96
High	13.64	15.24	20.12
LSD(.05)†	2.96	2.96	2.96

† For comparing density means in the same or different size column.

were significant making identification of meaningful relationships difficult (Appendix Table 12).

Embryo Length

Embryo length was significantly affected by only seed size (Appendix Table 13) and increased as seed size increased (Table 17).

Embryo Width

Embryo width increased significantly with seed size but also was affected by population (Table 17, Appendix Table 13). Embryo width for HMP 550, Serere 3A and Senegal was 10.28, 11.58, and 11.49 mm respectively [L.S.D. (.05) = .48]. Effect of density on embryo width approached significance at the .05 level and appeared to be positive.

Seed Length

Seed length was significantly affected by population, density, and size as determined by initial sieve separation (Tables 18 and 19, Appendix Table 13). Length for seeds of low, medium, and high density was 35.19, 34.09, and 38.20 mm, respectively [L.S.D. (.05) = 1.17]. Seed length increased with seed size.

Seed Width

Seed width increased significantly with seed size and

Table 16. Effect of day on seedling respiration. Senegal.

Day	Respiration/hr (μ moles CO_2)	Respiration/hr/g (μ moles CO_2)
2	7.33	14.45
3	13.24	25.80
4	17.72	34.99
5	16.71	33.34
LSD(.05)	1.93	4.18

Table 17. Effect of seed size on embryo length and width.

Seed size	Embryo length (mm)†	Embryo Width (mm)†
Small	19.89	9.12
Medium	21.87	11.07
Large	23.53	11.64
LSD(.05)	1.32	.48

Table 18. Effect of population on seed length and width.

Population	Seed length (mm)†	Seed width (mm)†
HMP 550	35.71	23.20
Serere 3A	37.74	27.26
Senegal	33.87	24.29
LSD(.05)	1.17	1.04

† Measured from photographs enlarged 10X.

varied significantly with population (Tables 18 and 19, Appendix Table 13).

Area of Embryo

Area of embryo increased significantly with seed size as determined by sieve separation (Table 20, Appendix Table 13). Effect of density on embryo area approached significance at the .05 level with seeds of low, medium, and high density having mean embryo areas of 2.04, 1.71, and 2.11, respectively [L.S.D. (.05) = .19].

Area of Seed

Area of seed increased significantly with seed size and varied significantly with population (Table 20, Appendix Table 13). Seed area for HMP 550, Serere 3A, and Senegal was 6.32, 8.06, and 6.24 respectively [L.S.D. (.05) = .47].

Ratio of Embryo Width to Embryo Length

This varied significantly with population and seed size (Tables 21 and 22, Appendix Table 13). Small seeds had a lower ratio (i.e. more elongate embryos) than medium-sized or large seeds.

Ratio of Seed Width to Seed Length

This varied significantly with population, seed density, and seed size (Tables 21 and 22, Appendix Table 13). For

Table 19. Effect of seed size on seed length and width.

Seed size	Seed length (mm)†	Seed width (mm)†
Small	32.65	19.62
Medium	34.25	23.72
Large	36.92	26.69
LSD(.05)	1.17	1.04

Table 20. Effect of seed size on area of embryo and area of seed.

Seed size	Area of embryo† (cm^2)	Area of Seed† (cm^2)
Small	1.25	4.76
Medium	1.86	6.16
Large	2.12	7.56
LSD(.05)	.19	.47

† Measured from photographs enlarged 10X.

Table 21. Effect of population on indicated ratios.

Population	Embryo width/length	Seed width/length
HMP 550	.45	.65
Serere 3A	.48	.72
Senegal	.54	.72
LSD(.05)	.03	.03

Table 22. Effect of seed size on indicated ratios.

Seed size	Embryo width/length	Seed width/length
Small	.46	.60
Medium	.51	.69
Large	.50	.73
LSD(.05)	.03	.03

seeds of low, medium, and high density the ratio was .72, .70, and .68, respectively [L.S.D. (.05) = .03]. That is, high-density seeds were elongate while low-density seeds were more spheroid in appearance. Small seeds, on the other hand, were elongate while large seeds tended to be more spheroid.

Ratio of Area of Embryo to Area of Seed

Ratio of embryo area to seed area was unaffected by any identifiable source of variation (Appendix Table 13).

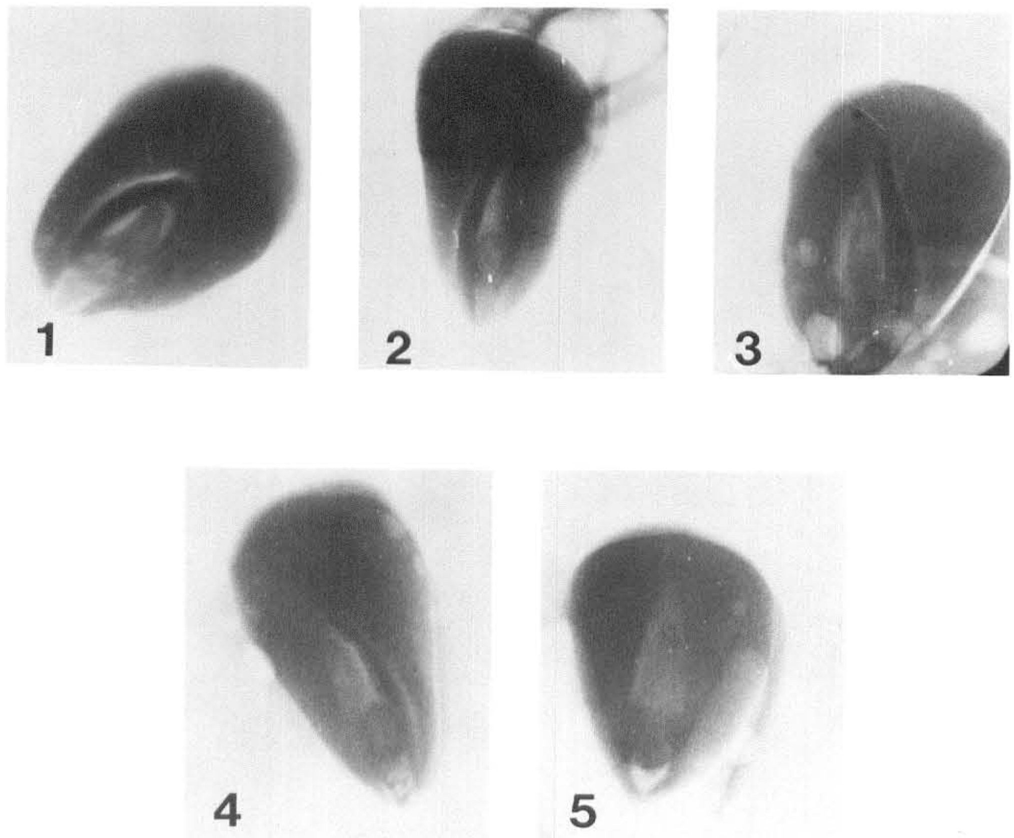


Fig. 6. Enlarged prints (10X) from x-ray radiographs of pearl millet seed: (1) medium-density, large seed of HMP 550; (2) high-density, medium-sized seed of HMP 550; (3) high-density, large seed of Serere 3A; (4) high-density, large seed of HMP 550; (5) medium-density, large seed of Serere 3A.

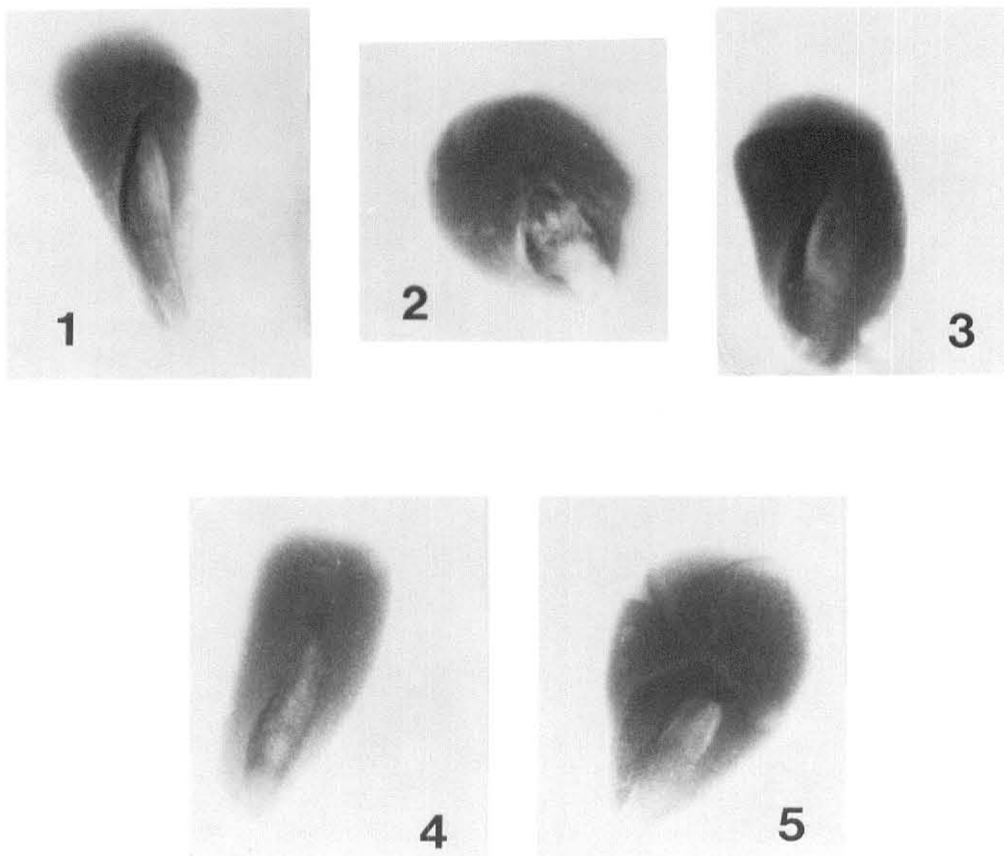


Fig. 7. Enlarged prints (10X) from x-ray radiographs of pearl millet seed: (1) medium-density, small seed of Senegal; (2) high-density, large seed of HMP 550; (3) medium-density, medium size of HMP 550; (4) medium-density, small seed of HMP 550; (5) medium-density, large seed of Senegal.

DISCUSSION

Gravity table separation divided seed of each population into seed-density classes, but actual seed density of each class was not measured. There is, therefore, no assurance that seed-density classes were consistent across populations. Lack of consistency across populations would tend to exaggerate the magnitude of population x density and population x density x size effects.

Failure of seed density by water displacement to be significantly affected by density as established by gravity-table separation (Appendix Table 4) is cause for concern. It must be noted, however, that density by water displacement was not significantly affected by any factor, a result suggesting that the water-displacement technique lacked the sensitivity required to detect differences among seed lots in this study. It is reassuring that seed density as established by gravity table separation was the only factor approaching significance (P = .0897) in the analysis of variance for density by water displacement.

Seed size separation through use of sieves probably was affected by differences in seed shape. Elongate seeds would tend to pass through smaller holes, and, hence, to yield lower size estimates than spheroid seeds of equal volume. Estimates of size effects and of interactions involving size would tend to be distorted by this relationship

Field results agreed with findings of Gardner (1980), Kiesselbach (1924), and Smith and Camper (1975). Those writers also reported close positive relationships among seed size, seedling vigor, and grain yield, as well as between seed density and grain yield.

The nature of the seed density x seed size interaction implies a compensatory relationship between those variables in seedling emergence. Low-density seeds gave satisfactory emergence provided they were sufficiently large; conversely, small seeds performed satisfactorily when they were high in density. There also was a suggestion of a compensatory relationship between density and size in heads per hectare and days to anthesis. A compensatory relationship between seed density and seed size (volume) suggests that those traits are important primarily as components of seed mass (weight) in which case seed weight should be a more comprehensive criterion of seed quality than either density or size. No such relationship was apparent, however, in seedling vigor where neither size effects nor the density x size interaction was significant (Appendix Table 1). Absence of a significant density x size interaction in several other traits, including total germination (Appendix Tables 1 and 2) further complicates the picture. Density x size interactions with non-compensatory features occurred in germination index (Table 4) and in seedling respiration for 50 seeds for Senegal (Table 15).

The tendency of density and size effects to lose significance when weight of seed is held constant, as occurred in seedling respiration for populations combined (Appendix Table 7), also implies that the major effects of seed density and seed size are integrated in the effects of seed weight. In the case cited, however, density and density x size effects approached significance of the .05 level when the weight of seed was constant. Moreover, the relationship varied from population to population. With HMP 550, effects of seed density and seed size remained highly significant when weight of seed was fixed (Appendix Table 9). There would appear to be some density and size effects which are not directly attributable to the role of those traits as components of seed weight. Copeland (1976) reported that heavy or high-density seeds produced vigorous seedlings due to a higher respiratory rate and production of a greater amount of energy (ATP). Woodstock and Feeley (1965) reported that respiration rate of germinating corn seeds might indicate seed vigor. A regression and correlation analysis of relationships among seed density, seed volume, seed mass, and various establishment-oriented traits of pearl millet would be helpful, both from a practical standpoint, in seed quality evaluation, and as a means of delineating the pathways through which variation in seed density and seed size impact on field establishment.

Starch appearance may provide some insight into seed density effects in pearl millet. Density effects on starch appearance were highly significant (Appendix Table 3), with seeds of high density having more vitreous starch than those of low density (Table 7). Moreover, starch of large seeds was more vitreous than that of small and medium sized seeds, except in Senegal. It has generally been assumed that opaque (chalky) endosperm is synonomous with soft endosperm (Francisco, et al., 1980).

Study of seed protein content promises little insight into the mechanisms of seed density effects in pearl millet. Absence of significant density effects in protein content, and highly significant interactions in that variable among density, size, and population (Appendix Table 12) make it unlikely that major density effects on seedling emergence or other traits can be associated in any meaningful way with variation in seed protein content. Gardner (1980) reported that percent protein of pearl millet seed was negatively correlated with percent emergence. Low density seeds were found to have high protein content. However, Smith and Werker (1968) in a breeding study, noted that high seed density was associated with high protein content. It would be helpful, in assessing the relationship between seed density and seed protein content, to differentiate between protein residing in the embryo and that present in the endosperm.

Seed colors observed in this study differed from those reported by Athwal (1966) indicating that the range of seed colors existing in pearl millet is greater than that observed in either study. Color variation with respect to population, density, and size effects was complex and, as categorized in this study, offers little insight into the significance of seed-density differences.

It is difficult to evaluate the relationship between seed density and relative embryo size. High density and large seeds appeared to have relatively large embryos when observed in lateral cross section under the microscope. These results agree with findings of Muchena and Grogan (1977) and of Bartee and Kreig (1974). However, the ratio of embryo area to seed area, as determined from measurements of x-ray prints, appeared to be a constant, being unaffected by population, seed density, or seed size. These apparently contradictory findings may result from the fact that observations on apparent relative embryo size were made in a lateral plane of the seed while x-ray print measurements were made in a dorsiventral plane. It is difficult, however, to visualize a mechanism whereby seed density effects on relative embryo size would be manifest in one plane of the seed and not in another. Ratings of apparent relative embryo size were subjective and may have been influenced by differences in seed shape which was shown to be affected by variation in seed density.

CONCLUSIONS

1. Results confirmed findings of earlier studies indicating that seedling emergence and other traits are positively affected by seed density and seed size.

2. Seed density and seed size interact in their effects on several traits. In seedling emergence and heads per hectare the nature of the interaction implies a compensatory relationship between density and size suggesting that those traits are important mainly as components of seed weight. In some traits, however, the density x size interaction possesses non-compensatory aspects while in other cases the interaction is nonsignificant.

3. In seedling respiration, significant effects of seed density and seed size tend to disappear when weight of seed is held constant, again suggesting that major effects of density and size are integrated in those of seed weight. Exceptions, however, indicate that there are some density and size effects which are not fully accounted for by effects of seed weight.

4. Generally, starch of high-density seeds is more vitreous in appearance than that of low-density seeds. There is a tendency for starch appearance to be more vitreous in large seeds than in small seeds, but this relationship varies with population.

5. Study of seed protein content promises little insight into

the mechanisms of seed density effects in pearl millet. Protein content is not significantly affected by seed density but is involved in highly significant interactions among density, seed size, and population.

6. Seed color of pearl millet exhibits a complex pattern of variation and, as categorized in this study, offers little insight into the significance of seed-density differences.

7. The relationship between seed density and relative embryo size is not clear. High-density seeds observed in lateral cross section under a microscope appear to have relatively large embryos. However, the ratio of embryo area to seed area, as determined from measurements of x-ray prints, appears to be unaffected by seed density.

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APPENDIX

Appendix Table 1. Analysis of variance summaries for six field variables.

Source of variation	DF	Probability of F ratio for indicated variable					
		Percent emergence	Seedling vigor (cm)	Days to anthesis	Heads per hectare	Head Weight (g)	Grain Yield (kg/ha)
Total	100						
Replication	2						
Population	3	.0002	.0131	.0000	.0000	.0454	.0732
Error A	6	45.08†	17.43†	3.70†	481.90†	27.69†	104117.79†
Density	2	.0000	.0000	.0000	.0000	.0173	.0003
Size	2	.1365	.4243	.0320	.1571	.0843	.1897
Density x size	4	.0022	.8768	.0140	.0136	.1598	.1812
Population x density	6	.1522	.7756	.6899	.6428	.4151	.7756
Population x size	6	.8951	.0597	.1496	.7213	.9185	.8278
Population x density x size	10	.3291	.8471	.0696	.0907	.2167	.0000
Error B	59	47.63†	8.55†	9.90†	518.80†	9.61†	76624.64†
C.V.		12.9	12.3	5.2	34.7	38.8	49.3

† Mean sqare for indicated error.

Appendix Table 2. Analysis of variance summaries for five laboratory variables.

		Probability of F ratio for indicated variable				
Source of variation	DF	Total germination	Germination index	Seed weight (g)	Average seed diameter (mm)	Seed shape
Total	92					
Replication	2					
Population	3	.0001	.0003	.0000	.0000	.0000
Error A	6	5.40†	500.25†	.0014†	.0009†	.0088†
Density	2	.0000	.0000	.0000	.0010	.0000
Size	2	.4126	.0121	.0000	.0000	.0000
Density x size	4	.2065	.0373	.7935	.0000	.0000
Population x density	6	.0058	.0008	.0010	.0000	.0000
Other interactions‡	13	.6671	.4465	.0161	.0000	.0000
Error B	54	9.04†	257.36†	.0026†	.0024†	.0110†
C.V.		6.8	6.6	12.8	3.4	10.3

† Mean square for indicated error.

‡ Population x size
Population x density x size.

Appendix Table 3. Analysis of variance summaries for starch appearance and apparent relative embryo size.

		Probability of F ratio for indicated variables	
Source of variation	DF	Starch appearance	Relative embryo size
Total	101		
Replication	2		
Population	3	.0001	.0197
Error A	6	.0625†	.1167†
Density	2	.0000	.0049
Size	2	.0218	.0018
Density x size	4	.3942	.3037
Population x density	6	.0022	.0542
Population x size	6	.0010	.7135
Population x density x size	10	.0993	.2514
Error B	60	.0830†	.0948†
C.V.		11.8	9.5

† Mean square for indicated error.

Appendix Table 4. Analysis of variance for seed density by water displacement (g/cm^3).

Source of variation	DF	Probability of F ratio
Total	47	
Replication	2	
Population	3	.2751
Error A	6	.0023†
Density	2	.0897
Size	2	.7888
Interactions‡	11	.1278
Error B	21	.0038†
C.V.		4.3

† Mean square for indicated error.

‡ Density x size
Population x density
Population x size
Population x density x size.

Appendix Table 5. Analysis of variance for daily seedling respiration per hour (μ moles CO_2).

Source of variation	DF	Probability of F ratio for indicated day 2	3	4	5
Total	76				
Replication	2				
Population	3	.0485	.4400	.3605	.0704
Error A	6	2.59†	62.58†	71.43†	24.92†
Density	2	.0018	.0003	.0021	.0023
Size	2	.0044	.5221	.0789	.0396
Density x size	4	.4841	.1283	.1151	.2969
Population x size	6	.0033	.0000	.0439	.0521
Other interactions‡	9	.2921	.2761	.3574	.5016
Error B	42	5.66†	10.13†	17.52†	22.04†
C.V.		34.3	24.9	26.1	30.5

† Mean square for indicated error.

‡ Population x density
Population x density x size.

Appendix Table 6. Analysis of variance for daily seedling respiration per hour per gram (μ moles CO_2).

Source of variation	DF	Probability of F ratio for indicated day			
		2	3	4	5
Total	76				
Replication	2				
Population	3	.0264	.9388	.3719	.2071
Error A	6	10.90†	162.74†	231.95†	108.14†
Density	2	.0627	.3911	.1762	.5643
Size	2	.5023	.0005	.5121	.3488
Density x size	4	.3087	.0592	.1973	.1773
Population x size	6	.0162	.0001	.0568	.0539
Other interactions‡	9	.4183	.0471	.5096	.5176
Error B	42	23.94†	33.59†	67.48†	93.32†
C.V.		37.2	25.6	26.8	33.6

† Mean square for indicated error.

‡ Population x density
Population x density x size.

Appendix Table 7. Analysis of variance for seedling respiration averaged across days.

		Probability of F ratio for indicated variable	
Source of variation	DF	Average respiration/hr (μ moles CO_2)	Average respiration/hr/gm (μ moles CO_2)
Total	76		
Replication	2		
Population	3	.1176	.3441
Error A	6	16.22†	56.26†
Density	2	.0000	.0768
Size	2	.0144	.1427
Density x size	4	.0820	.0669
Population x size	6	.0000	.0012
Other interactions‡	9	.2608	.4475
Error B	42	5.03†	22.56†
C.V.		17.8	19.5

† Mean square for indicated error.

‡ Population x density
Population x density x size.

Appendix Table 8. Analysis of variance summaries for seedling respiration. RMP 1

		Probability of F ratio for indicated variable	
Source of variation	DF	Respiration/hr (μ moles CO_2)	Respiration/hr/gm (μ moles CO_2)
Total	55		
Replication	2		
Size	2	.3947	.8905
Density	1	.5195	.9798
Error A	8	36.28†	246.01†
Day	3	.0000	.0000
Size x day	6	.2509	.2024
Density x day	3	.1902	.3266
Error B	30	5.54†	36.99†
C.V.		34.3	35.9

† Mean square for indicated error.

Appendix Table 9. Analysis of variance summaries for seedling respiration. HMP 550

		Probability of F ratio for indicated variable	
Source of variation	DF	Respiration/hr (μ moles CO_2)	Respiration/hr/gm (μ moles CO_2)
Total	79		
Replication	2		
Size	2	.0001	.0001
Density	2	.0004	.0087
Error A	13	17.51†	73.34†
Day	3	.0001	.0001
Size x day	6	.8341	.7901
Density x day	6	.6510	.5103
Error B	45	19.54†	65.97†
C.V.		33.9	35.1

† Mean square for indicated error.

Appendix Table 10. Analysis of variance summaries for seedling respiration. Serere 3A.

		Probability of F ratio for indicated variable	
Source of variation	DF	Respiration/hr (μ moles CO_2)	Respiration/hr/gm (μ moles CO_2)
Total	63		
Replication	2		
Size	2	.0521	.0676
Density	2	.2576	.5409
Error A	9	26.40†	52.47†
Day	3	.0212	.0014
Size x day	6	.5272	.2517
Density x day	6	.9711	.9916
Error B	33	24.83†	43.24†
C.V.		35.7	34.1

† Mean square for indicated error.

Appendix Table 11. Analysis of variance summaries for seedling respiration. Senegal.

Source of variation	DF	Probability of F ratio for indicated variable: Respiration/hr (μ moles CO_2)	Respiration/hr/gm (μ moles CO_2)
Total	107		
Replication	2		
Size	2	.0001	.0160
Density	2	.0001	.4144
Size x density	4	.0483	.3714
Error A	16	11.69†	67.24†
Day	3	.0001	.0001
Size x day	6	.5055	.3395
Density x day	6	.4265	.5441
Size x density x day	12	.5195	.7247
Error B	54	12.60†	59.06†
C.V.		25.8	28.3

† Mean square for indicated error.

Appendix Table 12. Analysis of variance for percent protein.

Source of variation	DF	Probability of F ratio
Total	89	
Replication	2	
Population	3	.0000
Error A	6	.1185†
Density	2	.1754
Size	2	.0000
Density x size	4	.0000
Population x density	6	.0000
Other interactions‡	12	.0000
Error B	52	.1136†
C.V.		6.1

† Mean square for indicated error.

‡ Population x size
Population x density x size.

Appendix Table 13. Analysis of variance summaries for nine variables dealing with embryo and seed dimensions.

		Probability of F ratio for indicated variable								
Source of variation	DF	Embryo length (mm)	Embryo width (mm)	Seed length (mm)	Seed width (mm)	Area of Embryo (cm^2)	Area of Seed (cm^2)	Embryo width/length	Seed width/length	Area embryo/seed
Total	41									
Population	2	.0711	.0000	.0017	.0101	.1426	.0167	.0000	.0000	.2279
Density	2	.0766	.0556	.0003	.7359	.0584	.2121	.1759	.0003	.5775
Size	2	.0144	.0000	.0059	.0000	.0001	.0000	.0131	.0000	.3373
Interactions‡	7	.6093	.1021	.7506	.4585	.1547	.2777	.7349	.6482	.8264
Error	28	2.91†	.38†	2.29†	1.80†	.06†	.37†	.0013†	.0011†	.0016†
C.V.		7.4	6.1	4.1	5.5	13.7	9.4	7.0	4.6	13.4

† Mean square for indicated error.

‡ Density x size
Population x density
Population x size
Population x density x size.

Appendix Table 14. Effect of seed density on daily seedling respiration per hour for fifty seeds.†

	Day			
Seed Density	2	3	4	5
Low	6.10	10.55	14.48	13.70
Medium	7.56	12.86	16.63	14.62
High	7.07	14.54	16.56	16.72
LSD(.05)	1.33	1.78	2.34	2.62

† μ moles CO_2.

Appendix Table 15. Effect of population and seed size on daily seedling respiration per hour for fifty seeds.†

	Day															
	2				3				4				5			
Population	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)
RMP 1	4.52	6.17	9.37	3.89	9.54	11.99	9.88	5.20	12.67	12.88	13.56	6.84	8.70	12.46	13.56	7.67
HMP 550	4.14	9.28	5.70	3.89	12.50	16.72	11.15	5.20	11.82	18.62	14.99	6.84	11.95	18.32	15.88	7.67
Serere 3A	5.57	6.71	9.63	3.89	20.27	14.19	13.59	5.20	15.96	15.50	18.97	6.84	17.23	11.91	18.97	7.67
Senegal	6.14	7.54	8.31	3.89	10.39	12.44	16.89	5.20	15.74	17.00	20.41	6.84	15.40	15.00	19.72	7.67
LSD(.05)	4.33	4.33	4.33		11.89	11.89	11.89		13.25	13.25	13.25		10.02	10.02	10.02	

† μ moles CO_2.

Appendix Table 16. Effect of population and seed size on daily seedling respiration per hour/per gram.†

	Day															
	2				3				4				5			
Population	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)	Small	Medium	Large	LSD(.05)
RMP 1	12.26	14.27	21.79	7.99	25.99	27.92	22.98	9.46	34.64	30.00	31.53	13.41	23.69	29.05	31.53	15.78
HMP 550	9.57	16.76	7.94	7.99	28.88	30.64	16.13	9.46	27.14	34.18	20.24	13.41	27.05	33.63	21.50	15.78
Serere 3A	11.14	10.63	12.27	7.99	40.54	21.80	17.18	9.46	31.92	23.78	24.09	13.41	32.46	18.24	23.94	15.78
Senegal	15.65	14.18	13.51	7.99	26.67	23.05	27.67	9.46	39.93	31.95	33.11	13.41	39.94	27.82	32.24	15.78
LSD(.05)	8.90	8.90	8.90		19.63	19.63	19.63		31.14	31.14	31.14		20.69	20.69	20.69	

† μ moles CO_2.

Appendix Table 17. Effect of seed density and size on percent protein.

	Seed size		
Seed density	Small	Medium	Large
Low	10.64	10.62	10.42
Medium	10.73	10.51	11.12
High	10.99	10.83	11.46
LSD(.05)	.30	.30	.30

Appendix Table 18. Effect of population and seed density on percent protein.

	Seed density			
Population	Low	Medium	High	LSD(.05)
RMP 1	10.67	10.43	10.73	.55
HMP 550	11.00	11.50	11.11	.55
Serere 3A	8.23	7.81	8.83	.55
Senegal	12.73	13.17	12.72	.55
LSD(.05)	.63	.63	.63	

Appendix Table 19. Explanations for identification code from Tables 20-26.

Populations:

1. RMP 1
2. HMP 550
3. Serere 3A
4. Senegal

Density:

1. Low
2. Medium
3. High

Size:

1. Small
2. Medium
3. Large

Appendix Table 20. Individual-plot data for field studies.

Observation	Emergence (%)	Plants/ hectare (000)	Days to anthesis	Seedling vigor (cm)	Heads/ hectare (000)	Heads/ plant	Grain yield (kg/ha)	Head weight (g)	Grain moisture (%)	Identification code			
										Replication	Population	Density	Size
1	66.36	157.09	56	21	79.55	0.51	585.00	7.35	12.1	1	3	3	1
2	68.18	161.39	55	26	74.34	0.46	790.00	10.62	11.8	1	3	1	3
3	70.91	167.85	55	25	92.60	0.55	855.00	9.24	12.0	1	3	2	2
4	73.64	174.30	56	31	84.77	0.49	847.00	9.99	15.1	1	3	3	3
5	66.36	157.09	56	24	80.86	0.51	1058.00	13.08	12.0	1	3	1	2
6	56.36	133.42	56	26	101.72	0.76	1154.00	11.35	13.2	1	3	2	1
7	67.73	160.31	56	28	66.51	0.41	994.00	14.94	11.7	1	3	2	3
8	64.55	152.78	56	28	74.34	0.49	935.00	12.57	13.0	1	3	3	2
9	50.91	120.50	56	25	100.42	0.83	1213.00	12.08	15.3	1	3	1	1
10	42.73	101.14	66	22	89.99	0.89	804.00	8.94	21.4	1	1	2	2
11	35.00	82.85	66	21	93.90	1.13	635.00	6.76	22.4	1	1	3	1
12	36.82	87.15	66	17	88.68	1.02	538.00	6.06	12.4	1	1	2	1
13	44.09	104.37	63	17	59.99	0.57	412.00	6.86	19.5	1	1	1	1
14	27.73	65.63	63	20	95.20	1.45	389.00	4.09	15.5	1	1	1	2
15	40.91	96.83	61	20	97.81	1.01	515.00	5.27	19.4	1	1	3	2
16	57.27	135.57	63	26	117.37	0.87	846.00	7.21	24.8	1	2	2	2
17	40.91	96.83	66	23	59.99	0.62	299.00	4.98	27.0	1	2	1	2
18	71.36	168.92	63	28	54.77	0.32	636.00	11.61	17.1	1	2	3	1

Appendix Table 20. Individual-plot data for field studies.

Observation	Emergence (%)	Plants/ hectare (000)	Days to anthesis	Seedling vigor (cm)	Heads/ hectare (000)	Heads/ plant	Grain yield (kg/ha)	Head weight (g)	Grain moisture (%)	Identification code			
										Replication	Population	Density	Size
19	60.45	143.10	69	27	75.64	0.53	733.00	9.69	26.5	1	2	3	2
20	37.73	89.30	69	17	46.95	0.53	274.00	5.84	23.4	1	2	1	1
21	55.91	132.34	69	27	62.60	0.47	358.00	5.72	22.2	1	2	1	3
22	60.45	143.10	66	27	54.77	0.38	764.00	13.95	21.4	1	2	2	1
23	59.09	139.87	69	23	54.77	0.39	567.00	10.35	20.8	1	2	2	3
24	70.45	166.77	63	25	91.29	0.55	835.00	9.15	16.3	1	2	3	3
25	35.91	85.00	73	14	20.87	0.25	0.01	0.01	0.0	1	4	1	1
26	55.45	131.26	63	22	88.68	0.68	815.00	9.19	22.3	1	4	3	1
27	59.09	139.87	63	22	122.59	0.88	672.00	5.48	17.9	1	4	2	1
28	54.55	129.11	63	16	104.33	0.81	306.00	2.93	14.6	1	4	1	3
29	44.55	105.44	63	17	65.21	0.62	331.00	5.08	19.0	1	4	1	2
30	54.09	128.04	59	26	100.42	0.78	1017.00	10.12	20.5	1	4	2	2
31	55.45	131.26	59	21	86.07	0.66	516.00	5.99	16.0	1	4	3	2
32	55.00	130.19	59	29	87.38	0.67	546.00	6.25	14.6	1	4	3	3
33	63.18	149.55	63	26	57.38	0.38	348.00	6.06	20.0	1	4	2	3
34	70.91	167.85	56	24	61.30	0.37	365.00	5.96	10.8	2	3	3	1
35	69.09	163.54	56	28	56.08	0.34	387.00	6.90	11.0	2	3	2	3
36	97.73	231.33	59	25	112.16	0.48	898.00	8.01	12.2	2	3	2	1

Appendix Table 20. Individual-plot data for field studies.

Observation	Emergence (%)	Plants/ hectare (000)	Days to anthesis	Seedling vigor (cm)	Heads/ hectare (000)	Heads/ plant	Grain yield (kg/ha)	Head weight (g)	Grain moisture (%)	Identification code: Replication	Population	Density	Size
37	67.27	159.24	56	31	187.80	1.18	1654.00	8.81	14.9	2	3	3	3
38	44.55	105.44	73	22	67.82	0.64	540.00	7.97	12.0	2	3	1	2
39	72.73	172.15	59	23	79.55	0.46	778.00	9.78	17.8	2	3	2	2
40	61.82	146.33	63	20	43.04	0.29	360.00	8.36	17.3	2	3	1	1
41	55.91	132.34	56	25	58.69	0.44	571.00	9.73	14.1	2	3	1	3
42	65.00	153.86	59	26	80.86	0.53	1041.00	12.88	11.5	2	3	3	2
43	24.55	58.10	71	12	0.01	0.01	0.01	0.00	0.0	2	1	1	1
44	43.64	103.29	69	15	70.42	0.68	184.00	2.61	10.1	2	1	3	1
45	39.55	93.61	66	21	112.16	1.20	166.00	1.48	18.8	2	1	2	1
46	38.18	90.38	66	15	78.25	0.87	261.00	3.33	15.1	2	1	2	3
47	46.82	110.82	63	22	95.20	0.86	543.00	5.71	21.3	2	1	3	2
48	26.36	62.40	69	19	83.47	1.34	509.00	6.10	28.9	2	1	1	2
49	38.64	91.45	63	20	86.07	0.94	686.00	7.97	10.6	2	1	2	2
50	67.27	159.24	66	31	32.60	0.20	509.00	15.60	23.5	2	2	3	3
51	52.27	123.73	69	22	48.25	0.39	582.00	12.07	24.1	2	2	1	3
52	67.73	160.31	63	29	49.56	0.31	533.00	10.76	19.8	2	2	3	1
53	67.27	159.24	69	30	50.86	0.32	1170.00	23.01	18.3	2	2	2	2
54	55.45	131.26	66	24	53.47	0.41	543.00	10.16	29.2	2	2	2	1

Appendix Table 20. Individual-plot data for field studies.

Observation	Emergence (%)	Plants/ hectare (000)	Days to anthesis	Seedling vigor (cm)	Heads/ hectare (000)	Heads/ plant	Grain yield (kg/ha)	Head weight (g)	Grain moisture (%)	Identification code			
										Replication	Population	Density	Size
55	69.09	163.54	69	24	70.42	0.43	680.00	9.66	24.0	2	2	3	2
56	40.91	96.83	73	30	45.65	0.47	304.00	6.67	25.6	2	2	1	1
57	63.18	149.55	66	26	30.00	0.20	307.00	10.24	19.9	2	2	2	3
58	49.09	116.20	66	22	27.39	0.24	461.00	16.85	18.0	2	2	1	2
59	45.91	108.67	73	14	62.60	0.58	283.00	4.52	21.0	2	4	1	2
60	59.55	140.95	66	20	78.25	0.56	577.00	7.38	27.2	2	4	3	1
61	38.64	91.45	76	18	18.26	0.20	112.00	6.11	45.5	2	4	1	1
62	59.09	139.87	63	23	122.59	0.88	612.00	4.99	20.3	2	4	3	3
63	72.73	172.15	56	21	83.47	0.48	1098.00	13.15	10.6	2	4	2	1
64	73.18	173.22	56	26	93.90	0.54	1648.00	17.56	12.9	2	4	1	3
65	61.82	146.33	66	18	59.99	0.41	387.00	6.45	24.4	2	4	3	2
66	53.64	126.96	66	24	53.47	0.42	397.00	7.42	18.4	2	4	2	3
67	56.36	133.42	66	20	79.55	0.60	605.00	7.60	21.2	2	4	2	2
68	70.91	167.85	69	30	84.77	0.51	1011.00	11.93	22.5	3	2	3	1
69	45.91	108.67	69	19	41.73	0.38	487.00	11.66	14.3	3	2	1	2
70	62.27	147.40	66	27	67.82	0.46	827.00	12.20	26.5	3	2	2	3
71	60.91	144.17	63	21	73.03	0.51	854.00	11.70	24.1	3	2	2	2
72	27.27	64.56	75	18	0.01	0.01	0.01	0.00	0.0	3	2	1	1

Appendix Table 20. Individual-plot data for field studies.

Observation	Emergence (%)	Plants/ hectare (000)	Days to anthesis	Seedling vigor (cm)	Heads/ hectare (000)	Heads/ plant	Grain yield (kg/ha)	Head weight (g)	Grain moisture (%)	Identification code			
										Replication	Population	Density	Size
73	55.91	132.34	66	23	44.34	0.34	679.00	15.30	19.6	3	2	2	1
74	62.27	147.40	73	19	30.00	0.20	302.00	10.08	26.1	3	2	1	3
75	52.73	124.81	69	26	62.60	0.50	761.00	12.15	15.0	3	2	3	3
76	65.45	154.93	66	26	67.82	0.44	1212.00	17.88	22.3	3	2	3	2
77	35.91	85.00	78	21	0.01	0.01	0.01	0.00	0.0	3	4	1	1
78	47.27	111.90	66	17	33.91	0.30	211.00	6.22	17.5	3	4	2	2
79	55.00	130.19	63	25	69.12	0.53	525.00	7.59	21.1	3	4	2	1
80	49.09	116.20	66	24	49.56	0.43	390.00	7.88	15.2	3	4	3	3
81	58.64	138.80	66	23	65.21	0.47	542.00	8.32	29.3	3	4	3	1
82	49.09	116.20	63	25	91.29	0.79	719.00	7.88	21.9	3	4	2	3
83	46.36	109.74	66	24	65.21	0.59	535.00	8.20	27.9	3	4	1	3
84	33.64	79.62	69	19	39.12	0.49	148.00	3.77	27.9	3	4	1	2
85	47.73	112.97	63	24	73.03	0.65	1035.00	14.17	29.0	3	4	3	2
86	37.27	88.23	66	21	93.90	1.06	500.00	5.32	30.2	3	1	3	2
87	40.91	96.83	63	22	129.11	1.33	1033.00	8.00	27.9	3	1	3	1
88	36.36	86.07	69	23	50.86	0.59	154.00	3.03	24.7	3	1	2	1
89	40.45	95.76	63	22	79.55	0.83	422.00	5.31	13.1	3	1	2	2
90	37.73	89.30	66	20	37.82	0.42	54.00	1.43	29.7	3	1	2	3

Appendix Table 20. Individual-plot data for field studies.

Observation	Emergence (%)	Plants/ hectare (000)	Days to anthesis	Seedling vigor (cm)	Heads/ hectare (000)	Heads/ plant	Grain yield (kg/ha)	Head weight (g)	Grain moisture (%)	Identification code Replication	Population	Density	Size
91	23.64	55.95	78	17	0.01	0.01	0.01	0.00	0.0	3	1	1	1
92	23.64	55.95	66	20	0.01	0.01	0.01	0.00	0.0	3	1	1	2
93	70.00	165.69	59	30	91.29	0.55	992.00	10.86	17.5	3	3	3	2
94	55.00	130.19	59	25	75.64	0.58	602.00	7.95	16.0	3	3	2	1
95	63.64	150.63	63	20	48.25	0.32	397.00	8.22	18.4	3	3	1	3
96	57.27	135.57	63	18	48.25	0.36	337.00	6.98	22.5	3	3	1	1
97	67.27	159.24	59	26	106.94	0.67	620.00	5.80	19.2	3	3	3	3
98	72.73	172.15	56	25	91.29	0.53	890.00	9.75	13.0	3	3	2	3
99	68.18	161.39	56	28	75.64	0.47	790.00	10.44	14.2	3	3	3	1
100	69.55	164.62	59	23	76.95	0.47	461.00	5.99	14.2	3	3	2	2
101	62.27	147.40	59	25	62.60	0.42	540.00	8.63	12.0	3	3	1	2

Appendix Table 21. Individual-plot data for observations on seed weight, sieving results, seed shape, total germination, germination index, and seed diameter.

Observation	Identification code: Replication	Population	Density	Size	Seed weight (g)	Number of seeds out of 50 retained on sieves of indicated hole diameter (mm): 2.62	2.01	1.65	1.45	Seed shape	Total germination	Germination index	Average seed diameter (mm)
1	1	3	3	1	0.44	0	50	0	0	3	46	258	2.0100
2	1	3	1	3	0.65	46	4	0	0	4	44	227	2.5712
3	1	3	2	2	0.58	21	29	0	0	2	49	274	2.2662
4	1	3	3	3	0.79	47	3	0	0	2	47	272	2.5834
5	1	3	1	2	0.50	19	31	0	0	3	44	240	2.2418
6	1	3	2	1	0.42	0	50	0	0	2	47	267	2.0100
7	1	3	2	3	0.68	33	17	0	0	3	48	268	2.4126
8	1	3	3	2	0.56	20	30	0	0	3	46	264	2.2540
9	1	3	1	1	0.59	0	50	0	0	4	46	253	2.0100
10	1	1	2	2	0.35	2	44	4	0	4	38	194	2.0056
11	1	1	3	1	0.31	0	42	8	0	4	41	213	1.9524
12	1	1	2	1	0.26	0	31	19	0	4	39	202	1.8732
13	1	1	1	1	0.21	0	30	20	0	4	35	173	1.8660
14	1	1	1	2	0.34	6	44	0	0	4	31	154	2.0832
15	1	1	3	2	0.38	4	43	3	0	4	35	188	2.0372
16	1	2	2	2	0.49	6	42	2	0	2	45	259	2.0688
17	1	2	1	2	0.43	11	39	0	0	3	34	184	2.1442

Appendix Table 21. Individual-plot data for observations on seed weight, sieving results, seed shape, total germination, germination index, and seed diameter.

Observation	Identification code: Replication	Population	Density	Size	Seed weight (g)	Number of seeds out of 50 retained on sieves of indicated hole diameter (mm): 2.62	2.01	1.65	1.45	Seed shape	Total germination	Germination index	Average seed diameter (mm)
18	1	2	3	1	0.39	0	44	6	0	3	47	279	1.9668
19	1	2	3	2	0.52	5	45	0	0	3	48	279	2.0710
20	1	2	2	1	0.37	0	37	12	1	2	48	288	1.9124
21	1	2	2	3	0.58	19	30	1	0	3	44	253	2.2346
22	1	2	3	3	0.39	17	32	1	0	2	46	270	2.2102
23	1	4	1	1	0.26	0	8	42	0	4	41	234	1.7076
24	1	4	3	1	0.36	0	40	9	1	4	38	222	1.9340
25	1	4	2	1	0.37	0	37	12	1	3	47	261	1.9124
26	1	4	1	3	0.39	20	27	3	0	4	50	246	2.2324
27	1	4	1	2	0.42	8	42	0	0	4	41	216	2.1076
28	1	4	2	2	0.37	6	43	1	0	4	43	233	2.0760
29	1	4	3	2	0.46	9	41	0	0	3	42	241	2.1198
30	1	4	3	3	0.71	46	4	0	0	4	44	250	2.5712
31	1	4	2	3	0.42	24	25	1	0	4	46	243	2.2956
32	2	3	3	1	0.63	0	50	0	0	3	50	292	2.0100
33	2	3	2	3	0.63	36	14	0	0	3	39	220	2.4492
34	2	3	2	1	0.42	0	50	0	0	3	49	283	2.0100

Appendix Table 21. Individual-plot data for observations on seed weight, sieving results, seed shape, total germination, germination index, and seed diameter.

	Identification code				Seed weight	Number of seeds out of 50 retained on sieves of indicated hole diameter (mm)				Seed	Total	Germination	Average seed diameter
Observation	Replication	Population	Density	Size	(g)	2.62	2.01	1.65	1.45	shape	germination	index	(mm)
35	2	3	3	3	0.70	47	3	0	0	2	49	284	2.5834
36	2	3	1	2	0.53	20	30	0	0	3	46	268	2.2540
37	2	3	2	2	0.54	16	34	0	0	2	46	271	2.2052
38	2	3	1	1	0.37	2	48	0	0	4	47	265	2.0344
39	2	3	1	3	0.63	46	4	0	0	4	43	222	2.5712
40	2	3	3	2	0.61	17	33	0	0	3	46	270	2.2174
41	2	1	1	1	0.18	0	22	28	0	4	34	172	1.8084
42	2	1	3	1	0.35	0	36	14	0	4	35	190	1.9092
43	2	1	2	1	0.27	0	32	16	2	4	42	228	1.8724
44	2	1	3	2	0.37	4	38	8	0	4	43	236	2.0012
45	2	1	1	2	0.30	3	47	0	0	4	35	184	2.0466
46	2	1	2	2	0.30	4	40	6	0	4	41	221	2.0156
47	2	2	3	3	0.53	15	35	0	0	2	49	289	2.1930
48	2	2	3	1	0.40	0	41	9	0	3	48	288	1.9452
49	2	2	2	2	0.51	5	45	0	0	2	50	296	2.0710
50	2	2	2	1	0.33	0	35	15	0	2	50	300	1.9020
51	2	2	3	2	0.50	4	45	1	0	3	48	287	2.0516

Appendix Table 21. Individual-plot data for observations on seed weight, sieving results, seed shape, total germination, germination index, and seed diameter.

Observation	Identification code: Replication	Population	Density	Size	Seed weight (g)	Number of seeds out of 50 retained on sieves of indicated hole diameter (mm): 2.62	2.01	1.65	1.45	Seed shape	Total germination	Germination index	Average seed diameter (mm)
52	2	2	2	3	0.49	36	14	0	0	3	44	263	2.4492
53	2	2	1	2	0.51	2	46	2	0	3	38	223	2.0200
54	2	4	1	2	0.39	10	38	2	0	4	44	235	2.1176
55	2	4	3	1	0.35	0	37	13	0	4	40	231	1.9164
56	2	4	1	1	0.26	0	23	26	1	4	39	215	1.8116
57	2	4	3	3	0.68	45	5	0	0	4	43	249	2.5590
58	2	4	2	1	0.36	0	39	11	0	3	48	285	1.9308
59	2	4	1	3	0.43	23	23	4	0	4	42	234	2.2618
60	2	4	3	2	0.53	8	42	0	0	3	39	225	2.1076
61	2	4	2	3	0.42	20	25	4	1	4	47	255	2.2140
62	2	4	2	2	0.46	10	40	0	0	4	49	290	2.1320
63	3	2	3	1	0.38	0	36	14	0	3	45	268	1.9092
64	3	2	1	2	0.44	6	44	0	0	3	39	208	2.0832
65	3	2	2	3	0.63	21	27	2	0	3	43	246	2.2518
66	3	2	2	2	0.49	13	37	0	0	2	44	259	2.1686
67	3	2	2	1	0.30	0	28	22	0	2	44	263	1.8516
68	3	2	3	3	0.55	13	35	2	0	2	47	272	2.1542

Appendix Table 21. Individual-plot data for observations on seed weight, sieving results, seed shape, total germination, germination index, and seed diameter.

	Identification code				Seed weight	Number of seeds out of 50 retained on sieves of indicated hole diameter (mm)							Average seed diameter
Observation	Replication	Population	Density	Size	(g)	2.62	2.01	1.65	1.45	Seed shape	Total germination	Germination index	(mm)
69	3	2	3	2	0.46	4	45	1	0	3	48	280	2.0516
70	3	4	1	1	0.22	0	16	34	0	4	41	221	1.7652
71	3	4	2	2	0.33	6	43	1	0	4	44	250	2.0760
72	3	4	2	1	0.21	0	32	18	0	3	48	272	1.8804
73	3	4	3	3	0.72	48	2	0	0	4	40	212	2.5956
74	3	4	3	1	0.35	0	37	13	0	4	43	245	1.9164
75	3	4	2	3	0.50	20	24	6	0	4	35	199	2.2108
76	3	4	1	3	0.43	19	29	2	0	4	39	199	2.2274
77	3	4	1	2	0.28	4	41	5	0	4	38	192	2.0228
78	3	4	3	2	0.52	9	41	0	0	3	43	229	2.1198
79	3	1	3	2	0.35	2	41	7	0	4	38	204	1.9840
80	3	1	3	1	0.29	0	43	7	0	4	31	164	1.9596
81	3	1	2	1	0.21	0	34	16	0	4	36	192	1.8948
82	3	1	2	2	0.37	2	41	6	1	4	40	203	1.9800
83	3	1	1	1	0.17	0	20	28	2	4	37	201	1.7860
84	3	1	1	2	0.34	3	46	1	0	4	37	191	2.0394
85	3	3	3	2	0.59	0	38	12	0	3	48	288	1.9236

Appendix Table 21. Individual-plot data for observations on seed weight, sieving results, seed shape, total germination, germination index, and seed diameter.

	Identification code				Seed weight	Number of seeds out of 50 retained on sieves of indicated hole diameter (mm)				Seed	Total	Germination	Average seed diameter
Observation	Replication	Population	Density	Size	(g)	2.62	2.01	1.65	1.45	shape	germination	index	(mm)
86	3	3	2	1	0.43	0	48	2	0	2	47	278	1.9956
87	3	3	1	3	0.62	48	2	0	0	4	35	206	2.5956
88	3	3	1	1	0.38	1	49	0	0	4	44	246	2.0222
89	3	3	3	3	0.67	47	3	0	0	2	50	295	2.5834
90	3	3	2	3	0.64	34	16	0	0	3	49	284	2.4248
91	3	3	3	1	0.45	0	50	0	0	3	49	286	2.0100
92	3	3	2	2	0.51	14	36	0	0	2	47	280	2.1808
93	3	3	1	2	0.51	17	33	0	0	3	46	270	2.2174

Appendix Table 22. Individual-plot data for observations on starch appearance and relative embryo size.

Observation	Identification code				Starch appearance	Apparent relative embryo size
	Replication	Population	Density	Size		
1	1	3	3	1	3.1	3.2
2	1	3	1	3	3.0	3.4
3	1	3	2	2	2.8	3.3
4	1	3	3	3	2.8	3.8
5	1	3	1	2	3.2	3.4
6	1	3	2	1	3.1	2.7
7	1	3	2	3	2.5	3.6
8	1	3	3	2	2.6	3.2
9	1	3	1	1	2.9	3.4
10	1	1	2	2	2.5	3.1
11	1	1	3	1	1.6	3.5
12	1	1	2	1	2.3	3.8
13	1	1	1	1	2.7	3.4
14	1	1	1	2	3.0	3.0
15	1	1	3	2	2.0	3.5
16	1	1	2	3	1.9	3.1
17	1	2	2	2	2.3	2.6
18	1	2	1	2	3.1	2.0
19	1	2	3	1	2.3	3.4
20	1	2	3	2	2.8	3.2
21	1	2	1	1	3.0	2.7
22	1	2	1	3	2.4	3.6
23	1	2	2	1	2.6	3.1
24	1	2	2	3	2.7	2.7
25	1	2	3	3	2.0	3.6

Appendix Table 22. Individual-plot data for observations on starch appearance and relative embryo size.

Observation	Identification code				Starch appearance	Apparent relative embryo size
	Replication	Population	Density	Size		
26	1	4	1	1	2.1	3.6
27	1	4	3	1	1.5	3.6
28	1	4	2	1	1.8	3.5
29	1	4	1	3	3.3	3.6
30	1	4	1	2	2.6	3.8
31	1	4	2	2	2.3	3.6
32	1	4	3	2	1.7	3.3
33	1	4	3	3	1.6	3.7
34	1	4	2	3	2.0	3.7
35	2	3	3	1	2.7	3.8
36	2	3	2	3	3.1	2.9
37	2	3	2	1	3.2	3.5
38	2	3	3	3	2.6	4.0
39	2	3	1	2	3.2	3.1
40	2	3	2	2	2.7	3.5
41	2	3	1	1	3.5	2.6
42	2	3	1	3	3.1	3.5
43	2	3	3	2	3.6	3.0
44	2	1	1	1	3.3	3.0
45	2	1	3	1	2.0	3.5
46	2	1	2	1	2.6	3.3
47	2	1	2	3	1.7	3.1
48	2	1	3	2	2.2	2.9
49	2	1	1	2	3.6	3.6
50	2	1	2	2	2.5	2.9

Appendix Table 22. Individual-plot data for observations on starch appearance and relative embryo size.

Observation	Identification code: Replication	Population	Density	Size	Starch appearance	Apparent relative embryo size
51	2	2	3	3	2.8	3.9
52	2	2	1	3	2.9	3.5
53	2	2	3	1	2.1	2.8
54	2	2	2	2	2.4	3.5
55	2	2	2	1	3.1	3.2
56	2	2	3	2	2.5	3.6
57	2	2	1	1	2.6	2.3
58	2	2	2	3	2.6	3.4
59	2	2	1	2	3.4	3.4
60	2	4	1	2	1.6	3.5
61	2	4	3	1	1.7	3.2
62	2	4	1	1	3.0	3.6
63	2	4	3	3	1.9	4.0
64	2	4	2	1	1.6	3.7
65	2	4	1	3	2.5	3.7
66	2	4	3	2	1.6	3.7
67	2	4	2	3	2.4	3.7
68	2	4	2	2	2.2	3.5
69	3	2	3	1	2.3	3.6
70	3	2	1	2	3.2	2.9
71	3	2	2	3	2.7	2.8
72	3	2	2	2	2.3	3.1
73	3	2	1	1	3.4	2.8
74	3	2	2	1	2.7	2.5
75	3	2	1	3	3.0	3.8

Appendix Table 22. Individual-plot data for observations on starch appearance and relative embryo size.

Observation	Identification code: Replication	Population	Density	Size	Starch appearance	Apparent relative embryo size
76	3	2	3	3	2.3	3.7
77	3	2	3	2	2.3	3.6
78	3	4	1	1	3.0	3.5
79	3	4	2	2	2.3	3.7
80	3	4	2	1	1.7	3.5
81	3	4	3	3	2.2	3.8
82	3	4	3	1	1.2	3.3
83	3	4	2	3	2.7	3.8
84	3	4	1	3	2.5	3.6
85	3	4	1	2	2.6	3.6
86	3	4	3	2	2.0	2.9
87	3	1	3	2	1.8	3.3
88	3	1	3	1	1.7	3.0
89	3	1	2	1	2.6	3.0
90	3	1	2	2	2.9	3.1
91	3	1	2	3	2.0	3.4
92	3	1	1	1	3.6	2.7
93	3	1	1	2	3.6	2.7
94	3	3	3	2	2.8	3.5
95	3	3	2	1	3.1	2.8
96	3	3	1	3	3.2	3.3
97	3	3	1	1	3.5	2.9
98	3	3	3	3	2.3	3.8
99	3	3	2	3	2.7	3.8
100	3	3	3	1	2.9	3.7

Appendix Table 22. Individual-plot data for observations on starch appearance and relative embryo size.

Observation	Identification code				Starch appearance	Apparent relative embryo size
	Replication	Population	Density	Size		
101	3	3	2	2	3.0	2.8
102	3	3	1	2	3.2	3.2

Appendix Table 23. Individual-plot data for observations on seed density by water displacement.

Observation	Identification code: Replication	Population	Density	Size	Seed density by water displacement
1	1	3	3	2	1.25
2	1	1	3	1	1.35
3	1	2	2	3	1.25
4	1	2	3	1	1.28
5	1	3	1	3	1.16
6	1	4	1	1	1.19
7	1	1	3	2	1.32
8	1	4	2	2	1.25
9	1	4	3	2	1.25
10	1	1	2	2	1.22
11	1	2	2	2	1.25
12	1	2	3	2	1.52
13	1	1	2	1	1.28
14	1	4	2	1	1.25
15	1	4	3	1	1.28
16	1	2	3	3	1.25
17	1	3	3	3	1.25
18	1	2	2	1	1.25
19	1	3	2	3	1.25
20	2	1	3	2	1.32
21	2	4	2	2	1.28
22	2	1	2	2	1.25
23	2	4	3	2	1.32
24	2	2	2	2	1.28
25	2	3	3	2	1.28

Appendix Table 23. Individual-plot data for observations on seed density by water displacement.

Observation	Identification code				Seed density by water displacement
	Replication	Population	Density	Size	
26	2	2	3	2	1.32
27	2	4	1	1	1.25
28	2	1	2	1	1.28
29	2	4	2	1	1.28
30	2	4	3	1	1.32
31	2	2	3	3	1.35
32	2	3	3	3	1.32
33	2	2	2	1	1.32
34	2	3	2	3	1.28
35	3	1	3	2	1.32
36	3	4	2	2	1.28
37	3	4	3	2	1.32
38	3	2	2	2	1.32
39	3	2	3	2	1.32
40	3	1	2	1	1.28
41	3	4	2	1	1.28
42	3	4	3	1	1.32
43	3	2	3	3	1.28
44	3	3	3	3	1.32
45	3	2	2	1	1.32
46	3	1	2	2	1.52
47	3	3	3	2	1.28
48	3	3	2	3	1.25

Appendix Table 24. Individual-plot data for observations on seedling respiration µ moles /hr, seedling respiration/hr/g, average seedling respiration/hr, and average seedling respiration/hr/g. (µ moles CO_2)

	Identification code				Respiration/hr				Respiration/hr/g				Average respiration/hr	Average respiration/hr/g
Observation	Replication	Population	Density	Size	Day 2	Day 3	Day 4	Day 5	Day 2	Day 3	Day 4	Day 5		
1	1	3	3	1	5.57	20.27	15.96	17.23	11.14	40.54	31.92	34.46	14.76	29.52
2	1	3	1	3	8.61	8.61	19.00	21.28	10.63	10.63	23.46	26.27	14.38	17.75
3	1	3	2	2	8.87	6.33	10.39	5.57	14.54	10.38	17.03	9.13	7.79	12.77
4	1	3	3	3	11.91	2.28	26.09	21.79	14.01	2.68	30.69	25.64	15.52	18.26
5	1	3	2	3	13.43	12.92	20.52	23.05	17.67	17.00	27.00	30.33	17.48	23.00
6	1	3	3	2	9.12	11.65	19.51	21.03	15.20	17.39	29.12	31.39	15.33	22.87
7	1	1	2	2	6.33	9.12	14.95	7.60	14.07	20.27	33.22	16.89	9.50	21.11
8	1	1	3	1	2.53	10.13	14.44	11.40	6.49	25.97	37.03	29.23	9.63	24.68
9	1	1	2	1	7.35	8.61	12.67	7.85	22.27	26.09	38.39	23.79	9.12	27.64
10	1	1	3	2	11.40	19.00	23.05	23.31	24.78	41.30	50.11	50.67	19.19	41.72
11	1	1	2	3	10.13	10.64	14.95	12.92	23.56	24.74	34.77	30.05	12.16	28.28
12	1	2	2	2	16.47	14.95	21.53	20.52	28.40	25.78	37.12	35.38	18.37	31.67
13	1	2	1	2	3.04	12.16	11.91	17.48	6.76	27.02	26.47	38.84	11.15	24.77
14	1	2	3	1	3.55	9.88	10.64	23.31	7.55	21.02	22.64	49.60	11.84	25.20
15	1	2	3	2	11.65	25.08	10.39	28.12	20.80	44.79	18.55	50.21	18.81	33.59
16	1	2	2	1	3.80	13.93	14.70	12.92	9.05	33.17	35.00	30.76	11.34	26.99

Appendix Table 24. Individual-plot data for observations on seedling respiration μ moles/hr, seedling respiration/hr/g, average seedling respiration/hr, and average seedling respiration/hr/g. (μ moles CO_2)

	Identification code				Respiration/hr				Respiration/hr/g				Average respiration/hr	Average respiration/hr/g
Observation	Replication	Population	Density	Size	Day 2	Day 3	Day 4	Day 5	Day 2	Day 3	Day 4	Day 5		
17	1	2	2	3	5.07	9.12	11.91	13.68	8.18	14.71	19.21	22.06	9.94	16.04
18	1	2	3	3	7.85	15.96	22.55	22.80	11.38	23.13	32.68	33.04	17.29	25.06
19	1	4	1	1	6.33	8.36	20.27	15.71	19.18	25.33	61.42	47.60	12.67	38.38
20	1	4	3	1	8.36	14.44	15.71	20.77	19.90	34.38	37.40	49.45	14.82	35.29
21	1	4	2	1	8.87	10.89	21.03	25.33	21.63	26.56	51.29	61.78	16.53	40.32
22	1	4	1	3	5.32	19.00	18.49	14.19	10.64	38.00	36.98	28.38	14.25	28.50
23	1	4	1	2	7.60	8.87	18.49	9.37	16.89	19.71	41.09	20.82	11.08	24.62
24	1	4	2	2	2.79	15.20	22.55	19.51	4.89	26.67	39.56	34.23	15.01	26.33
25	1	4	3	2	11.40	18.75	23.81	18.75	19.32	31.78	40.36	31.78	18.18	30.81
26	1	4	3	3	12.67	24.32	28.32	28.30	15.45	29.66	34.54	34.51	23.40	28.54
27	1	4	2	3	10.39	14.19	22.29	27.36	17.03	23.26	36.54	44.85	18.56	30.42
28	2	3	2	3	10.13	17.99	24.07	24.57	13.33	23.67	31.67	32.33	19.19	25.25
29	2	3	3	3	6.33	25.33	26.09	26.09	7.36	29.45	30.34	30.34	20.96	24.38
30	2	3	2	2	5.07	22.04	21.53	19.25	7.92	34.44	33.64	30.08	16.97	26.52
31	2	3	1	3	8.36	14.44	23.81	16.97	12.12	20.93	34.51	24.59	15.90	23.04
32	2	3	3	2	6.33	15.71	15.71	7.35	9.74	24.17	24.17	11.31	11.27	17.34

Appendix Table 24. Individual-plot data for observations on seedling respiration μ moles/hr, seedling respiration/hr/g, average seedling respiration/hr, and average seedling respiration/hr/g. (μ moles CO_2)

	Identification code				Respiration/hr				Respiration/hr/g				Average respiration/	Average respiration/
Observation	Replication	Population	Density	Size	Day 2	Day 3	Day 4	Day 5	Day 2	Day 3	Day 4	Day 5	hr	hr/g
33	2	1	3	1	5.32	7.60	14.69	9.88	14.00	20.00	38.66	26.00	9.37	24.67
34	2	1	2	1	5.07	8.61	8.87	6.59	11.52	19.57	20.16	14.98	7.28	16.55
35	2	1	2	3	8.61	9.12	12.16	14.19	20.02	21.21	28.28	33.00	11.02	25.63
36	2	1	3	2	5.07	7.35	8.61	12.16	11.79	17.09	20.02	28.28	8.30	19.29
37	2	1	2	2	6.33	9.88	8.61	5.07	15.07	23.52	20.50	12.07	7.47	17.79
38	2	2	3	3	6.33	15.71	9.88	13.43	10.21	25.34	15.94	21.66	11.34	18.28
39	2	2	3	1	2.53	10.13	8.61	7.09	6.02	24.20	20.50	16.88	7.09	16.89
40	2	2	2	2	10.39	18.75	21.28	17.48	18.23	32.89	37.33	30.67	16.97	29.77
41	2	2	2	1	5.57	15.45	10.64	13.93	13.26	36.78	25.33	33.17	11.40	27.14
42	2	2	3	2	10.89	15.96	19.76	25.46	19.80	29.02	35.93	46.29	18.02	32.76
43	2	2	2	3	5.83	7.60	18.75	20.27	3.89	5.07	12.50	13.51	13.11	20.48
44	2	2	1	2	4.05	5.83	10.89	5.32	8.44	12.15	22.69	11.08	6.52	13.59
45	2	4	1	2	8.61	8.87	15.20	14.44	18.72	19.28	33.04	31.39	11.78	25.61
46	2	4	3	1	8.61	8.87	17.99	5.32	19.13	19.71	39.98	11.82	10.20	22.66
47	2	4	1	1	3.04	7.85	8.36	14.95	9.50	24.53	26.13	46.72	8.55	26.72
48	2	4	3	3	9.12	16.21	21.53	19.76	11.12	19.77	26.26	24.10	16.66	20.31

Appendix Table 24. Individual-plot data for observations on seedling respiration μ moles/hr, seedling respiration/hr/g, average seedling respiration/hr, and average seedling respiration/hr/g. (μ moles CO_2)

	Identification code				Respiration/hr				Respiration/hr/g				Average respiration/	Average respiration/
Observation	Replication	Population	Density	Size	Day 2	Day 3	Day 4	Day 5	Day 2	Day 3	Day 4	Day 5	hr	hr/g
49	2	4	2	1	9.63	9.37	14.95	18.75	25.34	24.66	39.34	49.34	13.17	34.67
50	2	4	1	3	9.63	11.15	15.96	22.55	20.93	24.24	34.69	49.02	14.82	32.22
51	2	4	3	2	5.32	13.93	10.13	19.51	9.02	23.61	17.17	33.07	12.22	20.71
52	2	4	2	3	5.07	16.47	16.97	16.47	8.74	28.40	29.26	28.40	13.74	23.70
53	2	4	2	2	8.87	13.43	23.31	13.43	15.84	23.98	41.63	23.98	14.76	26.36
54	3	2	3	1	2.53	9.37	11.40	8.36	5.27	19.52	23.75	17.42	7.92	16.69
55	3	2	2	3	3.80	10.39	9.12	15.20	5.94	16.23	14.25	23.75	9.63	15.05
56	3	2	2	2	8.61	21.28	28.63	8.61	15.94	39.41	53.02	15.94	16.78	31.08
57	3	2	2	1	6.84	16.21	14.95	6.08	16.29	38.60	35.60	14.48	11.02	26.24
58	3	2	3	3	5.32	8.11	17.73	9.88	8.06	12.29	26.86	14.97	10.26	15.54
59	3	2	3	2	9.12	19.76	24.57	23.56	15.72	34.07	42.36	40.62	19.25	33.20
60	3	4	1	1	3.04	9.88	6.08	8.11	9.21	29.94	18.42	24.58	6.78	20.54
61	3	4	2	2	12.41	10.39	18.49	16.72	22.56	18.89	33.62	30.40	14.50	26.37
62	3	4	2	1	2.79	8.36	22.29	14.19	6.34	19.00	50.66	32.25	11.91	27.06
63	3	4	3	3	8.11	21.28	28.75	23.05	10.67	28.00	37.83	30.33	20.30	26.71
64	3	4	3	1	4.56	15.45	14.95	15.45	10.60	35.93	34.77	35.93	12.60	29.31

Appendix Table 24. Individual-plot data for observations on seedling respiration μ moles/hr, seedling respiration/hr/g, average seedling respiration/hr, and averaged seedling respiration/hr/g. (μ moles CO_2)

	Identification code				Respiration/hr				Respiration/hr/g				Average respiration/	Average respiration/
Observation	Replication	Population	Density	Size	Day 2	Day 3	Day 4	Day 5	Day 2	Day 3	Day 4	Day 5	hr	hr/g
65	3	4	2	3	9.63	14.95	15.71	13.43	16.05	24.92	26.18	22.38	13.43	22.38
66	3	4	1	3	4.81	14.44	15.71	12.41	10.93	32.82	35.70	28.20	11.84	26.92
67	3	4	1	2	2.79	9.63	10.39	9.12	5.94	20.49	22.11	19.40	7.98	16.98
68	3	4	3	2	8.11	12.92	10.64	14.19	14.48	23.07	19.00	25.34	11.46	20.47
69	3	1	3	2	2.79	13.68	7.09	11.40	6.20	30.40	15.76	25.33	8.74	19.42
70	3	1	3	1	3.55	9.63	10.39	6.33	8.66	23.49	25.34	15.44	7.47	18.22
71	3	1	2	1	3.29	12.67	14.95	10.13	10.61	40.87	48.23	32.68	10.26	33.10
72	3	1	2	2	5.07	12.92	14.95	15.20	13.70	34.92	40.41	41.08	12.03	32.52
73	3	3	3	2	5.57	13.43	14.44	8.61	8.07	19.46	20.93	12.48	10.51	15.24
74	3	3	1	3	10.13	8.61	8.11	9.88	13.51	11.48	10.81	13.17	9.18	12.24
75	3	3	3	3	7.60	18.49	9.88	14.69	8.64	21.01	11.22	16.69	12.67	14.39
76	3	3	2	3	10.13	13.68	13.17	12.41	13.16	17.77	17.10	16.12	12.35	16.04
77	3	3	2	2	5.32	15.96	11.40	9.63	8.31	24.94	17.81	15.05	10.58	16.53

Appendix Table 25. Individual-plot data for observations on percent protein.

Observation	Identification code: Replication	Population	Density	Size	Percent protein
1	1	3	1	3	7.7
2	1	3	2	2	6.9
3	1	3	3	3	9.2
4	1	3	1	2	9.3
5	1	3	2	1	7.6
6	1	3	2	3	8.3
7	1	3	3	2	8.8
8	1	3	1	1	7.3
9	1	1	2	2	10.8
10	1	1	3	1	11.1
11	1	1	2	1	10.2
12	1	1	1	1	11.2
13	1	1	1	2	10.4
14	1	1	3	2	10.7
15	1	2	2	2	11.4
16	1	2	1	2	10.7
17	1	2	3	1	10.8
18	1	2	3	2	11.4
19	1	2	2	1	11.9
20	1	2	2	3	11.8
21	1	2	3	3	10.8
22	1	4	1	1	13.4
23	1	4	3	1	11.2
24	1	4	2	1	13.3
25	1	4	1	3	12.8

Appendix Table 25. Individual-plot data for observations on percent protein.

Observation	Identification code: Replication	Population	Density	Size	Percent protein
26	1	4	1	2	11.5
27	1	4	2	2	12.9
28	1	4	3	2	12.7
29	1	4	3	3	14.0
30	1	4	2	3	13.5
31	2	3	2	3	8.6
32	2	3	2	1	7.7
33	2	3	3	3	9.3
34	2	3	1	2	9.2
35	2	3	2	2	7.7
36	2	3	1	1	7.7
37	2	3	1	3	8.0
38	2	3	3	2	8.5
39	2	1	1	1	10.6
40	2	1	3	1	10.7
41	2	1	2	1	9.4
42	2	1	3	2	10.7
43	2	1	1	2	10.6
44	2	1	2	2	11.7
45	2	2	3	3	11.7
46	2	2	3	1	10.3
47	2	2	2	2	10.8
48	2	2	2	1	12.4
49	2	2	3	2	11.4
50	2	2	2	3	11.2

Appendix Table 25. Individual-plot data for observations on percent protein.

Observation	Identification code				Percent
	Replication	Population	Density	Size	protein
51	2	2	1	2	11.6
52	2	4	1	2	11.9
53	2	4	3	1	11.4
54	2	4	1	1	13.7
55	2	4	3	3	13.7
56	2	4	2	1	13.2
57	2	4	1	3	12.6
58	2	4	3	2	12.3
59	2	4	2	3	13.1
60	2	4	2	2	13.2
61	3	2	3	1	11.0
62	3	2	1	2	10.7
63	3	2	2	3	11.4
64	3	2	2	2	10.7
65	3	2	2	1	11.9
66	3	2	3	3	11.2
67	3	2	3	2	11.4
68	3	4	1	1	13.3
69	3	4	2	2	12.6
70	3	4	2	1	13.4
71	3	4	3	3	14.7
72	3	4	3	1	11.9
73	3	4	2	3	13.3
74	3	4	1	3	13.3
75	3	4	1	2	12.1

Appendix Table 25. Individual-plot data for observations on percent protein.

Observation	Identification code: Replication	Population	Density	Size	Percent protein
76	3	4	3	2	12.6
77	3	1	3	2	10.7
78	3	1	3	1	10.5
79	3	1	2	1	9.8
80	3	1	2	2	10.7
81	3	1	1	1	11.3
82	3	1	1	2	9.9
83	3	3	3	2	8.7
84	3	3	2	1	7.9
85	3	3	1	3	8.1
86	3	3	1	1	7.3
87	3	3	3	3	8.5
88	3	3	2	3	8.9
89	3	3	2	2	6.7
90	3	3	1	2	9.5

Appendix Table 26. Individual-plot data for observations on embryo and seed dimensions.

	Identification code				Embryo length (mm)	Embryo width (mm)	Seed length (mm)	Seed width (mm)	Area of embryo (cm^2)	Area of seed (cm^2)	Ratios		
Observation	Replication	Population	Density	Size							Width/ length (embryo)	Width/ length (seed)	Embryo/ seed (area)
1	1	2	2	1	21.00	8.88	34.50	18.50	1.33	4.77	0.422857	0.536232	0.278826
2	1	2	2	2	20.20	9.90	33.90	22.20	1.47	5.59	0.490099	0.654867	0.262970
3	1	2	2	3	20.67	10.22	34.44	24.78	1.69	6.91	0.494436	0.719512	0.244573
4	1	2	3	2	22.90	11.30	35.20	21.30	1.77	6.08	0.493450	0.605114	0.291118
5	1	2	3	3	25.70	11.00	38.80	24.00	2.01	6.69	0.428016	0.618557	0.300448
6	1	3	1	3	21.43	10.86	36.29	27.57	1.97	7.99	0.506766	0.759713	0.246558
7	1	3	2	3	23.11	12.00	35.44	27.44	2.15	7.79	0.519256	0.774266	0.275995
8	1	3	3	3	22.43	12.43	37.57	27.14	2.04	7.94	0.554169	0.722385	0.256927
9	1	4	1	2	22.22	11.88	33.67	24.11	2.37	6.22	0.534653	0.716068	0.381029
10	1	4	2	1	18.67	8.83	32.67	19.00	1.18	4.49	0.472951	0.581573	0.262806
11	1	4	2	2	20.38	11.38	33.16	24.13	2.04	5.94	0.558391	0.727684	0.343434
12	1	4	2	3	23.89	13.00	33.89	25.22	1.93	6.27	0.544161	0.744172	0.307815
13	1	4	3	2	20.56	9.78	33.11	22.44	2.07	5.37	0.475681	0.677741	0.385475
14	1	4	3	3	23.25	12.25	38.63	27.75	2.58	7.57	0.526882	0.718354	0.340819
15	2	2	2	1	20.90	9.00	32.10	20.60	1.14	5.28	0.430622	0.641745	0.215909

† Measurements taken from enlarged prints (10X) of x-ray radiographs.

Appendix Table 26. Individual-plot data for observations on embryo and seed dimensions.

	Identification code										Ratios		
Observation	Replication	Population	Density	Size	Embryo length (mm)	Embryo width (mm)	Seed length (mm)	Seed width (mm)	Area of embryo (cm^2)	Area of seed (cm^2)	Width/ length (embryo)	Width/ length (seed)	Embryo/ seed (area)
16	2	2	2	2	25.11	11.22	34.67	23.22	1.51	6.47	0.446834	0.669743	0.233385
17	2	2	2	3	22.90	10.80	35.80	26.40	1.72	7.03	0.471616	0.737430	0.244666
18	2	2	3	2	27.10	10.60	38.20	24.30	2.05	6.68	0.391144	0.636126	0.306886
19	2	2	3	3	25.11	11.44	39.89	26.22	2.38	8.02	0.455595	0.657308	0.296758
20	2	3	1	3	21.22	10.00	35.78	25.00	1.89	7.11	0.471254	0.698714	0.265823
21	2	3	2	3	24.88	11.38	38.88	29.75	2.27	8.76	0.457395	0.765175	0.259132
22	2	3	3	3	25.11	12.67	38.89	26.11	1.97	7.77	0.504580	0.671381	0.253539
23	2	4	1	2	19.75	11.38	32.00	23.50	1.85	5.66	0.576203	0.734375	0.326855
24	2	4	2	1	18.88	9.75	32.25	20.88	1.15	4.95	0.516419	0.647442	0.232323
25	2	4	2	2	17.56	10.78	31.11	22.00	1.54	5.42	0.613895	0.707168	0.284133
26	2	4	2	3	23.71	13.00	33.71	27.29	1.55	7.02	0.548292	0.809552	0.220798
27	2	4	3	2	21.90	12.60	34.20	24.70	1.90	6.13	0.575342	0.722222	0.309951
28	2	4	3	3	21.89	12.67	34.11	26.11	1.85	7.08	0.578803	0.765465	0.261299
29	3	2	2	1	20.40	8.10	34.40	19.60	1.36	4.93	0.397059	0.569767	0.275862
30	3	2	2	2	22.10	10.70	33.30	22.10	1.77	5.30	0.484163	0.663664	0.333962

† Measurements taken from enlarged prints (10X) of x-ray radiographs.

Appendix Table 26. Individual-plot data for observations on embryo and seed dimensions.†

	Identification code				Embryo	Embryo	Seed	Seed	Area of	Area of	Ratios		
Observation	Replication	Population	Density	Size	length (mm)	width (mm)	length (mm)	width (mm)	embryo (cm)	seed (cm)	Width/ length (embryo)	Width/ length (seed)	Embryo/ seed (area)
31	3	2	2	3	23.80	10.50	37.00	26.40	1.96	7.47	0.441176	0.713514	0.262383
32	3	2	3	2	22.10	10.10	36.00	24.20	1.70	6.36	0.457014	0.672222	0.267296
33	3	2	3	3	22.40	10.50	37.50	24.20	2.31	7.17	0.468750	0.645333	0.322176
34	3	3	1	3	24.30	11.10	37.70	26.30	2.29	7.65	0.456790	0.697613	0.299346
35	3	3	2	3	25.50	11.80	38.40	27.90	2.71	8.33	0.462745	0.726562	0.325330
36	3	3	3	3	26.40	11.80	40.70	28.10	2.64	9.22	0.446970	0.690418	0.286334
37	3	4	1	2	21.50	10.90	35.70	26.30	1.89	7.99	0.506977	0.736695	0.236546
38	3	4	2	1	19.50	10.13	30.00	19.13	1.36	4.11	0.519487	0.637667	0.330900
39	3	4	2	2	21.90	12.30	33.40	26.60	2.04	6.41	0.561644	0.796407	0.318253
40	3	4	2	3	21.22	12.78	32.78	28.11	2.01	6.56	0.602262	0.857535	0.306402
41	3	4	3	2	22.70	11.20	36.10	24.70	1.86	6.71	0.493392	0.684211	0.277198
42	3	4	3	3	25.30	12.20	39.10	28.80	2.57	8.50	0.482213	0.736573	0.302353

† Measurements taken from enlarged prints (10X) of x-ray radiographs.

Appendix Table 27. Explanations for populations and density-size combinations in Table 28.

Populations

1. RMP 1
2. HMP 550
3. Serere 3A
4. Senegal

1. Low density-small size (11)
2. Low density-medium size (12)
3. Low density-large size (13)
4. Medium density-small size (21)
5. Medium density-medium size (22)
6. Medium density-large size (23)
7. High density-small size (31)
8. High density-medium size (32)
9. High density-large size (33)
10. Original (00)

†Regular density-size combinations substituted with original due to shortage of seeds.

Appendix Table 28. Split plot design for field experiment

Replication																								
Replication III	Population		3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1		Population
	Density-Size		2	5	7	6	10	9	1	3	4	8	2	1	6	5	4	10	3†	7	8	9†		Density-Size
	Plot No.		340	339	338	337	336	335	334	333	332	331	330	329	328	327	326	325	324	323	322	321		Plot No.
	Population		2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	4		Population
	Density-Size	P	7	2	10	6	5	1	4	3	9	8	1	10	5	4	9	7	6	3	2	8		Density-Size
	Plot No.	M H	301	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	329	P	Plot No.
Replication II	Population		4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	M	Population
	Density-Size	R	5	6	8	3	10	4	9	1	7	2	10	2	6	1	8	4	5	7	3	9	H	Density-Size
	Plot No.	E D	240	239	238	237	236	235	234	233	232	231	230	229	228	227	226	225	224	223	222	221	R E	
	Population	R	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	D	Population
	Density-Size		7	6	4	10	9	2	5	1	3	8	1	10	7	4	6	8	2	9†	5	†3	R	Density-Size
	Plot No.	O B	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	O B	Plot No.
Replication I	Population		4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2		Population
	Density-Size		6	9	8	5	2	3	4	10	7	1	10	9	6	4	3	1	8	7	2	5		Density-Size
	Plot No.		140	139	138	137	136	135	134	133	132	131	130	129	128	127	126	125	124	123	122	121		Plot No.
	Population		3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1		Population
	Density-Size		7	3	5	9	2	4	10	6	8	1	5	7	4	1	9†	2	8	10	6†	†3		Density-Size
	Plot No.		101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120		Plot No.

BASIS FOR SEED DENSITY AND SIZE DIFFERENCES OF PEARL MILLET [*PENNISETUM AMERICANUM* (L.) LEEKE]

by

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AN ABSTRACT OF A MASTER's THESIS

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ABSTRACT

Research has shown that seed density and size of pearl millet [Pennisetum americanum (L.) Leeke] are positively related to stand establishment. The objective of this study was to confirm results of previous studies, investigate the nature of the seed density x size interaction, and to explore the basis for seed-density and seed-size effects on establishment.

Four seed lots (populations), RMP 1, HMP 550, Serere 3A, and Senegal bulk (Senegal), were each divided into three seed-density fractions by gravity-table separation. Each density fraction subsequently was divided into three seed-size fractions. Seedling emergence, seedling vigor, days to anthesis, heads per hectare, head weight and grain yield were determined for all possible density-size combinations, in each population, in a field study at Manhattan, Kansas. Observations on seed germination, seed weight, average seed diameter, seed shape, seed color, seed starch appearance, relative embryo size, seedling respiration and seed protein content were made in the laboratory.

Field studies confirmed earlier findings that seedling emergence and other traits are positively affected by seed density and seed size. The nature of the density x size interaction in seedling emergence and heads per hectare implied a compensatory relationship between seed density and seed size,

suggesting that those traits are important mainly as components of seed weight or mass. In some variables, however, the density x size interaction was nonsignificant, while in others it possessed non-compensatory features. In seedling respiration, significant effects of seed density and seed size tended to disappear when weight of seed was held constant, again suggesting that major effects of density and size are integrated in those of seed weight.

Generally, starch of high-density seeds was more vitreous in appearance than that of low-density seeds. Starch of large seeds tended to be more vitreous than that of small seeds, but the relationship varied with population.

Relationships involving seed protein content were complex and offered little insight into the mechanisms of seed-density and seed-size effects.

Significant differences in seed color were observed but it was not possible to relate these, in any meaningful way, to differences in seed density or seed size.

High-density seeds observed in cross section under a microscope appeared to have relatively larger embryos than low-density seeds. However, the ratio of embryo area to seed area, as determined from measurements of x-ray prints, was unaffected by seed density.