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FAST NEUTRON INDUCED GENETIC VARIABILITY IN COWPEA [VIGNA UNGUICULATA (L.) WALP.] VARIETIES.

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ABSTRACT

*Cowpea (*Vigna unguiculata *L. Walp.) is an important grain legume cultivated widely in sub-Saharan Africa, yet its productivity is constrained by narrow genetic diversity. This study was conducted to estimate genetic variability for agronomic traits in M_2 generation induced by fast neutron irradiation in two cowpea varieties (SAMPEA 21 and SAMPEA 20T). Seeds were irradiated with varying doses of fast neutron (0.85–11.1 µSv for SAMPEA 21; 0.70–16.40 µSv for SAMPEA 20T) at the Nigeria Research Reactor-1 (NIRR-1), Zaria. M_1 plants were raised in a randomized complete block design, and M_2 progenies were evaluated in an augmented design for ten agronomic traits. Analysis of variance revealed significant differences ($p<0.05$ and $p<0.01$) among M_2 progenies for most traits, including number of pods per plant, number of peduncles per plant, number of seeds per pod, pod length, hundred seed weight, and plant yield. Genotypic coefficient of variation (GCV) ranged from 1.39% to 60.81%, while phenotypic coefficient of variation (PCV) ranged from 3.37% to 69.15%. Broad-sense heritability estimates ranged from 17.09% to 93.42%, with number of pods per plant (76.45% in SAMPEA 21; 76.03% in SAMPEA 20T), hundred seed weight (90.01% in SAMPEA 21; 93.42% in SAMPEA 20T), and number of pods per peduncle (77.35% in SAMPEA 20T) recording high heritability coupled with moderate to high GCV. Substantial variability was observed among M_2 progenies for yield and yield-related traits, with several mutants outperforming parental lines. The study demonstrates that fast neutron irradiation effectively induces heritable genetic variability in cowpea, providing a useful foundation for selecting promising mutant lines for further breeding and cowpea improvement.*

Key Words: Coefficient of variation, Cowpea, Fast neutron, Genetic variability, Heritability, Mutation breeding

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] Is a self-pollinated primary pulse crop with chromosome number 2n = 2x = 22 (Herniter *et al*., 2019; Omirou *et al*., 2019). It is a legume belonging to the family Fabaceae and is speculated to have originated from Africa (Steele, 1976). Nigeria is the world's largest cowpea producer, contributing approximately 3.58 million metric tons from 4.3 million hectares of land (FAOSTAT, 2023). The crop serves as an inexpensive plant-based protein resource, complements protein-deficient cereal-based diets, and replenishes soil fertility through biological nitrogen fixation (Horn *et al*., 2016). Its grains are rich in protein, carbohydrates, dietary fiber, vitamins, antioxidants, polyphenols, and polyunsaturated fatty acids (Ngoma *et al*., 2018; Ketema *et al*., 2020; Nkomo *et al*., 2021).

Despite the importance of cowpea, its annual average production is low compared to other grain legumes, primarily due to narrow genetic variability and the low yielding potential of existing genotypes (Raina *et al*., 2020). The consistent use of conventional breeding approaches has reduced genetic variability, which is the main prerequisite for crop improvement programs (Holme *et al*., 2019). Therefore, new breeding techniques such as induced mutagenesis are required to accomplish the goals of increased genetic variability.

Mutation breeding is the creation of mutations at will and their utilization for the production of new crop varieties. Mutagenesis is a very important tool in plant breeding and genetic research, allowing scientists to create genetic variations and study their effects on plant development and traits (Shu *et al*., 2012; Maghuly *et al*., 2018). Fast neutron irradiation, a form of physical mutagenesis, induces mutations by breaking DNA strands and causing chromosomal aberrations. It has been used effectively to generate mutants with desirable traits in various crops, including cowpea (Ibrahim *et al*., 2024; Ahmed *et al*., 2023), rice (Li *et al*., 2023), soybean (Wu *et al*., 2022), wheat (Zhang *et al*., 2021), and sorghum (Musa *et al*., 2022).

The estimation of genetic variability parameters, including genotypic and phenotypic coefficients of variation and heritability, is crucial for understanding the nature and magnitude of induced variation and for planning effective selection strategies (Singh and Chaudhary, 1985). High heritability coupled with high genetic advance indicates the presence of additive gene effects and is more reliable for effective selection (Johnson *et al*., 1955). This study was therefore conducted to estimate variability for agronomic traits in M_2 generation induced by fast neutron in cowpea varieties, with the aim of identifying promising mutant lines for future breeding programs.

MATERIALS AND METHODS

Study Area

The research was conducted at the Zoological Garden of the Department of Biological Sciences, Kaduna State University, Kaduna (10° 20°N and 7° 45°E) in the northern Guinea savanna agro ecological zone of Nigeria with a mean annual rainfall of about 1,173.47 mm for Kaduna town specifically, with a spread from 859 mm to 1,530 mm.

Source of Plant Materials

Uniform and healthy seeds of two cowpea varieties, SAMPEA 20T and SAMPEA 21 (Table 3.1) obtained from Institute for Agricultural Research (IAR) Samaru, Ahmadu Bello University, Zaria, Kaduna State were used as the experimental materials.

Fast Neutron Irradiation Treatment

Healthy, dry, and uniform seeds of the two varieties were grouped into batches of 50 seeds and irradiated using Fast Neutron for 2 (FN1), 4 (FNI2), 6 (FNI3), 8 (FNI4), 10 (FNI5), 12

(FNI6), 14 (FNI7), 16 (FNI8), 18 (FNI9) and 20 (FNI10) seconds. The irradiations were carried out at the Nigeria Research Reactor-1 (NIRR-1), a 30-kW miniature neutron source reactor (MNSR) located at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria in 2025. The fast neutron irradiation was conducted under controlled reactor conditions, and neutron dosimetry was carried out to confirm the delivered fluence per treatment level (Yahaya *et al*., 2023; Ibrahim *et al*., 2024). Control seeds remained untreated with fast neutrons to serve as baseline (Raina *et al*., 2022; Yahaya *et al*., 2023)

Table 1. Description of selected cowpea varieties

Variety name	Year / Place of release	Distinguishing characters/ Potential yield
SAMPEA 20T	2019/ IAR, Nigeria	Resistance to the legume pod borer, early maturity (65-75 days) and potential yield of 2.9t/ha.
SAMPEA 21	2022/ IAR, Nigeria	Resistance to *Striga* and bacterial blight, medium maturity (70-85 days) and potential yield of 2.0t/ha

Raising the first mutant (M_1) generation

The treated seeds and the control of each variety were sown on 3 m row plot at a distance of 75 cm inter-row and 30 cm intra-row spacing to raise the M_1 generation. The experiment was set out in Randomized Complete Block Design (RCBD) with two replications. Each replication consisted of 11 plots per replication and 22 plots per variety. Recommended agricultural practices such as weeding and plant protection methods were carried out during the growth of the crop. At maturity, all the seeds from M_1 plants with survival percentages of 50% and above of each variety were be harvested separately and stored for raising M_2 generation.

Raising the second mutant (M_2) generation

Ten healthy seeds from each M_1 plant harvested were sown to raise M_2 generation of each variety using augmented design in the Zoological Garden during the 2025 rainy season. Seeds were sown at a distance of 75 cm inter-row and 30 cm intra-row spacing to raise the M_2 generation. Recommended agricultural practices such as weeding and plant protection methods were carried out during the growth of the crop.

Data Collection

M_1 evaluation

Data were collected on plot basis on the M_1 plants for the following traits:

Seed germination

seed germination of each replication was recorded on the 18th day after sowing and the average was recorded as expressed below:

$$\text{Seed germination (\%)} = \frac{\text{Number of seeds geminated}}{\text{Number of seeds planted}} \text{x}100$$

Seedling Survival

This was observed after six weeks of seedling emergence and per cent survival was calculated as follows:

$$\text{Seedling survival (\%)} = \frac{\text{Number of seedlings survived}}{\text{Number of seeds germinated}} \text{x}100$$

The following data were also collected on the M_1 plants to estimate growth reduction:

Shoot length (cm)

This is the height measured from the base up to the apex and mean of five randomly selected plants was recorded.

Stem girth (cm)

This is the circumference measured and mean of five randomly selected plants was recorded.

Number of leaves

This is the total number of leaves per plant counted and mean of five randomly selected plants was recorded.

Leaf area

Leaf length and leaf breadth per plant and mean of five randomly selected plants was recorded and the leaf area was obtained by multiplying the leaf length and breadth.

Branches per plant (number)

This is the total number of branches per plant counted and mean of five randomly selected plants was recorded.

M_2 evaluation

Days to first flower (days):

This is the number of days taken from sowing to the date of opening of the first flower in a plot.

Plant height (cm):

At maturity five plants were randomly selected and measured using a meter rule (cm) from the base up to the apex of the plant and mean was recorded.

Number of branches per plant (number):

This is the total number of branches of five randomly selected plants counted and mean was recorded.

Number of pods per plant:

This is the total number of pods of five randomly selected plants counted and mean was recorded.

Number of pods per peduncle:
This is the total number of pods per peduncle of five randomly selected plants counted and mean was recorded.
Number of peduncles per plant:
This is the total number of peduncles of five randomly selected plants counted and mean was recorded.
Number of seed per pod:
This is the total number of seeds of five randomly selected plants counted and mean was recorded.

Pod length (cm):
Pod length was measured from the base to the tip of the pods of five randomly selected plants and the mean was recorded.

Hundred seed weight (g):
This the weight of a random sample of hundred seeds per plot.

Plant yield (g):
This is the weight of the total number of seeds harvested per plot divided by the number of plants in that plot.

Data Analysis
Data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) version 9.13 (SAS Institute, 2011). Mean separation was done using Duncan Multiple Range Test (DMRT) at 5% level of probability for M_1 generation and Fischer's Least Significant Difference for M_2 generation.

Estimation of Genetic Variability Parameters
Phenotypic and genotypic coefficients of variation and broad-sense heritability were computed according to Singh and Chaudhary (1985) as follows:

Phenotypic coefficient of variation (P.C.V %) = $\dfrac{\sqrt{\sigma^2_{ph}}}{\overline{X}} \, x\,100$

Genotypic coefficient of variation (G.C.V %) = $\dfrac{\sqrt{\sigma^2_{g}}}{\overline{X}} \, x\,100$

Where σ^2_{ph}, σ^2_{g} and $\overline{X}$ are phenotypic variance, genotypic variance and mean of the character, respectively. GCV and PCV values were classified as low (<10%), moderate (10-20%) and high (>20%) as indicated by Sivasubramanian and Menon (1973).

Broad-sense heritability $(h^2_b) = \dfrac{\sigma^2_g}{\sigma^2_{ph}} \, \mathrm{x}\, 100\,\%$

Where σ^2_{ph} and σ^2_g are phenotypic variance and genotypic variance. Heritability estimates were grouped as high (> 50%), moderate (20 – 50 %) and low (< 20 %) as suggested by Stansfield, (1986).

RESULTS AND DISCUSSION

Analysis of Variance and Mean Performance of M_2 Progenies of SAMPEA 21

Mean square for effect of fast neutron on agronomic traits of M_2 generation SAMPEA 21 evaluated at KASU in 2025 are presented in **Table 2**. There was significant difference ($p< 0.05$) among entries for number of peduncle per plant. there was highly significant difference ($p< 0.01$) among control for days to first flowering, while for number of peduncle per plant was significant at ($p< 0.05$). There were significant differences ($p< 0.05$) among mutants for number of peduncles per plant, number of seed per pod and plant yield.

The contrast between mutants and their respective control was highly significant ($p<0.01$) for days to first flowering and 100 seed weight and were significant ($p<0.05$) for number of peduncles per plant, number of seeds per pod and plant yield.

Mean performance of agronomic traits in M_2 progenies of mutants derived from SAMPEA 21 subjected to different doses of fast neutron irradiation evaluated at KASU in 2025 are presented **Table 3**. Days to first flowering (DTF) showed narrow variation across treatments, with mean values ranging from 44.40 (S21-0.99-3, S20T-0.70-3, S20T-1.02-3 and S20T-6.73-2) to 49.40 (S21-1.36-4 and S21-1.50-5). Plant height (PH) ranged from 3.20 (S20T-6.73-4) to 28.70 cm (S21-0.85-1), while the parental lines recorded 16.60 (SAMPEA 21) and 19.80 (SAMPEA 20T). The number of branches per plant (NB) ranged from 11.60 (observed in several S21 mutants (S21-0.85-5, S21-0.99-5, S21-1.36-4 and S21-1.50-4) to 17.10 (S20T-1.02-3 and S20T-6.73-1). Number of pods per plant (NP) ranged from 4.70 (S20T-1.02-3) to 28.70 (S20T-1.02-4).

The number of pods per peduncle (NPP) varied from 0.50 (S21-0.99-5, S21-1.36-2, S21-1.36-3, S21-1.36-4 and S21-1.50-1) to 4.00 (S21-1.50-5 and S20T-0.70-4). Number of peduncles per plant (NPPP) ranged from 0.00 (S21-1.50-5) to 15.70 (S20T-0.70-1). Number of seeds per pod (NSPP) ranged from 4.50 (S20T-6.73-4 and S20T-6.73-5) to 17.00 (S20T-1.02-3), Pod length (PL) ranged from 10.91 (S20T-6.73-4 and S20T-6.73-5) to 21.26 cm (S20T-1.02-4). Hundred seed weight (100SW) ranged from 15.00 g (S20T-6.73-3) to 17.50 (recorded in several S21 mutants including S21-0.99-4, S21-1.36-1, S21-1.36-2, S21-1.36-3, S21-1.36-4 and S21-1.50-1), Plant yield (PY) ranged from 92.00 g (S20T-6.73-4 and S20T-6.73-5) to 105.00 g (S20T-1.02-3). Plant height (PH) ranged from 3.20 (S20T-6.73-4) to 28.70 cm (S21-0.85-1), while the parental lines recorded 16.60 (SAMPEA 21) and 19.80

Mean performance of agronomic traits in M_2 progenies of mutants derived from SAMPEA 21 is presented in **Table 4**. Days to first flowering showed narrow variation, ranging from 44.40 to 49.40 days. Plant height ranged from 3.20 to 28.70 cm, compared to the parental line value of 16.60 cm. Number of branches per plant ranged from 11.60 to 17.10. Number of pods per plant ranged from 4.70 to 28.70. Number of pods per peduncle varied from 0.50 to 4.00. Number of peduncles per plant ranged from 0.00 to 15.70. Number of seeds per pod ranged from 4.50 to 17.00. Pod length ranged from 10.91 to 21.26 cm. Hundred seed weight ranged from 15.00 to 17.50 g, while plant yield ranged from 92.00 to 105.00 g. Several mutants outperformed the parental control (SAMPEA 21: 16.60 cm plant height, 11.00 pods per plant, 15.94 cm pod length, 16.40 g hundred seed weight, 99.00 g plant yield).

(SAMPEA 20T). The number of branches per plant (NB) ranged from 11.60 (observed in several S21 mutants (S21-0.85-5, S21-0.99-5, S21-1.36-4 and S21-1.50-4) to 17.10 (S20T-1.02-3 and S20T-6.73-1). Number of pods per plant (NP) ranged from 4.70 (S20T-1.02-3) to 28.70 (S20T-1.02-4).

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Analysis of Variance and Mean Performance of M_2 Progenies of SAMPEA 20T

Mean squares for the effect of fast neutron irradiation on agronomic traits of M_2 generation SAMPEA 20T evaluated at KASU in 2025 are presented in **Table 4**. There was a highly significant difference ($p < 0.01$) among entries for number of pods per plant (NP), hundred seed weight (100SW), and significant difference ($p < 0.05$) for number of pods per peduncle (NPPPED) and pod length (PL). The control (C) showed significant variation at $p < 0.05$ for number of branches per plant (NB) and highly significant differences ($p < 0.01$) for plant height (PH) and hundred seed weight (100SW).

Among the mutants (M), there were significant differences ($p < 0.05$) for plant height (PH), number of branches per plant (NB), number of pods per plant (NP), number of pods per peduncle (NPPPED), and pod length (PL), while highly significant differences ($p < 0.01$) were observed for hundred seed weight (100SW). The contrast between mutants and control (M vs C) did not show statistically significant differences for any of the traits at the 0.05 or 0.01 probability levels.

Mean performance of agronomic traits in M_2 progenies of mutants derived from SAMPEA 20T subjected to different doses of fast neutron irradiation evaluated at KASU in 2025 are presented **Table 5**. Days to first flowering (DTF) showed narrow variation across treatments, with mean values ranging from 44.40 (S21-0.99-3, S20T-0.70-3, S20T-1.02-3 and S20T-6.73-2) to 49.40 (S21-1.36-4 and S21-1.50-5). Plant height (PH) ranged from 3.20 (S20T-6.73-4) to 28.70 cm (S21-0.85-1), while the parental lines recorded 16.60 (SAMPEA 21) and 19.80 (SAMPEA 20T). The number of branches per plant (NB) ranged from 11.60 (observed in several S21 mutants (S21-0.85-5, S21-0.99-5, S21-1.36-4 and S21-1.50-4) to 17.10 (S20T-1.02-3 and S20T-6.73-1). Number of pods per plant (NP) ranged from 4.70 (S20T-1.02-3) to 28.70 (S20T-1.02-4).

The number of pods per peduncle (NPP) varied from 0.50 (S21-0.99-5, S21-1.36-2, S21-1.36-3, S21-1.36-4 and S21-1.50-1) to 4.00 (S21-1.50-5 and S20T-0.70-4). Number of peduncles per plant (NPPP) ranged from 0.00 (S21-1.50-5) to 15.70 (S20T-0.70-1). Number of seeds per pod (NSPP) ranged from 4.50 (S20T-6.73-4 and S20T-6.73-5) to 17.00 (S20T-1.02-3), Pod length (PL) ranged from 10.91 (S20T-6.73-4 and S20T-6.73-5) to 21.26 cm (S20T-1.02-4).

Hundred seed weight (100SW) ranged from 15.00 g (S20T-6.73-3) to 17.50 (recorded in several S21 mutants including S21-0.99-4, S21-1.36-1, S21-1.36-2, S21-1.36-3, S21-1.36-4 and S21-1.50-1), Plant yield (PY) ranged from 92.00 g (S20T-6.73-4 and S20T-6.73-5) to 105.00 g (S20T-1.02-3). Plant height (PH) ranged from 3.20 (S20T-6.73-4) to 28.70 cm (S21-0.85-1), while the parental lines recorded 16.60 (SAMPEA 21) and 19.80 (SAMPEA 20T). The number of branches per plant (NB) ranged from 11.60 (observed in several S21 mutants (S21-0.85-5, S21-0.99-5, S21-1.36-4 and S21-1.50-4) to 17.10 (S20T-1.02-3 and S20T-6.73-1). Number of pods per plant (NP) ranged from 4.70 (S20T-1.02-3) to 28.70 (S20T-1.02-4).

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Genetic Variability Estimates and Heritability of Agronomic Traits in M_2 progenies of SAMPEA 21

The estimate of genotypic variance, phenotypic variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and broad sense heritability for ten quantitative traits evaluated in the M_2 generation of in M_2 generation of SAMPEA 21 evaluated at KASU in 2025are presented in **Table 6**. Estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (GCV) and broad sense heritability for 10 quantitative traits. Across all traits, PCV values were higher than their corresponding GCV values. Days to first flowering recorded relatively low GCV and PCV values, with high heritability (71.63%).

Plant height showed moderate GCV (11.52%) and PCV (15.15%) values, with heritability of 57.99%. Number of branches per plant exhibited low GCV (1.81%) and PCV (7.23%) values, accompanied by moderate heritability (53.04%). Number of pods per plant recorded relatively high GCV (9.13%) and PCV (18.33%) values, with high heritability (76.45%). Number of pods per peduncle and number of peduncles per plant recorded high PCV values relative to GCV, with low to moderate heritability estimates (30.00% and 40.54%, respectively). Number of seeds per pod exhibited moderate GCV and PCV values with heritability of 53.03%. Pod length recorded low GCV (12.22%) but high PCV (22.76%), resulting in low heritability (20.38%). Hundred seed weight showed high heritability (90.01%) with moderate GCV and PCV values, Plant yield exhibited moderate variability with heritability of 53.03%.

Genetic Variability Estimates and Heritability of Agronomic Traits in M_2 progenies of SAMPEA 20T

The estimates of genotypic variance, error variance, phenotypic variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and broad sense heritability for ten quantitative traits evaluated in the M_2 generation of SAMPEA 20T at KASU in 2025 are presented in **Table 7**. Across all traits, PCV values were higher than their

corresponding GCV values. Days to first flowering recorded very low GCV (1.39%) and low PCV (3.37%) values, accompanied by low heritability (17.09%). Plant height (cm) showed high GCV (36.83%) and high PCV (47.26%) values, with moderate heritability (60.74%). Number of branches per plant exhibited high GCV (36.65%) and high PCV (48.36%) values, with moderate heritability (57.45%).
Number of pods per plant recorded high GCV (36.10%) and high PCV (41.40%) values, with high heritability (76.03%). Number of pods per peduncle displayed very high GCV (60.81%) and very high PCV (69.15%) values, coupled with high heritability (77.35%). Number of peduncles per plant had moderate to high GCV (24.58%) and high PCV (49.01%) values, but low heritability (25.16%). Number of seeds per pod showed moderate to high GCV (24.11%) and high PCV (33.06%) values, with moderate heritability (53.21%). Pod length (cm) recorded low GCV (8.48%) and moderate PCV (11.14%) values, with moderate heritability (57.92%). Hundred seed weight (g) exhibited low GCV (7.62%) and low PCV (7.88%) values, with very high heritability (93.42%). Plant yield (g) showed moderate GCV (12.14%) and moderate PCV (26.94%) values, but low heritability (20.32%).

Variability Induced by Fast Neutron Irradiation

The significant variation observed among M_2 progenies for most agronomic traits confirms that fast neutron irradiation successfully induced genetic variability in cowpea. The wide ranges recorded for traits such as plant height, number of pods per plant, number of peduncles per plant, pod length, and plant yield indicate that fast neutron irradiation effectively altered the genetic architecture of these traits. This is consistent with previous reports on induced mutagenesis in cowpea and other legumes (Raina *et al*., 2020; Oladosu *et al*., 2016). The increased variability observed in irradiated populations indicates the creation of new allelic combinations and disruption of gene linkages.

The narrow variation observed for days to first flowering suggests that this trait is under strong genetic control and is less influenced by irradiation-induced mutations. Similar findings have been reported in cowpea and groundnut, where flowering time exhibited low variability following mutagenic treatments (Mensah and Obadoni, 2007; Abimiku and Bello, 2010). This trait's stability is desirable as it allows breeders to maintain maturity duration while improving other agronomic characteristics.

Plant height recorded wide variation across irradiation doses, with both increases and decreases relative to the control. The reduction in plant height observed at higher doses may be attributed to impaired cell elongation and reduced internodal growth, while increases at moderate doses may result from stimulation of growth hormones or altered gene expression (Hanan *et al*., 2011). Such bidirectional shifts in mean values indicate the induction of polygenic variability, which is essential for quantitative trait improvement.

Yield-related traits exhibited pronounced variability in the mutant populations. The wide ranges observed for number of pods per plant (4.70–28.70), number of peduncles per plant (0.00–21.00), and plant yield (14.02–120.12 g) indicate that fast neutron irradiation effectively altered the genetic architecture of these traits. The increase in pod number and plant yield at moderate doses, particularly in SAMPEA 20T-derived mutants, suggests the presence of beneficial mutations that enhance reproductive efficiency. This is consistent with findings by Wang *et al*. (2015) who observed variations in pod number and size in peanut mutants derived from fast neutron irradiation combined with in vitro culture. Similarly, Falusi *et al*. (2012) reported significant variation in fruit number and yield traits in *Capsicum* species following fast neutron irradiation.

The stability observed for hundred seed weight across irradiation treatments indicates that this trait is highly heritable and less influenced by environmental factors. This finding is supported by the high heritability estimate recorded for hundred seed weight in the present study. Similar results have been reported in cowpea and groundnut, where seed weight showed high genetic control and stability across environments (Nadaf *et al*., 2009).

Genetic Variability Parameters

The consistently higher phenotypic coefficient of variation (PCV) compared to genotypic coefficient of variation (GCV) across all traits indicates the influence of environmental factors on trait expression. However, PCVs were slightly higher than corresponding GCVs for all traits, indicating that environment played a minimal role in the expression of these traits. Similar results were reported by Rajyalakshmi and Umajyothi (2014) in ginger and by Abimiku and Bello (2010) in cowpea.

The classification of GCV and PCV values according to Sivasubramanian and Menon (1973) revealed varying levels of variability among traits. In SAMPEA 21, traits such as number of pods per plant, number of pods per peduncle, number of peduncles per plant, and number of seeds per pod exhibited high GCV and PCV values, indicating substantial genetic variability that could be exploited through selection. In SAMPEA 20T, plant height, number of branches per plant, number of pods per plant, number of pods per peduncle, and number of peduncles per plant showed high GCV and PCV values, suggesting greater genetic diversity in this variety.

High GCV values for yield-related traits indicate the presence of sufficient genetic variability, which is a prerequisite for effective selection. Johnson *et al*. (1955) emphasized that GCV along with heritability estimates gives a better picture of the amount of genetic advance expected through selection. The moderate to high GCV values observed for most yield-related traits in both varieties suggest that these traits would respond positively to selection in mutation breeding programs.

Heritability Estimates

Heritability estimates provide valuable information on the extent to which traits are transmitted to progeny and thus guide selection strategies. In this study, broad-sense heritability estimates ranged widely, from 17.09% for days to first flowering in SAMPEA 20T to 93.42% for hundred seed weight in SAMPEA 20T.

Traits with high heritability (>50%) included days to first flowering (71.63%), number of pods per plant (76.45%), and hundred seed weight (90.01%) in SAMPEA 21, and plant height (60.74%), number of branches per plant (57.45%), number of pods per plant (76.03%), number of pods per peduncle (77.35%), number of seeds per pod (53.21%), pod length (57.92%), and hundred seed weight (93.42%) in SAMPEA 20T. High heritability for these traits indicates that they are under strong genetic control and would respond favorably to selection (Singh and Chaudhary, 1985).

The very high heritability observed for hundred seed weight in both varieties (90.01% in SAMPEA 21; 93.42% in SAMPEA 20T) suggests that this trait is highly heritable and can be effectively improved through selection in early generations. This finding is consistent with reports by Nadaf *et al*. (2009) and Abimiku and Bello (2010) who observed high heritability for seed weight in cowpea.

Traits with moderate heritability (20–50%) included number of branches per plant, number of pods per peduncle, number of peduncles per plant, and number of seeds per pod in SAMPEA 21, and number of peduncles per plant and plant yield in SAMPEA 20T. While these traits may respond to selection, improvement may require more intensive selection over multiple generations or the use of complementary breeding approaches (Stansfield, 1986).

Low heritability was observed for pod length (20.38%) in SAMPEA 21 and days to first flowering (17.09%) in SAMPEA 20T. Low heritability for these traits suggests that environmental factors have a strong influence on their expression, and selection based on phenotypic expression alone may not be effective. Improving such traits may require multi-environment trials and advanced breeding techniques (Allard, 1960).

Implications for Cowpea Improvement

The substantial genetic variability induced by fast neutron irradiation in both varieties provides a valuable genetic resource for cowpea improvement. The identification of mutant lines with superior performance for yield and yield-related traits, such as S21-1.36-9 (28.70 pods per plant, 21.26 cm pod length, 16 seeds per pod, 104.00 g plant yield) and S20T-0.70-6 (17.90 pods per plant, 120.12 g plant yield), demonstrates the potential of mutation breeding to generate elite genotypes with improved agronomic performance.

The high heritability coupled with moderate to high GCV for traits such as number of pods per plant and hundred seed weight indicates that these traits would respond effectively to selection. Abimiku and Bello (2010) emphasized that traits with high heritability and genetic variability respond effectively to selection. Therefore, selection for these traits in the M_3 and subsequent generations could lead to significant genetic gains.

The varietal differences observed in radiosensitivity and genetic variability suggest that mutation breeding programs should be tailored to specific genotypes. SAMPEA 21 exhibited lower LD_{50} and GR_{50} values, indicating higher sensitivity to fast neutron irradiation, while SAMPEA 20T showed greater tolerance and wider variability for several traits. This underscores the importance of preliminary radiosensitivity tests and determination of optimum mutagen doses for each genotype before initiating large-scale mutation breeding programs (Bado *et al*., 2022; Raina *et al*., 2024).

The significant contrast between mutants and their respective controls for multiple traits indicates that the observed variability is attributable to induced mutations rather than random environmental effects or natural variation. This validates the effectiveness of fast neutron irradiation as a mutagenic agent for creating novel genetic variability in cowpea.

Table 2. Mean Square for effect of fast neutron on agronomic traits of M_2 generation of SAMPEA 21

Source of variation	Df	DTF	PH	NB	NP	NPPPED	NPPP	NSPP	PL (cm)	100sw (g)	PY (g)
Block	4	15.90**	27.49	2.14	48.52	0.96	12.57*	7.74	4.83	0.69**	7.744
Entries	41	0.9	25.6	0.1	0.4	0.4	12.10*	1.6	1.02	0.1	1.6
Control (C)	1	16.69**	27.95	2.2	48.66	0.99	12.61*	7.75	4.87	0.72	7.754
Mutants (M)	39	0.41	11.52	1.81	9.13	0.05	11.52*	13.52*	7.22	0.01	13.52*
M vs C	1	34.60**	68.15	1.85	42.65	0.2	18.15*	15.75*	12.22	1.00**	15.75*
Error	4	0.4	64.84	1.85	32.15	1.4	6.85	6.35	9.73	0.1	6.35

NOTE: *and**= significant at 0.05 and 0.01 probability levels, respectively, DTF = Days to first flowering, PH= Plant height, NB= No. of branches per plant, NP= No of Pod per plant, NPPPED= No of Pod per peduncle, NPPP= no. of peduncle per plant, NSPP= No of seed per pod, PL (cm) = pod length cm, 100sw= hundred seed weight (g), PY (g) = Plant yield (g)

Table 3 Mean performance of agronomic traits in M_2 progenies of mutants derived from SAMPEA 21 subjected to different doses of fast neutron irradiation evaluated at KASU in 2025

Treatment	DTF	PH (cm)	NB	NP	NPP	NPPP	NSPP	PL (cm)	100SW (g)	PY (g)
S21-0.85-1	48.40	28.70	13.60	17.70	2.50	9.70	8.00	14.26	16.50	96.00
S21-0.85-2	46.40	26.70	14.60	16.70	2.50	12.70	13.00	15.26	16.50	101.00
S21-0.85-3	48.40	24.70	14.60	14.70	1.50	13.70	10.00	14.76	15.50	98.00
S21-0.85-4	45.40	10.70	14.60	17.70	2.50	10.70	13.00	16.26	16.50	101.00
S21-0.85-5	47.40	14.70	11.60	24.70	3.50	7.70	11.00	15.76	16.50	99.00
S21-0.85-6	46.40	15.70	12.60	12.70	1.50	8.70	10.00	13.56	16.50	98.00
S21-0.85-7	48.40	6.70	13.60	19.70	3.50	7.70	8.00	13.26	16.50	96.00
S21-0.85-8	44.40	11.70	12.60	8.70	2.50	5.70	11.00	15.76	16.50	99.00
S21-0.85-9	47.40	20.70	16.60	18.20	1.50	10.20	10.50	15.76	17.50	98.50
S21-0.85-10	45.40	20.70	11.60	15.20	0.50	13.20	12.50	18.76	16.50	100.50
S21-0.99-1	47.40	12.70	14.60	14.20	2.50	6.20	14.50	16.26	17.50	102.50
S21-0.99-2	47.40	8.70	15.60	13.20	0.50	15.20	6.50	13.26	17.50	94.50
S21-0.99-3	46.40	7.70	15.60	10.20	0.50	12.20	9.50	14.26	17.50	97.50
S21-0.99-4	49.40	10.70	11.60	11.20	0.50	12.20	9.50	14.26	17.50	97.50
S21-0.99-5	47.40	12.70	13.60	10.20	1.50	4.20	8.50	14.26	17.50	96.50
S21-0.99-6	47.40	9.70	13.60	10.20	0.50	12.20	7.50	13.26	17.50	95.50
S21-0.99-7	45.40	13.20	13.60	7.20	2.00	2.70	9.00	14.01	15.50	97.00
S21-0.99-8	46.40	20.20	13.60	18.20	3.00	5.70	12.00	15.01	16.50	100.00
S21-0.99-9	48.40	19.20	11.60	7.20	2.00	2.70	11.00	15.01	16.50	99.00
S21-0.99-10	49.40	16.20	13.60	11.20	4.00	0.00	10.00	16.51	16.50	98.00
S21-1.36-1	45.40	19.20	12.60	20.20	2.00	15.70	8.00	14.01	16.50	96.00
S21-1.36-2	47.40	14.20	11.60	13.20	2.00	8.70	11.00	16.01	16.50	99.00
S21-1.36-3	44.40	27.20	11.60	5.20	2.00	0.70	13.00	17.01	16.50	101.00
S21-1.36-4	46.40	23.20	12.60	9.20	4.00	0.70	12.00	15.01	16.50	100.00
S21-1.36-5	47.40	22.20	13.10	20.70	2.50	8.20	11.00	15.96	16.50	99.00
S21-1.36-6	46.40	27.20	13.10	26.70	2.50	10.20	15.00	16.56	16.50	103.00
S21-1.36-7	45.40	25.20	13.10	18.70	2.50	6.20	12.00	18.06	16.50	100.00
S21-1.36-8	44.40	28.20	17.10	4.70	1.50	0.20	17.00	20.06	16.50	105.00
S21-1.36-9	46.40	23.20	13.10	28.70	2.50	12.20	16.00	21.26	16.50	104.00
S21-1.36-10	47.40	21.20	15.10	14.70	2.50	5.20	11.00	15.56	16.50	99.00
S21-1.50-1	46.40	25.20	14.10	10.70	1.50	8.20	14.00	16.56	16.50	102.00
S21-1.50-2	45.40	22.20	13.10	12.70	2.50	5.20	13.00	16.56	16.50	101.00
S21-1.50-3	46.40	5.20	15.10	11.20	1.50	8.20	12.50	14.91	16.00	100.00
S21-1.50-4	47.40	13.20	14.10	13.20	1.50	9.20	6.50	13.41	16.00	94.00
S21-1.50-5	45.40	14.20	12.10	20.20	2.50	9.20	14.50	18.91	16.00	102.00
S21-1.50-6	47.40	17.20	17.10	24.20	2.50	9.20	11.50	15.91	17.00	99.00
S21-1.50-7	44.40	9.20	13.10	12.20	2.50	6.20	6.50	12.41	16.00	94.00
S21-1.50-8	46.40	17.20	14.10	13.20	1.50	7.20	9.50	12.91	15.00	97.00
S21-1.50-9	47.40	3.20	12.10	12.20	2.50	6.20	4.50	10.91	16.00	92.00
S21-1.50-10	46.40	10.20	12.10	12.20	1.50	7.20	4.50	10.91	16.00	92.00
SAMPEA 21	46.60	16.60	13.20	11.00	2.20	5.60	11.60	15.94	16.40	99.00
SAMPEA 20T	47.20	19.80	13.00	11.40	1.80	7.80	12.40	16.58	16.60	100.40
Mean	46.69	17.06	13.55	14.41	2.07	7.87	10.76	15.36	16.52	98.65
CV	2.72	40.02	10.77	38.37	41.89	50.04	26.72	13.86	3.41	2.99
LSD	3.03	6.63	2.78	4.42	3.57	7.89	7.60	9.40	3.02	7.60

DTF= Days to first flowering, PH= Plant height, NB= Number of branches per plant, NP= Number of pods per plant, NPP= Number of Pods per peduncle, NPPP= number of peduncles per plant, NSPP= No of seed per pod, PL (cm) = pod length cm, 100sw= hundred seed weight (g), PY (g) = Plant yield (g)

Table 4. Mean squares for effect of fast neutron irradiation on agronomic traits of M_2 generation of SAMPEA 20T evaluated at KASU in 2025

Source of variation	df	DTF	PH	NB	NP	NPPPED	NPPP	NSPP	PL (cm)	100SW (g)	PY (g)
Block	4	1.15	65.15*	0.35	28.6*	6.35*	16.25	21.40	1.10	4.00**	271.60
Entries	41	1.92	17.06	1.08	18.29**	2.79*	19.82	14.51	2.64*	1.45**	286.20
Control (C)	2	0.40	108.90**	3.60*	0.40	0.90	8.10	2.50	1.29	0.10	582.20
Mutants (M)	39	1.99	32.65*	2.35*	18.36**	2.87*	20.51	14.96	2.59*	1.52**	285.90
M vs C	1	0.72	90.45	1.62	33.62	1.81	4.80	8.82	5.75	0.18	2.20
Error	4	1.65	12.82	1.00	4.40	0.65	15.35	7.00	1.09	0.10	227.80

NOTE: *and**= significant at 0.05 and 0.01 probability levels, respectively, DTF= Days to first flowering, PH= Plant height, NB= Number of branches per plant, NP= Number of Pod per plant, NPPPED= Number of Pod per peduncle, NPPP= Number. of peduncle per plant, NSPP= Number of seed per pod, PL (cm)= pod length, 100SW= hundred seed weight (g), PY (g)= Plant yield (

Table 5. Mean performance of agronomic traits in M_2 progenies of mutants derived from SAMPEA 20T subjected to different doses of fast neutron irradiation evaluated at KASU in 2025

Treatment	DTF	PH (cm)	NB	NP	NPP	NPPP	NSPP	PL (cm)	100SW (g)	PY (g)
S20T-0.70-1	42.40	18.60	3.00	8.60	3.20	7.60	11.20	14.00	15.40	54.64
S20T-0.70-2	42.40	12.00	4.20	8.20	2.60	9.40	10.20	13.28	15.60	69.90
S20T-0.70-3	40.20	17.30	5.60	9.90	1.40	13.50	12.20	16.14	15.50	47.02
S20T-0.70-4	44.70	0.80	4.10	7.90	3.40	10.50	10.20	13.14	15.50	53.22
S20T-0.70-5	43.70	17.80	4.10	10.90	1.90	21.00	8.20	12.94	16.00	77.82
S20T-0.70-6	44.70	19.80	3.10	17.90	2.90	11.00	12.20	13.94	15.00	120.12
S20T-0.70-7	42.20	18.80	3.60	9.40	3.40	7.00	11.20	13.14	15.00	65.37
S20T-0.70-8	44.70	0.80	3.10	11.90	2.40	12.50	11.20	14.14	15.50	48.92
S20T-0.70-9	41.20	6.80	2.60	13.40	2.40	7.00	12.20	13.14	16.50	91.87
S20T-0.70-10	42.70	20.30	3.10	12.90	2.90	12.50	11.20	13.94	16.00	92.82
S20T-1.02-1	41.20	8.80	4.60	6.40	3.40	7.00	14.20	15.14	15.50	45.27
S20T-1.02-2	42.70	17.30	3.10	12.90	1.40	8.00	11.20	14.94	15.00	85.52
S20T-1.02-3	40.20	16.80	4.60	6.40	2.40	4.00	10.20	11.14	15.50	58.17
S20T-1.02-4	40.20	6.30	2.60	5.40	2.90	14.00	10.20	14.64	16.50	87.07
S20T-1.02-5	41.20	12.30	1.60	3.90	1.40	8.00	12.20	14.14	15.50	62.57
S20T-1.02-6	40.20	16.30	2.60	6.40	2.90	8.00	10.20	15.14	15.50	51.32
S20T-1.02-7	42.20	15.30	2.60	9.90	2.40	9.00	15.20	14.14	15.50	47.37
S20T-1.02-8	43.70	2.80	4.10	12.90	2.90	6.00	12.20	14.14	15.50	66.22
S20T-1.02-9	41.20	15.30	1.60	8.90	2.40	12.00	10.20	14.14	16.50	62.97
S20T-1.02-10	40.20	12.30	2.60	8.90	1.90	12.50	15.20	17.14	15.0	46.22
S20T-1.84-1	41.20	16.80	1.60	4.40	1.40	8.00	14.20	16.54	15.50	47.77
S20T-1.84-2	42.70	17.80	3.10	15.90	1.90	0.50	9.20	12.94	15.50	78.52
S20T-1.84-3	43.70	0.80	4.10	10.90	2.40	11.00	9.20	13.40	15.50	26.52
S20T-1.84-4	44.20	10.30	0.60	14.90	1.90	8.00	11.20	14.14	15.50	31.87
S20T-1.84-5	43.20	15.30	0.60	9.90	1.90	0.50	18.20	15.14	15.50	57.37
S20T-1.84-6	41.70	15.80	5.10	10.90	3.90	11.00	10.20	15.44	16.00	14.02
S20T-1.84-7	43.70	1.80	4.10	17.90	2.40	8.00	13.20	14.14	15.50	80.32
S20T-1.84-8	40.20	16.30	3.60	8.90	2.40	15.00	9.20	14.14	15.50	74.72
S20T-1.84-9	43.70	18.30	3.10	8.90	1.90	4.00	13.20	15.94	15.00	26.07
S20T-1.84-10	38.20	6.30	3.60	8.90	1.90	13.50	11.20	14.14	16.50	60.32
S20T-6.73-1	41.20	18.30	3.60	7.90	2.40	10.50	14.20	18.34	15.50	62.97
S20T-6.73-2	42.20	8.30	2.60	4.40	1.40	8.00	12.20	17.14	16.50	49.07
S20T-6.73-3	42.20	11.30	2.60	15.90	2.90	12.50	12.20	14.14	15.50	63.52
S20T-6.73-4	40.20	11.30	2.60	7.90	2.40	5.00	9.20	13.04	15.50	97.72
S20T-6.73-5	37.20	16.30	2.60	13.90	2.40	14.00	10.20	14.64	15.50	39.17
S20T-6.73-6	42.70	9.30	2.60	15.90	2.90	8.50	8.20	14.14	16.50	72.82
S20T-6.73-7	40.20	2.80	3.10	10.90	3.40	9.50	16.20	17.14	15.50	52.32
S20T-6.73-8	41.20	1.80	4.10	7.90	4.40	9.00	13.20	15.14	15.50	70.42
S20T-6.73-9	41.70	15.30	4.60	9.90	1.40	7.50	12.20	13.64	15.50	72.37
S20T-6.73-10	42.70	14.80	2.60	11.40	2.40	6.50	10.20	13.14	15.50	69.72
SAMPEA 21	41.70	18.80	3.10	14.90	1.90	8.00	11.20	13.94	16.50	61.82
SAMPEA 20T	42.70	2.80	3.10	8.90	3.40	10.50	12.20	14.14	15.50	88.00
Mean	41.92	12.09	3.17	10.35	2.45	9.24	11.70	14.45	15.64	62.77
CV	3.06	45.31	47.31	20.89	31.99	42.96	22.93	7.31	2.02	24.07
LSD	3.67	10.23	2.86	6.00	2.30	11.20	7.56	2.98	0.90	43.14

DTF= Days to first flowering, PH= Plant height, NB= Number of branches per plant, NP= Number of pods per plant, NPP= Number of Pods per peduncle, NPPP= number of peduncles per plant, NSPP= No of seed per pod, PL (cm) = pod length cm, 100sw= hundred seed weight (g), PY (g) = Plant yield (g)

Table 6. Estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (GCV) and broad sense heritability for 10 quantitative traits in M_2 generation of SAMPEA 21 evaluated at KASU in 2025

Traits	σ_g^2	σ_e^2	σ_{ph}^2	GCV (%)	PCV (%)	h_b^2
Days to first flowering	10.10	4.00	14.10	6.81	8.04	71.63
Plant height (cm)	6.68	4.84	11.52	15.15	19.90	57.99
Number of branches per plant	0.96	0.85	1.81	7.23	9.93	53.04
Number of pods per plant	6.98	2.15	9.13	18.33	20.97	76.45
Number of pods per peduncle	0.60	1.40	2.00	37.42	68.32	30.00
Number of peduncles per plant	4.67	6.85	11.52	27.56	43.29	40.54
Number of seed per pod	7.17	6.35	13.52	24.89	34.17	53.03
Pod length (cm)	2.49	9.73	12.22	10.27	22.76	20.38
Hundred seed weight (g)	9.01	1.00	10.01	18.17	19.15	90.01
Plant yield (g)	7.17	6.35	13.52	2.71	3.72	53.03

σ_g^2: Genotypic variance, σ_e^2: error variance; σ_{ph}^2: phenotypic variance; h_b^2: broad sense heritability; GCV: genotypic coefficient of variation; PCV: phenotypic coefficient of variation

Table 7. Estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (GCV) and broad sense heritability for 10 quantitative traits in M_2 generation of SAMPEA 20T evaluated at KASU in 2025

Traits	σ_g^2	σ_e^2	σ_{ph}^2	GCV (%)	PCV (%)	h_b^2
Days to first flowering	0.34	1.65	1.99	3.37	1.39	17.09
Plant height (cm)	19.83	12.82	32.65	47.26	36.83	60.74
Number of branches per plant	1.35	1.00	2.35	48.36	36.65	57.45
Number of pods per plant	13.96	4.40	18.36	41.40	36.10	76.03
Number of pods per peduncle	2.22	0.65	2.87	69.15	60.81	77.35
Number of peduncles per plant	5.16	15.35	20.51	49.01	24.58	25.16
Number of seed per pod	7.96	7.00	14.96	33.06	24.11	53.21
Pod length (cm)	1.50	1.09	2.59	11.14	8.48	57.92
Hundred seed weight (g)	1.42	0.10	1.52	7.88	7.62	93.42
Plant yield (g)	58.10	227.80	285.90	26.94	12.14	20.32

σ_g^2: genotypic variance; σ_e^2: error variance; σ_{ph}^2: phenotypic variance; h_b^2: broad sense heritability; GCV: genotypic coefficient of variation; PCV: phenotypic coefficient of variation

CONCLUSION

Fast neutron irradiation effectively induced genetic variability in cowpea, as evidenced by significant changes in the mean values and wide ranges of key agronomic traits across M_2 generations. Traits such as number of pods per plant, number of peduncles per plant, number of seeds per pod, pod length, hundred seed weight, and plant yield exhibited substantial variability, with several mutants outperforming parental lines.

The high PCV and GCV values in the M_2 generation highlight enhanced genetic variation, particularly in yield-related traits, underscoring the potential of fast neutron irradiation as a tool for yield improvement in cowpea.

High heritability estimates for traits such as number of pods per plant, number of pods per peduncle, and hundred seed weight indicate strong genetic control and good prospects for improvement through selection.

The study demonstrates that fast neutron irradiation is a valuable tool for broadening the genetic base of cowpea and generating useful variability for breeding programs.

RECOMMENDATIONS

The subsequent generations (M_3 and beyond) should be evaluated to identify stable and heritable mutations that may contribute to improved agronomic traits such as yield, stress tolerance, and disease resistance.

Promising mutant lines identified in this study (such as S21-1.36-9, S21-1.50-6, S20T-0.70-6, and S20T-6.73-4) should be advanced and evaluated in multi-location trials to assess their performance across different environments.

Molecular and cytogenetic analyses should be incorporated to quantify mutation frequency, characterize induced genetic variations, and identify the specific genomic regions affected by fast neutron irradiation.

Crosses between selected mutants with complementary desirable traits should be made to combine beneficial mutations and develop superior cowpea varieties.

Further investigation is required to determine the genetic basis of produced mutations and evaluate their long-term stability. This will optimize the advantages of mutation breeding for crop enhancement and sustainable agriculture.

Additional cowpea genotypes should be included in future studies to broaden understanding of genotypic variation in mutagen sensitivity and support national cowpea breeding programmes.

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