Towards the Development of a Finger Millet *(Elesine Coracana) l. Garten)* Breeding Programme in Zambia: A Multivariate Analysis of Agronomic Traits of Mutation Derived Lines

Rachel Nyembezi Nguluwe-Msikita[*,1], **Davies Malekani Lungu**[1], **Richard Chanda**[2]

[1]University of Zambia School of Agricultural, Department of Plant Science, P.O. Box 350199, Lusaka, ZAMBIA. [2]Seed Control and Certification Institute-Ministry of Agriculture, Chilanga 13201, P.O. Box 350199, ZAMBIA.

*Corressponding Author: **Rachel Nyembezi Nguluwe-Msikita**, Email: rachelmsikita@gmail.com

Doi 10.53974/unza.jabs.6.4.976

ABSTRACT

Finger millet (*Eleusine coracana (*L.) Gaertn) is one of the climate-resilient cereal crops with the potential to mitigate the effect of climate change among the smallholder farmers who are the major growers of finger millet. It can adapt to extreme environmental conditions and grow under a wide range of diverse agroecologies, which is an advantage to breeding high-yielding stress-tolerant genotypes. However, the strength of breeding high-yielding, climate-resistant genotypes is highly or largely dependent on the genetic information of the base breeding population. The lack of knowledge on the genetic information of finger millet in Zambia has hampered the breeding of climate-resilient genotypes. Therefore, a study assessed the diversity of M_6 mutant lines. The mutants were selected from a pure line selection derived from a landrace finger millet variety called Mutubila. The Mutubila pure line was irradiated with a dose of 100gy gamma rays. The irradiated seed was planted to raise the M_1 generation for eventual advancement to the sixth generation. From the M_2 to M_4 generations, mutants were selected based on the number of productive tillers and finger length using the independent culling selection approach at a selection intensity of 10%.

In the M_5 and M_6 generations, however, the selection of advanced lines was expanded to include the number of fingers per ear head and other important agronomic traits. This resulted in 40 mutant lines being selected in the M_6 generation. The 40 mutant lines and eight checks were planted using an Alpha Lattice design with two replications and eight blocks. The 48 genotypes were evaluated for agronomic performance, and the data collected was analysed using R software. The results revealed that the mutant lines were diverse in the number of productive tillers per plant (3 to 15), main ear length (4.4 to 14.5cm), number of fingers per ear head (3 to 17) and grain yield (0.58 to 2.95tons/ha).

The yield components (number of productive tillers, Finger length, number of fingers, strawweight, and thousand seed weight) were strongly and positively correlated to grain yield ($R^2 > 0.67$) as well as strongly and positively inter-correlated. Days to flowering were weakly and negatively correlated to grain yield ($R^2 > -0.17$.

The Mahalabonis analysis grouped the genotypes into ten (10) clusters, with cluster I having the highest number of sub-clusters (11) and cluster IX and X having the lowest sub-clusters (1). The highest inter-cluster distance (> 572,618) was observed between clusters V and IV; V and VII; V and IX; and VII and XI, indicating wider divergence among these clusters. The least inter-cluster distance (<6,043) was observed between II and III; VIII and X; and I and VIII. Distant clusters provide opportunities for breeding by crossing genotypes from two distinct clusters to generate superior cultivars. The study showed that selecting yield components as the mutants is advanced results in divergent lines, which can be recombined to breed high-yielding genotypes with multiple stress tolerance. We conclude, therefore, that mutation breeding for finger millet can be used to generate diversity and the identified divergent lines that can be recombined to develop improved finger millet varieties that can be commercialised.

Keywords: Finger millet, Induced mutation, agronomic traits, genotype, genetic, divergence and cluster.

INTRODUCTION

Finger millet (*Eleusine coracana (L.) Gaertn*) is an annual small-grain cereal crop widely grown as a grain crop, mostly in Africa and India. It is highly self-pollinated, with a 1% cross-pollination, primarily by wind [1, 2]. As an essential small-grain cereal crop, it ranks fourth in importance after sorghum, pearl millet and foxtail millet [3]. In Zambia, known as Kambale, Lupoko, Mawale, Majothi, Amale, Bule, and Bulo [4], finger millet cultivation is more widespread regarding its geographical adaptation than other millets. In Zambia, it is grown mainly by small-scale farmers under the slash-and-burn farming systems in Region III, the high rainfall area [5].

The yield of finger millet is generally low compared to other cereal crop species. The average yield of finger millet worldwide is estimated to be 689 kg ha^{-1}, while in Africa, it is 885 kg ha$^{-1,}$ about 400 kg ha^{-1} in Zambia [6]. Generally, finger millet has poor productivity, which can be attributed to many factors. One of the factors is little plant breeding directed at developing improved varieties, coupled with a lack of agronomic research on best agronomic practices to achieve high productivity. This unavailability of improved cultivars has left farmers to depend on the recycled seed of landraces of finger millet crop species [7]. When it comes to breeding, the flowers of finger millet are very small, thus making it difficult to emasculate them to achieve successful artificial hybridisation. Finger millet is, therefore, not amenable to artificial hybridisation for creating variation, which is needed for crop improvement. Therefore, the most practical way of creating genetic variation in finger millets is through the induced mutation approach [8].

Mutation breeding is useful in breeding. Some studies were conducted to evaluate the quantitative variation of traits for 40 mutants of cultivar VL-149, which was irradiated with gamma rays [9]. The results showed that gamma –rays were effective, giving higher-yielding mutant lines [9]. Another study on developing early maturing millet lines revealed that mutants had higher yielding and improved yield components [10]. Despite this, the success of mutation depends on the extent of genetic variation generated. The extent of genetic variation unravelled through induced mutation depends on the dose and genotype of the parent variety, which is subjected to mutagenic treatment [9]. Hence, the genetic divergence in a parent (s) can influence the genetic diversity in the mutation-derived lines.

Diversity studies have greatly used morphological descriptors that include attribute characteristics or measurable traits. They have also greatly used measurable descriptor traits observed in an accession. This implies that understanding the level of diversity from mutant lines is critical for designing a successful and robust finger millet breeding programme.

Therefore, this study assessed the phenotypic diversity of mutants derived from a landrace line finger millet variety, Mutubila. This research was conducted to characterise and group the genotypes into their distinct clusters based on their agronomic traits to enable breeders to have a wide range of genotypes in a segregating population, hence, creating a higher chance of selecting for a genotype with the desirable trait(s) [9]. Several algorithms are available to understand the divergence. One of the algorithms is the Mahalanobis distance, D^2 statistics. The Mahalanobis distance D^2 statistics have been used to study the genetic diversity in this study. They effectively determine the divergence based on agronomic traits [11].

MATERIALS AND METHODS

One (1) 1kg of Mutubila variety was subjected to irradiation treatments at four levels: 0Gy (control), 100Gy, 150Gy and 200Gy. The irradiated seed samples (M_1 seed) were subjected to a germination test. The germination test gave the following results: 99.8% germination for 0Gy (control), 78% germination for 100Gy, 8% germination for 150Gy and 0% germination for 200Gy. The material from the 100Gy with 78% germination was considered the appropriate dose for this study, and only generations arising from this dose were used in this study.

Single plant selection advanced the lines from M_2 to M_4. The single plants were simultaneously selected for the number of productive tillers per plant and ear length. In each selection cycle, different minimum selection thresholds were used for each trait at each stage of advancement. The minimum thresholds for the number of productive tillers per plant were 3, 7 and 10 for M_2, M_3 and M_4, respectively. The minimum threshold for selecting ear length was 5, 7 and 10cm for M_2, M_3 and M_4, respectively.

In the M_5 generation, mutants that had grain yield greater than 0.559 tons/ha and straw yield greater than 1.072 tons/ha, compared to the parent, Mutubila, were selected and advanced to M_6. Therefore, forty (40) mutants were advanced to M_6 and evaluated.

The forty mutants, in their sixth generation (M_6), including seven checks and the parent, Mutubila, were planted at the Zambia Agriculture Research Institute Research Station in the Northern Province during the 2018/2019 rainy season. The 48 genotypes were planted in an Alpha lattice design with two replications and six blocks. Each plot had four rows 3m long, with an intra-row space of 0.30m and inter-row spacing of 0.30m. Data was collected on five plants randomly selected within the two middle rows. The following agronomic data was collected: Days to 50% flowering, plant height (centimetre), number of productive tillers per plant, number of fingers per main ear head per plant, finger length of middle finger (centimetre), harvest index (%), one thousand seed weight (grams), straw weight (ton/hectare), and grain yield (ton/hectare). The data collected was analysed statistically using R-software (R-4.2.2. for Windows).

Person's correlation of agronomic traits was conducted using the agricolae package, while the multivariate analysis was done using the bio tools package to calculate the Mahalanobis's D^2 statistics [10]. The Mahalanobis's D^2 statistics were used because they are the most effective in calculating divergence [11] and are thus commonly used.

RESULTS AND DISCUSSION

(a) Response of Finger Millet to different Gamma-ray Irradiation

Higher dosage reduced the germination percentage; therefore, the lower dose of 100Gy was more effective, with 70% plant survival compared to the other three doses. The results obtained in this study conform with a study by [12]. In their study, they used four doses of gamma rays (400Gy, 500Gy. 600Gy and 700Gy), and their results showed that the lower the dosage, the more effective, while the higher dose decreased the growth of shoots and roots in finger millet seed.

(b) Analysis of Variance for Agronomic Traits

The analysis of variance for nine characters showed that the genotypes used in the study were significantly different (p=0.01) except for plant height, main finger length and harvest index (**Table 1**).

Table 1: Analysis of variance for nine characters among forty-eight Finger millet [Eleusine Coracana (L. Garten)] genotypes in the sixth generation.

Serial number	Character	Mean sum of squares			
		Replication	Block	Genotypes	Errors
1	Days to 50% flowering	133.01**	23.27	35.96**	25.64
2	Plant height (centimetre)	1.08	18.87	78.60	48.89
3	Number of productive tiller number per plant	19.984	11.459**	25.576**	4.424
4	Number of fingers per earhead	1.000	17.731**	25.194**	0.74
5	Main earhead length (centimetre)	8.085	3.016	9.509	2.007
6	1000 seed Weight (gram)	0.120	0.716**	0.946**	0.096
7	Harvest index (%)	0.00011	0.00011	0.0001	0.0001
8	Grain yield (ton per hectare)	0.011	0.011	0.489**	0.045

=** Significant differences at P-value 0.01, = serial number the number of characters measured and analysed

Days to 50% flowering among the 48 genotypes ranged from 49.0 to 73.00 days, with a mean of 66.82 days. The parent *Mutubila* variety (**Table 3)** flowered within 60 days, and late flowering was observed in line 33 within 73.5 days. Meanwhile, plant height ranged between 48.2cm to 72.3cm, with a mean of 61.7cm. Mutant line 2 was the shortest, 48.2 cm, and the tallest was Mutant line 17, 71.3cm. Productive tiller number per plant ranged from 3 to 15 with a mean of 9.5 tiller number per plant, and the highest number was observed in Mutant line 25 with 15.0, while the lowest number was observed in two genotypes: Mutant line 7 with 4 including parent *Mutubila* variety with 4. The main ear head length ranged between 4.4 to 14.5cm with a mean of 7.0cm. A longer main ear head was found in Mutant line 13 at 14.5cm, while the shortest was found in the parent *Mutubila* variety at 4.0cm. The range for finger number per ear was between 3.0 and 17 with a mean of 7.7; the highest number was observed in genotype 27 with 16.5, and the least was in parent *Mutubila* with 3.0. A 1000 seed weight ranged between 0.34 and 3.3 g with a mean of 1.6 g, with genotype 27 having 3.2g, while the parent *Mutubila* variety had the lowest weight with 1.3g. The harvest index percentage ranged from 0.34% to 0.46%, with a mean of 0.43%. This trait was higher in genotype 27 (0.45%) and lower percent in line ML13 (0.39%). The strawweight (tonnage/hectare) ranged from 0.811 to 6.684 with a mean of 2.586; higher tonnage was observed in genotype 13 with 6.684, and the parent *Mutubila variety* had the lowest with 0.813. Grain yield (tonnage/hectare) ranged from 0.5830 to 2.9500, with a mean of 1.121. The higher yields were observed in genotype 13 (2.500), and a lower yield was observed in parent *Mutubila* variety 0.5830. The performance of the lines was highly significant compared to the other genotypes. Results agree with studies done by [14]. The work done in Nagali showed that productive tillers per plant and finger length are important yield contributors, and he emphasised that they need to be given to productive tillers per plant and finger length while selecting grain yield improvement in finger millet. A study by [15] showed that the tiller habits played a role in the increased yield, which influences yield in the spacing between rows and between plants. The more space, the higher the yields (Table. 2).

Table 2: The range and mean for nine characteristics among forty-eight finger millet

[Eleusine Coracana (L. Garten)] genotypes		
Characteristics	Range	Mean
Days to 50% flowering	50.00-75.00	66.82
Plant height (centimetre)	44.80-75.80	61.67
Number of productive tillers number per plant	2.0 -19.00	9.5
Number of fingers per earhead per plant	2.0-17.0	7.7
Main earhead length(centimetre)	3.0 -11.7	7.0
1000 seed weight (gram) per Mutation derived line	0.34-3.3	1.6
Grain yield (ton/hectare)	0.235-2.952	1.121

The subsequent selections in each generation were evident from these results. The selection was based on three-grain yield contributing factors (number of a productive tiller, length of main earhead finger and number of fingers per plant). Twenty-five mutation lines (Table 3) had the yield components above the trial mean of 1.121 tons per hectare and were significantly different from the parent Mutubila variety, showing that these are the most important factors contributing to grain yield. The present study findings agree with other studies. According to [14], the work done in Nagali showed that productive tillers per plant and finger length are important yield contributors, and he emphasised the need to be given to productive tillers per plant and finger length while selecting grain yield improvement in finger millet. This study agrees with the findings by [15] in which a study showed that tiller habits played a role in the yield increase. Also, it was observed that what influenced yield was the spacing between rows and between plants. The more space the plants have, the higher the yields. This was the fact in the present study, as the spacing was wider, 30cm and 30cm.

Table 3a: Agronomic performance of 40 mutants and eight commercial checks

Genotype	50 % days to flowering	Plant height (cm)	Productive tiller number	Finger number	Finger length (cm)	Harvest index %	1000 seed weight (gm)	Straw-weight (t/ha)	Grain yield (t/ha)
ML1	72.5	67.1	11.0	10	9.6	0.43	1.9	3.045	1.323
M L 2	72.0	48.2	5.0	4.0	6.1	0.43	0.8	1.303	0.567
M L3	72.0	66.9	11.0	7.0	6.5	0.43	1.9	2.980	1.294
M L 4	64.0	56.0	4.5	3.0	4.4	0.43	0.7	1.147	0.498
M L 5	63.0	60.9	9.5	9.0	9.5	0.43	1.5	2.376	1.049
M L 6	72.0	64.2	11.0	8.5	8.9	0.43	1.9	2.981	1.590
M L 7	65.0	58.1	3.0	3.5	5.2	0.43	0.5	0.811	0.351
M L 8	49.0	72.0	10.0	8.0	8.8	0.43	1.8	2.844	1.235
M L 9	62.5	59.0	7.0	5.0	7.5	0.43	1.2	1.897	1.177
M L 10	72.0	65.1	11.5	8.0	7.8	0.43	1.4	2.370	1.029
M L 11	71.0	61.3	11.5	8.0	6.9	0.43	2.4	3.795	1.648
M L 12	65.0	52.1	9.0	5.5	5.4	0.43	1.5	2.438	1.059
M L 13	66.5	67.3	14.5	14.5	14.5	0.39	2.9	6.684	2.500

M L 14	67.5	58.6	12.5	7.0	4.7	0.43	1.7	2.711	1.178
M L 15	68.5	50.5	12.5	8.0	6.4	0.43	2.1	3.386	1.470
M L 16	67.5	56.5	6.5	4.5	4.7	0.43	1.1	1.684	0.731
M L 17	65.0	71.3	10.5	9.0	9.7	0.43	2.4	2.845	1.236
M L 18	62.5	67.2	9.5	7.0	8.5	0.43	1.6	2.574	1.118
M L 19	62.5	66.3	9.5	6.0	8.4	0.43	1.4	2.303	1.000
M L 20	67.5	61.7	7.5	4.0	4.4	0.43	0.9	1.538	0.668
M L 21	69.5	58.2	9.0	7.0	6.6	0.43	1.0	3.088	1.341
M L 22	72.0	70.0	11.0	6.0	6.2	0.43	1.9	2.980	1.294
M L 23	62.5	66.6	12.5	11.0	10.5	0.43	2.2	3.479	1.511
M L 24	67.0	61.2	7.5	4.5	4.5	0.43	1.7	2.032	0.883
Mean	**66.8**	**61.7**	**9.5**	**7.7**	**7.0**	**0.43**	**1.6**	**2.586**	**1.121**
LSD	**5.8**	**15.1**	**4.2**	**1.7**	**1.2**	**0.02**	**0.1**	**1.2**	**0.4**

*Denotes parent variety Mutubila used as control a non-irradiated

Table 3b: Agronomic performance of 40 mutants and eight commercial checks.

Genotypes	50 % days to flowering	Plant height (cm)	Productive tiller number	Finger number	Finger length (cm)	Harvest index %	1000 Grain weight (gm)	Straw-weight (t/ha)	Grain yield (t/ha)
*Mutubila	60.0	53.7	3.0	4.0	4.0	0.44	0.5	0.813	0.583
M L 25	67.5	55.4	15.0	13.5	7.4	0.43	2.6	4.066	1.766
M L 26	68.5	71.2	8.5	6.0	8.0	0.43	1.5	2.303	1.000
M L 27	62.5	71.0	13.0	16.5	8.8	0.45	3.2	5.076	2.264

M L 28	72.0	68.8	5.5	4.0	5.7	0.43	0.9	1.442	0.625
M L 29	69.0	64.6	13.5	13.5	8.5	0.43	2.3	3.658	1.589
M L 30	70.0	64.7	13.0	11.0	8.8	0.44	2.2	3.490	1.531
M L 31	71.0	70.2	14.0	15.0	9.4	0.43	2.7	4.277	1.858
M L 32	62.0	61.8	14.0	12.5	10.9	0.43	2.4	3.836	1.666
M L 33	73.5	62.7	11.0	9.0	9.3	0.43	1.7	2.719	1.181
M L 34	62.5	66.3	8.5	6.0	4.9	0.43	1.3	2.167	1.181
M L 35	72.0	58.7	13.5	12.0	8.6	0.43	2.4	3.722	1.617
M L 36	67.5	68.2	13.5	13.0	10.8	0.43	2.3	3.677	1.597
M L 37	72.0	60.6	6.0	5.0	4.9	0.43	0.9	1.375	0.597
M L38	73.0	61.8	13.5	11.5	9.7	0.43	2.2	3.482	1.512
M L 39	65.0	57.9	14.5	14.0	10.0	0.43	2.5	3.928	1.706
M L 40	67.5	56.0	8.5	7.0	7.1	0.43	1.3	1.990	0.868
Namwenya	64.5	73.0	10.5	6.0	5.4	0.43	1.9	2.650	1.299
Sumina	70.9	72.1	14.5	9.5	7.6	0.43	0.8	2.548	1.246
Nyika	51.1	75.3	9.0	8.5	6.7	0.43	0.6	0.798	0.388
Senga	51.2	57.3	6.5	5.1	4.6	0.43	0.7	0.690	0.339
Mwangwa-	59.9	67.9	9.5	8.0	6.6	0.43	0.7	0.769	0.377
Mabutila	66.4	72.1	6.0	5.9	5.2	0.43	0.4	0.618	0.303
Iyakashika	54.2	88.1	3.2	3.3	5.0	0.43	0.5	0.701	0.344
Mean	**66.8**	**61.7**	**9.5**	**7.7**	**7.0**	**0.43**	**1.6**	**2.586**	**1.121**
LSD	**5.8**	**15.1**	**4.2**	**1.7**	**1.2**	**0.02**	**0.1**	**1.2**	**0.4**

*Denotes parent variety Mutubila used as control a non-irradiated and those in italics used as checks in the study

Grain yield was significant (p=0.01) and positively correlated to plant height (r^2 =0.269) and thousand seed weight. (r^2 =0.975), productive tiller per plant (r^2 =0.847), finger length per plant (r^2 =0.645), number of Finger per main head (r^2 = 0.847) and strawweight (r^2 = 0.987). Furthermore, strong positive correlations were observed among grain yield and yield components (protective tiller, finger length and Finger number). The observed strong and positive correlations among yield and yield components have been reported before [16]. The observed correlations also give hope for using yield components in breeding as selection indices. There was a weak positive correlation between grain yield and plant height, and these results agree with work done by [17]. The study showed that plant height and days of flowering do not contribute to grain yield, as they were weakly correlated to grain yield **(Table 4)**. The study also shows that setting thresholds for several productive tillers and ear lengths will result in having mutant lines with a high likelihood of selecting for yield based on secondary traits.

Table 4: Correlation coefficient of traits for forty-eight finger millet [Eleusine Coracana (L. Garten)] genotypes

Character	Days to 50 percent flower-ing	Plant height	Thousand grains Weight	Productive tiller number Plant	Finger length	Fingers number	Straw-weight	Grain yield
Days to 50 percent flowering	1	0.036	0.195*	0.229*	0.228*	0.214*	0.174*	-0.167
Plant height (centime-tre)		1	0.246*	0.221*	0.382**	0.254*	0.272**	0.259**
Thou-sand seed weight(-gram)			1	0.846**	0.665**	0.893**	0.978**	0.975**
Productive tiller per plant				1	0.632**	0.805**	0.822**	0.847**
Finger length per plant (cen-timetre)					1	0.746**	0.633**	0.645**
Number of Fingers per main head						1	0.855**	0.885**
Straw-weight (ton per hectare)							1	0.987**
Grain yield (ton per hect-are)								1

Level of Significance is shown with asterisks as: *Significantly at P- value of 0.05 and **Significantly at P- value of 0.0.1.

A positive, strong correction was observed for grain yield with all measured characters at a p-value of 0.001except plant height, which had a negative

Morphological Divergence of Genotypes

The Mahalanobis's D^2 statistics divided the 48 genotypes into 10 clusters (Table 5 and Figure 1). Two major groups could be identified, with group IV having 4 commercial checks. Group 1 had two commercial checks, Group III had two checks, Group IV had one check, and Group X had one check. This indicates that group IV checks can be crossed with checks in other groups. Cluster I had the highest number of genotypes (11), while the minimum number of genotypes was in clusters IX and X (1). This implies that genotypes in clusters IX and X are unique, requiring further investigations. Genotypes found in a cluster are similar, and the intra-cluster distance gives an overview of their closeness. Genotypes in clusters II and III were very close compared to genotypes in cluster IX (Table 5 and Fig 1).

The dendrogram (Figure 1) shows that the commercial check, Mabutila, is unique, being separated from the rest. Therefore, two major groups were identified as A and B, with group A having more genotypes and sub-clusters. Group B had a few sub-clusters, showing that the parent is closely related to Lyakashi, Nyika and Chibuli commercial checks. Furthermore, the genotypes in the cluster having Sumina and Namwenya commercial checks were closely related.

Table 5: The grouping of forty-eight finger millet genotypes [Eleusine Coracana (L. Garten)] based on Mahalanobis's method

Cluster number	Number of Genotypes'	Name of the Genotypes
I	11	Mutant line 3, Mutant line 22, Mutant line 6, Namwenya, Mutant line 1, Mutant line 33, Mutant line 11, Sumina, Mutant line 7, Mutant line 8, Mutant line 5
II	9	Mutant line 29, Mutant line 36, Mutant line 35, Mutant line 31, Mutant line 38, Mutant line 13, Mutant line 30, Mutant line 14, Mutant line 32
III	7	Mutant line 21, Mutant line 40, Mutant line 34, Mutant line 26, Mutant line 12, Mutant line 18, Mutant line 19
IV	4	Mutant line 4, Mabutila, Mutant line 2, Mutant line 28
V	4	Mutant line 15, Mutant line 23, Mutant line 27, Mutant line 10
VI	5	Parent Mutubila variety, Lyakashika, Mutant line 7, Nyika, Chibuli
VII	4	Mutant line 20, Mutant line 24, Mutant line 9, Mutant line 16
VIII	2	Mutant line 25, Mutant line 39
IX	1	Mutant line 37
X	1	Mwangwa

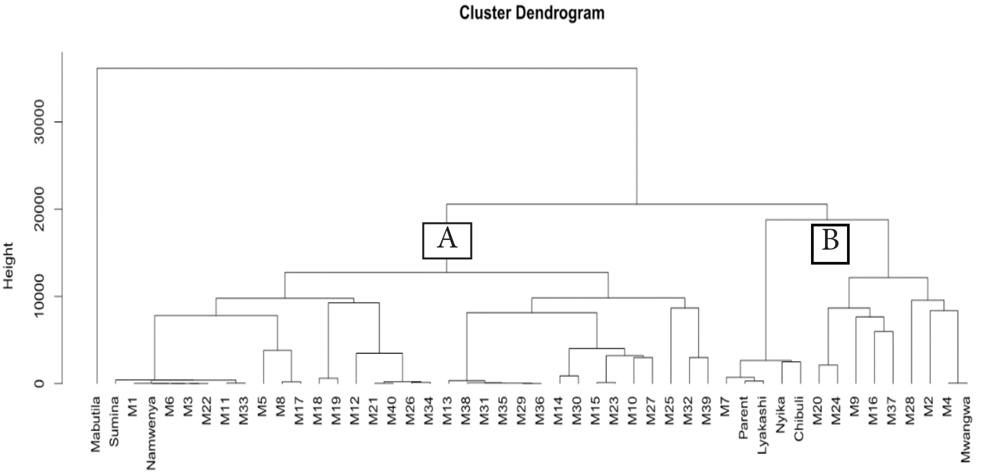

Figure 1: Clustering the 48 finger millet genotypes based on eight analysed traits using the Single agglomerative method of the D statistics distance (Tocher distance)

The characteristic of each cluster revealed that cluster I had genotypes that flowered early (59days) that are short, with a relatively high number of tillers, number of finger couple with the highest biomass yield (3.0tons/ha) and grain yield of more than 1.0ton/ha (Table 6). Cluster VIII genotypes flowered at 67 days (8 days later than cluster I), having a high grain yield of 1.5 tons/ha with a high number of productive tillers, fingers, and straw yield. The grain yield and straw yield ratio for genotypes in clusters I and VIII were similar (0.45 and 0.44, respectively). The slightly lower harvest index of (0.01) in cluster VIII had resulted in a 0.2ton increase in yield. This indicates selection for harvest index could improve grain yield in finger millet.

The analysed characters per cluster revealed that 50 percent of days to flower ranged from 61.7 to 69.8. In cluster II, the genotypes flowered earlier compared to the other clusters. Late flowering was observed in cluster VI, with a mean of 69.81 days. Plant height ranged from 57.0 to 65.2cm, and shorter plants were observed in cluster III at 57.0cm compared to cluster IX with taller plants at 65.0cm. The range in tiller number per plant was from 2.6 to 14.6. The lower number of tillers per plant was observed in cluster I, with 2.6, and the higher number in cluster X, with 14.6 tillers per plant. Finger numbers ranged between 3.1 and 13.3; the highest was in cluster X, with 13.3 fingers per ear head, and cluster I had 3.1, where one of the check landraces was. The shortest finger length was in cluster I at 3.9cm, while the longest finger length was in cluster IX at 9.6. The 1000 seed weight was greater in cluster VIII, 2.52gram and the lowest was in cluster I, 0.52 grams. Cluster IX had the highest straw weight of 4.250 tons/ha compared to other clusters, and the lowest was in cluster I with 0.6874 tons/ha. The highest yield was observed in cluster IX, 1.779ton/ha, compared to other clusters, and the other clusters had yields of more than 0.5000 ton/ha except for cluster I with 0.2980ton/ha and cluster II, with 0.3976 ton/ha being the lowest. Performance on characters measured (Table. 2) was observed to be higher in clusters that did not contain parent Mutubila variety and landrace checks. This showed that the mutation-derived lines were monogenetic.

The overall means for 50 percent days to flower were 66.82 days, plant height 61.67cm, productive tiller number 9.5, finger length middle finger 7.0 cm, finger number per ear head 7.7, thousand seed weight 1.63gms, straw yield 2.586tons/ha and grain yield 1.116tons/ha. **(Table 2)**. Results showed that these genotypes share the divergence to the parental line Mutubila variety cluster VI with the highest number of mutation derived lines 8 showed that the derived lines possess enough divergence from the parents in the eight analysed traits. These results also showed that the 8 mutation-derived lines did possess enough divergence from the parent Mutubila variety in the eight analysed traits **(Table 6)**.

Table 6: Agronomic characteristics analysed among forty-eight genotypes of Finger millet [Eleusine (L. Garten) Coracana]

Characteristics	Cluster										Cluster average
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Days to 50 percent flower	58.8.	61.7	67.7	66.5	65.0	69.8	65.8	67.2	68.8	66.1	66.8
Plant height (centimetre)	56.6	64.79	69.0	66.5	65.0	69.8	65.8	67.2	68.8	66.1	61.9
Productive tiller number per plant	11.0	3.4	5.4	6.9	8.7	8.7	10.0	12.5	13.7	14.6	9.5
Finger number per plant	8.1	3.5	3.7	4.9	5.6	7.6	7.9	10.2	13.2	13.3	7.7
Finger length (centimetre)	7.8	4.3	4.8	5.2	6.4	7.5	8.2	7.9	9.6	9.6	7.0
Thousand seed weight (grams)	1,6	0.58	1.1	1.2	1.5	1.6	1.8	2.5	2.5	2.5	1.6
Strawweight (tons per hectare)	2.888	0.92	1.28	1.70	1.10	3.5	2.59	3.42	4.25	3.94	2.57
Grain yield (tons per hectare)	1. 309	0.40	0.55	0.74	0.84	1.23	1.12	1.50	1.78	1.78	1.12

The characters' performance was higher in clusters that did not contain parent Mutubila variety and landrace checks. This showed that the mutation-derived lines were monogenetic.

The Intra and Inter-cluster

The intra and inter-cluster D^2 and D values measured in the ten clusters are shown in Table 7, and the relationship between clusters is shown in **Figure 2**. The use of average intra and inter-clusters Euclidean distances. The results showed a range between 6043.1 to 572,618.8 among ten clusters, with a maximum of 572,618.8 in a cluster (10) and a minimum of 6043.1 in a cluster (5). The distance between the clusters showed significant differences for clusters 1 and II. It was very close, with 8329.1 showing similarities and variations that, when crossed, could be minimal compared to other clusters. The maximum inter-cluster distances were observed between clusters V and IV (2,086,390.4), V and VII (906,995.1), V and IX (1,320,215) and VII and X (5,726,184.8). This indicates a wider divergence among these clusters and that genotypes in one cluster differ completely from those in the other. While the minimum distance was between II and III (737,376.9), VIII and X (47,951.1), I and VIII (71,034.7). The closer the distance between clusters, the more the genetic makeup of genotypes. These results are in line with what was reported by [18] in a study where forty-finger millet genotypes were evaluated, and the results on the closest intra-cluster distance indicated that the genotypes in the cluster might be genetically similar with each genotype most likely having evolved from the same gene pool. The farther the genotypes are from each other, the more variations occur. This is very useful to a breeder in the improvement of this crop. These results align with what was reported by [19] when 68 genotypes were evaluated for their yield characteristics. The results showed that some genotypes were far from other clusters. This would be very useful in contributing to the breeding programme as the increase in variation among segregates would be advantageous in advancing generations with superior characteristics. The clusters IX and X were solitary clusters with zero intra-cluster distance results in agreement with **(Table 7 and Figure 2).**

Table 7: Average intra (bold) and inter-cluster values (D^2) among ten clusters for forty-eight finger millet [Eleusine Coracana (L. Garten)] genotypes

Cluster Number	1	2	3	4	5	6	7	8	9	10
1	**8,329.1**	244,912.4	144,235.8	1,272,281.7	71,034.7	2,019,609.5	490,613.1	529,967.2	801,436.9	2,788,085.2
2		**11,015.9**	737,376.9	2,601,685.5	60,583.5	3,636,121.3	1,400,871.2	63,650.0	1,906,936.0	4,647,421.1
3			**15,102.1**	586,511.4	394,300.2	1,117,617.6	120,505.2	1,196,537.5	284,292.9	1,703,222.5
4				**16,901.7**	1,908,484.1	96,359.3	199,881.3	3,421,111.0	59,401.37	303,552.2
5					**6,043.1**	2,806,390.4	906,995.1	224,374.7	1,320,215.5	3,702,218.9
6						**6,948.9**	538,278.1	4,596,053.3	279,147.5	65,182.9
7							**20,283.9**	2,015,207.1	4,7951.1	960,897.5
8								**8,671.2**	2,616,813.8	5,726,14.8
9									**0.0000**	60,1417.03
10										**0.0000**

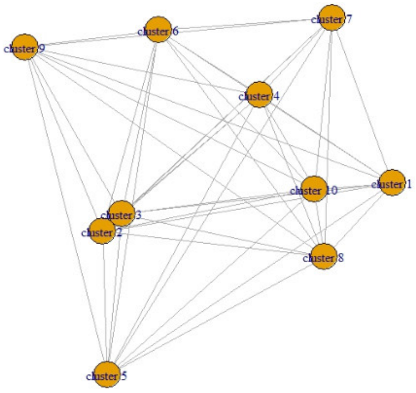

Figure 2: Cluster diagram of forty-eight finger miller [Eleusine Coracana (L. Garten)] for forty-eight genotypes.

Showing the cluster distance between the clusters, significant differences were seen in clusters I and II, which were close to D2=8329.1 showing similarities with some variations if crossed, there could be very minimal compared to other clusters, while the maximum inter distances were observed between clusters V and IV (D=2,086,390.4)

Contribution of Characters to Divergence

The number of fingers explained 50.4 % for the divergence of 48 genotypes of finger millet, followed by grain yield explaining 9.33%. Plant height explained the least (2.9%), like days to flowering (3.9%). The results in this study agree with what [20] found in a study of 18 elite finger millets, where they observed high heritability and genetic advance for ear head yield, ear head length, and number of fingers per ear head. They recommend that selection be based on ear head yield, ear head length and number of fingers per ear head. These characters would greatly increase the yield portfolio of finger millet. In our study, the high positive correlations observed between finger length and the number of fingers can be used in breeding high-yielding finger millet, following the recommendations of [20].

The coefficient of determination, obtained by squaring the correlation coefficient, can be used to assess the strength of the model. The study indicates that the variation in the number of fingers explains 78.3% of the variation in grain yield and 55.6% in finger length, while finger length explains 41.6% in grain yield. Therefore, the study suggests that selecting the number of fingers is a better selection trait to increase yield. **(Table 8 and Figure 3).**

Table 8: Contribution of different characters towards genetic divergence in forty-eight finger millet [Eleusine Coracana (L. Garten)] genotypes

Serial number	Source	Contribution (percentage)
1	Days to 50 percent flowering	3.6
2	Plant height (centimetres)	2.9
3	Productive tiller number	8.5
4	Finger number	50.4
5	Finger length per main earhead (centimetres)	6.8
6	Thousand seed weight (grams)	8.3
7	Harvest index (percentage)	2.7
8	Strawweight (kilogram)	7.5
9	Grain yield (kilogram)	9.3

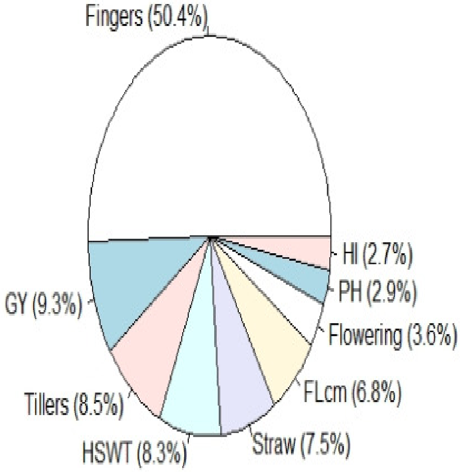

Figure 3: Contribution of different measured characteristics towards genetic divergence in forty-eight finger millet [Eleusine Coracana (L. Garten)] genotypes.

The figure also revealed that harvest index (2.7%) and plant height (2.9%) were the least contributors.

CONCLUSION

Mahalanobis's D^2 statistics showed a wider genetic variability among the forty-eight genotypes grouped in ten clusters. The agronomic characteristics of the clusters were divergent, which could allow for inter-mating during breeding. The study also revealed that the commercial checks are not divergent, so the variation created can be utilised in breeding. The commercial check, Mabutila, is unique, and, therefore, mutating this variety would add the divergence required in the breeding programme.

The study showed the utility of the induced mutation approach in the breeding of self-pollinated crop species where hybridisation is difficult due to their floral morphology and anthesis behaviour for creating genetic variation for improving such crops. This study showed that induced mutation created genetic variability that led to genetic divergence among selections from one parental variety, Mutubila, which was subjected to mutagenic treatment. These results further emphasised the importance of the induced mutation approach in generating genetic variation for crop improvement in self-pollinated crops, which poses a challenge in artificial hybridisation as a means of creating variation.

This study has also shown a greater scope in the improvement of some of the important yield components, such as the number of tillers per plant, number of fingers per ear and finger length, as can be observed on the average differences among lines of the cluster that contained parent Mutubila variety and those that did not.

ACKNOWLEDGEMENT

This research was funded by the National Scientific Technological Council of Zambia (NSTC) under the Strategic Research Fund Grant 2013 funding grant. The authors extend their thanks for making it possible to achieve this research.

REFERENCES

[1]. Jansen PCM and Ong HC. Eleusine coracana (L.) Gaertn. In: Grubben GHJ, Partohardjonos, editors. Plant Resources of South-East Asia. No. 10 Cereals. Backhuys Publishers, Leiden. The Netherlands. 1996. p. 90.

[2]. Michael PSJ and Shahmugam A. A study on millets-cultivation and Consumption in India. International *Journal of Marketing. Financial Services and Management Research* 2013 2(4): 49-50.

[3] Upadhyaya HD, Gowda CLL, Reddy. VG. Morphological diversity in finger germplasm introduced from Southern and Eastern Africa. Andhra: Millet ICRISAT. (2007).

[4]. Singh P and Raghuvanshi S. Finger millet for food and nutritional Security. *African Journal of Food Science,* http//dx.doi.org/10.5897/AjF 2012 6 (4),77-84. SX 10.010.

[5]. Kakeya MS and Yuko OS. The Citemene Systems, Social Levelling Mechanism and Agrarian Changes in the Bemba village of Northern Zambia. African study monographs.2006.

[6]. Food and Agricultural Organisation-FAOSTAT. Retired from HTTP// Faostat.fao.or.2012

[7]. Oduori COA. The importance and research states of finger millet in Africa. A paper presentation at the

Mc Knight foundation collaborative crop research program workshop on Tef and finger millet: Comparative genomics of the chloridoid cereals at the biosciences for East and Central Africa (BECA) ILRI, Nairobi Kenya, 2005.28-30 June, pp. 12.

[8]. Eswari, K., Gogulan, G., Hari Prathab K.A., and Sakila, M. development of early maturing mutants in Finger Millet *(Research Journal of Agriculture and Forestry Sciences*, 2014.Vol. 2(6), 1-9.

[9]. Sneha R, Sapkal VV, Bhavsar and Barhate. Genetic divergence in Finger millet (Eleusine Coracana (L) Gaertn. Int.J. Curr.Microbia. App. Scie.2019.8. (06):.2230- 2242.Doi: http//dor.org10.20546/ijcmas.

[10]. Mahalanobis PC. On the generalised distance in Statistics, Proc. National Institute of Science, India. 1936.2:49-55. M.

[11]. Mishra M., Mahapatra K.C and Mohanty C.R. Classificatory analysis for genetic diversity in Dahlia. India Genet., 2006.61(2): 187 -189.

[12]. Ambavane. A.R., Sawardekar. S.V., Sawantdesai. S.A., Gokhale. N.B. Studies on mutagenic effectiveness and efficiency of gamma rays and its effect on quantitative traits in finger millet (*Eleusine Coracana* L. *Gaertn*). *Science Direct, Journal of Radiation Research Applied Science*: 2014. 121-123.

13. Mullainatan, K.A. Studies on the effect of Induced Mutagenesis on Finer Millet [*Eleusine Coracana (L.) Gaertn*]. Var-CO13 in M1 Generation. Horticultural Biotechnology Research, vol.4, pp.23-25, doi:10.25081/hbr. 2018.v4.3485.

[14]. Ganapathy, S., Nirmalakumari, A. and Muthiah, A.R. Genetic variability and interrelationships analysis for economic traits in finger millet germplasm. *World Journal of Agricultural Sciences*, 2011. 7(2): 185-188.

[15]. Bhatta, L.R, Subedi, R., Joshi. P and. Gurung, S.B. 2017. Effect of crop establishment methods and varieties on tillering habit, growth rate and yield of finger–millet. Institute of Agriculture and Animal Science, Lamjung Campus, Nepal.: 001- 002, 26.

[16]. Muduli KC. and Misra RC. “Efficacy of Mutagenic Treatment in producing useful mutants in finger millet [*Eleusine Caracana (Gaertin*)]. *Indian Journal of Genetics and Plant Breeding*. 2007.67(3): 232-237.

[17]. John.K. Variability and correlation studies in quantitative traits of Finger (Elusine Coracana. Agricultural Science Digest 2006.26(3):166-169.

[18]. Sneha R. Sapkal, VV, Bhavsar and Barhate. Genetic divergence in Finger millet (*Eleusine coracana (L). Gaertn.Int*.J. Curr.Microbia. App.Scie. 2019.8(06):2230- 242. Doi: http// dor. Org 10.20546/ ijcmas.

[19]. Sarjansinh DD, Manjuu S., and Intawala Genetic Divergence Studies in Finger Millet [*Eleusine Caracana (L.) (Gaertin*)]. *International Journal of Current Microbiology and Applied Sciences* 2017: ISSN: 2319-7706Volume 6 Number 11. 2017-2022.

[20]. Chandra Mohan Reddy CV, Reddy PVRM, Munirathnam p and Gowda.

J. Studies of genetic variability in yield and yield attributing traits of finger millet. [*Eleusine Caracana (L.) (Gaertin*)] *Indian Journal of Agricultural Research. 2013*. 47(6):549-552.