

Original Research Paper

Influence of Drought Stress on Growth and Yield of Soybean (*Glycine max* L.) Genotypes in Northern Ghana

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Abstract: Studies on induced mutation were conducted and the results indicated that stable, but desirable soybean mutant genotypes with improved agronomic traits have been produced. A series of evaluations of these mutant genotypes had earlier on been carried out and high-yielding ones such as 150, 200, 250, and 300 Gy have been identified. In the present study, the above genotypes were planted together with an improved variety, Jenguma (standard check), to evaluate them for drought tolerance. Pot and field experiments were conducted in the dry and wet seasons of the year 2020, using factorial experiments in RCBD at Nyankpala in the Guinea Savannah agroecological zone of Ghana. In the pot experiment, 150, 120, 90, and 60 mL/day of water was applied, whilst two different planting date regimes were involved in the field study. Data on growth, yield parameters, as well as water use efficiency were taken for statistical analysis using Genstat statistical package edition 12. From the two experiments, the 150, 200, and 250 Gy mutants performed better (relative to 300 and Jenguma) in terms of grain yield, yield components, and growth parameters. These mutants also performed comparatively better in terms of reduced pod shattering. From the study, the mutants 150, 200, and 250 Gy were found to be tolerant to drought.

Keywords: Mutants, Irradiation, Gamma Rays, Pod Shattering, Northern Ghana

Introduction

Soybean (*Glycine max* L.) is reported as one of the most economically important oilseed crops worldwide (Agarwal *et al.*, 2013). Refined soybean is an important source of vegetable and protein feed oil (Bellaloui *et al.*, 2010). The crop (*Glycine max* L. Merrill) is a legume that belongs to the leguminaceae family and subfamily papilionaceae. It is also known as the "golden bean" of the twentieth century, due to its high nutritional value and use as a protein supplement. It is the leading oilseed crop worldwide. It is cultivated approximately in a global area of 108.75 million ha. Production of soybean crops was about 268 million tonnes, whilst productivity was also about 2.5 tonnes ha⁻¹ during the 2012-2013 cropping season (Jadhav *et al.*, 2014). Soybean is not only a source of macronutrients and minerals but also contains secondary metabolites such as isoflavones (Hasanah *et al.*, 2015). The flexibility of the crop against weather extremes (such as drought and excess heat) in Ghana and

Africa in general, as well as weather variation during the grain-filling stage, is considered to predict their adaptation to future climate change (Cutforth *et al.*, 2007). Soybean (*Glycine max* L.) plants rely on different types of mechanisms to be able to cope with drought stress. These mechanisms include Drought escape, drought avoidance, and drought tolerance (Turner *et al.*, 2001). Breeding for drought tolerance in crops will be difficult to achieve if the crop is subjected to water stress just for one cropping season. Efforts should therefore be made to subject the crop to the water stress conditions for a number of cropping seasons in order to properly determine the drought tolerance of the soybean crop. The genetic and physiological complexity of many crop plants makes it difficult to understand the mechanisms surrounding the response of many crop plants to drought. The variation in the rate of canopy wilting among crop plants is another mechanism that helps to determine drought tolerance among crops (Lawlor and Cornic, 2002). Soybean genotypes differ in how rapidly canopy wilting occurs

under water stress (Carter Jr *et al.*, 2006). The mechanisms that trigger variation in canopy wilting among soybean genotypes are only partially understood. One major mechanism determining genotypic differences in wilting is related to soil moisture conservation even before drought stress becomes severe (King *et al.*, 2009). Hong and Vierling (2000) reported that living organisms rely on an ancient and conserved adaptive response to attain thermos-tolerance to normally lethal temperatures. Achievement of thermos-tolerance is expected to be of particular significance to plants that experience day-to-day temperature fluctuations and are incapable of escaping to more favorable environments. Drought and soil heat account for about a 40% reduction in soybean yield (Specht *et al.*, 2001).

Soybean plants exhibit variation in Water Use Efficiency (WUE) from one genotype to another. The variation in WUE among soybean genotypes might be due to the variation in hybrid characteristics especially under drought conditions. The crop uses about 450-700 mm of water throughout the cropping season (Dogan *et al.*, 2011). Drought is the most recalcitrant factor among the various abiotic stresses that restrict crop productivity (Tuberosa and Salvi, 2006). Toker *et al.* (2007) also stated that drought is a very important abiotic stress affecting crop production, which is a result of inadequate rainfall and/or altered precipitation patterns. Drought drastically reduces plant growth and development on a large proportion of the world's agricultural land. Soybean is considered sensitive to drought stress during critical periods of plant development (Liu *et al.*, 2004). The most common sign of water stress injury is the inhibition of growth, which is manifested in the reduction of dry matter yield (Le Thiec and Manninen, 2003). Water deficit is a prime devastating abiotic stress militating against plant growth and development. With the unstable and unpredictable nature of the global climate, the available moisture and the soil moisture balance will also be unpredictable and this might lead to increased frequency of global drought. Water deficit triggers numerous physiological and biochemical responses in crop plants and this helps to boost the plant's adaptive characteristics to such limiting environmental conditions. Rainfall and irrigation water is used more efficiently among crop plants. However, adaptation of irrigation systems to improve the water supply to crop plants will substantially increase the costs of soybean production (Kebede *et al.*, 2014).

The effect of drought on soybean has been largely described, in conjunction with morphological variations of the vegetative plant and the decrease in seed quantity and quality. Methods for evaluating both quantitative and qualitative morphological parameters have been stated (Ku *et al.*, 2013). A number of approaches, such as agricultural practices and genetic improvement, have

been adopted primarily to improve soybean cultivars to address the negative implication of drought stress in soybean. The cultivation of drought-tolerant soybean varieties is vital to improve and maintain grain yield, particularly in drought-stress areas (Devi *et al.*, 2014). The development of traits not only to improve yield stability but also to increase survivability under drought conditions should be encouraged if drought tolerance is to be enhanced in soybean production. This is because drought stress is a serious phenomenon that is capable of reducing global soybean yield by more than 50% annually (Wang *et al.*, 2003). The effect of drought stress on soybean yield depends on the severity, duration, and timing of the stress during the growth stage of affected crops. Soybean is most susceptible to drought stress during the reproductive stage. However, when the plants are subjected to long-term severe water stress during the vegetative growth stage, the stress may be great enough to cause substantial yield losses.

Apart from the drought stress, the other major problems confronting soybean production in Ghana include the use of unimproved varieties, low soil phosphorus levels, high atmospheric and soil temperature levels as well as diseases and pest infestations (Lawson *et al.*, 2009). These factors all result in variations in crop yield, leading to a substantial decrease in soybean production (Parry *et al.*, 2004). Water deficit, extremely high temperatures, and low atmospheric humidity lead to drought, and these are one of the most debilitating factors militating against better plant performance and higher crop yield (Osakabe *et al.*, 2014). Therefore, resistance to abiotic stress is the most desired trait of crops. A new variety selection is however difficult because of the wide range of plant stress responses creating complex mechanisms of resistance (Bartels and Sour, 2003).

This study seeks to evaluate the influence of drought on the growth and production of soybean.

Materials and Methods

Experimental Site

The experiment was conducted at Nyankpala, in the Northern Savanna zone of Ghana. The area records one rainy season per annum, with a mean annual rainfall of 1034.4 mm which is widely distributed from April-November (SARI, 2008). The rainfall in the study area starts in April-May and reaches its apex from July to September every year. The rainfall then reduces massively in October and stops completely in November. The soil of the experimental site is that of savanna Ochrosol under the Ghana System of Classification. The soil is brownish and moderately sandy loam, free from a lot of pebbles. The soil is not too deep with a hardpan beneath the top few centimeters. The soil from the study area is developed from the Voltaian sandstone and classified as Nyankpala Series. The study area has an

average monthly temperature of 22°C during the wet season and a maximum of 34°C during the lean season. The relative humidity in the area is at its maximum with a monthly value of 53% during the dry season (SARI, 2008).

Experimental Design

The factors involved were Genotypes (150, 200, 250, 300 Gy and standard check-Jenguma) and, two planting regimes in Randomized Complete Block Design (RCBD) using 5 × 2 factorial experiments. Soybean seeds were irradiated with gamma-ray doses of 150, 200, 250, and 300 Gy. The research started in the 2013 cropping season during which M₁ was planted and the seeds of M₁ were used to raise the next generation of M₂ in the 2014 cropping season. Selected seeds were planted in 2015 as M₃ generation. In the 2016 cropping season, the improved useful mutant lines with desirable traits selected from the previous season were evaluated at the three (Nyankpala, Techiman, and Bawku) agroecological zone in Ghana.

Agronomic Practices

Land Preparation

The experimental sites were plowed with a tractor in June 2020. The sites were manually leveled after plowing and demarcations were made using a tape measure and garden pegs. The blocks and plots were labeled accordingly.

Planting

Experiment I was planted on the 5th of March 2020 and experiment II which consisted of two different plants was planted on the 17th of June and 17th of July, 2020.

Weed Control

Weeds were controlled on the 3rd, 6th, and 9th weeks after planting by hoeing and handpicking. No insect pests were observed.

Harvesting

Soybeans were ready for harvesting at 3-4 months after planting depending on the variety. The maturity of soybean was determined through the yellowing and dropping of the lower and the upper leaves. Harvesting was done manually. At maturity, the soybean was uprooted and gathered into smaller heaps. All the small heaps were then collected and spread on a tarpaulin spread on the ground. The plants were then threshed by beating the heap with sticks till the pods break open to release the beans. The beans were separated from the chaff by winnowing.

Data Collection

Data were taken on the following measurements; percentage emergence, plant height, number of leaves, number of nodules, days to 50% flowering, days to

maturity, soil moisture, a score of prevalence/susceptibility to common soybean diseases, soil/aerial temperature of the experimental fields and weather parameters (RH, rainfall and temperature), number of pods per plant, pod length, number of seeds per pod, 100-seed weight, pod shattering and total grain yield.

Data Analysis

The data for all the parameters collected in the study were subjected to ANOVA. Means were separated using the Least Significance Difference (LSD) at 5%. Results were presented in tables and graphs.

Results

Plant Height

The plant height of the soybean genotypes varied significantly ($p < 0.05$). Jenguma produced the highest height. This was followed by the mutant 150 and 250 Gy recorded as the lowest plant height (Fig. 1).

The interaction of soybean genotype and planting date for plant height at week 3 after planting varied significantly ($p < 0.05$). The 150 Gy recorded the highest plant height during the first planting while the Jenguma recorded the highest for the second planting. Generally, the soybean genotypes planted first recorded higher plant height as compared to genotypes from the second planting (Fig. 2).

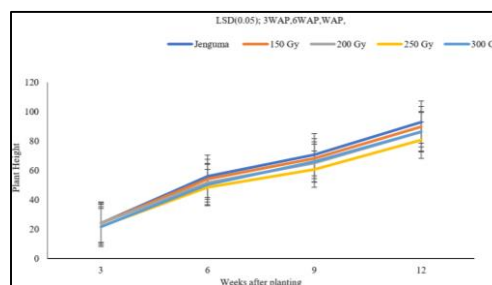


Fig. 1: Plant height of soybean (*Glycine max* L. Merrill) genotypes during the rainy season of 2020

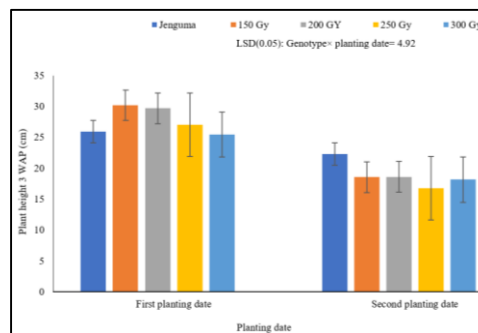


Fig. 2: Interaction of soybean genotype and planting date for plant height evaluated at the field during the 2020 cropping season

Leaf Area Index

The genotype × planting date interaction was also significant ($p < 0.05$) for the leaf area index. The 150 Gy from the first planting recorded the highest leaf area index while 250 Gy from the second planting at week 3 after planting recorded the lowest leaf area index (Table 1).

Chlorophyll Content

There was a significant ($p < 0.05$) interaction between the genotypes and planting date for chlorophyll content. The 200 Gy from the first planting recorded the highest chlorophyll content whereas the same soybean genotypes recorded the least chlorophyll content at the second planting (Table 2).

Biomass Accumulation

The interaction of planting date and genotypes for biomass accumulation showed significant variation ($p < 0.05$). Generally, plants from the first planting produced the highest root biomass as compared to those from the second planting (Fig. 3).

Figure 3 Interaction of soybean genotypes and planting date for dry biomass accumulation during the rainy season of 2020.

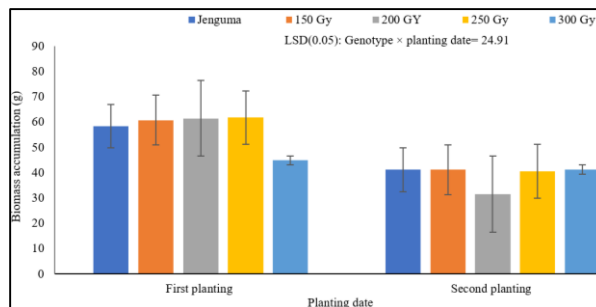


Fig. 3: Interaction of soybean genotypes and planting date for dry biomass accumulation during the rainy season of 2020

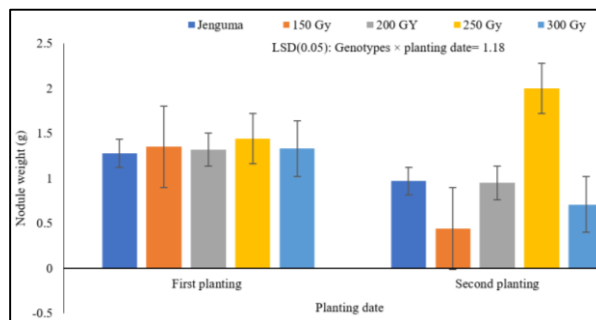


Fig. 4: Interaction of soybean genotypes and planting date for nodule weight during the 2020 cropping

Nodule Weight

There was a statistical difference ($p < 0.05$) in the interaction of soybean genotypes and planting dates for nodule weight. The 250 Gy from the second planting recorded the highest nodule weight while 150 Gy with the same planting date recorded the lowest nodule weight (Fig. 4).

Hundred Seed Weight

Both the single effects and all the interactions of the soybean for hundred seeds weight showed significant ($p < 0.05$) variation. Genotypes from 200 and 250 Gy recorded the highest seed weight whilst 150 Gy mutants recorded the lowest (Fig. 5).

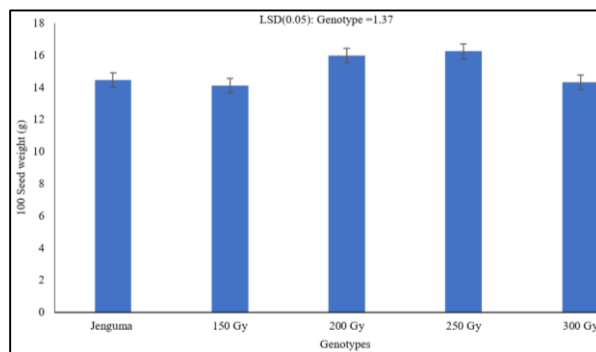


Fig. 5: Hundred seed weight of soybean (*Glycine max* L. Merrill) under field conditions during the 2020 rainy season

Table 1: Genotypes × planting date interaction for leaf area index during the rainy season of the 2020 cropping season

Genotypes	Weeks after planting							
	3		6		9		12	
	First planting	Second planting	First planting	Second planting	First planting	Second planting	First planting	Second planting
Jenguma	1.440	0.57	4.14	1.62	6.64	5.86	9.62	9.90
150 Gy	2.550	0.43	4.28	1.23	6.86	4.42	9.94	7.49
200 Gy	1.940	0.40	3.01	1.15	4.83	4.12	7.00	6.99
250 Gy	1.610	0.33	3.41	0.95	5.46	3.40	7.91	5.77
300 Gy	1.560	0.36	3.39	1.03	5.44	3.71	7.88	6.28
LSD (0.05)	0.428		1.12		2.07		6.35	

Table 2: Interaction of soybean genotypes and planting date for chlorophyll content during the 2020 rainy season

Genotype	Planting date	
	First planting date	Second planting date
Jenguma	36.170	34.30
150 Gy	36.470	34.28
200 Gy	38.040	32.57
250 Gy	37.150	33.06
300 Gy	37.660	32.72
LSD (0.05)	3.795	

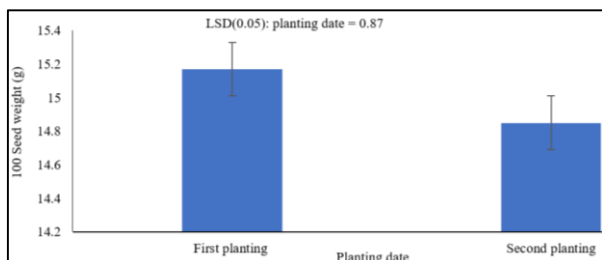


Fig. 6: Variation in planting date for hundred seed weight of soybean (*Glycine max* L. Merrill) under field conditions during the 2020 cropping season

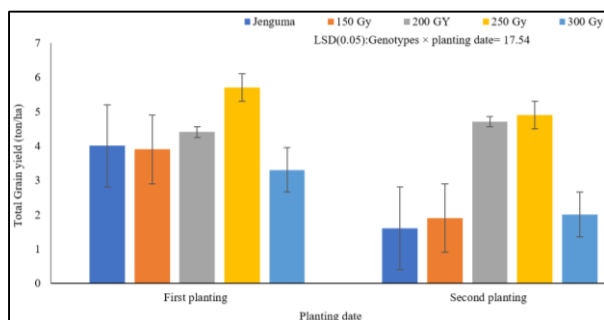


Fig. 7: Total grain yield of soybean (*Glycine max* L. Merrill) genotypes during the rainy season of 2020

The planting date for the hundred seeds' weight varied significantly ($p < 0.05$). Generally, the genotypes from the first planting recorded the highest hundred seed weight as compared to the genotypes from the second planting (Fig. 6).

Grain Yield

There was a significant ($p < 0.05$) interaction between the soybean genotype and planting date for grain yield. Genotype 250 Gy recorded the highest grain yield in both the first and second planting dates, even though grain yield was relatively higher on the first planting date as compared to the second. The grain yield in the 250 Gy mutant line was closely followed by 200 Gy on both planting dates. Grain yields in the irradiated control (Jenguma), 150 and 300 Gy were relatively better in the first planting relative to the second planting (Fig. 7).

Discussion

Growth Parameters

In general, the results of the different treatments (150, 200, 250, and 300 Gy), as well as the control (Jenguma), show that there were major differences in plant growth and output on plant height, the number of leaves per plant, days to 50% flowering, leaf area index, biomass accumulation, 100 seed weight and total grain yield per genotype. The degree of gamma irradiation used had a substantial impact on these agronomic parameters (Justin *et al.*, 2012).

There was a substantial difference in plant height among the soybean genotypes. Plant heights for the Jenguma and 150 Gy increased consistently during weeks 3, 6, 9, and 12 after planting. Plant height, on the other hand, decreased as gamma irradiation doses were increased. In comparison to the control and the 150 Gy, plant height was decreased among the 200, 250, and 300 Gy mutant lines. The mutagenic treatment may have harmed the mechanism of cell division and cell elongation, resulting in a reduction in plant height as reported by Asare *et al.* (2017). The difference in plant height reduction between the cultivars could be due to genotypic differences. Khan *et al.* (2014) also reported a decrease in plant height in soybean under water stress, which may be due to shorter internodes and leaf addition rates. The 150 Gy recorded the highest plant height during the first planting while the Jenguma recorded the highest for the second planting. Generally, the soybean genotypes from the first planting recorded higher plant height as compared to genotypes from the second planting.

Drought may also affect a variety of physio-morphological traits, such as chlorophyll output (Soval-Villa *et al.*, 2002), plant height, and leaf area index (Lee *et al.*, 2015). According to findings from the study, plants radiated with 250 dosages of gamma at weeks 3 and 6 after planting was leading in the plant height. However, a different result was observed at weeks 9 and 12 where the Jenguma which is the control took the lead as 250 Gy declined. Abdul *et al.* (2010) reported that gamma irradiation significantly affects the number of leaves. He did, however, reveal that with higher gamma irradiation dosages, growth indices such as leaf number tended to decline.

There was a statistical difference ($p < 0.05$) in the interaction of soybean genotypes and planting dates. The

200 Gy from the first planting recorded the highest chlorophyll content whereas the same soybean genotype recorded the least chlorophyll content at the second planting. Gamma irradiation probably triggered an increase in chlorophyll a, b, and total chlorophyll content in the soybean plants. This finding is in line with the observation made and cited in Saadati *et al.* (2022), who reported that exposing dried lupine seeds to a low dosage of gamma rays improved total chlorophyll content, soluble sugars, and photosynthetic activity. The reduced canopy sizes of some soybean crops could probably have contributed to the smaller amount of chlorophyll content produced per unit ground area and this is a useful measure for determining the rate and amount of radiation that may potentially be converted to plants. Hussain *et al.* (2018) reported that drought and heat stress caused a substantial decrease in pigment content, which was amplified when combined stresses were present. According to Majdi *et al.* (2020), the chlorophyll content of water-stressed soybean plants is 31% lower relative to the controlled plants. Atti *et al.* (2004) also made a similar observation and reported that drought stress causes light inhibition and light destruction of pigments and associated protein complexes, as well as disruption of the photosynthetic membrane. Water stress conditions lead to chlorophyll content reduction. This is because, under drought conditions, various enzymes that are involved in chlorophyll synthesis are destroyed, while the activities of enzymes that degrade chlorophyll content are increased (Dias and Brüggemann, 2010). Guo *et al.* (2006) also observed that heat stress causes a reduction in the chlorophyll content of crop plants by destroying the thylakoid membranes within the plant cells and tissues.

Generally, plants from the first planting produced the highest biomass accumulation as compared to those from the second planting. The soybean plants that were irradiated with gamma rays 150 Gy produced more biomass and grain yield than the control plants. The gamma irradiation might have resulted in increased leaf area, biomass production, grain yield, and yield-related parameters among the treated plants (Moussa, 2006). Yang *et al.* (2019) also reported that, in an ecosystem where interplant rivalry occurs, biomass and root-shoot ratio are essential measures of plant vigor. Plants with increased biomass accumulation and increased root mass might be able to compete more favorably in terms of accessing nutrients and moisture as compared with crop plants with less biomass accumulation. Drought stress reduced biomass accumulation by 63% and total biomass by 61%. This is because drought reduces the number of leaves per plant and the leaves size, which is a precursor for biomass accumulation in soybean. This finding agrees with Marron *et al.* (2003) who said continuous drought decreases the number of leaves and leaf area expansion rates. In addition, they continued to argue that shorter

cotyledonary branches and the main axis in water-stressed groundnut plants are seen. The finding is also supported by the observation made by Candido *et al.* (1999) that the availability of water influences stem elongation, plant height, number of leaves, and leaf size which results in an increase in dry matter accumulation.

Component of the Yield

All of the doses flowered early and there is a connection between day to 50% flowering and day to maturity. This result is in line with the findings of (Zaka *et al.*, 2004) when they observed that mutagenesis reduced the number of days to 50% flowering and days to maturity. In comparison to the regulation, gamma irradiation shortened the time to flowering. This result agrees with the assertion made by Mensah and Obadoni (2007) that increasing colchicine concentration and para-dichlorobenzene reduced flowering days and increased leaf number. The delay was more in the variety of Jenguma relative to the others. The same observation was made when water stress was imposed at the reproductive stage where the maturity was reduced.

The study also reveals a substantial variation ($p < 0.05$) in soybean nodule weight when genotype and planting date interaction was considered. Therefore, the 250 Gy planted late recorded the highest nodule weight as compared to the Jenguma with the same planting date which recorded the lowest in terms of nodule weight. Drought alters root development (root length, root branching, and root density), as well as the partitioning of root-to-shoot biomass as root mass increases according to Franco *et al.* (2011). In general, first-planted genotypes produced the most nodules as compared to second-planted genotypes.

The weight of the soybean hundred seeds showed considerable variance in both the single effects and all interactions. Also, the highest seed weight was found in genotypes 200 and 250 Gy. The weight of soybean hundred seeds differed significantly ($p < 0.05$) depending on the planting date. In general, genotypes from the first planting had the highest hundred seed weight relative to genotypes from the second planting. According to Udensi *et al.* (2011), the number of pods per plant, pod length, number of grains per pod, 100-grain weight and grain yield are all related. Gamma irradiation may have increased flower set and, as a result, pod production.

Grain Yield

For grain yield, the relationship between soybean genotypes and planting dates differed significantly ($p < 0.05$). The total grain yield of the 250 Gy from the first planting was the highest, while the total grain yield of the Jenguma from the second planting was the lowest. The soybean yield is primarily determined by plant number, dry biomass production, grain number, and grain size. Water

stress has been linked to decreased grain weight, dry biomass, pods per plant, grains per plant, grains per pod, and 100-grain weight, resulting in lower soybean yields according to Jumrani and Bhatia (2018). Unavailability of water during the flowering, pod development, and grain-filling stages of soybeans can cause changes in plant metabolism, resulting in fewer and smaller pods and seeds, lower seed weight, leaf senescence, and a shorter plant life cycle, all of which can reduce productivity as reported by Farooq *et al.* (2017).

Conclusion

Four levels of mutant soybean genotypes plus one standard check-Jenguma were planted against two levels of planting regimes. The 150, 200, and 250 Gy were observed and identified as promising genotypes. In general, genotypes from the first planting date produced outstanding results in almost all the parameters. In the Genotype \times planting date interaction, the first planting date produced outstanding results in almost all the parameters. The 200 Gy and first planting interaction also produced outstanding results in almost all the parameters as compared to others for chlorophyll, number of leaves, days to 50% flowering, and leaf area index.

Significant Statement

Soybean is a nutritious plant that plays a key role in improving nutrition among Ghanaians and sub-Saharan Africans in general. The cultivation of this crop will therefore help to improve food security among vulnerable groups and individuals in sub-Saharan Africa. In order to achieve total food security and food sustainability, there is a need to improve soybean production throughout the entire sub-Saharan Africa. Research scientists from universities and research institutions throughout Africa ought to collaborate to develop improved and high-yielding varieties in order to achieve maximum production levels and hence improve food security.

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Author's Contributions

Isaac Kwahene Addai and Alhassan Bawa: Research

designed, analysis, written first drafted and proof reading manuscript.

Maganoba Charles: Data collection statistical analysis and proof reading drafted manuscript.

Ethics

This article is original and contains unpublished materials. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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