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I am submitting herewith a thesis written by Larry Wayne Skinner entitled "Variability for Components of Yield Induced in Soybeans by Seed Treatment with Gamma Radiation, Fission Neutrons, and Ethylmethane Sulfonate." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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VARIABILITY FOR COMPONENTS OF YIELD INDUCED IN SOYBEANS BY
SEED TREATMENT WITH GAMMA RADIATION, FISSION NEUTRONS,
AND ETHYLMETHANE SULFONATE

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ABSTRACT

The primary objective of this study was to evaluate the variability for five individual yield components in soybean (Glycine max (L.) Merr.) induced by seed treatment with fission neutrons, ethylmethane sulfonate, and gamma radiation. Nine M_3 and nine M_4 populations, resulting from three doses of each mutagen, were compared with a control for pods per plant, number of seed per plant, number of seed per pod, weight per 100 seed, and total seed weight per plant.

Variability induced by the three mutagens was determined by the following four methods: analysis of variance of treatment means, ranges in population means, intraclass correlations of family means, and frequency distributions of family means. The latter was considered to be the most reliable measure of induced variability.

An analysis of variance of treatment means revealed differences between the various mutagen treatments, but in most cases, the control population means were equal to or higher than any of the mutagen treatments. In nearly all cases, ranges were increased by mutagen treatment for all yield components when compared with the control, especially in the M_3 population.

Although the values obtained for the intraclass correlations were biased upward, differences were observed for certain treatments. The most heritable yield component appeared to be weight per 100 seed while the other yield components showed variable heritability values from treatment to treatment. The M_4 population was more variable than the

M_3 population in intraclass correlation values although treatment means were less variable.

Differences were also noted for certain treatments when a comparison of frequency distributions was made. In the M_3 population, the 0.050 M EMS treatment was significantly different from the control for all three yield components, and the 0.025 M EMS and 1.5 krad N_f treatments were significantly different for two components each. In the M_4 population, the 0.025 M EMS treatments differed from the control for two yield components. All N_f treatments and the 20 and 30 krad gamma radiation treatments differed from the control for weight per 100 seed.

EMS was the most effective mutagen for increasing variability. Neutrons were the second most effective mutagen for increasing variability and gamma radiation the least effective.

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CHAPTER I

INTRODUCTION

Soybeans were initially grown almost exclusively as a forage crop. Until 1941, at least one half of the reported acreage of soybeans in the U.S. was harvested as forage. By 1962, however, 97 percent of the soybean acreage in the U.S. was harvested for grain (Probst and Judd, 1973).

Soybeans are ordinarily considered a short season crop, but there are cultivars ranging in maturity from 75 to greater than 200 days. Time of flowering and seed set are determined largely by photoperiod, soybeans being a short-day crop. Soybeans are a naturally self-pollinating crop species with a natural outcrossing percentage of less than one half of 1 percent. Even under controlled conditions with plants enclosed in cages filled with honeybees, the natural crossing rate was raised only to 5.2 percent. The flowers of soybeans can be white, purple, or a combination of these two colors. The flowers average 6-7 mm in length, and this makes controlled crossing very difficult. Each flower contains 10 stamens and 2-3 seed per pod usually develop. However, 75 percent of the flowers will not produce seed and will drop without production of a pod (Johnson and Bernard, 1963).

Existing genetic variability in plant species has been the primary source of germplasm for crop improvement, including increased yield. Although there have been significant breakthroughs for increased yield

of various crops, especially the cereal grains, no advance of similar magnitude has occurred in soybean. Soybean yields have increased very slowly from 11.0 bushels per acre in 1924 to 27.6 bushels per acre today (Probst and Judd, 1973).

Economically speaking, quantitative characters, including yield, are very important traits. Mutagens have been used successfully in several crop species for the induction of variability in quantitative traits. The first extensive study involved Gregory's (1955) experiments with peanut (Arachis hypogaea L.). Since then, mutations in quantitative traits have been induced in several other species including soybean (see reviews by Brock, 1965; Scossiroli, 1965; and Manual on Mutation Breeding, 1970). As a result of induced mutations, 145 new cultivars of crop plants have been released, including four cultivars of soybean (Sigurbjornsson and Micke, 1974).

Objectives of this study were:

1. To compare the effectiveness of ethylmethane sulfonate (EMS), gamma radiation, and fission neutrons (N_f) for increasing variability of yield components in soybean including total weight of seed per plant, weight per 100 seed, number of pods per plant, number of seed per plant, and number of seed per pod in the M_3 and M_4 populations.
2. To observe numbers and types of mutations induced by various levels of the above-mentioned mutagens.
3. To estimate heritability of previously mentioned yield components.

4. To apply selection pressure for establishment of increased yield characteristics.

CHAPTER II

LITERATURE REVIEW

Mutations are the ultimate source of variability in all organisms, but natural mutation frequencies are very low, ranging from between one in ten thousand to one in a hundred million gametes (Falconer, 1960). This frequency includes both forward (from wild type to mutant) and reverse mutations (from mutant to wild type) in about a 9:1 ratio (Muller and Oster, 1957). Mutation frequencies can be increased several fold, however, by the use of mutagenic agents.

Chemical mutagens were first used by Wolff (1909) and by Schieman (1912) in work with fungi, bacteria, and other micro-organisms. They recorded frequencies of mutations as being four times higher than the spontaneous rate. No conclusive results of chemically induced mutations were reported, however, until 1946 (Auerbach, Carr, and Robson, 1946). Muller (1927) is credited with proving that x-rays increase the frequency of mutations in Drosophila while Stadler (1928) obtained similar results with x-ray induced mutations in barley.

Induced mutations in higher plants began with Stadler's (1928) early work with barley and later with corn. Andersson and Olsson (1954) using x-rays, produced a variety of white mustard which yielded 7-8 percent more oil than the mother line. Zacharias (1956) adapted the germination of soybean seed to low temperatures by radiation induced mutations. Hagberg, Gustafsson, and Ehrenberg (1958) induced an erectoide mutation

in barley which resulted in a shorter internode length in the barley head and a stiffer straw, thus producing a plant that was highly resistant to lodging. Through considerable work with the erectoide mutations, the average internode length in barley was reduced from 33.3 mm to 15.5 mm. Chapman et al. (1959) developed a cultivar of oats through mutation breeding that was resistant to crown rust and was also superior in grain quality and lodging resistance to the mother line. Konzak (1959) induced a mutation in oats which showed resistance to stem rust. Stubbe (1959) developed a mildew resistant cultivar of barley through mutation breeding. By inducing a single gene mutation, Gustafsson, Hagberg, and Lundqvist (1960) developed an early maturing cultivar of barley.

A number of mutagenic agents have been used, with varying degrees of success, to induce mutations in various crop species. Since quantitative characters, including yield, are very important, economically speaking, this discussion is restricted to these traits. Genetic variance for yield of pods was increased by seed treatment of peanuts with x-irradiation (Gregory, 1955). Similar results have been reported in other crop species including oat (Griffiths and Johnston, 1962), rice (Saki and Suzuki, 1965), subterranean clover (Brock, 1965), barley (Gaul, 1964), and soybean (Papa, Williams and Hanway, 1961; Rawlings, Hanway, and Gardner, 1958). (For a more complete list, see Manual on Mutation Breeding, 1970.)

The effectiveness of the various mutagenic agents to induce mutations and consequently increase variability has also been studied extensively. Moh (1966), in studies with the common bean (Phaseolus vulgaris L.) found no differences between the numbers or kinds of

mutations induced by gamma radiation and EMS. Jain, Raut, and Khamajkar (1968), however, in comparing the mutagenic effect of hydrazine, hydroxylamine, EMS, and gamma radiation on tomato found the ^{60}Co gamma radiation to be less effective in inducing mutations at most loci than either of the other three mutagens. Goud (1967), in studies with six cultivars of bread wheat, found that mutations occurred with equal frequency regardless of which of the three mutagens that was used, namely, EMS, gamma radiation or neutrons. However, the mutation frequency did vary with cultivar. Also, growth and survival were somewhat inhibited by the EMS and 30 KR gamma treatments. Takeda (1964) reported favorable results for increased earliness and shorter stems in barley through the use of 15 KR irradiation. Okabe (1964) reported success in induced favorable mutations in rice with 10 KR and 20 KR doses of gamma radiation and in oats with neutrons. Saccardo and Deureux (1967) induced changes in plant height, leaf width, and floral characteristics of tobacco through the use of 1, 2, and 4 KR doses of gamma radiation.

Konzak et al. (1965) have shown that the effectiveness of various chemical mutagens to induce mutations in barley depends not only on the concentration and structure of the mutagen, but on various environmental influences such as temperature and concentration of metal ions such as Cu and Zn.

Success has also been reported in mutation studies with soybean and related crop species. Tedopagze (1965) reported that the best intermutant and variety-mutant hybrids of soya and beans had a higher yield (up to

91 percent higher) than their parent forms. He used 5-10 KR and 7 KR gamma radiation exposures for beans and soya, respectively.

Harn et al. (1968) studied soybean lines for five generations that had been treated with x-irradiation and thermal neutrons and reported no significance for increases in yield, plant height, or seed size. They did, however, report development of early lines (13 days earlier) and increases in seed size in some lines.

Humphrey (1954), by irradiation of seed with thermal neutrons, obtained many strains of the 'Dortchsoy 2' cultivar of soybeans with increased vigor. He also developed one strain that produced a significantly higher yield than the parent cultivar.

Rawlings et al. (1958) reported that irradiation of seeds of 'Adams' and 'Hawkeye' cultivars of soybean with x-rays and thermal neutrons significantly increased the genetic variability for yield, plant height, maturity, and seed size. The estimates of genetic variability were five times as great in the irradiated populations as in the control populations. Additionally, the predicted genetic gains from selection indicated that an advance could be expected for all characters except plant height. They concluded, however, that increased variability in yield was in the negative direction, and higher yielding genotypes could not easily be extracted directly from irradiated populations.

Zacharias (1956) obtained early maturing soybean mutants which, although low yielding, were expected to provide breeding material for further crosses. He also selected several small- and large-seeded mutants ranging from 7.2-19.0 grams per 100 seed from the cultivar 'Heimkraft I' which has an average seed size of 14.7 grams per 100 seed.

Papa et al. (1961) sampled the third generation of the two soybean populations obtained from the irradiation of the Adams and Hawkeye cultivars of soybean with x-rays and thermal neutrons. Their goal was to determine the effectiveness of selection for the quantitative characters: yield, maturity, seed weight, oil content, and protein content. Selection for high yield was effective in both the irradiated and nonirradiated populations of Hawkeye but ineffective in the Adams cultivar. For the more heritable characters such as maturity, seed weight, oil and protein content, selection was generally more effective in the irradiated populations. They reported that although a selection advantage existed for yield in the irradiated populations, the amount of gain was not enough to compensate for the lower initial yields of the irradiated populations.

Williams and Hanway (1961) reported the genetic variation in oil and protein content of the soybeans harvested by Rawlings et al. (1958) as reported earlier. They found significant amounts of variability in all populations derived from irradiation, but only one instance of significant variability in a control population. Estimates of heritability and genetic variance were several times greater in the irradiated populations than in the control populations. The heritabilities reported were similar to those expected for F_2 segregating populations. Sterility was a major factor in increasing the amount of variability in the irradiated populations over the nonirradiated populations, but there was still significantly higher genetic variance in irradiated populations after the effect of observed sterility was eliminated. Also, the range in oil and protein content was found to be

greater in the irradiated populations although the mean yields were lower than the control population.

For further information on the induction of mutations in quantitative traits in soybean as well as in other crop species, see reviews by Brock (1965), Scossiroli (1965), and in Manual on Mutation Breeding (1970).

CHAPTER III

MATERIALS AND METHODS

Preliminary Study-CARL-1971 and Knoxville Plant Sciences Farm-1972

Seeds of a sib-line of the 'Forrest' cultivar (Hartwig and Epps, 1973) of soybean designated as 'D68-127' were adjusted to 13 percent moisture content prior to treatment of the first (M_1) generation. Several treatments (including controls) of each of the following three mutagens composed the M_1 generation: ^{60}Co gamma radiation, EMS, and N_f . The gamma radiation was performed at the Variable-Dose-Rate Irradiation Facility at the Comparative Animal Research Laboratory (CARL) (Cheka et al., 1971). The neutron irradiation was conducted at the Health Physics Research Reactor at Holifield National Laboratory (Auxier, 1965). Seeds were presoaked for 16 hours in air-bubbled water at 22 C and then soaked for eight hours at 22 C in air-bubbled EMS buffered at pH 7.5 with 0.1 M phosphate for each of the EMS treatments. The seeds were then rinsed in running tap water for several minutes prior to planting in the field. [See Constantin, Klobe, and Skold (1976) for more specifics on treatment of the M_1 generation.]

Individual plant selections were made from the M_1 plants and utilized for plant-to-row progenies for the M_2 generation. The treatment levels of each mutagen selected to provide seed from the M_2 for the M_3 population were those that gave similar levels of damage as measured by M_1 plant survival, growth, and seed yield according to Constantin et al.

(1976). These mutagen levels were 20, 25, and 30 krads of gamma radiation; 0.010, 0.025, and 0.050 M EMS; 1.0, 1.5, and 2.0 krads of N_f ; and controls.

From the M_2 population, 100 individual plants were selected from each treatment and 100 from the control (each from a different progeny row), except for the 2.0 krads N_f , 0.050 M EMS, and 30 krads gamma radiation treatments which had 90, 66, and 66 plants, respectively.

M_3 Population—Knoxville Plant Sciences Farm

Conventional methods of seedbed preparation were used and fertilizer application consisted of 17.6 lb./acre and 32.8 lb./acre of P and K, respectively. Weed control methods consisted of 3/4 lb. active ingredient 'Treflan' preplant incorporated per acre, 3/4 lb. active ingredient 'Lorox' applied as preemergent spray, and mechanical cultivation and hand hoeing as needed. The M_3 population consisted of 100 blocks of 10 rows each. One row of each of the nine treatments, plus the control, was represented in each block except the last 34 blocks, which had missing treatments (see above). Each row represented the progeny from a separate M_2 plant, and each M_2 plant furnished seed for only one M_3 row. Twenty seed were hand planted and spaced six inches apart in each row of 10 feet length. Between-row spacing was 36 inches.

A systematic design was used and considered to be adequate because of: (1) the homogeneity of the field plot used, (2) the large number of families, and (3) the effects of spacing and plant types within rows would have far greater environmental influences than between-row effects.

Harvesting was initiated in October of 1973 and completed in early December of the same year. Three plants were harvested at random from each M_3 row (family) with the exception that no sterile plants were selected and each plant was individually bagged. An attempt was made to harvest competitive plants to minimize possible effects of within-row spacing.

Data collected on each individual plant included: number of pods per plant, weight of seed per plant (yield in grams), and weight per 100 seed (grams). From these measured yield components, number of seed per pod and number of seed per plant were calculated. The number of pods per plant was determined by manually stripping the pods from the plant and recording the counted numbers. These pods were returned to the same bag so that individual plant identity was maintained. The pods were threshed by manually crushing the dried pods and removing the chaff with a hand-cranked forced air cleaner. Seed weights were determined by using a scale balance. One hundred seed were counted by using a specially designed wooden counter which had 100 holes drilled through it. The 100 seed filled the holes and were released by removing a sliding door. Weights were then determined by using the scale balance. Number of seed per plant was calculated by dividing total seed weight by weight per 100 seed and multiplying by 100. Number of seed per pod was determined by dividing number of seed per plant by the number of pods per plant.

In addition to these measurements, observations were made on pubescence color, plant height, plant type, maturity dates, number of

sterile plants, susceptibility to plant pathogens, and other deviations from 'normal' cultivar characteristics.

All seed from the M_3 population were saved and 30 seeds from each plant were hand-counted and put in coin envelopes to be used for the M_4 population.

M_4 Population—Knoxville Plant Sciences Farm—1974

All cultural practices utilized for the M_3 population were again used for the M_4 population, except for the planting technique. Since a larger number of rows (2,766) were to be planted, a tractor mounted cone planter was used. Also, since within-row spacing could not be regulated as efficiently as with hand spacing, 30 seeds per row were used. The cone planter was calibrated to plant the seed in a 10.5 ft. row with between-row spacing again being 36 inches. A systematic serpentine design was used for the M_4 population, but this time, alleys were only two feet wide.

The harvesting procedure was also altered from the previous generation. Two plants per row (family) and 40 replications were considered sufficient to estimate the variability of the M_4 population. In addition, a number of plants were selected on the basis of superior agronomic qualities as well as selection based on parental performance (pedigree). Number of pods per plant was determined in the same manner as for the M_3 generation. Threshing of the M_4 plants was accomplished with a motor-driven single plant thresher. Some efficiency was sacrificed, but the speed of the operation was greatly accelerated. An electronic torsion balance scale was used and weights were recorded to

the nearest 0.1 g. Calculations of the other yield components were conducted the same as for the M_3 population.

Statistical Analysis

Since some blocks in the M_3 population were not complete (some treatments missing), the 66 complete replications were used in the analysis of treatment means. The statistical computations were performed on an IBM 360/65 computer at the University of Tennessee Computing Center, Knoxville, and followed procedures outlined in Statistical Analysis Systems by Service (1972). All other statistical procedures, including Duncan's New Multiple Range Test for mean separations, chi square "goodness of fit" test, and intraclass correlations followed methods outlined in Statistical Methods by Snedecor and Cochran (1971).

CHAPTER IV

RESULTS AND DISCUSSION

Population Means— M_3 Generation

One method of illustrating differences in variability is an analysis of variance of treatment means. The overall means of the five yield components analyzed for the M_3 population are presented in Table 1. Growing conditions were excellent during the summer of 1973 and, consequently, overall yield was quite good for all treatments. Population means are characteristically reduced when a mutagenic agent is applied as shown by Rawlings et al. (1958) in an M_2 generation of soybeans, by Gregory (1955) with peanuts, by Bhatia and Swaminathan (1962) in hexaploid bread wheat, by Scossiroli (1966) with durum wheat, and by Gaul (1964) with barley. However, for the yield component pods per plant, the 0.050 M EMS and 30 krad gamma radiation treatments showed significantly higher numbers of pods. This was probably due to plant competition differences since these highest levels of mutagens sometimes resulted in lower plant survival. However, differences in means between control and mutagen-treated populations could probably be expected to be less with advanced generations. All other treatments were equal to the control for the yield component pods per plant.

For the yield component, weight per 100 seed, there were no significant differences between any two treatments or between any one treatment and the control. This is in contrast to results obtained by

Table 1. Means for Pods per Plant, Total Seed Weight per Plant, Weight per 100 Seed, Number of Seed per Plant, and Number of Seed per Pod in the Control and Nine Different M_3 Populations of Soybean

Treatment	Pods per plant	Total seed weight per plant, g	Weight per 100 seed, g	No. seed per plant	No. seed per pod
Control	257.1 ab*	77.1 ab	14.7 a	525.4 ab	2.05 d
1.0 krad s N_f	262.8 abcd	76.5 ab	15.2 a	504.7 ab	1.93 bcd
1.5 krad s N_f	277.6 bcd	80.8 b	15.1 a	535.7 b	1.93 bcd
2.0 krad s N_f	259.9 abc	74.0 a	15.1 a	492.3 a	1.90 bc
0.010 M EMS	254.9 a	74.1 a	14.7 a	503.1 ab	1.99 d
0.025 M EMS	265.7 abcd	73.0 a	14.9 a	490.9 a	1.86 b
0.050 M EMS	280.6 cd	74.5 ab	15.0 a	491.8 a	1.75 a
20 krad s γ	271.5 abcd	77.8 ab	14.9 a	524.0 ab	1.94 cd
25 krad s γ	267.5 abcd	76.0 ab	14.9 a	511.4 ab	1.93 bcd
30 krad s γ	281.6 d	79.2 ab	14.7 a	537.5 b	1.92 bcd

*Those numbers followed by the same letter are not significantly different at the 5 percent level of probability.

Rawlings et al. (1958) which showed increased seed weights in the irradiated populations over the control populations. Krull and Frey (1961) also reported slight shifts toward heavier seed weight in an M_2 generation of oats after seed treatment with thermal neutrons.

Although the number of seed per plant varied between treatments, no treatment was different from the control. The highest level of neutrons (2.0 krad) and the two highest levels of EMS (0.025 and 0.050 M) resulted in the lowest number of seed per plant and the 1.5 krad N_f and 30 krad gamma radiation treatments had the highest number of seed per plant among the nine mutagenic treatments.

There were differences revealed in the number of seed per pod with some treatments lower than the control. The 2.0 krad N_f , 0.025 M EMS, and 0.050 M EMS treatments had lower numbers of seed per pod than the control with the 0.050 M EMS treatment significantly lower than all other treatments as well as lower than the control. This resulted from a larger number of partially sterile plants in this treatment that produced one-seeded pods. Partial sterility was also observed in the other mutagenic treatments, but not to the extent at which it occurred in the 0.050 M EMS treatment.

In the most important trait, total seed weight per plant, no treatment was different from the control. However, the 1.5 krad N_f treatment was higher yielding than either of the following three treatments: 2.0 krad N_f , 0.010 M EMS, and 0.025 M EMS. The latter treatments were lower yielding due primarily to the presence of a larger number of dwarfed and "stunted" plant types. The total yields of the

treatments were not significantly different from the control even though some of the individual yield components were higher or lower than the control.

Population Means— M_4 Generation

The overall means for the five yield components for the M_4 populations are presented in Table 2. Overall yield in the M_4 population was considerably lower than the M_3 population primarily due to two factors. Excessive rainfall during May and the first two weeks of June in 1974 delayed planting until the third week of June. The second factor was a shortage of rainfall during the flowering and pod-filling periods of that same year. These factors caused plants to be shorter in height with less photosynthetic area, thus total yield was reduced. The environmental conditions were uniform, however, and all treatments were similarly affected.

Under the stress conditions of 1974, the control population means reacted in a manner as previously reported by various researchers (Rawlings et al., 1958; Gregory, 1955; Bhatia and Swaminathan, 1962; Scossiroli, 1966; and Gaul, 1964). For all yield components except weight per 100 seed, the controls were greater than or equal to all mutagenic treatments.

For the number of pods per plant, the 1.5 krad N_f treatment was equal to the control and both were significantly higher than any other treatment. The 25 krad gamma radiation treatment had a lower number of pods than any other treatment. All other treatments were somewhat intermediate in number of pods per plant.

Table 2. Means for Pods per Plant, Total Seed Weight per Plant, Weight per 100 Seed, Number of Seed per Plant, and Number of Seed per Pod in the Control and Nine Different M_4 Populations of Soybean

Treatment	Pods per plant	Total seed weight per plant, g	Weight per 100 seed, g	No. seed per plant	No. seed per pod
Control	173.1 a*	55.1 a	14.5 bc	379.8 a	2.20 a
1.0 krad N _f	161.5 e	49.9 cd	14.6 ab	338.5 ab	2.10 a
1.5 krad N _f	173.1 a	53.2 ab	14.6 ab	361.6 ab	2.10 a
2.0 krad N _f	160.3 e	48.5 de	14.6 ab	331.4 b	2.07 a
0.010 M EMS	160.5 e	50.2 cd	14.5 bc	346.1 ab	2.15 a
0.025 M EMS	163.7 cd	47.6 e	14.4 bc	328.2 b	2.03 a
0.050 M EMS	162.2 de	47.4 e	14.6 abc	324.4 b	1.98 a
20 krad γ	164.8 c	51.4 bc	14.8 a	348.0 ab	2.12 a
25 krad γ	156.6 f	47.1 e	14.3 c	328.5 b	2.10 a
30 krad γ	167.1 b	51.5 bc	14.6 ab	353.1 ab	2.13 a

*Those numbers followed by the same letter are not significantly different at the 5 percent level of probability.

Contrary to the M_3 population where no differences were observed in weight per 100 seed of the different treatments, one treatment (20 krad gamma) was higher than the control. All other treatments had intermediate values with little difference observed.

No significant differences were found for the number of seed per plant between mutagenic treatments. However, the 2.0 krad N_f , 0.025 M EMS, and 0.050 M EMS treatments were significantly lower than the control. No other treatments were different from the control. Also, no significant differences between the nine treatments and the control were observed for number of seed per pod.

For total seed weight per plant, the control was significantly higher than all mutagenic treatments except the 1.5 krad N_f treatment. The 0.025 M EMS, 0.050 M EMS, and 25 krad gamma radiation treatments showed the lowest overall yields with the other five treatments being somewhat intermediate in yield.

For the most part, the means for both the M_3 and M_4 populations reveal little about the variability induced by the various mutagenic treatments. They do, however, show the lower valued mean yields expected of mutagen-treated populations. Based on populations means alone, the 1.5 krad N_f treatment reduced yield the least in the M_4 population or increased yield the most in the M_3 population. The second most effective treatment appeared to be 30 krad gamma radiation. On comparing the three mutagens, disregarding level of dosage; N_f reduced yields the least, EMS reduced yields the most, and gamma radiation was intermediate in yield reduction.

Population Ranges— M_3 Generation

A second and somewhat more effective method than mean analysis to estimate variability is a comparison of population ranges. Ranges for the five yield components of the M_3 population are presented in Table 3. In all cases for the yield component pods per plant, the ranges for all mutagenic treatments were greater than the control. For some treatments, the ranges were almost twice as great. In all cases for the mutagen treatments, the low end of the range was lower than the control and the high end of the range was higher than the control. The most effective treatments for increasing the range in number of pods per plant were: 0.050 M EMS, 30 krads gamma radiation, 0.025 M EMS, 1.5 krads N_f , and 25 krads gamma radiation treatments (given in decreasing order of effectiveness).

Similar results were obtained for the other yield components included in this study. For the component weight per 100 seed, ranges in the mutagen-treated populations exceeded those of the control population in all cases except the 0.010 M EMS treatment. Ranges in number of seed per plant also were greater in all mutagen-treated populations than in control populations. The greatest ranges occurred in the 1.5 krads N_f , 0.050 M EMS, and 30 krads gamma radiation treatments. Again, this was probably due to some instances of reduced plant competition resulting from lowered plant survival. Although the ranges in number of seed per pod were greater in the mutagen-treated populations, most of the differences from the control population were found on the low end of the range. Variation in total yield per plant was increased in mutagen-treated populations over the control populations as shown by

Table 3. Ranges for Pods per Plant, Total Seed Weight per Plant, Weight per 100 Seed, Number of Seed per Plant, and Number of Seed per Pod in the Control and Nine Different M_3 Populations of Soybean

Treatment	Pods per plant	Total seed weight per plant, g	Weight per 100 seed, g	No. seed per plant	No. seed per pod
Control	143-395	41.9-124.2	12.2-18.2	286-858	1.60-2.52
1.0 krad N_f	136-427	34.9-131.9	12.4-18.7	240-823	1.21-2.44
1.5 krad N_f	136-544	29.7-168.0	10.4-19.5	234-1,105	1.28-2.43
2.0 krad N_f	131-438	34.5-134.2	11.9-19.6	242-906	1.09-2.57
0.010 M EMS	135-423	38.6-120.5	12.0-16.8	258-872	1.28-2.49
0.025 M EMS	131-562	26.4-149.8	11.0-19.7	215-958	1.20-2.40
0.050 M EMS	72-579	11.3-174.6	10.5-20.7	108-1,051	1.13-2.38
20 krad γ	128-439	35.3-125.1	11.9-19.9	243-845	1.27-2.37
25 krad γ	122-516	34.7-146.8	12.1-18.8	230-979	1.21-2.55
30 krad γ	110-583	25.2-165.4	10.6-20.2	216-1,097	1.26-2.47

increased ranges. Variation was shown here in both a positive and negative direction. The greatest ranges were again attained in the same three treatments as previously mentioned and probably for the same reasons.

Population Ranges— M_4 Generation

Ranges for the five yield components included in this study for the nine mutagen-treated populations and the control population are presented in Table 4. Total yield and actual numbers of the various yield components were lower than for the M_3 populations for the reasons given in an earlier segment of this chapter. Less difference between treatments and the control could probably be expected in an M_4 generation than in an M_3 generation. In nearly all cases where the ranges in mutagen-treated populations were greater than in the control populations, most of the difference occurred in the negative direction. As was the case for the M_3 generation, ranges were greatest in the following three mutagen treatments: 1.5 krads N_f , 0.050 M EMS, and 30 krads gamma radiation. This was found to be the case in all yield components except number of seed per pod where differences between treatment and control populations were not very pronounced. These ranges showed that variation had been increased by some mutagen treatments, but the significance of this increase was not ascertained by this method.

Intraclass Correlations— M_3 Population

A third method of estimating variability induced by the mutagens used in this study was by determining the extent to which the heritability values were altered. There were a number of methods through which

Table 4. Ranges for Pods per Plant, Total Seed Weight per Plant, Weight per 100 Seed, Number of Seed per Plant, and Number of Seed per Pod in the Control and Nine Different M_4 Populations of Soybean

Treatment	Pods per plant	Total seed weight per plant, g	Weight per 100 seed, g	No. seed per plant	No. seed per pod
Control	85-291	26.9-95.3	13.1-15.7	190-659	1.79-2.62
1.0 krad N_f	63-276	17.1-92.5	12.2-17.1	120-600	1.60-2.57
1.5 krad N_f	82-317	21.5-101.7	12.3-17.5	163-658	1.60-2.53
2.0 krad N_f	75-258	19.7-77.7	12.6-16.8	138-512	1.43-2.50
0.010 M EMS	92-258	27.4-85.2	12.9-15.9	197-572	1.77-2.59
0.025 M EMS	81-273	24.0-85.0	11.8-17.4	173-547	1.52-2.45
0.050 M EMS	64-303	15.1-99.5	10.5-18.0	112-666	1.45-2.46
20 krad γ	88-279	24.7-79.5	13.0-16.5	173-595	1.79-2.48
25 krad γ	76-241	21.5-75.0	12.2-16.5	163-512	1.64-2.44
30 krad γ	82-298	23.4-94.5	12.5-16.3	164-636	1.70-2.46

heritabilities of the various yield components could have been determined. These methods included: regression of M_4 progeny on M_3 parents, analysis by covariance of parents and offspring, and the method that was used, namely, intraclass correlations. Since the M_3 and M_4 populations were grown in separate years under distinctly different environments, the regression and covariance methods were not used since there was no valid way of separating environmental variances from genetic variances.

The method that was chosen, intraclass correlations, was not without faults. This method assumed that there was no interaction between adjacent family lines and that variation within families was less than that between families. These assumptions may not be valid. Due to the systematic design of the experiment, all environmental variance could not be separated from genetic variance; consequently, all heritability values are biased, presumably upward. If there was no interaction between families, this bias was constant for all families. Even with all the deficiencies of the intraclass correlation method for determining heritability, it probably was the best method available.

The intraclass correlations for the control and nine M_3 populations for five yield components of soybean are presented in Table 5. For the yield component pods per plant, heritability values ranged from a low of 0.22 for the 0.050 M EMS treatment to a high of 0.63 for the 30 krad gamma radiation treatment. The 25 krad gamma radiation treatment with a value of 0.49 appeared to be greater than the control value of 0.34. All other treatments had similar values as the control. The heritability values determined in this experiment compared favorably with heritability

Table 5. Intraclass Correlations on the Control and Nine Different M_3 Populations for Five Yield Components of Soybean

Treatment	Pods per plant	Total seed weight per plant, g	Weight per 100 seed, g	No. seed per plant	No. seed per pod
Control	.34	.29	.59	.29	.28
1.0 krad N_f	.28	.17	.50	.25	.44
1.5 krad N_f	.27	.35	.58	.34	.52
2.0 krad N_f	.32	.43	.62	.48	.62
0.010 M EMS	.32	.21	.64	.16	.23
0.025 M EMS	.30	.38	.73	.34	.65
0.050 M EMS	.22	.17	.61	.15	.51
20 krad γ	.31	.33	.58	.27	.53
25 krad γ	.49	.55	.61	.52	.46
30 krad γ	.63	.56	.56	.53	.46

values for pods per plant (0.22-0.50) reported by Johnson, Robinson, and Comstock (1955).

Intraclass correlation values determined for weight per 100 seed were consistently higher than for any other yield component. These values ranged from a low of 0.50 for the 1.0 N_f treatment to a high of 0.73 for the 0.025 M EMS treatment. All other values were very close to the heritability value of 0.59 determined for the control population. These values also compared favorably to the range of values [0.35 (Hanson and Weber, 1962) to 0.92 (Johnson et al. 1955)] and the range of values (0.31-0.85) reported by Parameswarappa (1971).

Number of seed per plant appeared to be the least heritable of the individual yield components determined in this study. Values ranged from 0.15 for the 0.050 M EMS treatment to 0.52 and 0.53 for the 25 krad gamma and 30 krad gamma radiation treatments, respectively. The 2.0 krad N_f , 25 krad gamma, and 30 krad gamma treatments had higher heritability values than the control while the 0.010 M EMS and 0.050 M EMS treatments were lower than the control. All other treatment values were similar to those values determined for the control. Johnson et al. (1955) reported heritability values ranging from 0.10 to 0.55 for number of seed per plant.

All heritability values for number of seed per pod of the mutagen populations except the 0.010 M EMS treatment were higher than the value determined for the control. While the control value was 0.28, eight of the mutagen population values ranged from 0.44 to 0.65. These values compared favorably to the 0.35 to 0.69 range of heritability values reported by Johnson et al. (1955) for number of seed per pod.

Intraclass correlation values for total seed weight per plant ranged from 0.17 for the 1.0 krad N_f and 0.050 M EMS treated populations to 0.56 for the 30 krad gamma radiation population. All gamma treatments had higher heritability values than the control as did also the two higher levels of N_f and the 0.025 M EMS treatment. These values compared to 0.02-0.68 heritabilities reported by Parameswarappa (1971) and 0.77-1.00 heritabilities reported by Mahmud and Kramer (1951).

Except for the yield component weight per 100 seed, variability was increased by use of mutagen-treated seed. Gamma radiation appeared to be the most effective mutagen for increasing variability as measured by heritability values with N_f and EMS somewhat less effective when M_3 populations were evaluated.

Intraclass Correlations— M_4 Population

Intraclass correlation values for the control and nine different M_4 populations for five yield components of soybean are presented in Table 6. The negative values for some yield components resulted when the residual mean squares were greater than the family mean squares as evidenced by F values less than 1. This probably could have been corrected by either increasing the number of families harvested, by harvesting a greater number of individual family members, or by using an experimental design that would have allowed removing the environmental variance. These negative values were ignored for purposes of estimating induced variability, and were considered to be part of the environmental bias that could not be removed by this method of evaluation.

Table 6. Intraclass Correlations on the Control and Nine Different M₄ Populations for Five Yield Components of Soybean

Treatment	Pods per plant	Total seed weight per plant, g	Weight per 100 seed, g	No. seed per plant	No. seed per pod
Control	.29	.16	-.13	.20	.29
1.0 krads N _f	.09	-.01	.48	-.03	.19
1.5 krads N _f	.18	.25	.61	.11	.15
2.0 krads N _f	.45	.42	.56	.45	.76
0.010 M EMS	.03	-.11	.42	-.08	.20
0.025 M EMS	.41	.26	.53	.20	.63
0.050 M EMS	.17	.28	.33	.36	.53
20 krads γ	.13	.26	.43	.18	.18
25 krads γ	-.05	-.04	.38	-.09	.40
30 krads γ	.30	.26	.64	.31	.23

For pods per plant, heritability values ranged from 0.03 to 0.45. The 2.0 krad N_f and 0.025 M EMS treatments had higher values than the control, but values for other mutagen populations generally were lower, except for the 30 krad gamma treatment which was equal to the control. Heritability values determined for number of pods per plant were generally lower than those reported by Johnson et al. (1955).

As was the case in the M_3 population, weight per 100 seed was the most highly heritable trait with number of seed per pod the second highest. Values for weight per 100 seed ranged from 0.33 to 0.64 while values for number of seed per pod ranged from 0.18 to 0.76. These values were consistent with heritability values reported by previously mentioned researchers (Johnson et al., 1955; Parameswarappa, 1971; and Mahumd and Kramer, 1951).

Discounting the negative values obtained for total seed weight per plant for some mutagen treatments, all other treatments gave higher heritability values than the control. These values ranged from 0.25 to 0.42 as compared with a control value of 0.16.

Family Frequency Distributions— M_3 Population

The fourth method utilized to evaluate variability was a comparison of frequency distributions of family means for the three actually measured yield components, namely, number of pods per plant, weight per 100 seed, and total seed weight per plant. Since the other two yield components were calculated from data obtained for the three previously mentioned components, these frequency distributions would not be unlike the latter three distributions. Frequency distributions of the 66 individual

families (three plants per family) for the control and the nine treatments for the three yield components (pods per plant, weight per 100 seed, and total seed weight per plant) are presented in Figures 1, 2, and 3, respectively. The frequency distributions for some of the mutagen treatments have a more diverse appearance than the control distribution. The number of families in the highest class of the three yield components; i.e., greater than 330 pods per plant, greater than 16.2 grams per 100 seed, and greater than 100 grams of seed per plant, was three to four times greater in some mutagen treatments than for the control.

A chi square test was used to test for significant differences between treated populations and the control population. The 0.050 M EMS treatment differed from the control for all three yield components while the 1.5 krad N_f and 0.025 M EMS treatments differed for two of the three yield components. No differences between the control and the gamma radiation treatments were observed for M_3 frequency distributions.

Family Frequency Distributions— M_4 Population

The number of families (66) and plants per family (three) harvested for the M_3 generation were considered to be more than were needed to estimate induced variability. Consequently, only 40 families each containing two plants were harvested for the M_4 generation. Since overall yield was lower in the M_4 generation, the class values were altered from the M_3 values that were used in order to compensate for this lowered yield. Family frequency distributions for pods per plant, weight per 100 seed, and total seed weight per plant for the various

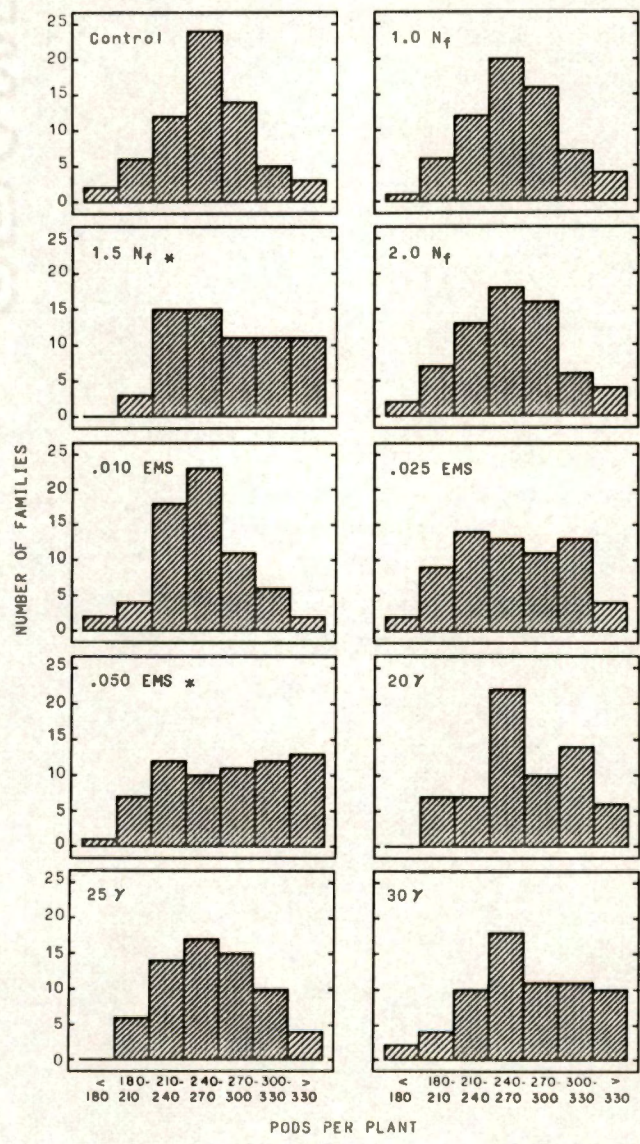


Figure 1. Frequency distributions of individual families for number of pods in the control and nine M_3 populations.

*Indicates significance at $P = 0.05$, according to chi square test.

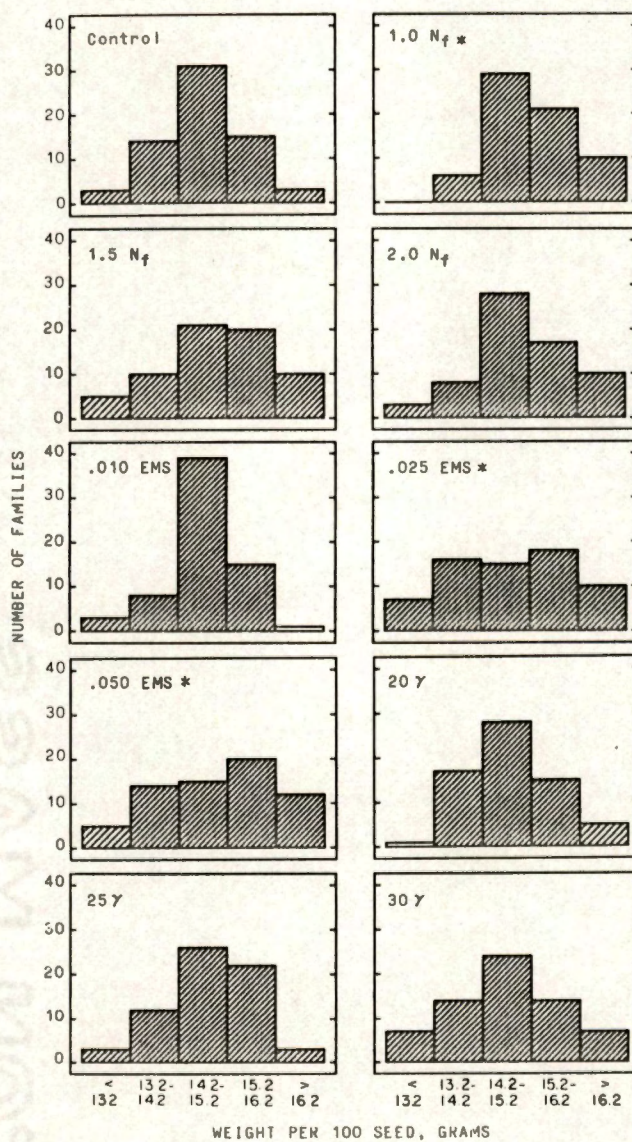


Figure 2. Frequency distributions of individual families for weight per 100 seed (grams) in the control and nine M_3 populations.

*Indicates significance at $P = 0.05$, according to chi square test.

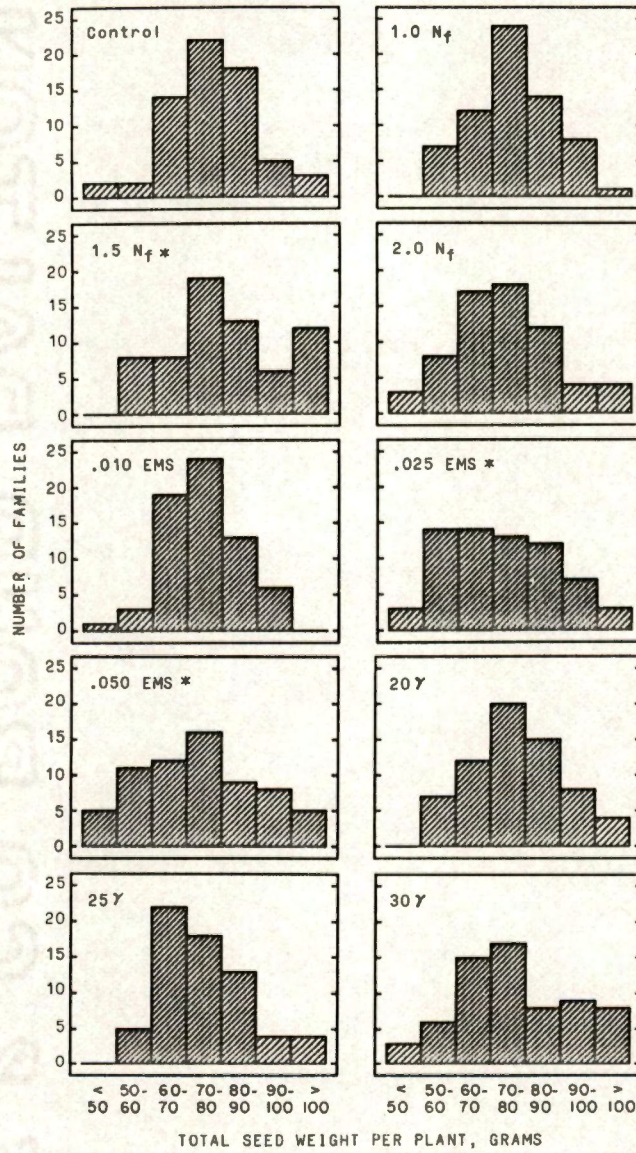


Figure 3. Frequency distributions of individual families for total seed weight per plant (grams) in the control and nine M_3 populations.

*Indicates significance at $P = 0.05$, according to chi square test.

treatments and the control are presented in Figures 4, 5, and 6, respectively. No significant differences were found in frequency distributions for pods per plant between control and mutagen-treated populations. For weight per 100 seed, all mutagen-treated populations except the 0.010 M EMS and 25 krad gamma radiation treatments had frequency distributions that were different from the control.

Variability was extended in the M_4 generation as evidenced by frequency distributions of treated populations that differed from the control populations. Once again, EMS appeared to be the most effective mutagen for inducing variability for these yield components of soybean with gamma radiation the least effective mutagen for inducing variability in these quantitative traits. However, in the M_4 generation, mutagen-treated populations had their highest values in the lowest class of each individual yield component. This indicated that although variability had been extended in the M_4 generation, a large portion of this variability was in the negative direction. This is in agreement with lowered yield values in an irradiated population as reported by Papa et al. (1961).

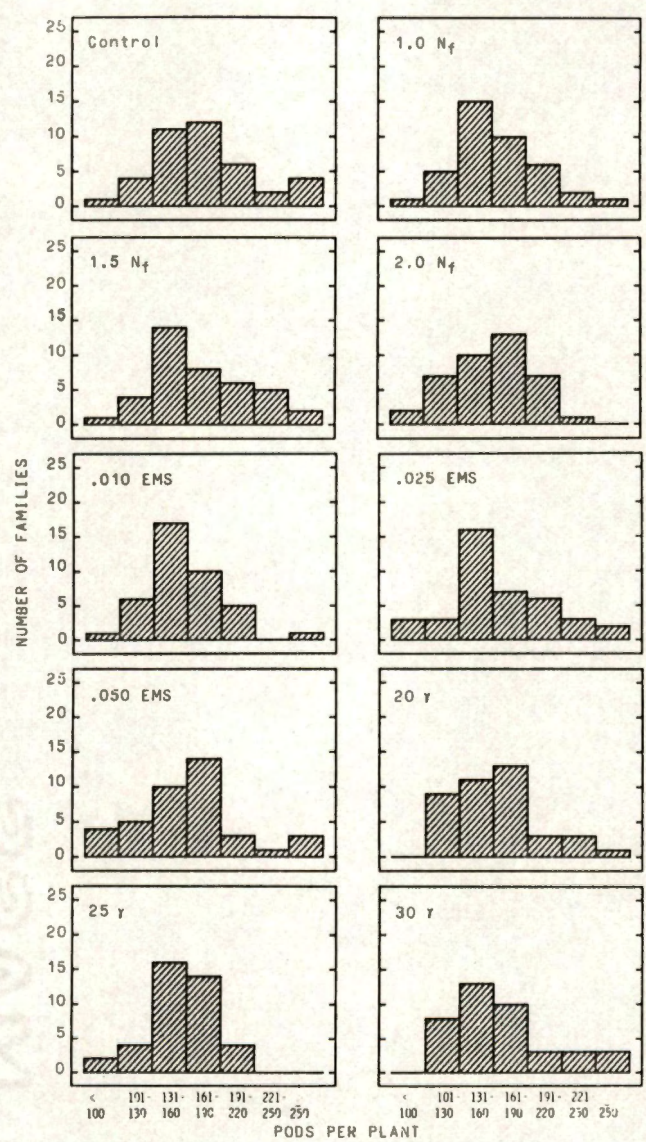


Figure 4. Frequency distributions of individual families for number of pods in the control and nine M_4 populations.

*Indicates significance at $P = 0.05$, according to chi square test.

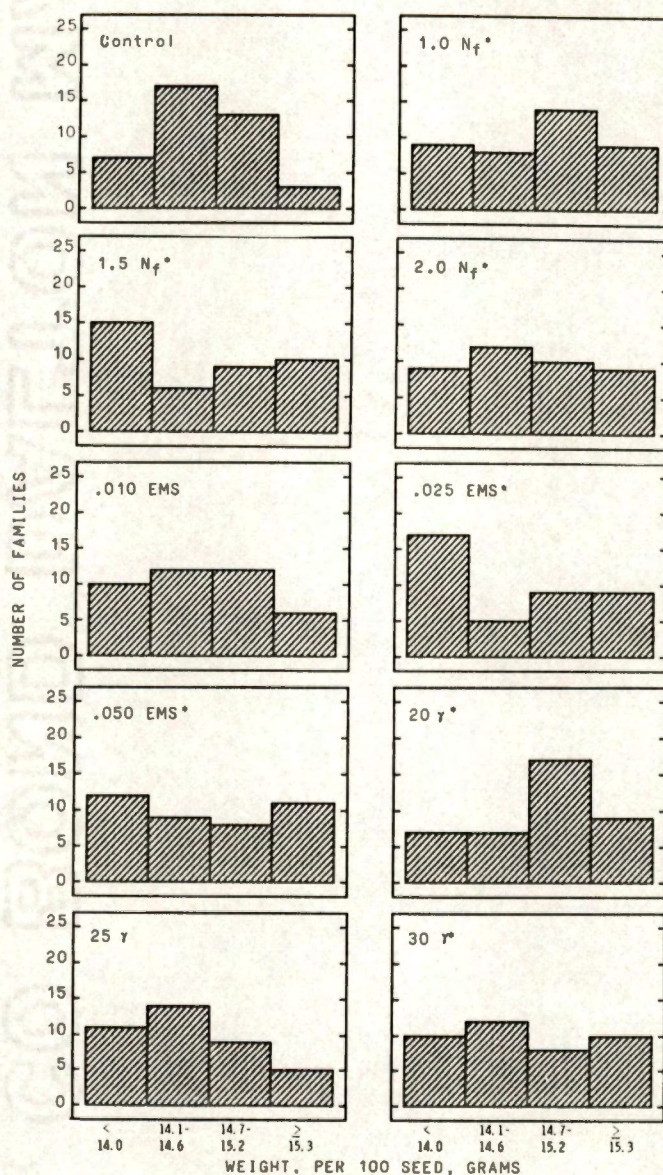


Figure 5. Frequency distributions of individual families for weight per 100 seed (grams) in the control and nine M_4 populations.

*Indicates significance at $P = 0.05$, according to chi square test.

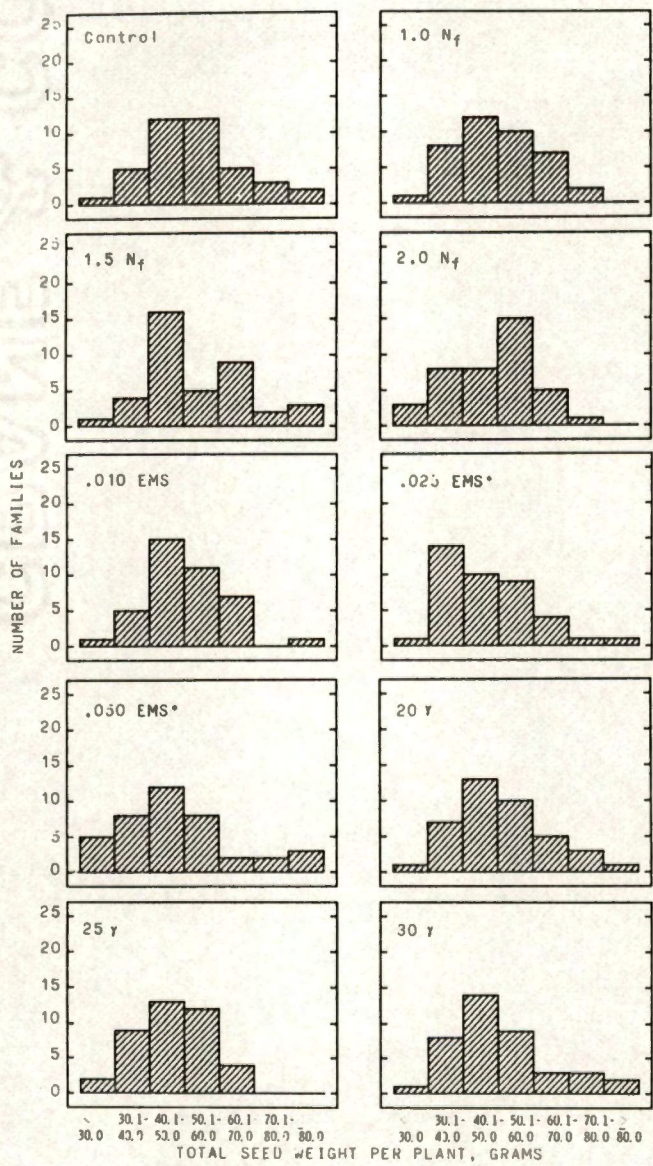


Figure 6. Frequency distributions of individual families for total seed weight per plant (grams) in the control and nine M_4 populations.

*Indicates significance at $P = 0.05$, according to chi square test.

CHAPTER V

SUMMARY AND CONCLUSIONS

Seeds of a sibline of the Forrest cultivar of soybeans designated as D68-127 were subjected to three levels of each of the following mutagens: gamma radiation, N_f , and EMS. The M_2 through M_4 generations from these treated seed were grown at the Knoxville Plant Sciences Farm at Knoxville, Tennessee primarily for the purpose of providing material for a mutation-breeding program at the University of Tennessee. The study covered by this thesis attempted to determine the extent to which variability for yield components in soybeans was induced by the various mutagens for the M_3 and M_4 generations.

Variability for the control and nine treatment populations of soybean was determined for number of pods per plant, weight per 100 seed, number of seed per plant, number of seed per pod, and total seed weight per plant. This was accomplished by the following four methods: analysis of variance of population means, estimation of heritability by family intraclass correlations, range of population means, and frequency distributions of family means.

The effectiveness of the various levels of the mutagens to induce variability for the various yield components was determined and varied according to the method of evaluation that was used. When the criterion of evaluation was by population means, gamma radiation was the most effective for increasing variability followed by N_f with EMS the least

effective. However, when variability was measured by alterations in ranges of the various yield components, the order of decreasing effectiveness of the mutagens was EMS, N_f , and gamma radiation. The third method of evaluation was an estimation of heritability of the various yield components by family intraclass correlations. Gamma radiation was the most effective for increasing variability with N_f and EMS of equally lowered effectiveness. The method of evaluation that was thought to be the most reliable indicator of increased variability was comparison of frequency distributions. When determined by family frequency distributions, EMS was the most effective mutagen for increasing variability followed by N_f and gamma radiation.

A visual observation of plants growing in the field was made at periodic intervals. Notes were taken on such characteristics as pubescence color, sterile plants, plant height, plant type, susceptibility to insects, and several other traits. This subjective indicator of variability also revealed more diversity among all mutagen treatments when compared with the control.

In conclusion, all mutagen treatments increased variability for the five yield components studied without a significant decrease in yield. EMS appeared to be the most effective mutagen for increasing variability when all methods of evaluation were considered. The plants selected for this study have been propagated through an M_5 generation and selected lines were put in a replicated preliminary yield trial.

LITERATURE CITED

LITERATURE CITED

- Andersson, G., and G. Olsson. 1954. Svalof's Primex white mustard—a market variety selected in x-ray treated material. *Acta Agric. Scand.* 4:574-577 (cited by Gustafsson, 1963).
- Auerbach, C., J. G. Carr, and J. M. Robson. 1946. The chemical production of mutations. *Science* 105:243-247.
- Auxier, J. A. 1965. The Health Physics Research Reactor. *Health Phys.* 11:89-93.
- Bhatia, C. R., and M. S. Swaminathan. 1962. Induced polygenic variability in bread wheat and its bearing on selection procedures. *Z. Pflzucht.* 48:317-326.
- Brock, R. D. 1965. Induced mutations affecting quantitative characters. In *The use of induced mutations in plant breeding. Radiat. Bot.* 5 (Suppl.):451-464.
- Chapman, W. H., H. H. Luke, A. T. Wallace, and A. O. Lunden. 1959. Multiple variation including crownrust resistance in irradiated Floriland oats. *Agron. J.* 51:163-165.
- Cheka, J. S., E. M. Robinson, L. Wade, Jr., and W. A. Gramly. 1971. The UT-AEC Agriculture Research Laboratory variable gamma dose rate facility. *Health Phys.* 20:339-343.
- Constantin, M. J., W. D. Klobe, and L. N. Skold. 1976. Effects of physical and chemical mutagens on survival, growth, and seed yield of soybeans. *Crop Sci.* (in press).
- Falconer, D. S. 1960. *Introduction to Quantitative Genetics.* New York: The Ronald Press Company.
- Gaul, H. 1964. Mutations in plant breeding. *Radiat. Bot.* 4:155-232.
- Goud, J. V. 1967. Induced mutations in bread wheat. *Indian J. of Genet. and Plant Breeding* 27:40-55.
- Gregory, W. C. 1955. X-ray breeding of peanuts (Arachis hypogaea L.). *Agron. J.* 47:396-399.
- Griffiths, D. J., and T. J. Johnston. 1962. The use of an irradiation technique in oat breeding. *Radiat. Bot.* 2:41-52.

- Gustafsson, A. 1963. Mutations and the concept of viability, p. 89-104. In E. Akerberg, A. Hagberg, G. Olsson, and O. Tedin [ed.] Recent plant breeding research. John Wiley & Sons, New York.
- Gustafsson, A., A. Hagberg, and U. Lundqvist. 1960. The induction of early mutants in Bonus barley. *Hereditas* 46:675-699 (cited by Gustafsson, 1963).
- Hagberg, A., A. Gustafsson, and L. Ehrenberg. 1958. Sparsely contra densely ionizing radiations and the origin of erectoid mutations in barley. *Hereditas* 44:523-530. (cited by Gustafsson, 1963).
- Hanson, W. D., and C. R. Weber. 1962. Analysis of genetic variability from generations of plant-progeny lines in soybean. *Crop Sci.* 2:63-67.
- Harn, Chang Yawl, Shin Han Kwon, Chi Moon Kim, and Kun Hyuk Lim. 1968. Soybean improvement by application of x-ray and thermal neutron in Korea. *J. Nucl. Sci.* 8:131-138.
- Hartwig, E. E., and J. M. Epps. 1973. Registration of Forrest soybeans. *Crop Sci.* 13:287.
- Humphrey, L. M. 1954. Effects of neutron irradiation on soybeans. *Soybean Dig.* 14:18-19.
- Jain, H. K., R. N. Raut, and Y. G. Khamajkar. 1968. Base specific chemicals and mutation analysis in Lycopersicon. *Heredity* 23:247-256.
- Johnson, H. W., and R. L. Bernard. 1963. Soybean genetics and breeding, pp. 1-74. In A. G. Norman [ed.] *The soybean*. Academic Press, New York and London.
- Johnson, H. W., H. F. Robinson, and R. E. Comstock. 1955. Estimates of genetic and environmental variability in soybeans. *Agron. J.* 47:314-318.
- Konzak, C. F. 1959. Radiation-induced mutations for stem rust resistance in oats. *Agron. J.* 51:518-520.
- Konzak, C. F., R. A. Nilan, J. Wagner, and R. J. Foster. 1965. Efficient chemical mutagenesis. In *The use of induced mutations in plant breeding*. *Radiat. Bot.* 5 (Suppl.):49-70.
- Krull, C. F., and K. J. Frey. 1961. Genetic variability in oats following hybridization and irradiation. *Crop Sci.* 1:141-146.
- Mahmud, I., and H. H. Kramer. 1951. Segregation for yield, height, and maturity following a soybean cross. *Agron. J.* 43:605-608.

- Manual on Mutation Breeding. 1970. Tech. Rep. Ser. No. 119, International Atomic Energy Agency, Vienna.
- Moh, C. C. 1966. The genetic behavior of mutants induced by ethylmethane sulfonate in the common bean (Phaseolus vulgaris L.). Interamer. Inst. of Agr. Sciences, Turrialba, Costa Rica. (Abstr.)
- Muller, H. J. 1927. Artificial transmutation of the gene. *Science* 66:84-87.
- Muller, H. J., and I. I. Oster. 1957. Principles of back mutation as observed in Drosophila and other organisms. In *Advances in Radiobiology. Proc. 5th Int. Conf. Radiobiol.* [Stockh]., 1956. Edinburgh: Oliver & Boyd. pp. 407-415 (cited by Falconer, 1960).
- Norman, A. G. [ed.]. 1963. *The Soybean*. Academic Press, New York and London. 239 p.
- Okabe, Shiro. 1964. Mutations induced in quantitative characters in rice and oats. *Gamma Field Symp.* No. 3:49-58.
- Papa, K. E., J. H. Williams, and D. G. Hanway. 1961. Effectiveness of selection for quantitative characters in the third generation following irradiation of soybean seeds with x-rays and thermal neutrons. *Crop Sci.* 1:87-90.
- Parameswarappa, Raravi. 1971. Association and heritability studies of oil, protein, and agronomic characters in two soybean hybrids. Ph.D. Dissertation. Univ. Tennessee. 99 p.
- Probst, A. H., and R. W. Judd. 1973. pp. 1-15. In B. E. Caldwell [ed.] *Soybeans: improvement, production, and uses*. American Society of Agronomy, Madison, Wisconsin.
- Rawlings, J. O., D. G. Hanway, and C. O. Gardner. 1958. Variation in quantitative characters of soybeans after seed irradiation. *Agron. J.* 50:524-528.
- Saccardo, F., and M. Deureux. 1967. Morphological characteristics and cytogenetics of fifteen tobacco mutants. *Caryologia* 20:239-256.
- Saki, Kan-Ich, and Akio Suzuki. 1965. Induced mutation and pleiotrophy of genes responsible for quantitative characters in rice. *Radiat. Bot.* 4:141-151.
- Schieman, E. 1912. Mutationen be: Aspergillus niger. *Zeitschr. ind. Abst. u. Vererb. Lehre* 8:1-25 (cited by Gustafsson, 1963).
- Scossiroli, R. E. 1965. Value of induced mutations for quantitative characters in plant breeding. In *The use of induced mutations in plant breeding. Radiat. Bot.* 5 (Suppl.):443-450.

- Scossiroli, R. E. 1966. Wheat mutagenesis in quantitative traits. [Second Int. Wheat Genet. Symp., Lund]. *Hereditas* 2 (Suppl.):85-101.
- Service, J. 1972. A user's guide to the statistical analysis system. North Carolina State University, Raleigh.
- Sigurbjornsson, B., and A. Micke. 1974. Philosophy and accomplishments of mutation breeding, pp. 303-343. In *Polyploidy and induced mutations in plant breeding*. (Proc. Meeting, Bari, 1972). IAEA, Vienna.
- Snedecor, G. L., and W. G. Cochran. 1971. *Statistical Methods*. The Iowa State University Press, Ames.
- Stadler, L. J. 1928. Mutations in barley induced by x-rays and radium. *Science* 68:186-187.
- Stubbe, H. 1959. Some results and problems of theoretical and applied mutation research. *Indian J. Genet. and Plant Breeding* 19:13-29 (cited by Gustafsson, 1963).
- Takeda, G. 1964. Selection in mutation breeding in barley. *Gamma Field Symp. No. 3*:59-73. (Abstr.)
- Tedopagze, S. G. 1965. Utilization of bean and soya radiomutants in selection work. Translated from *Genetika*, No. 1.
- Williams, J. H., and D. G. Hanway. 1961. Genetic variation in oil and protein content of soybeans induced by seed irradiation. *Crop Sci.* 1:34-36.
- Wolff, F. 1909. Über Modifikationen und experimentell ausgelöste Mutationen von Bacillus prodigiosus und anderen Schizophyten. *Zeitschr. ind. Abst. u. Vererb. lehre* 2:90-132 (cited by Gustafsson, 1963).
- Zacharias, M. 1956. Mutation trials of cultivated plants VI. Roentgen irradiation of soybeans. [Transl. from German] Vol. 26, No. 11. *Der Zuchter*.

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