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Research Article

Effects of Mutagenic Treatments on Drought Tolerance Indices of Selected Cowpea Mutant Lines from Niger State, Nigeria

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Abstract

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important legume crop cultivated in many regions of Nigeria. It serves as a source of protein, nutrients and income for communities. However, its production and yield potential are severely affected by drought which has been a prevalent constraint over the years, posing a significant threat to cowpea production and food security hence the need to develop mutant lines that can withstand drought conditions for continuous sustenance of lives and livelihoods. This study aimed to determine the effects of mutagens on drought tolerance indices in selected cowpea mutant lines treated with gamma irradiated and Ethyl Methane Sulphonate (EMS) collected from the gene bank of Plant Biology, Federal University of Technology Minna, Niger State. These mutant lines were subjected to water stress for two weeks and assessed for drought tolerance potential. The study revealed that gamma rays and EMS had significantly effects on drought tolerance indices. The Geometric Mean Productivity (GMP) ranged from 4.11 (V2G4) to 7.11 (V3EG3). Stress Intensity (SI) values ranged from 0.050 (V1EG4) to 0.585 (V2G4). V1EG4 exhibited the lowest SI. The SSI values of the cowpea mutant lines ranged from 0.43 in genotype V1EG4 to 2.69 in genotype V2G4. It was observed that four mutant lines namely; V1EG4 (0.43), V1G4 (0.47), V3EG3 (0.48), VIEG3 (0.58), V3EG1 (0.95) respectively had SSI value less than one (1). The Tolerance Index (TOL) ranged from 8.60 (V3EG3) to 12.93 (V2G4). The TOL values of the mutant lines V3EG3 exhibited the lowest and in contrast; V2G4 had the highest TOL, Stress Tolerance Index (STI) values of the cowpea mutant lines ranged from 0.407 in genotype V2G4 to 1.949 in genotype V3EG3. Mutant lines VIG4 (1.741) V1EG3 (1.893), V1EG4 (1.816) and V1EG3 (1.893) also had higher STI as compared to mutant lines V2EG4 (0.892), V1EG2 (0.714) V3G4 (0.709) and V3G1 (0.548). YI values ranged from 0.32 in genotype V2G4 to 2.24 in genotype V3EG3. The HM values ranged from 3.86 in genotype V2G4 to 7.08 in genotype V3EG. Drought tolerance indices studied confirms that mutagen treatments such as gamma rays and EMS significantly affected the tolerance and productivity of cowpea positively. Mutant lines such as such as V3EG3, V1G4 and V1EG4 exhibited enhanced drought tolerance as evidenced in their high MP, GMP, and STI values, along with low TOL and SSI values suggesting this mutant lines could be used for improving drought tolerance in cowpea breeding initiatives.

Keywords

Cowpea Mutant Lines, Drought Tolerance, EMS, Gamma Irradiation

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1. Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is an important legume crop which serves as food and animal feed crop grown in the semi-arid tropics covering Africa, Asia, Europe, the United States, and Central and South America. This legume crop is cultivated in several regions of Nigeria including Niger State. It serves as a vital source of protein, essential nutrients, and income for both small-scale farmers and rural communities. It also has an incredible capacity to improve soil fertility and avert erosion which makes it an important economic crop in so many developing countries like Nigeria [1]. However, the production and yield capacity of cowpea are brutally affected by drought stress which is a prevailing constraint in these regions [2].

Drought is a complex abiotic stress condition that adversely affects plant growth, development, and productivity leading to a major cause of the reduction of global agricultural production. It is characterized by lengthened periods of limited water availability, increase in temperature and decrease in the relative humidity which results to wilting, reduced photosynthesis, and ultimately yields losses of the plants. Drought is a limiting factor for both quality and production in several plants with agronomic potentials including cowpea. The occurrence of drought during the growing, development, reproductive and maturity stages of cowpea usually results in lower growth rates, development, flower abortion, lower weight of the aerial part of the plant, reduction in the expansion rate of leaf area and severe reductions in gas exchange thus complicating the reproduction process in cowpea [3].

Despite the demands of cowpea outweighs the market supply due to increase in consumer's preference and its various uses in the production of African cake and oil over the years, its production is generally low as a result of some factors such as drought. This can also be traced to lack of improved mutant lines for drought and insignificant increase in production via conventional breeding [4]. In Niger State where cowpea is one of the major food crop widely grown, the crop is yet to witness successful breeding programme for its improvement and to further enhance its productivity to the fullest. Scientists have developed high yielding mutant lines with early or medium maturity period, consumer preferred traits and resistance to some of the major diseases, pests, nematodes, and parasitic weeds. Conversely, little or nothing has been done on identifying the gene responsible for drought tolerance and breeding drought tolerant mutant lines in Niger State, Nigeria. Hence, an urgent needs to identify mutant lines with drought tolerance and water stress sensitivity characteristics [5].

Induced mutation as plant breeding strategy has been recognized to be harmless and low-cost technique [6]. According to [7], genetic variability for several desired characters can be induced successfully through mutations and its realization for plant improvement programmes has been well established. Exploring the techniques for assessment of genetic diversity is crucial for efficient identification and selection of drought resistant gene. According to [8], gamma irradiation has been reported to be a rapid method of improving the qualitative and quantitative traits of many crops and used to produce a number of useful mutants. Ethyl methane sulfonate (EMS) has been shown to be a very effective and efficient chemical mutagen for inducing variability in plant due to its reactive alkyl groups, which are transferred to other molecules at higher electron density [9]. Therefore, the effects of mutagenic treatments on drought tolerance indices of selected cowpea cowpea [Vigna unguiculata (L.) Walp.] mutant lines from Niger State, Nigeria was evaluated with the aim of identifing and selecting promising mutants lines with enhanced drought tolerance.

2. Materials and Methods

2.1. Collection of Mutant Lines

Cowpea mutant lines treated with four different doses of gamma irradiation namely; 200Gy, 400Gy, 600Gy and 800Gy and a constant concentration of 0.372v/v of ethyl Methane Sulphonate (EMS) were selected from the gene bank of Plant Biology, Federal University of Technology Minna, Niger State, Nigeria.

2.2. Experimental Site

The experiment was conducted at the experimental garden of the Department of Plant Biology, Federal University of Technology, Minna, Nigeria. Minna is geographically located in the North Central Zone of Nigeria, within longitude 60 33' East and latitude 90 37' North. It is basically a grassland savannah area, and has a tropical climatic condition with a mean annual temperature, relative humidity and rainfall of 20-300C, 61.00% and 1334.00 cm respectively. The climate brings about two seasons: a rainy season between May and October and a dry season between November and April [10].

2.3. Experimental Design

The experimental design used for this study is a Completely Randomized Design (CRD). Identification numbers were assigned to the seventeen mutant line seeds. The seeds of each mutant lines were planted with five replication which made a total of eighty-five planting pots. Four healthy seeds were planted in 10- litre experimental pots filled with 10 kg of topsoil. The plants were thinned from four to two seeds per pot after 8 days of planting (DAP) for optimal growth [11]

2.4. Induced Water Stress

The mutant lines and control plants were watered daily until the 40th day after planting, and the mutant lines were subjected to water stress while the control plants were still watered. The mutant lines were not watered for two weeks and watering was reintroduced. Mutant lines which had at least 10 % survival after exposure for two weeks drought were recorded and selected for further studies on drought tolerance indices.

2.5. Determination of Drought Tolerance Indices

Drought tolerance indices were determined according to the method of [12]. The following drought tolerance indices were determined for each of the genotype treatments.

Tolerance index (TOL) = Ypi - Ysi [13] (1)

Mean productivity (MP) = Ypi + Ysi/ 2 [13] (2)

Geometric mean productivity (GMP) = (Ypi - Ysi) 1/2 [14] (3)

Stress intensity (SI) = 1- (Ys/Yp) [12] (4)

Stress susceptibility index (SSI) = (1-Ysi / Ypi) /SI [12] (5)

Stress tolerance index (STI) = Ypi ×Ysi / Yp2 [14] (6)

Yield index (YI) = Ysi/ Ys [15] (7)

Harmonic Mean = 2 (Ypi x Ysi) / Ypi + Ysi [15] (8)

(Ysi = Yield in stress environment; Ypi = Yield in Non-stress environment; Ys = Mean yield in stress environment; Yp = Mean yield in non-stress environment)

3. Results

The effects of mutagenic treatments on drought tolerance indices of selected mutant lines is presented in (Tables 1 and 2). The Mean Productivity (MP) ranged from 4.37 in genotype V2G4 to 7.13 in genotype V3EG3The Geometric Mean Productivity (GMP) ranged from 4.11 in V2G4 to 7.11 in V3EG3. Stress Intensity (SI) values ranged from 0.050 (V1EG4) to 0.585 (V2G4). V1EG4 exhibited the lowest SI. The SSI values of the cowpea genotypes ranged from 0.43 in genotype V1EG4 to 2.69 in genotype V2G4. It was observed that four genotypes namely; V1EG4 (0.43), V1G4 (0.47), V3EG3 (0.48), VIEG3 (0.58), V3EG1 (0.95) respectively had SSI value less than one (1).

The Tolerance Index (TOL) ranged from 8.60 (V3EG3) to 12.93 (V2G4). The TOL values of the genotypes V3EG3 exhibited the lowest and in contrast; V2G4 had the highest TOL, Stress Tolerance Index (STI) values of the cowpea genotypes ranged from 0.407 in genotype V2G4 to 1.949 in genotype V3EG3. Genotypes VIG4 (1.741) V1EG3 (1.893), V1EG4 (1.816) and V1EG3 (1.893) also had higher STI as compared to genotypes V2EG4 (0.892), V1EG2 (0.714) V3G4 (0.709) and V3G1 (0.548). YI values ranged from 0.32 in genotype V2G4 to 2.24 in genotype V3EG3. The HM values ranged from 3.86 in genotype V2G4 to 7.08 in genotype V3EG3.

Table 1. *Effect of Gamma Irradiation and EMS on drought tolerance indices of Cowpea Mutant lines.*

MUTANT LINES	TOL	MP	GMP	SI
V3G1	10.64	5.65	5.64	0.108
V1EG3	10.80	7.07	6.06	0.560
V3EG3	8.60	7.13	7.11	0.062
V1EG4	11.10	5.42	5.39	0.050
V2EG4	11.20	5.52	5.51	0.106
V3EG1	11.20	5.37	5.34	0.201
V3G4	11.74	5.10	5.03	0.291
V1G4	9.77	7.00	6.81	0.085
V1EG2	12.14	6.40	6.31	0.280
V2G4	12.93	4.37	4.11	0.585

Keys: TOL: Stress tolerance, MP: Mean productivity, GMP: Geometric mean productivity, SI: Stress index. Where Ys and Yp represent yield in stress and non-stress conditions, Ys and Yp: mean yield of all mutant lines in stress and non-stress conditions respectively.

Table 2. *Effect of Gamma Irradiation and EMS on drought tolerance indices of Cowpea Mutant lines.*

MUTANT LINES	SSI	STI	YI	HM
V3G1	1.13	0.548	1.09	5.63
V1EG3	0.58	1.893	2.04	6.55
V3EG3	0.48	1.949	2.24	7.08
V1EG4	0.43	1.816	1.10	5.37
V2EG4	2.85	0.892	1.53	5.50
V3EG1	0.95	1.499	1.84	5.30
V3G4	1.98	0.709	1.24	4.95
V1G4	0.47	1.741	2.01	6.58
V1EG2	1.48	0.714	1.42	6.23
V2G4	2.69	0.407	0.32	3.86

SSI: Stress susceptibility index, STI: Stress tolerance index, YI: Yield index, HM: Harmonic mean. Where Ys and Yp represent yield in stress and non-stress conditions, Ys and Yp: mean yield of all mutant lines in stress and non-stress conditions respectively.

4. Discussion

Drought tolerance indices which provides a measure for determining the level of drought based on its evaluation on its yield loss under stressed conditions as compared to non-stressed conditions has been used to screen for drought tolerant genotypes [16] and the result revealed that The Mean Productivity (MP) which is the average yield of a plant under both non-stress and stress conditions was highest in genotype V3EG3 and lowest in genotype V2G4. According to [9], higher MP indicates better overall performance of a plant and V3EG3 had the highest MP signifying superior performance of the cowpea genotype in both stressed and non-stressed conditions, whereas V2G4 had the lowest MP, indicating the poorest performance of the genotype among others. In addition; The Geometric Mean Productivity (GMP) which is the square root of the product of the yields under non-stress and stress conditions helps to provide a balanced measure of performance under both conditions. V3EG3 recorded the highest GMP indicating that V3EG3 has a stable performance across conditions. Similar to what was obtained as the MP, V3EG3 also showed the highest GMP, reinforcing its resilience, while V2G4 had the lowest GMP, indicating less stability. This result is in line with the findings of [17]. Furthermore, Stress Intensity (SI) is used to measure the severity of stress impact on the yield of plant. A lower SI values suggest less severe stress impact on yield. V1EG4 exhibited the lowest SI, indicating minimal yield reduction under stress, whereas V2G4 had the highest SI, suggesting significant stress impact [18]. Stress Susceptibility Index (SSI) compares the reduction in yield under stress to the average reduction of all plants. Lower SSI indicates better stress tolerance A genotype with SSI value lesser than one (1) is considered to be tolerant to drought [19]. The SSI values of the cowpea genotypes V1EG4, V1G4, V3EG3, VIEG3, V3EG1 respectively had SSI value less than one (1) indicating the high resistance to drought with genotypes V1EG4 exhibiting the lowest SSI making it the most drought-tolerant genotype, while V2G4 had the highest SSI indicating high susceptibility to drought stress [18]. Selection based on SSI alone cannot be used to distinguish genotypes with high yield from those with low yield as changes caused by drought stress to genotypes is revealed better through the Tolerance Index (TOL) of the plant. Tolerance Index (TOL) is used to measure the difference in yield between non-stress and stress conditions. A lower level of TOL index indicates less change and better tolerance to stress [20]. The TOL values of the genotypes V3EG3 exhibited the lowest TOL suggesting it as the most tolerant to drought stress. In contrast, V2G4 had the highest TOL, indicating lower drought tolerance. This result aligns with the findings of [9]. Stress Tolerance Index (STI) measures the plant's yield potential under both conditions relative to the average yield. Higher STI indicates better stress tolerance. V3EG3 had the highest value of STI while V2G4 had the lowest value. Genotypes VIG4, V1EG3, V1EG4 and V1EG3 also had higher STI as compared to genotypes V2EG4, V1EG2, V3G4 and V3G1, this result revealed that genotype V3EG3 performed best under stress conditions, while V2G4 had the lowest STI, indicating poor performance [21]. Yield Index (YI) is the ratio of the yield under stress conditions to the yield under non-stress conditions. Higher YI indicates better yield under stress. Higher YI values indicate better yield under stress conditions relative to non-stress conditions. Genotypes V3EG3 had the highest YI, suggesting it maintained higher yields under stress, while V2G4 had the lowest YI [22]. Harmonic Mean (HM) is a tolerance index that is useful when the average of rates is desired. It provides a balanced measure of yield under both conditions. Higher HM values indicate better overall performance and genotypeV3EG3 had the highest HM, showing superior performance across conditions, whereas V2G4 had the lowest HM, indicating poorer performance (Kobayashi et al., 2019).

The drought tolerance indices reveal that V3EG3, V1G4 and V1EG4 are among the most resilient genotypes V3EG3 consistently showed high performance across most indices, indicating strong resilience and productivity under both stress and non-stress conditions. On the other hand, V2G4 consistently showed lower performance, indicating it is less suitable for drought-prone environments. The study confirms that mutagen treatments, such as gamma rays and ethyl methane sulphonate, can significantly affect the drought tolerance and productivity of cowpea landraces. Treatments like V3EG3, V1G4 and V1EG4 exhibit enhanced drought tolerance, as evidenced by their high MP, GMP, and STI values, along with low TOL and SSI values. This suggests that these treatments could be potential candidates for improving drought resilience in cowpea crops.

5. Conclusions

Based on this study, it can be conclude that the mutant lines collected from the gene bank of the Department of Plant Biology, Federal university of Technology, Minna, Nigeria embraced wide ranges of genetic diversities with distinctive morphological characteristics and identities that can be selected and used in crop improvement programmes. Also, the mutant lines responded in different ways to water stress which indicates variability in their genetic makeup which provides a good basis for selecting the best drought tolerant genotypes in a cowpea improvement programme. The study also revealed that the mutant lines; V3EG3, V1G4 and V1EG4 were the most droughts tolerant as evident by their high MP, GMP, and STI values, along with low TOL and SSI values. This suggests that these mutant lines could be potential candidates for improving drought resilience in cowpea crops.

Abbreviations

EMS	Ethyl Methane Sulphonate
TOL	Tolerance Index
MP	Mean Productivity
GMP	Geometric Mean Productivity
SI	Stress Intensity
SSI	Stress Susceptibility Index
STI	Stress Tolerance Index
YI	Yield Index
HM	Harmonic Mean

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Author Contributions

Ibikunle Kehinde Bukola: Conceptualization, Resources, Data curation, Funding acquisition, Writing – original draft, Investigation, Visualization

Falusi Ahmed Olamide: Methodology, Supervision, Validation, Writing – review & editing

Daudu Oladipupo Abdulazeez: Methodology, Project administration, Supervision, Validation, Writing – review & editing

Abubakar Abdulhakeem: Formal Analysis, Project administration, Software, Writing – review & editin

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Ibikunle Kehinde Bukola is a graduate of Biological Sciences at Federal University of Technology, Minna, Nigeria. She has an M. Tech degree in Applied Plant Genetics and Breeding from the same institution. As a PhD student, she is currently working on Mutation Induced Drought Tolerance in selected Cowpea (*Vigna unguiculata* L. Walp) Landraces in Niger State, Nigeria. She is interested in exploring some of the indigenous crops in Nigeria. Other aspects of her research include but not limited to: a. Biochemical composition analyses of the selected mutant lines b. Molecular characterisation and quantitative trait loci of potential drought tolerant lines.

Research Fields

Ibikunle Kehinde Bukola: Applied Genetics, Plant Breeding, Genomics, Bioinformatics and Mutation.

Falusi Ahmed Olamide: Cytology, Advance Genetics, Genetic Engineering, Mutaion Breeding, Plant Breeding.

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