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Genetic Algorithm for Forecasting Bioinformatic Outcomes of Mutation-induced Cowpeas for Sustainable Development

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Abstract

The application of data engineering techniques like a genetic algorithm in forecasting outcomes in plant genetics and breeding can help solve the twin problems of food insecurity and insufficiency. To demonstrate the practicality of using artificial intelligence (AI) to address these problems, the genetic algorithm is applied to genetic engineering (genetic mutation) of cowpea in a crop improvement program to generate useful bioinformatic information for further improvement of the crop. The aim of this work is to address malnutrition, immune deficiency, hunger, and poverty as canvassed in United Nations Sustainable Development Goals 1 and 2 (SDGs 1 and 2). Three genotypes (specifies) of cowpea obtained from Kontagora in Niger State of Nigeria were treated with chemical and physical mutagens: 200, 400, 600, and 800 of ethyl methane sulphonate (EMS) and 0.372gy of gamma rays. The study applied genetic algorithm as a stochastic optimizer using Python programming to determine the convergence pattern for obtaining an optimal cowpea solution that combines high yield and drought-tolerance. Huge data was generated in three iterative experiments. The outcomes of the three experiments showed that in experiment 1, the convergence occurred in the 9412th generation while in experiment 2, we obtained convergence in the 899th generation of the cowpea. Experiments show that the genetic mutation resulted in phenotypic traits in the first-generation offspring. The result of the third experiment indicated that the optimal cowpea solution was obtained in the 14338th generation. This implies that the use of AI (genetic algorithm) in ensuring food security and sufficiency may be time-consuming but would result in the desired traits in crops for meeting the 4 pillars of sustainability (human, social, economic and environmental).

Keywords

Bioinformatics, Cowpea, Genetic algorithm, Mutation, Sustainable development goals

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Introduction

In a bid to address poverty everywhere as encapsulated in the United Nations Sustainable Development Goal (SDG) 1 and solve the problems of hunger, food insecurity, malnutrition, and unsustainable agriculture as captured in SDG 2, different approaches suitable for respective global domains are being adopted (Report, 2016). Sustainable development (SD) refers to meeting the needs of the present generation without compromising the needs of future generations (Okewu et al., 2020). This means that any SD initiative must ensure right balance among the four pillars of sustainability (human, social, economic and environmental). Towards this end, a global socio-economic plan has been put in place by the United Nations to guide global efforts towards enhancing the welfare and well-being of people all over the world. This global socio-economic blueprint called the Sustainable Development Goals (SDGs) covers the period 2015-2030 with clear-cut 17 goals to guide rural, state, and regional socio-economic plans in various countries (Report, 2016).

Developing economies like Nigeria are still battling with meeting basic human needs like food and shelter while the developed nations are pursuing higher sustainable development objectives such as climate change mitigation, conservation of natural ecosystems, and strategic partnership for sustainable development, among others (Okewu et al., 2019). To address the twin issues of malnutrition and immune deficiency on one hand, and improve the income-earning capacity of Nigerian farmers on the other hand, agricultural biotechnologists are exploring the use of genetic engineering (GE) for boosting food production. Such research effort is appreciated in light of the reality that the mainstay of the Nigerian economy is agriculture (Ayodele, 2019). Also, awareness needs to be raised on the principles of the four pillars of sustainability as both private and institutional investors in the agricultural biotechnology sector globally can only invest when they are assured of policy commitment to balancing people, society, planet and profit.

Though GE's efforts geared toward improving food security and food sufficiency focus on plant and animal breeding, the initiative we used as a case study in this paper is plant breeding using GE. The study used chemical and physical mutagens to induce mutation in cowpea for improved drought tolerance and high-yield capabilities. Cowpea is a leguminous crop with a high protein content that can augment the diet of the masses in developing economies who cannot afford exorbitant animal protein. This will help solve the problems of food insecurity as characterized by malnutrition, immune deficiency, and hunger. Also, developing climate-resilient and high-yielding crop means improved income-generating capacity of the largely subsistence farmers in Nigeria. Three species of cowpeas (*dan muzakkari*, *gidigiwa*, *and dan mesera*) were selected from Kontagora in Niger State of Nigeria and treated with ethyl methyl sulphonate (EMS) and gamma rays. In the first (M1) generation, both treated and untreated (control) cowpeas were planted and their offspring observed for mutation-induced traits. The M1 mutagenic process was also formulated as a computational problem with a view to finding cowpea with drought-tolerant and high-yield qualities. Since the search for an optimal cowpea solution is influenced by uncertainties posed by biotic factors (weed, intruders, etc.) and abiotic factors (rainfall, wind, sunshine, etc.), we classify the task aa a stochastic optimization problem. Because the heuristic search can take series of generations to achieve with humungous dataset generated, we applied genetic algorithm (GA) to forecast bioinformatic outcomes that would guide the crop improvement program.

The aim of the study is to improve cowpea production for human sustainability and the attainment of the United Nations SDGs. The specific objectives are:

i. Improve drought-tolerance capability of cowpea using physical and chemical mutagens
ii. Formulate genetic mutation in cowpea as a string manipulation using a genetic algorithm
iii. Guide the cowpea improvement program with bioinformatic information generated from the implementation of genetic algorithm

Plant Breeding and Genetic Engineering

Globally, the human population is increasing day by day and is expected to reach 9 billion by 2050 and which will lead to food scarcity on earth. To overcome challenges posed by increased demand for food and proper nourishment, an improvement in food production is urgently needed (Gupta & Kaushal, 2018). The envisaged increase in food production is daunting because of limited arable land, depleting water resources, and varying climatic conditions. The difficulties are also compounded by urbanization, salinization, biotic stress, drought, and desertification that result in a reduction of arable land. Moreover, changing climatic conditions and subsequent variations also limit food production (Ayodele, 2019). The use of intelligent food production techniques for resolving the problem therefore underscores the application of genetic algorithm in crop genetic breeding and engineering. This data-driven AI-based technique is employed in harnessing the heritable variations encoded in the genetic makeup of cowpea and other existing crop plants so as to use them in crop improvement programs which will in turn help in attaining goal 11 of the United Nations Sustainable Development Goals by the year 2030.

Genetic Mutation of Cowpea as String Manipulation

Genetic algorithm (GA) as an evolutionary algorithm is an adaptive heuristic search algorithm that aims at a desired solution (Mishra et al., 2017). Some of the desired traits farmers want in crops are drought tolerance and high yield as part of promoting climate-resilient crops. These can be achieved through genetic mutation (Savitri & Fauziah, 2020). Chromosomes that constitute solution candidates in every generation are subjected to mutation, crossover, and selection in a bid to generate an improved population whose candidates are closer to the desired solution. A unary operator, the Mutation Operator requires just one parent to perform on. This is achieved by choosing some genes from the selected chromosome and subsequently applying the desired algorithm.

GA is a data engineering technique that involves iterating from random string (e.g., initial cowpea chromosome/genotype) to target string (e.g., desired cowpea chromosome/genotype). Both random and target strings are represented as string data. The target string is the optimal solution that combines the desired traits for achieving the balance between human, social, economic and environment in line with the principles of sustainability. In this study, we used GA to formulate the genetic mutation of cowpea for drought tolerance as a string manipulation with the target string as “mutation-induced drought tolerant cowpea”. Both the entities and relationships in the cowpea improvement research are captured in the Entity Relationship Diagram in Fig. 1.

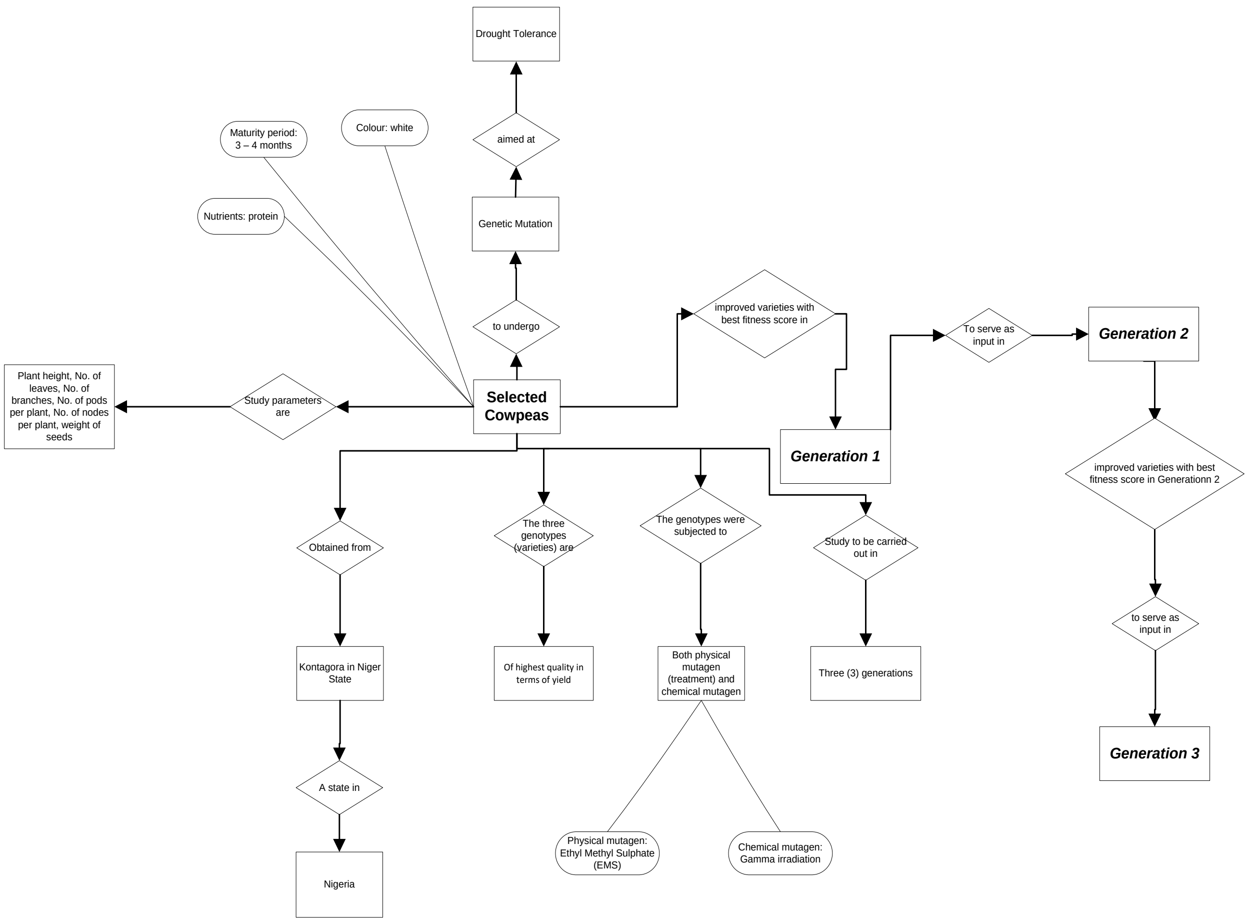

Figure 1. An entity relationship diagram for mutation-induced tolerance in selected cowpea landraces

Previous Work

In (Mohammed et al., 2021), the study focused on the impact of abiotic factors on cowpea production in Northern Nigeria. Using Gombe State in Nigeria as a case study, the researchers examined the impact of temperature, rainfall, and relative humidity on the yield of cowpea over a period of a decade. Using an ex-post facto research design, secondary data were collected from the Metrological Office while agronomic data were obtained from the Ministry of Agriculture in Gombe State. The data were analyzed using Simple Linear Regression, Pearson Product Moment Correlation, and Analysis of Variance (ANOVA). Relative humidity, rainfall, and area of land/ha revealed a negative relationship in the study while temperature showed that a positive relationship existed in cowpea. The researchers recommended new measures for cowpea farmers such as the use of resistant varieties, early planting, supplementary irrigation, and contour farming to conserve water so as to cope with the adverse effects of climate change on the yield and production of cowpea in Gombe State (Mohammed et al., 2021). While this study was carried out in Gombe State, our present study focused on Niger State. Also, the authors refrained from studying the mutation-induced drought tolerance of cowpea; a major consideration of our present work.

In (Mishra et al., 2017), the authors opined that the genetic algorithm (GA) is readily used to generate important solutions for search and optimization problems. As a search heuristic, it resolves optimization problems with the aid of techniques that are inspired by natural evolution. Natural evolution includes mutation, inheritance, crossover, and selection. The study affirmed that

GA is among the best ways to resolve problems with scanty facts. GAs are general algorithms that are very efficient in all search spaces. As a result, they are implementable as a global optimization tool for analyzing huge data sets. The work, however, did not discuss how GA could be used to obtain optimal cowpea solutions in a cowpea improvement program for human sustainability as done in this present study.

Reference (Mohamed et al., 2020) used mutation breeding was used as a tool for crop improvement with a view to improving yield and general polygenic traits. Because the male sterile system used for hybridization is lacking in cowpea, the study focused on creating variation using chemical mutagens with a view to inducing genetic variability, analyzing how sensitive different morphological traits are to chemical mutagens, fixing LD 50 value for Ethyl Methane Sulphonate (EMS) and study M1 generation genetic variability. The induction of genetic variability in the Vamban 2 cowpea variety was achieved using eight treatments (10, 20, 30, 40, 50, 60, 70, and 80 mM) of chemical mutagen EMS after which the LD50 values were obtained based on observations on root length, seed germination, and shoot length under laboratory conditions. Raising the M1 generation was done under field conditions to evaluate parameters like single plant yield, 100 seed weight, number of seeds per pod, number of pods per plant, number of branches per plant, pollen fertility, germination of seeds, and plant height at maturity. The study outcomes indicated that increased concentration of EMS had a negative correlation with yield characters and phenotypic expression. The researchers observed that in marginal lands, cowpea is an essential component of sustainable agriculture just as it is a good source of protein with amino acids such as tryptophan and lysine. The paper added that it is a nutritious grain legume cultivated extensively in semiarid and arid tropics and has free metabolites or other toxins. However, the study only considered the chemical mutagen of cowpea, unlike our present study which uses both chemical mutagen EMS and physical mutagen gamma irradiation. The current study also targets the drought tolerance of cowpea as a technique for attaining the SDGs.

In (Naveena et al., 2020), the investigation focused on assessing the mutagenic efficiency and effectiveness of physical mutagen (gamma rays) and chemical mutagen (EMS) in the Hibiscus flowers. Specifically, the authors evaluated the extent of chlorophyll mutation in Hibiscus rosa-Sinensis L. Cultivar Red Single and studied mutagen impact in the variety 1 of the M1 (M1V1) generation. The methodology involved treating semi-hard-wood cuttings Hibiscus separately with three doses each of gamma rays (25Gy, 30Gy, and 35Gy) and EMS (0.8% or 64.43 mM, 0.9% or72.48 mM, and 1.0% or 80.54 mM). The study outcomes show physical high frequency and wide spectrum of chlorophyll mutants were created by physical mutagens while a total of five species of chlorophyll mutants emerged as a result of the physical and chemical mutation (albino, xantha, viridis, chlorina, and xantha-viridis). The parameters for calculating the mutagenic efficiency and effectiveness were biological damage and chlorophyll mutation frequency on M1V1 plants. It was observed that higher mutagenic effectiveness and efficiency were recorded in gamma radiation-induced plants specifically at a lower dose of 25 Gy. Also, the investigation revealed that the highest mutation rate with respect to efficiency and effectiveness was recorded in gamma rays than in EMS. The study focused on the Hibiscus plant while our current study is on cowpea mutation. Also, the work did not link mutation breeding to the achievement of the SDGs as done in this present investigation. The use of a stochastic optimizer like GA for forecasting the timeline of obtaining a candidate transgenic plant that offers an optimal solution in terms of drought tolerance and high yield was not discussed as done in this present work.

The work in (Chen et al., 2020) focused on peanut improvement programs using mutation breeding, specifically chemical mutagen. Though peanut is globally recognized as a significant food crop and oil seed, the development of new cultivars is constrained by low genetic variability. In a bid to improve the genetic diversity of peanuts, two genotypes (Huayu 22 and Yueyou 45) were treated with different doses of EMS for different periods. Using the median lethal dose (LD50) value, the identification of optimal EMS treatment doses per duration was done for each genotype. The experimental outcome revealed that mutants that were induced by EMS showed different phenotypic traits such as plant yield/quality of M2 generation, leaf characteristics, number of branches, and plant height. Furthermore, the researchers observed that among the M2 candidate plants, potentially useful mutants were associated with seed size, high oil/protein content, test color, leaf colour/shape, and dwarfism. The study also showed that M3 generation individuals inherited mutations on a sustainable basis. The mutants offered valuable germplasm resources for integration into peanut improvement programs. This is besides their contribution to the study in terms of explaining mechanisms behind agronomic traits expressed. The study focused on peanut improvement programs using only chemical mutagen EMS while our current study is on cowpea improvement programs using both chemical mutagen EMS and physical mutagen gamma irradiation. The present study also formulated the search for an optimal cowpea solution for drought tolerance and high yield as a stochastic optimization problem with the genetic algorithm as the stochastic optimizer. Our search for desirable traits in cowpea is targeted at attaining the SDGs.

Savitri and Fauziah in (Savitri & Fauziah, 2020) dwelt on mutation induction and mutation detection in soybeans. For mutation detection, the researchers used molecular markers in characterizing the genetic diversity of the treated soybeans. Mutation induction was performed to derive a high degree of genetic diversity as a yardstick for plant breeding with a view to obtaining desirable traits and varieties. The mutation was performed physically using gamma rays and chemically relying on EMS mutagen. In figuring out the effectiveness of the combined treatments in the black soybeans genetic diversity induction, the research used a 5-primer ISSR molecular marker (UBC 810, UBC 811, UBC 812, UBC 828, and K18 primers). Success was recorded as the primers adequately demonstrated and amplified genetic diversity in the black soybeans treated with EMS administration and gamma-ray irradiation. The study outcomes showed that gamma-ray irradiation performed better than the EMS treatment and untreated control in terms of polymorphism. Hence, in further treatments, it was resolved to apply gamma irradiation to candidate parent plants. In our current study, the focus is on using an artificial intelligence tool (genetic algorithm) to project when a treated candidate cowpea plant that optimizes drought tolerance and high yield will be obtained for attaining sustainable development objectives.

In all of the above research, none formulated the mutation induction of cowpea for drought tolerance as a string manipulation as done in this present study. Neither did any work apply GA for forecasting bioinformatic outcomes that have the potential for guiding cowpea improvement programs for obtaining an optimal cowpea solution.

Methodology

Field Experiment – Treatment and Planting of Cowpeas

Our study subjected three genotypes of cowpea from Kontagora in Niger State of Nigeria to both chemical treatment and physical treatment. The three species are *dan muzakkari, gidigiwa*, and *dan mesera*. The chemical treatment involved the use of ethyl methyl sulphonate (EMS) while we used gamma irradiation for the physical treatment (Naveena et al., 2020). There were four treatment doses of gamma irradiations represented as Gi (i=1,2,3,4) with G1 = 200ml, G2 = 400ml, G3 = 600ml and G4 = 800ml. The quantity of EMS used was 0.372. Each variety had three replicates as a proactive measure against the possibility of cowpea seedlings that may die during the field experiment. Each variety also had a control that was not treated with either gamma irradiation or EMS. Table 1 shows the array of treated seeds for all the genotypes (V1, V2, and V3).

Table 1. Chemical and physical treatments of selected cowpeas from Kontagora, Niger sate, Nigeria for genetic mutation.

Variety 1 (V1)			Variety 2 (V2)			Variety 3 (V3)		
Seed	Treatment	Replicate	Seed	Treatment	Replicate	Seed	Treatment	Replicate
V_1	None (control)	3	V2	None (control)	3	V3	None (control)	3
V_1G_1	200ml	3	V_2G_1	200ml	3	V_3G_1	200ml	3
V_1G_2	400ml	3	V_2G_2	400ml	3	V_3G_2	400ml	3
V_1G_3	600ml	3	V_2G_3	600ml	3	V_3G_3	600ml	3
V_1G_4	800ml	3	V_2G_4	800ml	3	V_3G_4	800ml	3
V_1G_1E	200ml + 0.372	3	V_2G_1E	200ml + 0.372	3	V_3G_1E	200ml + 0.372	3
V_1G_2E	400ml + 0.372	3	V_2G_2E	400ml + 0.372	3	V_3G_2E	400ml + 0.372	3
V_1G_3E	600ml + 0.372	3	V_2G_3E	600ml + 0.372	3	V_3G_3E	600ml + 0.372	3
V_1G_4E	800ml + 0.372	3	V_2G_4E	800ml + 0.372	3	V_3G_4E	800ml + 0.372	3
V_1E	0.372	3	V_2E	0.372	3	V_3E	0.372	3

V1= variety 1
V2= variety 2
V3= variety 3
G1= gamma irradiation treatment 1
G2= gamma irradiation treatment 2
G3= gamma irradiation treatment 3
G4= gamma irradiation treatment 4
E= Ethyl methanesulfonate

The control cowpea plants were watered twice (morning and evening) while the treated cowpea plants were watered once on the first day. On the second and subsequent days, both the control and treated cowpea plants were watered once daily.

As shown in Table 1 above, each variety has 10 seeds. Vi where i=1,2,3 represents the control without any treatment. Each treated seed such as V1G1 means the variety 1 cowpea was treated with 200ml of gamma irradiation while V1G4E means variety 1 cowpea was treated with 800ml of gamma irradiation and 0.372 of EMS. Since each seed was replicated 3 times and we have 10 seeds of each variety, we used a total of 30 pots for each genotype of cowpea.

For the field experiment, a total of 90 pots were arranged for the seeds at the Botanical Garden of Plant Sciences Department of the Federal University of Technology, Minna, Nigeria using a randomized complex block design as shown in Figure 2 below.

Figure 2. Arranging treated cowpea pods using a randomized complex box design

Outcomes of experiments involving plant breeding genetics can be affected by many environmental factors and natural elements such as sunshine, water, wind, etc. As a result, we deliberately arranged the pots in a completely randomized block design to avoid bias (Grant, 2019). This was done to ensure that all the varieties and treatments were subjected to the same conditions in the Postgraduate Botanical Garden of the Federal University of Technology, Minna, Nigeria which was used for our field experiment. Table 2 illustrates the arrangement of the cowpea pots in the garden using a completely randomized block design.

Table 2. randomized complete block diagram for mutation-induced drought resistance cowpeas

V1	V2G3	V1E	V3G1	V2G4	V1 G1	V1 G2	V2E	V1G3
V2	V3G3	V3G4	V2G1	V1G4	V3	V2 G2	V3E	V3G2
V3	V1G4	V2G4	V1G1	V3G3	V2	V3 G2	V3E	V2G2
V1G1	V2G4	V1G4	V3	V2 G3	V1	V1 G3	V2E	V1G2
V2G1	V3G4	V3G3	V2	V1 G3	V3	V2 G3	V1E	V3G1
V3G1	V1E	V2G3	V1	V3 G2	V2	V3 G3	V3 G4	V2G1
V1G2	V2E	V1G3	V3E	V2 G2	V1	V1 G4	V2 G4	V1G1
V2G2	V3E	V3G2	V2E	V1 G2	V1 G1	V2 G4	V1 G4	V1
V3G2	V3E	V2G2	V1E	V3 G1	V2 G1	V3 G4	V3 G3	V2
V1G3	V2E	V1G2	V3G4	V2 G1	V3 G1	V1E	V2 G3	V3

Computational Problem Formulation

The problem being resolved is the search for a drought-tolerant cowpea using genetic mutation. Challenges posed by climate change include drought and this creates a research gap. It has become necessary to develop cowpea species that can resist drought. However, the heuristic search for a solution requires iterative processes across many generations. As a result, mathematical methods like linear approaches or exhaustive methods are inadequate. Also, accurate bioinformatic information needs to be generated to guide the cowpea improvement program. Hence, we formulated the problem as a computational problem.

Proposed Solution

In order to forecast when an optimal cowpea solution could be found, we formulated the cowpea mutation for drought tolerance as string manipulation and used the following mutation (genetic) algorithm:

```
1)  Target String (desired cowpea chromosome/genotype) = mutation-induced drought-tolerant cowpea

2)  Length (Target String) = 40

3)  Random String (initial cowpea chromosome/genotype) =
    tttaaa!!!!&&&&&7777%%%%5555ffff999$$$rr

4)  Fitness Score (Genetic Distance) = the number of characters in Target Sring that are different from
    those in Random String

5) While Fitness Score (Genetic Distance) > 0 repeats:

  a) Choose parents from the population

  b) Implement mutation on a new population to get New String

  c) Calculate the Fitness Score (Genetic Distance) for the new population

  d) Random String =      New String
```

The implementation of the above genetic algorithm was done using Python programming and a series of experiments were performed as discussed in the following section.

Results and Discussion

The foliage of cowpea treated with ethyl methyl sulphonate (EMS) and gamma irradiation in the first (M1) generation as observed in the botanical garden of the Plant Science Department of the Federal University of Technology, Minna, Nigeria are shown in Figures 3 – 6 below.

Figure 3. V2E

Figure 4. V2G3

Figure 5. V1E

Figure 6. V1G4

The foliage images above (Figures 3 – 6) show various phenotypic traits induced by the genetic mutations using EMS and gamma rays (Savitri & Fauziah, 2020; Mohamed et al., 2020), V2E in Figure 3 implies that cowpea variety 2 was treated with 0.372 of EMS resulting in a spear-shaped leaf while V2G3 in Figure 4 means cowpea variety 2 was treated with 600ml of gamma irradiation. The V1E in Fig. 5 means cowpea variety 1 was treated with 0.372 of EMS just as the

V1G4 in Figure 6 means cowpea variety 1 was treated with 800ml of gamma irradiation with resultant foliage appearance as shown. In Fig. 5, mutation-induced phenotypic traits like white stripes on the leaves could be seen.

For an offspring of M1 generation to be selected as input for the second (M2) generation, it has to be within the genetic distance (fitness score) of 15. The genetic distance (or fitness score) of 15 implies that the M1 offspring has the desired characteristic genetic traits of drought tolerance and high yield to be among the best selected as input in subsequent generation

The desired characteristic traits of cowpea offspring in the M1 generation were measured by the following parameters:

1. Plant height
2. Number of leaves
3. Number of branches
4. Number of pods per plant
5. Number of nodes per plant
6. Weight of 100 seeds

Harvested seeds of the M1 offspring with the best fitness scores (within a genetic distance of 15) were further subjected to phytochemical and ash content analyses to ascertain the levels of mineral contents such as phosphorus, potassium, calcium, zinc, iron, and magnesium (Savitri & Fauziah, 2020).

The process of getting candidate cowpea solutions from one generation that served as input in subsequent generations until an optimal solution was obtained with a fitness score (or genetic distance) of zero was achieved with the implementation of the genetic algorithm (GA) using Python programming. to forecast when an optimal solution could be found. While the target string was “mutation-induced drought tolerant cowpea”, each experiment generated a random string and the heuristic search progressed from the generated random string to the target string when a fitness score (genetic distance) of zero was obtained. The outcomes of three experiments involving the heuristic search and optimization (Sanabria & Soh, 2004) for cowpea improvement are shown in Table 3 below.

Table 3. Experimental outcomes of the implementation of genetic algorithm for mutation-induced cowpea using python programming.

Experiment	Number of generations (iterations)	Final (target) string	Fitness score of optimal cowpea solution
1	9412	`mutation-induced drought tolerant cowpea`	0
2	9717	`mutation-induced drought tolerant cowpea`	0
3	14338	`mutation-induced drought-tolerant cowpea`	0

Based on the experimental results obtained, our study confirmed that GA is a stochastic optimizer (Liu, 2016) [14] as different iterative results were obtained for the same target string in corresponding iterations across the three experiments mentioned in Table III above. This accounted for the variance in the number of generations (iterations) required for convergence in the three experiments given as 9412, 9717, and 14338 in experiments 1, 2, and 3 respectively.

For a detailed view of patterns in the progress from the random string to the target string during implementation, we show an abridged version of the iterations in Experiment 1 in Table 4 below.

Table 4. Experiment 1 abridged iterations

Generation	Random String	Fitness Score
Generation 1	`Jdt?iiG&5"Bq=g0dD/B4P9evy[- 4gunLBkK&mw)`	36
Generation 2	`String: Jdt?iiG&5"Bq=g0dD/B4P9evy[- 4gunLBkK&mw)`	36
Generation 3	`Jdt?iiG&5"Bq=g0dD/B4P9evy[- 4gunLBkK&mw)`	36
Generation 4	`Jdt,iiG& "Bq,g0d;C{qPqevy[! 4gun2BKKw;w)`	35
Generation 5	`2B(PldT/WwnFjc dgMRn tyHYd)2e}2{j"TKwIea`	33
Generation 6	`2B(PldT/WwnFjc dgMRn tyHYd)2e}2{j"TKwIea`	33
Generation 7	`J3t8Mion3"n1,budp ZUPqTHXtL e&Z;2cX}2}e)`	31
Generation 8	`J3t8Mion3"n1,budp ZUPqTHXtL e&Z;2cX}2}e)`	31
Generation 9	`J3t8Mion3"n1,budp ZUPqTHXtL e&Z;2cX}2}e)`	31
Generation 10	`J3t8Mion3"n1,budp ZUPqTHXtL e&Z;2cX}2}e)`	31
….	….	…
Generation 9409	`mutation-induced dr}ught tolerant cowpea`	1
Generation 9410	`mutation-induced dr}ught tolerant cowpea`	1
Generation 9411	`mutation-induced dr}ught tolerant cowpea`	1
Generation 9412	`mutation-induced drought-tolerant cowpea`	0

The statistics from Table 3 and Table 4 show that the task of obtaining an optimal cowpea solution with a fitness score (error) of 0 will take many generations to achieve. Specifically, Table 3 indicate that in experiments 1, 2, and 3, the respective number of generations of cowpea required are 9412, 9717, and 14338. Table 4 provides detailed information on the steady decline of error (difference between target string and random string) from the first generation with fitness score of 36 to the last (9412th) generation with fitness score of 0.

The outcomes of the field experiment and the results of the computational experiments show that the cowpea improvement initiative in the M1 generation is progressing towards the actualization of cowpeas that are drought-tolerant. This implies that cowpea species that can withstand the vagaries of climate change will emerge in subsequent generations. The effort will impact on tackling hunger (human capital), improve income-earning capacity of farmers (economic capital), preserve native cowpea species (social capital), and protect the ecology (environmental capital). Therefore, the crop improvement program is meeting the needs of the present generation as well as responding to the needs of future generations as required by sustainable development.

From the foregoing, we have achieved the three specific objectives of this study. Firstly, using EMS and gamma irradiation, we achieved mutation induction in the treated cowpea plants as evident in the phenotypic traits of the offspring plants. We also formulated the genetic mutation in our cowpea improvement program as a string manipulation using a genetic algorithm. Finally, we implemented the GA using Python programming and showed how bioinformatic information from one generation was used in subsequent generation in a bid to obtain an optimal cowpea solution with drought tolerance and high yield traits.

Conclusion

Food security is key to human sustainability and the attainment of the UN SDGs by the target year 2030 (Muzhinji & Ntuli, 2021; Mukhtar, 2021). In developing economies, malnutrition, immune deficiency, and hunger persist (Akinbo et al., 2021). To solve this problem, this paper focused on improving the potential of a common leguminous crop in Nigeria with high protein content. Apart from its proteinous content, it is relatively cheap and affordable compared to animal protein which is elusive in the nutrition of many people in developing economies. Data mining and predictive analytics were explored using data-driven artificial intelligence-based approach involving the application of genetic algorithm for improvement purposes (Jena & Dehuri, 2022; Behera et al., 2020; Jena & Dehuri, 2019) [18, 19, 20]. After using physical and chemical mutagens to modify the genetic makeup of cowpea in a bid to achieve drought tolerance, high yield, and climate resilience, the search for an optimal cowpea solution was guided by genetic algorithm for forecasting bioinformatic outcomes. From our series of experiments, we showed that prudent use of bioinformatic information could aid the cowpea improvement program for human sustainability and attainment of the UN SDGs by the target year 2030. In future work, other genetic engineering and biotechnology techniques would be explored for improving cowpea.

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