E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(10): 703-709
Received: 03-08-2024
Accepted: 01-09-2024

HD Kadam
M.Sc. Students, Department of Genetics and Plant Breeding, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Dr. HV Kalpande
HOD, Department of Genetics and Plant Breeding, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Dr. RR Dhutmal
Associate Professor, Department of Genetics and Plant Breeding, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Dr. MP Wankhade
Assistant Seed Research Officer, STRU, Department of Genetics and Plant Breeding, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

RA Samale
M.Sc. Students, Department of Genetics and Plant Breeding, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Corresponding Author:
HD Kadam
M.Sc. Students, Department of Genetics and Plant Breeding, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Genetic parameters studies on morphophysiological trait in M_3 population *rabi* sorghum (*Sorghum bicolor* (L.) Moench)

HD Kadam, Dr. HV Kalpande, Dr. RR Dhutmal, Dr. MP Wankhade and RA Samale

DOI: https://doi.org/10.33545/2618060X.2024.v7.i10j.1878

Abstract
This study explores the generation of desirable variability in sorghum [*Sorghum bicolor* (L.) Moench] using electron beam irradiation to enhance seed yield and its component traits. Titled "Genetic Variability and Correlation Studies for Morphophysiological Traits in M_3 Generation of Mutagenized Population of *Rabi* Sorghum," the research focuses on estimating genetic variability, heritability, correlation, and path analysis. Parental material TSG-98 (Muguthi) was subjected to irradiation at doses of 100 Gy, 200 Gy, 300 Gy, 400 Gy, and 500 Gy. The resultant M_3 generation, comprising 60 mutants, was evaluated alongside controls during *Rabi* 2023-24. Fourteen traits, including days to flowering, plant height, and yield components, were assessed. Significant genetic variability was identified, with irradiated treatments outperforming controls in multiple traits. High heritability and moderate genetic advance were observed for grain yield-related traits. Correlation analysis revealed positive associations between grain yield and traits such as plant height and panicle length. Path analysis indicated that several traits directly contributed to grain yield at both genotypic and phenotypic levels.

Keywords: *Rabi* sorghum, mutagens, genetic variability, electron beam, irradiation, M_3 generation, heritability, path analysis, phenotypic variance, genotypic variance, correlation studies, fodder yield

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is predominantly cultivated in the USA, China, India and Africa for both human consumption and livestock feed. In 2024-2025, the production of sorghum projected to be 63.64 million metric tons worldwide. Nigeria leads the world in total production (12%) with 6.40 million metric worldwide tones, followed by the Brazil, Mexico and Ethiopia. India is the third largest producer's tons sorghum worldwide, with 4.40 million metric tons cultivated in 4.10 millon hectares in 2023-2024. In contrast, 4.20 million metric tons (1st advance estimates) of sorghum were produced in 3.80 million hectares in Kharif 2024-2025. (Anonymous, 2023") [1].

In India, the major sorghum growing states are Maharashtra, Karnataka and Rajasthan which contributes nearly 93 percent of area and production. Remaining area is distributed in states of Tamil Nadu, Gujarat and Madhya Pradesh. Sorghum is grown state wise in India as Maharashtra ranks first in area 16.00 lakh hectares and annual production 14.04 lakh tons and productivity is 878 kg/ha, Karnataka ranks second with an annual production 7.06 lakh tons and productivity is 1204 kg/ha, Rajasthan ranks third with area 5.09 lakh hectares and annual production 5 27 lakh tons and productivity is 1036 kg/ha, area of cultivation in Uttar pradesh is 2.89 lakh hectares, with an annual production 4.62 lakh tons and productivity is 1600 kg/ha, Andhra pradesh ranks fifth with an area 0.84 lakh hectares and an annual production 2.93 lakh tons. (Anonymous, 2023") [1].

A shorter rainy season and accompanying growth season have been observed in recent years as a result of climate change. In this scenario, water deficits lead to an inevitable shift in cropping patterns toward drought-tolerant food crops. Sorghum is one of the most drought-tolerant grain crops, making it an ideal choice for production in low rainfall areas.

The primary issue with sorghum cultivation is its lower productivity compared to other cereals particularly in *rabi* sorghum since 1990. The introduction of a high-yielding cultivar with a shorter duration could significantly enhance the potential for sorghum cultivation under moisture stress conditions, thereby expanding its use in challenging environments in the future.

Sorghum is a significant feed and food crop that is utilized worldwide to nourish millions of animals that provide milk and meat for human consumption. In many different industries, it is also utilized as an industrial raw material. In India, flour is used to make "*Bhakri*" after the grains have been ground. It is also consumed in modest amounts as popped and parched grain. In most parts of the world, sorghum serves as the staple food for both humans and animals. Its fodder is composed of about 50% digestible components, 2.5% fat, 8% protein and 45% nitrogen-free extract. People in some countries consume sorghum grains. A number of parameters including test weight, panicle length and number of grains per panicle affect sorghum grain yield. Collectively, these elements raise the yield.

Sorghum is a key green fodder crop, and despite India having the largest cattle population, the grain production is insufficient to meet their needs. In 2002, there was a significant shortfall of 45 million tonnes of fodder, with green fodder accounting for 66.5% and dry fodder for 25.9%. The main reason for low fodder production is a shortage of seeds. Some fodder sorghum varieties, such as CO (FS) 29 from TNAU, face issues with seed cracking, which reduces yields. In this context, increasing variability through induced mutation could enhance the potential for sorghum improvement.

In India, the productivity of *rabi* sorghum is very low and highly variable from year to year, primarily due to post-flowering drought. Despite this, *rabi* sorghum is highly valued for its excellent grain quality. The crop is typically affected by water stress at both pre-flowering and post-flowering stages, with the most adverse effects on yield occurring during these periods (Kebede *et al.* 2001) [2]. Drought tolerance is defined as the relative yield of a genotype compared with other genotypes subjected to the same drought stress (Hall, 2004) [3]. This tolerance depends on the plant developmental stage at the onset of stress, which can occur during early vegetative growth, panicle development and post flowering and the period between grain filling and physiological maturity. Drought tolerance in sorghum is a complex trait influenced by numerous genes that contribute to various aspects of tolerance (Tesfamichael *et al.* 2015) [4]. In the future, advancements in genetic research and breeding could lead to the development of sorghum varieties with enhanced drought tolerance, potentially improving yield stability and quality under variable climatic conditions.

Mutation breeding is a very rapid technique for improving a variety of crops and is acknowledged as one of the forces influencing evolution in order to influence choices for quantitatively inherited traits, breeders need genetic variation. Mutation breeding is one alternative stratergy for increasing genetic variability. It is frequently employed to remediate defects in a cultivar that possesses a number of advantageous agronomic traits. A wide range of physical mutagens including electron beams, x-rays, thermal neutrons, fast neutrons, ultraviolet radiation and beta radiation can affect plant growth and development. Of these, gamma rays are particularly well-known for their ability to cause cytological, physiological and morphological changes in somatic and germ line cells. There are numerous publications describing the use of gamma radiation by breeders to enhance yield and qualities that contribute to yield by producing genetic variability in quantitative features. High power linear electron accelerators with energies ranging from 500 keV and 10 MeV have become more significant recently for many kinds of uses. Similar to X-ray facilities, the accelerators function via a switch-on/off mechanism. It generates electron beams that are useful for high-throughput material irradiation. An effective method for increasing yield and improving quality traits is to expose plants to electron beam radiation, which also induces genetic diversity.

In addition to traditional methods, mutant breeding can significantly contribute to crop improvement by providing plant breeders with a new approach to increasing crop yield. It is particularly effective for achieving faster results in correcting minor flaws in various types of crops.

Artificial mutagenesis offers the potential to induce desired qualities that may be absent or not found naturally in crops, while mutation induction is a proven method for creating variation within a crop variety. Through induced mutations, targeted recombination can be achieved in a relatively short time without significantly impacting the yield and quality of currently popular varieties. Defect rectification in sorghum varieties for their improvement has been achieved through mutagenesis (Bhatnagar and Tiwari, 1992) [5]. There are two types of mutations *i.e.* spontaneous (natural) and artificial (induced). Due to the very low frequency of natural mutations, induced mutations are utilized to create genetic variability for both qualitative and quantitative traits.

Mutation inductions were greatly aided by the identification of a broad spectrum of chemical mutagens after Auerbach and Robson's (1946) research, which also revealed that X-rays were a potent physical mutagen (Muller, 1927 and Stadler, 1928) [7, 15]. The identification of base-specific mutagens such as hydroxylamine and ethyl methane sulphonate has reignited interest in chemical mutagenesis. Unlike gamma rays, which act randomly, these chemical mutagens react selectively with a certain base of DNA.

Any effective breeding program must have genetic diversity for economic qualities since the amount of variability determines how much a trait will respond to selection. Yield is a complicated characteristic of any crop that is influenced by numerous contributing characteristics that are governed by polygene and environmental factors. In order to plan an efficient selection process for creating genotypes with high yields, it is therefore vital to have an understanding of the genetics of yield, its component qualities and the relationship between each component trait and yield. However, variance in other characters which may result from pleiotropy or genetic linkage often influences the inheritance of quantitative features. Therefore, understanding the relationship between yield and its characteristics which can be found through estimating genotypic and phenotypic correlation helps in both choosing the right genotypes and estimating the amount of character improvement that could be possible. To create desired variability and change character association in sorghum, systematic attempts to combine recombination and induction of mutations have not yet been done. In order to improve economically significant features in sorghum, an effort was therefore made in the current study to assess various mutagens in producing desired variability for creating high yielding mutants and to change the character association.

Materials and Methods

The experimental material consisted of 60 M_3 mutant lines of rabi sorghum genotype "TSG-98" [*Sorghum bicolor* (L.)

Moench], provided by BARC, Mumbai, India. These lines were derived from five gamma radiation treatments (100 Gy, 200 Gy, 300 Gy, 400 Gy, 500 Gy) and two controls, with 12 mutants per treatment. The M_3 mutant lines were developed from a single sorghum genotype, TSG-98 (Muguthi) provided by the Bhabha Atomic Research Centre (BARC), Mumbai and their salient features of this genotype TSG-98 are shown in Table 1. The field experiment, conducted at VNMKV, Parbhani during rabi 2023-24, was laid out in a randomized block design (RBD) with two replications. Spacing between plants was maintained at 45 cm × 15 cm with each plot consisting of two rows (plot size: 0.9 m × 4 m). The experiment also included three checks: CSV-29R, Parbhani Moti, and Parbhani Supermoti. Quantitative traits such as days to 50% flowering, plant height, days to maturity, and yield components were recorded from five randomly selected plants per treatment. Drought tolerance parameters such as relative water content and chlorophyll content were also assessed. Statistical analysis was performed using ANOVA, and variability parameters such as genotypic and phenotypic coefficients of variation, heritability, and genetic advance were calculated. Correlation coefficients and path coefficient analysis were conducted to understand trait relationships and direct/indirect effects.

Table 1: The salient features of the genotype TSG-98

Sr. No.	Features	TSG-98 (Muguthi)
1.	Year of release	1969 (UAS Dharwad)
2.	Notification date	2/2/1976
3.	Pedigree	Selection from 5-4-1
4.	Yield	18-20 q/ha
5.	100 Seed weight	3.75-4.0 g
6.	Seed color	Pearl yellow
7.	Days to flower	60-70 days
8.	Days to maturity	110-120 days
9.	Plant height	220-240 cm
10.	Panicle length	20-22 cm
11.	Panicle width	5-7 cm
12.	Season adapted	*Rabi*

Result and discussion

The analysis of variance for thirteen traits is displayed in Table 1 indicating significant differences among the treatments for all the studied traits. A study was conducted to evaluate the mean performance of M_3 generation mutant genotypes of *rabi* sorghum (TSG-98) for 14 agronomic traits as shown in Table 2. The days to 50% flowering ranged from 65.50 to 81.25 days, with genotypes 200-19 and 100-5 flowering the earliest. Plant height varied from 223.50 cm to 297.95 cm, with mutant 500-60 recording the tallest height. Days to maturity ranged between 102.00 to 116.50 days, with 400-47 maturing the earliest. The number of primaries per panicle ranged from 28.71 to 130.90, while the number of grains per primary spanned 50.15 to 68.50. Panicle length and width varied from 17.82 to 27.15 cm and 6.90 to 8.55 cm, respectively. Seed weight per 100 seeds ranged from 3.05 g to 4.64 g, while fodder yield per plant ranged from 72.40 g to 105.50 g. Relative water content (RWC) showed significant variation, ranging from 39.55% to 61.51%. Chlorophyll content (SPAD values) was observed to range between 37.27 and 56.71. Grain yield per plant varied from 38.10 g to 64.65 g, with the mutant line 500-60 showing superior performance. Leaf area and flag leaf area ranged from 266.95 to 527.85 cm² and 191.60 to 388.55 cm², respectively. Several genotypes demonstrated superior performance for drought tolerance traits such as relative water content, chlorophyll content, and flag leaf area, indicating their potential as parents or advanced breeding lines for improving rabi sorghum yield.

The study examined the genetic variability of various traits in a set of sorghum mutant lines and checks. Key traits evaluated included days to 50% flowering, plant height, days to maturity, number of primaries per panicle, number of grains per primary, panicle length, panicle width, grain yield per plant, 100 seed weight, fodder yield per plant, relative water content (RWC), chlorophyll content, flag leaf area, and leaf area. In Table 3, Traits like number of primaries per panicle, grain yield per plant, flag leaf area and leaf area having a moderate (GCV) and (PCV) values it means that genotyping set having high heritability. Higher (GCV) and (PCV) values for no. of primeries per panicle was also observed by Narkhede *et al.* (2001) [8] and Zinzala *et al.* (2018) [10].

Across traits, in Table 3 phenotypic coefficient of variation (PCV) values exceeded genotypic coefficient of variation (GCV) values, indicating that environmental factors influenced trait expression to some extent, though the differences were relatively small. Similar results were reported by Balasubramanian *et al.* (2024) [11].

High heritability estimates coupled with high genetic advance were observed for flag leaf area, leaf area, no. of primaries per panicle, highlighting it as a promising trait for selection and have a great scope for selection as well as selecting this trait through simple selection method. Similar results were reported by Nguyen *et al.* (1998) [12], Narkhede *et al.* (2001) [8], Sami *et al.* (2013) [13], Zinzala *et al*. (2018) [10] and Ravali *et al.* (2021) [14].

High heritability was also observed for grain yield per plant (62%) and chlorophyll content (79.8%), with moderate genetic advances as presented in the form of graphs *viz.*, Fig 2 Conversely, traits such as 100 seed weight (40.6%) and fodder yield per plant (45.6%) exhibited lower heritability, with low genetic advances, indicating potential environmental influence.

Traits such as days to 50% flowering, plant height, and days to maturity exhibited medium heritability, suggesting moderate potential for selection. Additionally, phenotypic variance was generally higher than genotypic variance across all traits as presented in the form of graph *viz.*, Fig 1 implying that environmental factors impacted the phenotypic expression of these traits. These findings are consistent with prior studies by Narkhede *et al.* (2001) [8], Sami *et al.* (2013) [13], and Zinzala *et al.* (2018) [10].

Table 1: Analysis of variance for yield and yield contributing characters in TSG-98 rabi sorghum

Source of Variation	D.f.	Days to 50% Flowering	Plant Height (cm)	Days to Maturity	Primaries per Panicle	Grains per Primary	Panicle Length (cm)	Panicle Width (cm)
		1	2	3	4	5	6	7
Replication	1	9.84	745.51	38.28	16.26	15.95	5.71	0.18
Treatment	63	20.46**	573.36**	22.43**	844.93**	40.05**	7.51**	0.28**
Error	63	6.90	185.85	11.13	11.54	9.97	1.71	0.09

		Mean Sum of Square						
Source of variation	**D.f.**	**100 seed weight (g)**	**Fodder yield per plant(g)**	**RWC (%)**	**SPAD**	**Flag leaf area (cm^2)**	**Leaf area (cm^2)**	**Grain Yield per plant (g)**
		8	9	10	11	12	13	14
Replication	1	0.09	102.79	1.03	13.53	1244.81	7.26	79.64
Treatment	63	0.22**	79.14**	62.53**	51.07**	3278.76**	4318.07**	146.63**
Error	63	0.09	29.54	33.62	5.71	682.64	1485.53	33.37

* and ** Significant at 5% and 1% levels of significance, respectively

Table 2: Mean performances of fourteen characters studied in *rabi* sorghum genotypes

Sr. No.	Genotypes	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primaries per panicles	Number of grains per primary	Panicle length (cm)	Panicle width (cm)
1.	100-1	72.50	108.00	250.67	36.25	66.82	22.97	7.75
2.	100-2	67.00	107.00	263.15	35.35	68.50	22.99	7.52
3.	100-3	71.00	111.50	271.15	36.17	65.85	22.55	7.99
4.	100-4	71.00	116.00	260.50	34.45	62.50	26.22	8.15
5.	100-5	66.00	108.50	265.82	31.15	66.10	25.04	7.80
6.	100-6	67.50	104.50	269.50	31.82	66.65	23.55	8.39
7.	100-7	67.50	104.50	269.85	28.72	61.50	25.70	7.82
8.	100-8	69.50	108.50	279.00	35.25	62.52	25.55	7.95
9.	100-9	67.00	106.00	249.20	32.59	68.00	25.85	8.30
10.	100-10	69.50	110.50	263.35	30.69	63.50	25.32	8.07
11.	100-11	70.50	105.50	269.00	33.32	64.15	25.07	8.25
12.	100-12	66.50	106.50	265.50	31.84	58.65	25.50	8.19
13.	200-13	66.50	105.50	267.00	29.14	57.10	22.62	6.90
14.	200-14	68.50	108.50	251.10	32.17	55.25	21.25	7.80
15.	200-15	69.50	108.50	275.65	32.15	67.62	26.30	8.40
16.	200-16	69.00	111.00	268.15	35.69	66.35	24.25	7.99
17.	200-17	70.00	113.00	259.35	36.35	65.67	23.85	8.37
18.	200-18	66.50	106.50	277.42	36.30	62.05	22.67	8.20
19.	200-19	65.50	102.50	289.80	30.05	62.34	25.50	8.14
20.	200-20	71.00	112.00	280.75	33.40	64.35	23.75	7.55
21.	200-21	69.50	107.50	257.00	35.94	66.10	22.45	7.32
22.	200-22	67.50	104.00	293.60	33.85	68.35	25.55	7.95
23.	200-23	65.50	105.00	294.80	32.32	64.50	27.15	8.14
24.	200-24	68.50	113.00	264.50	36.55	56.70	22.34	7.92
25.	300-25	68.50	106.50	251.80	35.35	61.50	22.77	7.15
26.	300-26	68.50	109.50	252.85	35.17	52.50	24.49	8.34
27.	300-27	68.50	108.50	279.55	30.20	54.50	21.57	7.65
28.	300-28	68.00	109.00	249.65	31.40	65.85	22.00	7.65
29.	300-29	66.50	109.00	268.00	30.33	66.80	23.04	8.02
30.	300-30	69.50	110.50	288.00	36.17	63.17	22.55	8.22
31.	300-31	66.50	106.50	292.00	33.59	65.15	22.20	8.55
32.	300-32	68.50	110.50	242.35	37.40	55.65	22.29	7.59
33.	300-33	70.00	112.00	248.05	35.97	66.50	22.42	7.15
34.	300-34	71.50	113.00	254.70	37.15	65.60	22.14	7.42
35.	300-35	67.50	106.50	292.60	35.60	67.60	23.85	8.15
36.	300-36	66.50	105.00	285.55	31.15	60.34	22.95	7.70
37.	400-37	68.00	108.00	248.15	33.17	62.15	23.02	7.70
38.	400-38	68.00	105.50	262.25	33.34	61.00	23.85	7.60
39.	400-39	70.00	112.00	264.90	30.52	63.45	23.92	7.60
40.	400-40	68.50	108.50	280.45	34.52	62.25	21.99	7.45
41.	400-41	68.50	110.50	272.65	35.00	63.35	25.42	7.24
42.	400-42	71.50	114.00	262.20	33.50	63.35	23.54	7.30
43.	400-43	71.00	115.00	292.00	37.00	66.00	22.00	7.75
44.	400-44	68.00	116.50	293.85	31.35	63.70	24.40	7.79

Sr. No.	Genotypes	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primaries per panicles	Number of grains per primary	Panicle length (cm)	Panicle width (cm)
45.	400-45	69.50	111.50	223.50	30.82	66.17	22.25	7.25
46.	400-46	70.50	110.00	293.40	32.84	66.34	24.14	7.85
47.	400-47	70.00	102.00	274.50	34.17	58.85	22.95	7.85
48.	400-48	69.00	109.00	287.00	37.17	58.00	20.85	8.07
49.	500-49	66.50	104.50	293.80	31.17	65.35	25.50	7.90
50.	500-50	68.00	107.00	278.17	35.82	60.45	24.97	8.05
51.	500-51	67.50	105.50	289.90	31.83	66.15	21.95	8.04
52.	500-52	67.50	108.50	291.35	35.15	67.40	21.35	7.90
53.	500-53	68.50	108.50	284.35	29.35	65.20	20.79	7.40
54.	500-54	71.50	107.50	285.60	30.67	67.00	22.37	7.80
55.	500-55	66.00	108.00	244.50	29.34	63.65	24.40	8.05
56.	500-56	69.00	111.50	290.20	31.99	63.80	25.45	7.85
57.	500-57	71.00	115.00	290.90	30.50	62.00	22.30	7.49
58.	500-58	70.00	111.50	287.65	29.74	65.15	22.65	7.50
59.	500-59	71.50	113.50	294.95	38.35	59.40	22.34	8.05
60.	500-60	69.50	107.00	297.95	35.74	65.35	26.90	8.35
61.	Dry Control (TSG-98)	76.50	105.50	256.75	30.25	57.15	25.46	7.21
62.	Parbhani Moti	81.25	112.50	287.20	127.03	51.17	17.90	7.43
63.	Parbhani Supermoti	80.50	114.00	282.89	129.37	50.15	19.00	7.25
64.	CSV-29R	80.50	110.00	284.88	130.90	52.65	17.83	7.29
Mean		69.39	108.95	272.76	37.83	62.70	23.37	7.80
SE ±		1.85	2.35	9.63	2.40	2.23	0.92	0.22
CD at 5%		5.25	6.66	27.24	6.78	6.31	2.61	0.62

Sr. No.	Genotypes	100-seed Weight (g)	Grain yield per plant (g)	Fodder yield per plant (g)	Relative water content (g)	Chlorophyll content [SPAD values]	Leaf area [cm^2]	Flag leaf area [cm^2]
1.	100-1	4.15	58.70	89.25	44.41	46.50	400.70	300.10
2.	100-2	4.23	55.95	81.85	43.30	52.02	527.85	301.50
3.	100-3	4.14	58.40	90.05	42.15	52.20	266.95	303.70
4.	100-4	4.14	60.05	91.95	45.40	37.70	462.10	305.57
5.	100-5	4.17	58.24	83.55	44.60	40.55	443.25	284.00
6.	100-6	4.02	57.85	85.95	44.50	51.10	397.50	199.40
7.	100-7	3.89	54.55	80.30	42.99	49.69	379.55	361.97
8.	100-8	4.15	58.47	88.99	45.37	47.90	462.15	388.55
9.	100-9	4.10	59.99	98.50	43.41	39.20	518.00	365.00
10.	100-10	3.90	58.30	89.50	43.57	53.62	423.75	305.20
11.	100-11	4.20	58.25	91.50	41.25	46.75	482.50	224.20
12.	100-12	3.85	60.40	89.90	45.32	46.49	504.10	317.00
13.	200-13	3.55	46.65	80.40	50.85	52.05	415.35	279.35
14.	200-14	3.77	38.10	77.85	57.22	50.63	410.65	352.29
15.	200-15	4.12	61.85	105.50	52.13	45.60	419.55	359.00
16.	200-16	3.95	53.35	84.20	51.77	41.42	467.00	354.95
17.	200-17	4.05	52.90	83.90	52.69	48.54	445.35	340.03
18.	200-18	3.95	51.25	89.50	51.75	41.75	452.20	314.50
19.	200-19	4.09	60.20	89.90	52.12	46.53	378.35	277.50
20.	200-20	4.20	60.65	94.25	53.01	42.70	436.15	300.02
21.	200-21	3.89	38.95	79.95	52.64	45.05	500.45	272.00
22.	200-22	4.14	61.90	86.50	50.80	46.07	459.15	309.10

Sr. No.	Genotypes	100-seed weight (g)	Grain yield per plant (g)	Fodder yield per plant (g)	Relative water content (g)	Chlorophyll content [SPAD values]	Leaf area [cm^2]	Flag leaf area [cm^2]
23.	200-23	4.20	63.95	100.85	58.18	50.49	495.20	262.42
24.	200-24	3.85	53.50	85.65	53.96	51.92	351.05	317.60
25.	300-25	3.92	38.95	80.25	59.31	49.95	379.85	337.25
26.	300-26	3.75	40.90	79.25	57.13	44.37	439.80	262.78
27.	300-27	3.77	38.15	79.00	57.76	38.79	290.25	295.00
28.	300-28	3.69	41.40	76.40	54.49	40.67	421.80	295.00
29.	300-29	3.60	42.50	79.50	53.27	41.00	410.65	373.74
30.	300-30	3.60	58.00	86.45	58.49	45.65	438.45	303.65
31.	300-31	3.59	61.70	93.20	61.52	52.55	402.30	288.00
32.	300-32	3.35	49.55	84.95	55.05	48.69	449.20	234.20
33.	300-33	3.60	51.25	90.40	50.50	39.55	442.35	337.75
34.	300-34	3.45	40.55	80.70	59.09	38.69	395.85	294.70
35.	300-35	3.89	60.95	94.25	56.15	51.69	385.50	294.35
36.	300-36	3.27	40.45	85.35	56.16	50.25	406.70	295.00
37.	400-37	3.45	42.75	86.30	52.76	50.95	444.70	283.80
38.	400-38	3.65	44.00	89.40	50.04	41.49	466.35	340.63

Sr. No.	Genotypes	100-seed weight (g)	Grain yield per plant (g)	Fodder yield per plant (g)	Relative water content (g)	Chlorophyll content [SPAD values]	Leaf area [cm^2]	Flag leaf area [cm^2]
39.	400-39	3.50	49.55	87.30	54.60	44.62	408.10	331.33
40.	400-40	3.45	39.05	79.65	55.04	51.82	406.70	368.00
41.	400-41	3.39	40.80	81.25	54.46	47.00	376.05	268.29
42.	400-42	3.05	38.20	81.10	49.10	49.95	463.00	191.60
43.	400-43	3.82	60.25	92.40	41.32	41.14	485.80	310.60
44.	400-44	3.65	60.20	91.25	58.33	42.14	393.90	289.80
45.	400-45	3.40	52.70	86.00	49.31	40.89	386.10	361.70
46.	400-46	3.62	58.30	92.45	54.90	49.90	473.80	345.77
47.	400-47	3.25	38.70	85.10	53.70	40.93	476.40	319.14
48.	400-48	3.50	42.12	88.70	57.78	50.79	415.75	329.39
49.	500-49	3.70	58.85	92.35	60.79	51.37	420.75	347.15
50.	500-50	3.99	61.05	94.15	47.14	50.50	438.00	344.70
51.	500-51	3.89	52.25	86.15	50.92	46.90	476.75	296.00
52.	500-52	3.65	51.05	90.85	47.57	44.42	372.60	359.23
53.	500-53	3.15	41.40	85.75	49.92	56.72	400.35	273.50
54.	500-54	3.34	42.20	84.35	45.44	50.97	435.45	315.05
55.	500-55	4.27	61.40	93.65	50.56	49.79	419.35	326.04
56.	500-56	3.69	59.00	92.00	39.71	51.90	430.50	291.28
57.	500-57	3.70	59.60	92.00	52.37	55.89	385.95	335.73
58.	500-58	3.82	43.20	87.70	58.15	47.32	441.40	323.07
59.	500-59	3.90	59.70	92.90	39.55	43.81	416.25	386.25
60.	500-60	4.35	64.65	96.85	47.10	51.56	460.85	334.93
61.	Dry Control (TSG-98)	3.78	57.52	72.40	51.60	42.25	455.20	358.48
62.	Parbhani Moti	4.63	56.00	75.14	52.82	37.90	414.70	306.22
63.	Parbhani Supermoti	4.65	58.49	82.87	52.27	38.53	419.85	310.17
64.	CSV-29R	3.45	60.97	87.29	51.85	37.28	423.90	315.54
Mean		3.81	52.51	87.14	51.11	46.51	427.66	312.03
S.E.±		0.21	4.08	3.84	4.10	1.69	27.25	18.47
CD at 5%		0.62	11.54	10.86	11.58	4.77	77.02	52.21

Table 3: Genetic variability parameters for yield and yield contributing characters in M_3 generation of *rabi* sorghum

Sr. No.	Characters	Range		Mean	σ^2(g) (Genotypic variance)	σ^2(p) (Phenotypic variance)	GCV (%)	PCV (%)	h^2 b.s. (%)	GA	GA as% of mean
		Minimum	Maximum								
1.	Days to 50% flowering	65.50	81.25	69.38	6.77	13.68	3.75	5.33	49	3.77	5.44
2.	Days to maturity	223.50	297.95	272.76	193.75	379.61	5.10	7.14	51	20.48	7.51
3.	Plant height (cm)	102.00	116.50	108.95	5.65	16.78	2.18	3.76	33	2.84	2.60
4.	Number of primaries per panicle	28.71	130.90	37.83	416.69	428.24	53.95	54.69	97	41.48	109.63
5.	Number of grains per primary	50.15	68.50	62.70	15.03	25.01	6.18	7.97	60	6.19	9.87
6.	Panicle length (cm)	17.82	27.15	23.36	2.90	4.61	7.28	9.19	62	2.78	11.89
7.	Panicle width (cm)	6.90	8.55	7.80	0.09	0.19	3.89	5.60	48	0.43	5.59
8.	100-seed weight (g)	3.05	4.64	3.80	0.06	0.16	6.74	10.57	40	0.33	8.86
9.	Grain yield per plant (g)	38.10	64.65	52.51	56.62	90.00	14.33	18.06	62	12.29	23.41
10.	Fodder yield per plant (g)	72.40	105.50	87.13	24.79	54.34	5.71	8.45	45	6.93	7.95
11.	Relative water content (g)	61.51	72.40	51.11	14.45	48.07	7.43	13.56	30	4.29	8.40
12.	Chlorophyll content [SPAD values]	37.28	56.71	46.51	22.67	28.39	10.23	11.45	79	8.76	18.84
13.	Leaf area (cm^2)	266.95	527.85	427.65	1416.27	2901.80	8.79	12.59	48	54.16	12.66
14.	Flag leaf area (cm^2)	191.60	388.55	312.02	1298.05	1980.70	11.54	14.26	65	60.08	19.25

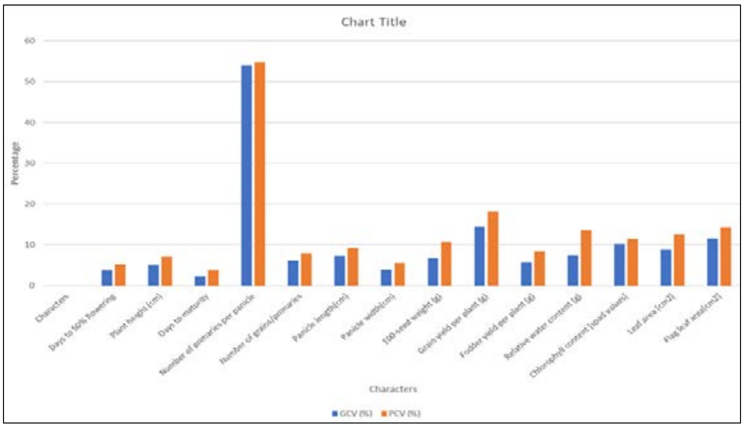

Fig 1: Genotypic and phenotypic coefficient of variation for yield and yield contributing characters in *rabi* sorghum TSG-98

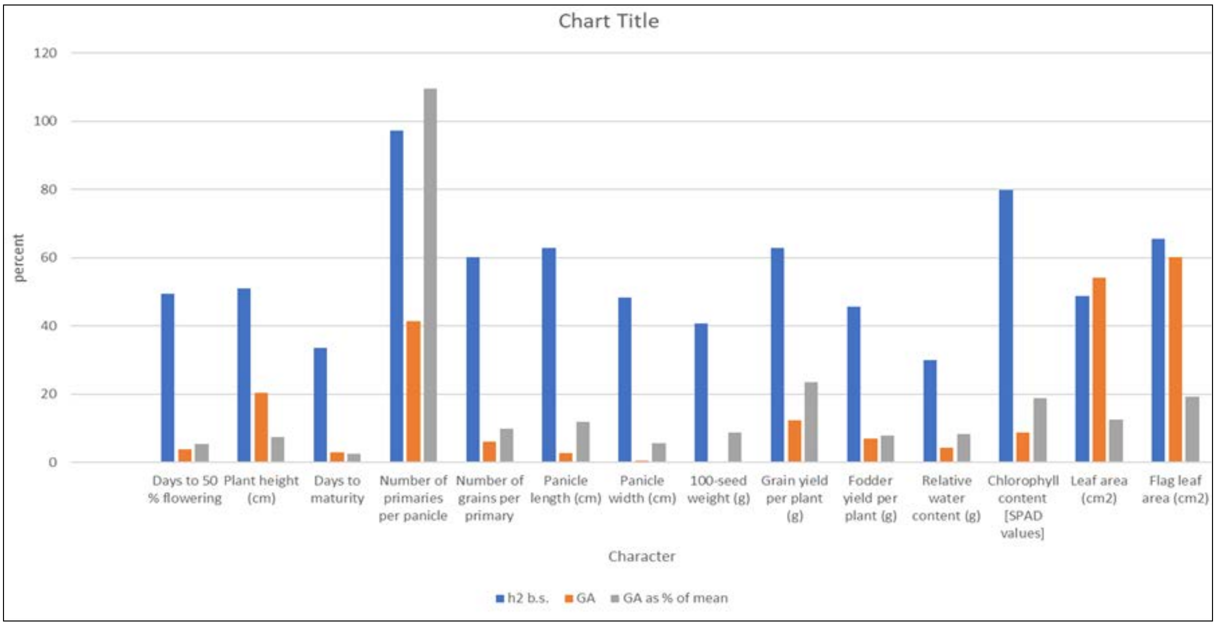

Fig 2: Heritability (h^2), Genetic Advance (GA) and Genetic Advance as percent of mean (GA%) in *rabi* sorghum TSG-98

Conclusion

In conclusion, the variability observed in this study offers useful insights for the selection of drought-tolerant and high-yielding sorghum lines. The high heritability of certain traits, flag leaf area, leaf area, the number of primaries per panicle and chlorophyll content, indicates their potential for use in sorghum breeding programs.

Acknowledgements

Acknowledgement I extend my special and heartiest thanks to my research guide, teachers, seniors and batchmates for their guidance, genuine interest, activeness and sharp insights. I deeply thank my beloved parents for their unwavering inspiration, continuous encouragement and steadfast support throughout my academic career.

Reference

1. Anonymous. FAOSTAT food statistics; c2023. Available from: http://faostat.fao.org/foodstat/collection
2. Kebede H, Subudhi PK, Rosenow DT, Nguyen HT. Quantitative trait loci influencing drought tolerance in grain sorghum (*Sorghum bicolor* L. Moench). Theor Appl Genet. 2001;103(2-3):266-76.
3. Hall AE. Breeding for adaptation to drought and heat in cowpea. Eur J Agron. 2004;21(4):447-54.
4. Tesfamichael A, Githiri SM, Kasili R, Woldeamlak A, Nyende AB. Genetic variation among sorghum (*Sorghum bicolor* L. Moench) landraces from Eritrea under post-flowering drought stress condition. Am J Plant Sci. 2015;6:1410-24.
5. Bhatnagar PS, Tiwari SP. Soybean improvement through mutation breeding in India. In: Plant mutation breeding for crop improvement, 1992, 1.
6. Auerbach C. Drosophila melanogaster: new mutants. Chem Induced Mutations and Rearrangements. Drosophila Inf Serv. 1943;17:48-50.
7. Muller A. An X-ray investigation of certain long-chain compounds. Proc R Soc Lond A Math Phys Eng Sci. 1927;114(768):542-61.
8. Narkhede BN, Akade JH, Awari VR. Variability studies of *rabi* sorghum local types (*Sorghum bicolor* (L.) Moench). J Maharashtra Agric Univ. 2001;25(3):300-2.
9. Deepalakshmi AJ, Ganesamurthy K. Studies on genetic variability and character association in kharif sorghum (*Sorghum bicolor* (L.) Moench). Indian J Agric Res. 2007;41(3):177-82.
10. Zinzala S, Davda BK, Modha KG, Pathak VD. Studies on variability, correlation and path coefficient analysis in sorghum (*Sorghum bicolor* (L.) Moench). Int J Agric Sci. 2018;10(19):7285-7.
11. Balasubramanian P, Vanniarajan C, Swaminathan V, Souframanien J, Suresh Devi, Ananthan M. Genetic variability studies in short statured early maturing M3 generation cluster bean (*Cyamopsis tetragonoloba* (L.) Taub.) mutants. Legume Res. 2024;47(4):525-30.
12. Nguyen DC, Haryano TAD, Yoshida. Genetic variability and characteristic association analysis in grain sorghum. J Fac Agric Kyushu Univ. 1998;43(1/2):25-30.
13. Sami RA, Yeye MY, Ishiyaku MF, Usman IS. Heritability studies in some sweet sorghum (*Sorghum bicolor* L. Moench) genotypes. J Biol Agric Healthcare. 2013;3(17):49-51.
14. Ravali K, Jahagirdar JE, Dhutmal RR. Genetic variability studies for morpho-physiological traits in relation to drought tolerance in rabi sorghum (*Sorghum bicolor* L. Moench). Pharma Innov J. 2021;10(6):313-7.
15. Stadler LJ. Genetic effects of X-rays in maize. Proceedings of the National Academy of Sciences. 1928;14(1):69-75.