INDUCED MUTATION STUDIES IN *RABI* SORGHUM [*Sorghum bicolor* (L.) Moench]

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CERTIFICATE

This is to certify that the thesis entitled **"INDUCED MUTATION STUDIES IN *RABI* SORGHUM [*Sorghum bicolor* (L.) Moench]"** submitted by **Miss. PREETI M. LADDI.** for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Dharwad is a record of research work done by her during the period of her study in this university, under my guidance and supervision and the thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles.

VIJAYAPUR
JULY, 2017

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With regard from memories…………

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CONTENTS

LIST OF ABBREVATIONS

*	:	significance at 5 per cent
**	:	significance at 5 per cent
%	:	per cent
±	:	plus (or) minus
>	:	more than
<	:	less than
µm	:	micrometer/s
µg	:	microgram/s
G	:	gram/s
Mg	:	milligram/s
Kg	:	kilogram/s
Ml	:	milliliter/s
Cm	:	centimeter/s
Cc	:	cubic centimeter/s
°C	:	degree Celsius
et al.,	:	and others
fig.	:	figure/s
Ha	:	hectare
m ha	:	million hectare
Mt	:	million tonnes
i.e.,	:	that is
no.	:	number
viz.,	:	namely
etc.,	:	many more
CD	:	critical difference
CV	:	co-efficient of variation
SE(m)	:	standard error of mean
ANOVA	:	analysis of variance
Df	:	degrees of freedom
Sl. No.	:	serial number
PCV	:	Phenotypiv variation
GCV	:	Genotypic variation
EMS	:	Ethyl Methane Sulphonate
γ rays	:	Gamma rays
Gy	:	Gray

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Introduction

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is normally self-pollinating but can cross pollinate, diploid (2n = 2x = 20) and belongs to the family Poaceae. It is a C4 plant with higher photosynthetic efficiency and higher abiotic stress tolerance (Nagy *et al.,* 1995). It is one of the most important cereal crop in the world because of its adaptation to a wide range of ecological conditions, suitability for low input cultivation and diverse uses.

Sorghum is the fifth most important cereal crop globally after wheat, rice, maize and barley in terms of production and utilization, and is the dietary staple of more than 500 million people in 30 countries. It is grown on 40 million ha in 105 countries of Africa, Asia, Oceania and the Americas. Africa and India account for the largest share (>70%) of global sorghum area, while USA, India, Mexico, Nigeria, Sudan and Ethiopia are the major sorghum producers (FAO, 2011).

Sorghum ranks third in the major food grain crops of our country. Besides a major source of staple food for humans, it serves as an important source of cattle feed and fodder. It has potential to compete effectively with crops like maize under good environmental and management conditions. The greatest merit with sorghum is that it has capacity to withstand drought. Its performance is better than maize in marginal lands as most widely grown dry land food grains in India. It does well even in low rainfall areas.

In India, sorghum is cultivated over an area of 6.24 million ha with an annual production of 5.28 million tonnes of grain with a productivity of 850 kg/ha. The first three largest producing states are Maharashtra, Karnataka and Madhya Pradesh (Anonymous, 2013). In Karnataka, it is cultivated in 1.26 million ha with an annual production of 1.315 million tonnes of grain (20.99 % of total global production) with a productivity of 1041 kg/ha.

In India, sorghum is cultivated in both the *kharif* (rainy) and *rabi* (post-rainy) seasons. During *rabi*, it is sown between September and end of October in the Deccan Plateau between 10° and 20° N latitude (Seetharama *et al*., 1990), and it accounts for 56.3 per cent of the total area under cultivation and 46.4 per cent of the total production. In India, sorghum grown in the rainy season is mainly utilized as feed, as the grain is often caught in rains prevailing during harvesting and the grain quality is affected due to molds. Therefore, post rainy sorghum is main source of food owing to its good *grain* quality having free from mold, it also serves as an important source of fodder, especially during dry seasons, since fodder from other crops is not available during the season, and is an important crop in lieu of food security (Sanjana Reddy and Patil, 2015).

The *rabi* sorghums are characterized by their response to shorter day lengths (photoperiod sensitivity), flowering and maturity occurring more or less at the same time irrespective of temperature fluctuations and sowing dates (thermo-insensitivity within the post-rainy season varieties). As not much progress has been made in the improvement of post rainy sorghums, the landraces with tolerance to shoot fly, terminal drought and charcoal rot and with bold, round and lustrous grain dominate the *rabi* sorghum tracts. All these characters exist in M 35-1, as a result this land race selection developed in 1937 still dominates the *rabi* sorghum areas in India (Sanjana Reddy *et al*., 2009). However, Maldandi and its relatives, which occupy major *rabi* sorghum areas are characterized by lower yield levels.

Rabi sorghum did not receive much emphasis until nineties for crop improvement. Rapid productivity enhancement has not been possible for *rabi* sorghum unlike *kharif* sorghum due to lack of success with hybrid technology. As the fodder is as important as grain, the varieties are selected to produce high biomass (grain and fodder) and have high lustrous grain with semi corneous endosperm. And therefore, focused breeding efforts on *rabi* sorghum led to development of several *rabi* sorghum varieties such as CSV 8R, Swati, CSV 14R, CSV 18R, CSV 216R, CSV 22, CSV 29R at national level. Heterosis breeding led to release of hybrids like CSH 8R, CSH 12R, CSH 13R, CSH 15R and CSH 19R. However, these varieties have become more popular compared to hybrids, a situation quite opposite to *kharif*. Though the hybrids are heterotic for grain yield, they have poor grain quality and are vulnerable to biotic and abiotic stresses (Shinde *et al*., 2010). The varieties or hybrids bred and released could not match M 35-1, a landrace variety that is grown for about seven and half decade, in yield or quality. However, lot of strategic research is required to develop new varieties and hybrids for post rainy season adaptation that can break the yield plateau (Sanjana Reddy and Patil, 2015).

Mutation breeding has played a productive role in sustainable agriculture, as it is a supplementary approach for crop improvement which increases unselected genetic variability for practical breeding application. Induced mutagenesis can be profitably employed as a complementary breeding procedure. It is directed to improve yield and other quantitative characters and specific defects in adopted varieties and to create sufficient genetic variability. Both physical and chemical mutagens have been employed to generate the desired variability. Studies on the relative merits of physical and chemical mutagens in inducing variability are needed to derive the maximum benefit from this tool. Research related to mutation breeding in sorghum has been limited. One of the main reasons for this has been the tremendous amount of unexploited natural variation present in these species. The evaluation and utilization of some of this variation has taken place in the past 20 years.

Unlike *kharif* sorghum progress in breeding research in *rabi* sorghum is limited due to availability of narrow genetic base in the existing breeding material. The efforts to achieve breakthrough in *Rabi* sorghum using hybrid technology has not been successful due to their poor grain quality and susceptibility to shoot fly. The high yielding (grain & fodder) varieties developed so far are maturing late (8-10 days later than M 35-1), suffer from terminal moisture stress and incidence of charcoal rot, prone to lodging (both mechanical and charcoal rot), and are suitable for deep soil areas. However, 65% of *rabi* sorghum area is comprised of medium soils. Hence, these high biomass varieties are to be improved for the above specific traits for their suitability to medium soils, hence to satisfy need for an alternative to M 35-1 in these soils. Therefore, in the present study high yielding varieties are subjected to mutagenic treatments to create genetic variability for these specific traits. The success in mutation breeding programme for any crop can be achieved by increasing the spectrum and frequency in viable mutations. Therefore, few doses chosen based on literature and applied in the present study.

The present study on induced mutagenesis in *rabi* sorghum has been designed to study mutagenic effects of physical (γ-irradiation) and chemical (EMS) mutagens and physical and chemical mutagen treatment for yield and yield components, to study induced changes with particular reference to genetic parameters of various characters, and to identify desirable mutants for reduced height, earliness and other yield related traits.

Keeping all these points in view the present study was initiated with the following broad objectives.

1. To compare and assess the effect of different mutagen treatment combinations on genetic variability for yield and yield components.
2. To study induced changes with reference to genetic parameters for yield and yield components.
3. To identify desirable mutants for reduced height, earliness and other yield related traits.

Review of Literature

2. REVIEW OF LITERATURE

Induced mutation breeding is where the initial material is induced with mutagens (such as χ ray, gamma ray, neutron, electron beam, proton, space environment, EMS, NaN3, etc.) to generate genetic mutations and then desirable mutants are selected from the subsequent progenies. Further lines are then selected as in conventional breeding programmes. The use of mutations is a valuable supplementary approach to plant breeding, particularly when it is desired to improve one or two easily identifiable traits in an otherwise well adapted breeding line. The main advantages of this approach are that the basic genotype of the original variety is only slightly altered, and that the time required for breeding the improved variety can be shortened compared to crossing to achieve the same result. A desired mutation can be recovered in a homozygous stage as early as in the M_2 or M_3 generation as compared with F6 or F7 in the case of hybridization (Guiying Li *et al*., 2000). Studies on induced mutation in sorghum are meagre, hence the available literature (1960’s to till date) are briefly reviewed under following sub headings.

2.1 Qualitative genetic changes

2.2 Quantitative genetic changes

2.3 Effectiveness of mutagens

2.1 Qualitative genetic changes

Qualitative or relatively simply inherited mutant characters have been most frequently induced, isolated and described in mutagenic studies. Some of the reasons for this is that (A) they are relatively easily recognized due to prominent phenotypic characteristics, (B) the probability of mutating one or a few genes is greater than many genes without selection and recurrent mutagen treatments, and (C) simply inherited recessive characteristics can be recovered more easily with smaller populations in the early (M_1 and M_2) generations than characters whose inheritance is complex. Although most induced mutations are undesirable, some agronomically valuable mutations have been induced. Seedling characteristics, seed set and the frequencies of chlorophyll-deficient mutants are usually used as indicators of the effectiveness of mutagens and for determining doses.

Harris *et al.,* (1965) treated seed (about 15% moisture) of 'Redbine 60' and 'Shallu' with 10, 20, 30, 40, and 50 kR of Cobalt gamma radiation. The critical dose (50% M1 sterility) was between 20 and 30 kR for Redbine 60 and between 40 and 50 kR for Shallu. Variety x dosage interactions were present for a number of seedling and seed characteristics. Higher doses resulted in significantly higher mutation frequencies expressed as lower seedling survival and increased sterility in the M_2 generation. Reddy and Smith (1975) also found that gamma rays caused a differential M_1 plant response and M_2 mutation frequency for two sorghum varieties.

The DES induced high lysine - high protein mutant, 'P-721', reported by Mohan and Axtell (1975) has exciting potential for improving grain quality. The lysine and protein content were 3.09 and 13.9% for P-721 compared to 2.09 and 12.9% for the normal, respectively. Porter *et al.* (1978) showed that brown midrib (bmr) mutants induced with DES had significantly lower lignin which resulted in higher dry matter digestibility of mature forage than the normal.

Hanna *et al.* (1981) reported that lower lignin-higher digestibility was already expressed in forage at one month after planting which emphasizes the potential of the bmr genes in improving quality of forage sorghums used for pasture, hay, and silage. Cytoplasmic male sterility has been induced with chemical mutagens in the M_1 generation by Malinovskii *et al.,* (1975), Erichsen and Ross (1963) and Chen and Ross (1963). Many types of early, dwarf, head, seed, and morphological mutations have been reported by Goud (1972), Harris *et al.,* (1965), Kapoor (1967), Sree Ramulu (1975), Patil and Goud (1979) and Barabas (1962).

EMS effects on varieties IS 7155, BD 569 and the hybrid IS 7155 x BD 569 of *Sorghum bicolor* (L.) Moench were studied by Sarada Mani (1989). Seedling characteristics, chlorophyll mutants, cytological aberrations in M_1, chlorophyll mutants and morphological mutants in M_2 were studied to assess the effects of EMS. Seedling characters decreased at 0.3% EMS in all the entries and however reduction was less in the hybrid indicating its resistance to the mutagen. The effectiveness of mutagen to induce high frequency of chlorophyll variants, chlorophyll mutants, and other morphological mutants was observed. The effectiveness of the mutagen was dose dependent both in the parents and hybrid.

In a study by Sarada Mani and Seetharami Reddi (1988), seeds of two cultivars of grain sorghum BD 569 and IS 2695 and their reciprocal hybrids were treated with 10, 20, 30, 40 and 50 kR gamma rays. Seedling characters, cytological aberrations, chlorophyll and morphological mutants were studied to assess the effects of gamma rays. Varieties were found to be more radiosensitive with respect to seedling characters. With regard to cytological aberrations and chlorophyll mutant segregation, the parent BD 569 and the hybrid where it was involved as female parent were more radiosensitive. No such conclusion was evident with respect to morphological mutants. Radiosensitivity of varieties and hybrids obviously tended to vary with criteria adapted.

Sattler *et al.* (2010) studied on brown midrib mutants have been isolated in maize (*Zea mays*), sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) arising by either spontaneous or chemical mutagenesis. The characteristic brown coloration of the leaf mid veins is associated with reduced lignin content and altered lignin composition, traits useful to improve forage digestibility for livestock. Brown midrib phenotype is correlated with two homologous loci in maize (*bm1* and *bm3*) and sorghum (*bmr6* and *bmr12*), which encode cinnamyl alcohol dehydrogenase (CAD) and a caffeic O-methyl transferase (COMT). In sorghum, yield reductions were apparent in near isogenic lines, but were ameliorated through construction of hybrids that maintain reduced lignin content and increased digestibility. Near-isogenic sorghum brown midrib lines and hybrids are dispelling old beliefs that brown midrib mutants are significantly more susceptible to plant pathogen attack and to lodging than their non-brown midrib counterparts. Brown midrib mutants from new chemically mutagenized populations hold promise of identifying a non-redundant set of genes involved in lignification of grasses. In addition, early reports indicate brown midrib mutants significantly increase conversion rate in the lignocellulosic bioenergy process.

Patil and Goud (1979) reported that three populations developed by random selection, selection for high yield and selection for low yield, respectively, were studied in the M_3 and M_4 after treatment of three varieties with gamma rays and ethyl methane sulphonate (EMS); the frequency of chlorophyll mutations decreased in successive generations and was higher (with a wider spectrum) after EMS treatment. Varietal differences in sensitivity to the mutagens were observed, 302 being the most resistant variety and RCR408 the most sensitive. Selection for yield did not affect the frequency of viable mutations, but did affect their spectrum; leaf modifications and reductions in flowering time were frequent in low-yielding selections, while height and grain weight mutations were frequent in high-yielding ones. Chlorophyll mutation frequency was higher in material selected for yield than in random progenies and higher in low-yielding than in high-yielding selections.

2.2 Quantitative genetic changes

Harris *et al.* (1965) did not find significant gains in genetic combining ability for sorghum grain yields after gamma irradiation. Barabas (1965) isolated a mutant from colchicine treated sorghum seedlings that yielded an average of 27% more dry matter over a period of four years. Ross (1965) lists five hybrids, three restorer lines, and one variety that were developed as a result of colchicine induced genetic variation.

Research on sorghum improvement through induced mutations has been conducted at the Center for the Application of Isotope and Radiation Technology, National Nuclear Energy Agency (BATAN), Indonesia by Soeranto and Sihono (2006). Durra variety was used as parental material in the breeding program. Induced mutation was made by Gamma irradiation on seed treatments. The optimal radiation dose was to be around 300-500 Gy. Through selection processes and direct screening for drought tolerance, a number of ten putative mutant lines were obtained. In dry season, the mutant lines B-68, B-72, B-95 and B-100 produced grain yield of 4.55, 4.50, 4.20 and 4.62 t/ha, respectively. These yields were significantly higher than the original parent Durra (3.50 t/ha) and the control check varieties UPCA (2.68 t/ha) and Hagari (3.75 t/ha).

Human *et al.* (2011) reported by taking 11 sorghum lines and varieties consisting of 8 mutant lines derived from induced mutations (B-100, B-95, B-92, B-83, B-76, B-75, B-69 and Zh-30) and 3 control varieties (Durra, UPCA-S1 and Mandau). All materials were grown in 10 agro ecologically different locations. Data of grain yield was used for evaluating genotypic stability using AMMI approach. Results revealed that sorghum mutation breeding had generated 3 mutant lines (B-100, B-76 and Zh-30) exhibiting grain yield significantly higher than the control varieties. These mutant lines were genetically stable in all locations.

Suthakar *et al.* (2014) studied the effectiveness and efficiency of mutagens in M_1 generation. In this regard, CSV-23 Variety of Sorghum was subjected to different concentration of gamma rays (20, 30, 40, 50 and 60 Kr) and EMS (20, 30, 40, 50 and 60 mM) for inducing mutation. The effect of Gamma rays and EMS with different doses/conc. on mutation frequency and mutagenic effectiveness were observed in M_1 generation. The survival percentage and mean value of M_1 generation were decreased with increasing doses/conc. of treatment. Mean performance of different quantitative traits were observed better in control when compared to treated plant.

A study was conducted by Larik *et al.,* (2009) in Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Pakistan. M_1 population of two varieties (DS- 75 and Giza-3) of sorghum derived from four irradiation treatments (Co^{60} gamma source with 10, 20, 30 and 40 kR) was critically examined for seedling emergence, days to 50% flowering, plants with abnormal leaves and stems, earhead length, 1000-seed weight and grain yield per plant. Genotypes varied significantly ($P < 0.01$) for all characters. Irradiation treatments were instrumental in creating significant variability for all traits except earhead length, indicating that varieties did not perform uniformly across different gamma rays treatments. However, variety x treatment effects were non-significant for earhead length as well as for 1000-seed weight, indicating stability of performance for both characters across different irradiation treatments. Mutagenic treatments shifted mean values towards negative direction for almost all traits. Mutagenic effectiveness was found to be dependent upon dose and genotype concerned. Heritability in broad sense showed high estimates (ranging from 95.86 to 97.80%) for yield components, indicating involvement of additive type of gene action. However, yield components failed to show high genetic advance, probably due to non-additive gene (dominance and epistasis) effects.

Jogendra Singh and Lata Chaudhary (2015) were investigated with multicut forage sorghum variety SSG 59-3 and its 15 mutants derived from gamma irradiation to identify the superior mutant genotypes for high fodder yield and quality in sorghum. Differences among the genotypes were found significant for all the quality traits and most of the yield traits studied at different cut(s). The mutant genotypes SSG 226 was the best performer for both quality and fodder yield and, another two mutant genotypes SSG 231 and SSG 222 was also good for fodder yield and quality, respectively but it performed poorer for vice-versa. The genotype SSG 226 produced green fodder yield (3.33, 1.52 and 0.95 g/plant/day) and dry fodder yield (1.03, 0.61 and 0.42 g/plant/day) at first, second and third cuts, respectively with crude protein (8.18) along with desirable lowest crude fibre (30.60) and highest ash content (8.39) at first cut.

Mani (1985) reported that after the γ irradiation of dry grains of two sorghum varieties and two F_1 hybrid populations, two height mutants were found in the M_2 from BD569 and 2 from BD569 X IS2695. Whereas BD569 averaged 109.3 cm in height, its mutants were 344.1 and 321.5 cm tall. They had more nodal tillers than normal plants but the number of basal tillers was unchanged. One of these mutants bore a lax, conical panicle with reddish brown grains and brown glumes, though in normal BD569 plants the panicle was semi-compact, with brick-red seeds in dark purple glumes. Mutant plants from BD569 X IS2695 were about 60% taller than normal plants. Though they reached maturity, they bore no grain.

Reddy and Smith (1976) they reported that grains of Tx414 were treated with 20, 35, and 50 kR of gamma rays and combinations of hydrazine (HZ), ethyl methane sulphonate (EMS) and methyl methane sulphonate (MMS) with cysteine, used as a pretreatment and post-treatment modifier. A number of morphological mutants affecting plant height, grain colour and shape, head size and shape and leaf-midrib colour were identified in the M_2 and M_3. Hydrazine induced the highest frequency of viable mutations (1.07%), followed by MMS (0.53%), EMS (0.36%) and gamma rays (0.13%). Cysteine by itself induced no mutations nor did it affect seed germination or seedling growth. In treatments combining gamma rays and chemical mutagens a less additive effect was observed for seed germination and reduction occurred in seedling growth. The frequency of viable mutations recovered from gamma rays + MMS (1.43%) and gamma rays + HZ (1.11%) treatments exceeded or equal to the recovery from separate treatments. Cysteine pretreatment and post treatment of HZ-treated seeds showed protective effects with respect to seed germination, seedling growth, fertility and survival of mature plants. A higher frequency (1.81%) and wider spectrum of viable mutations were recovered from cysteine treatments of HZ-treated seeds. Similarly cysteine posttreatments of gamma -irradiated seed increased the frequency of viable mutations recovered (2.1%). It is concluded that the most likely cause of the observed differences is that cysteine posttreatment reduced the effects of diplontic selection by scavenging free radicals which cause intracellular death, increasing the probability of transmission of induced recessive mutations.

Singh and Drolsom (1973) reported that of four mutants induced by diethyl sulphate, three (424, 433 and 515) had more nodes and flowered later than their parents, whilst 439 had fewer nodes. Two genes for culm height appeared to have mutated in 424 and a single gene in 433 and 515. Additive and dominance effects were important for culm height and internode length and additive effects were of major importance in the inheritance of number of nodes. Estimates of heterosis and inbreeding depression were higher for culm height and internodal length and usually lower for number of nodes.

Burow *et al.* (2014) reported that Sorghum [*Sorghum bicolor* (L.) Moench] has branched panicles with primary, secondary, and tertiary branches. These inflorescence branches are composed of a terminal triplet spikelet, consisting of one sessile (directly attached to the branch) and two pedicellate (spikelets attached to the branch through a short pedicel), followed by one or more spikelet pairs (one sessile and one pedicellate). In BTx623, and most sorghum lines, only the sessile spikelets can develop into seeds and the pedicellate spikelets, occasionally developing anthers, eventually abort. Here, we report the isolation and characterization of a stable multiseeded (*msd1*) mutant of sorghum (in BTx623 background, referred to as wild-type [WT]) in which both sessile and pedicellate spikelets are fertile. In addition, this mutant displayed increased length and total number of primary and secondary inflorescence branches. Genetic analysis showed that this multi-seeded mutation is a recessive trait. Pedicellate spikelets in *msd1* mutants exhibited complete flower with functional ovary and anthers, of which 75 to 95% can develop into viable seeds. The individual *msd1* seeds are smaller than WT; however, the results indicated that this reduction in seed weight can be compensated by the increase in seed number. The total seed weight per panicle in *msd1* mutants was increased by 30 to 40% as compared to the WT. Further experiments are needed to demonstrate whether the *msd1* mutation can increase grain yield under field conditions.

Reddy and Cheralu (1984) reported that in the M_2 of 4 varieties treated with hydrazine (HZ) and sodium azide (SA), viable mutants recovered included forms showing mutations in plant height, internodes and panicles (HZ and SA), and forms showing awn and midrib mutations (SA). SA was more efficient and effective than HZ though it was more toxic in the M_1, and Fara-Fara and Feterita were more sensitive than Aispuri or Shallu.

Chemical mutagens have become important tools in crop improvement. These mutagens are being used to produce resistance in various susceptible crops to improve their yield and quality traits against harmful pathogens. There are several mutagens available for crop improvement and each mutagen has its important role as positive or negative effect on crops. Suthakar *et al.* (2015) reported a comparative account of cytological and developmental effects on EMS (Ethyl Methane Sulphonate) and Gamma rays on meiotic features. Studies were undertaken in M_3 generation. CSV-23 variety of *Sorghum bicolor* (L.) Moench showed that both the mutagens EMS and Gamma rays induced various chromosomal aberrations. The chromosome of a treated and control plants under mitotic stages were observed. The common chromosomal aberrations are precocious movement, stickiness, bridges, fragments, laggards etc. As increase in the concentration, the frequency of cells showing chromosomal aberrations shows a linear increase up to a certain level compared to gamma rays in 40 mM EMS produced the highest chromosomal aberrations.

2.3 Effectiveness of mutagens

Most of the mutagens used on sorghum have been effective in inducing mutations. However, some mutagens such as ethidium bromide, streptomycin, and mitomycin have been more effective for cytoplasmic mutations (based on studies to induce cytoplasmic male sterility) and thermal neutrons and gamma rays more effective for inducing chromosomal breaks. Gamma rays, ethyl methane sulfonate, and diethyl sulfate appear to be three of the most effective mutagens for inducing a wide array of mutations in sorghum. Combination treatments of physical and chemical mutagens have generally been more effective for mutation induction than either mutagen by itself. Reports in the literature indicate that sorghum lines show differential genotypic response to the various mutagens and doses (Hanna, 1982).

In a study by Khizar Hayat *et al.* (1990), effects of 15, 25, 35 and 45 krad gamma radiation on seedling emergence percentage, days to 50% flowering, plant height, grain yield per plant of sorghum varieties DS-75 and Pak-SS-II were investigated. Highly significant differences in the mean values due to radiation doses for all the characters and due to varieties for days to 50% flowering, plant height and grain yield were obtained. However, the values for seedling emergence were non- significant. The maximum reduction as compared to control due to 45 krad was computed for all the characters. Variety DS-75 was more sensitive to radiation than Pak-SS-II for all the characters studied.

Jayaramachandran *et al.* (2010) reported that Gamma rays was used as a physical mutagen to create variability and to study the gene action through mutation in Grain sorghum variety CO(S) 28. The LD 50 for germination was observed as 35 kR and the treatment doses viz., 25 kR, 35 kR and 45 kR were fixed for creating variability. The M_1 generation of all the three treatment doses was raised and selfed plants were forwarded as M_2 generation. Approximately 1500 M_2 plants were raised in each treatment for recording observations. The frequency distribution for the yield and yield attributing traits viz., panicle length, number of primary branches per panicle, number of grains per panicle, 100 grain weight and grain yield per plant were obtained. The Skewness and Kurtosis estimate were calculated to study the gene action. The traits viz., number of grains per panicle and grain yield per plant recorded positive Skewness value in all the three irradiated doses. This indicates the presence of complementary epistatic gene action for these traits and if selection will be made intensively in the segregating generations the gain will be faster and mild selection resulted in slower gain.

Golubinova *et al.* (2011) conducted a study on the chromosome damage and physiological effects in the first generation (M1) of gamma-irradiated dry seeds of Sudan grass [*Sorghum sudanense* (Piper.) Stapf.], which is part of a study devoted to the assessment of the potential of a wide range of doses (100, 200, 300 and 400 Gy) of this mutagenic agent in inducing genetic changes in this crop. Three varieties of different origin, namely, Kazitachi (originating from Japan), Vercors (USA) and Voronejkaya (Russia) were subjected for irradiation treatment. The anaphase analysis of the chromosome aberrations did not reveal significant differences in the radiosensitivity of the varieties studied. Voronejkaya being however most resistant at the highest dose. The influence of gamma rays on three physiological parameters (germination, survival and sterility) of M_1 progeny of the varieties used were investigated. The data showed clearly pronounced "dose effect" with increasing dose the values obtained for each of these biological parameters decrease and the differences are statistically proven. Survival data followed similar trends as those for field germination.

In a study by Mani (1989) seeds of the hybrid IS7155 X BD569 and its parents were presoaked for 9 h and treated with 0.1, 0.2 and 0.3% ethyl methane sulfonate (EMS) for 8 hours. In the M_1, extent of reduction in seedling characters (germination, survival, seedling height and leaf numbers) was greater in the parents than the hybrid; the response was greatest with 0.3% EMS, except for survival which showed a dose-independent response. Chlorophyll variants were observed in all 3 EMS treatments in both parents and the hybrid; striata was the most common although xantha and zebra types were also seen. Averaged over EMS treatments, the percentage of M_1 plants showing meiotic aberrations was 11.5% in the hybrid, 12.8% in IS7155 and 15.7% in BD569; in the parents, frequency of aberration was higher at 0.1 and 0.2% EMS while in the hybrid the frequency of aberrant plants increased with increasing EMS dose. More chlorophyll mutants segregated in the M_2 and M_3 in the hybrid than in the parents.

Viraktamath and Goud (1977) reported that When grain of two varieties was subjected to 20, 30 and 40 kR gamma rays or 0.05, 0.07 and 0.10% EMS, the lowest radiation dosage was most effective with respect to the production of chlorophyll mutations in the M_2, while the lowest concentration of EMS was most effective in the variety 148; in the variety RCR408, mutagenic effectiveness increased with EMS concentration. With respect to viable mutations, 20 and 30 kR gamma rays and 0.05% EMS were the most effective. Data on the effects of each series of mutagenic treatments on sterility and germination within each group of mutants are also presented.

Shashidhar *et al.,* (1990) reported that treatment with methyl methanesulfonate and γ radiation of 3 varieties caused a linear decrease of germination, seedling growth and pollen fertility with increasing dose. In general, the mean values of the M_1 for days to 50% anthesis, plant height, ear weight and grain yield were increased. This was also the case for the M_2 and M_3 generations for some genotypes. Generally, variance for a character increased with increasing mutagen dose. Varieties differed in their response to mutagens.

Viraktamath (1976) reported that following treatment of five sorghum varieties with ethyl methane sulphonate and gamma rays, 302 was found to be fairly resistant to both mutagens. Viable mutants obtained included tall plants from 148 and dwarf, early or heavy-grained plants from RCR408. The means of characters such as number of leaves, height, grain yield and 100-grain weight were reduced by the treatment and their variance was increased; flowering date was delayed.

Mizuno *et al.* (2013) reported that epicuticular wax (bloom) plays important role in protecting the tissues of sorghum plants from abiotic stresses. However, reducing wax content provides resistance to greenbug and sheath blight-a useful trait in agricultural crops. We generated a sorghum *bloomless* (*bm*) mutant by gamma irradiation. One *bm* population segregated for individuals with and without epicuticular wax at a frequency of 72:22, suggesting that the *bm* mutation was under the control of a single recessive nuclear gene. Genes differentially expressed in the wild-type and the *bm* mutant were identified by RNA-seq technology. Of the 31 down-regulated genes, Sb06 g023280 was the most differentially expressed and was similar to *WBC11*, which encodes an ABC transporter responsible for wax secretion in Arabidopsis. An inversion of about 1.4 Mb was present in the region upstream of the Sb06 g023280 gene in the *bm* mutant; it is likely that this inversion changed the promoter sequence of the Sb06 g023280 gene. Using genomic PCR, they confirmed that six independent F_2 *bm* mutant-phenotype plants carried the same inversion. Therefore, they concluded that the inversion involving the Sb06 g023280 gene inhibited wax secretion in the *bloomless* sorghum.

Reddy (1979) reported that grain of NM31 was more sensitive to gamma rays (dosage 20, 35 and 50 kR) than that of TX414 on the basis of morphology in M_1 generation, and fertility and the number of chlorophyll mutants in the M_2. Mutants were recovered with changed grain colour, grain, glume and panicle morphology, plant height and leaf-midrib colour, when these varieties were treated with gamma rays and when TZ414 was treated with different concentrations of hydrazine and ethyl methanesulphonate, with and without cysteine treatment.

Gomathinayagam and Rajasekaran (1988) investigated that a total of 374 viable mutations were obtained from a very tall variety, Ingru Cholam, following treatments with γ rays and/or methyl methane sulphonate (MMS). There was a linear relationship between increasing mutagen dose and increasing frequency of viable mutations. Alternate treatments with γ rays and MMS produced a higher number and wider range of mutations than those provided by each treatment alone. The mutations included variations in height, growth period, the size and shape of leaves and panicles, and seed fertility.

Material and Methods

3. MATERIAL AND METHODS

The research on Induced mutation studies in *Rabi* sorghum [*Sorghum bicolor* (L.) Moench] was conducted at Regional Agricultural Research Station, Vijayapur during *rabi* season 2015-2016 (M_2) and 2016-17 (M_3). M_2 and M_3 generation material was derived from five mutation treatment combinations (EMS and Gamma) induced in three *rabi* sorghum varieties.

The details on material used and methods followed are given below.

3.1 Location

The experiment was laid out at Regional Agricultural Research Station, Vijayapur, University of Agricultural Sciences, Dharwad during *rabi* season of both 2015-2016 and 2016-17. Vijayapur is situated at $16^0$49' N latitude, $75^0$43' E longitude and 593 m elevation. Vijayapur comes under Northern Dry Zone of Karnataka with annual rainfall of 590.7 mm (Appendix I and II). The soil type and climatic conditions are well suited for *rabi* sorghum cultivation.

3.2 Experimental material

3.2.1. Biological materials

Three *rabi* sorghum varieties namely, DSV-5, DSV-4 and CSV 216R were chosen to study the effect of the physical and chemical mutagens on the induction of variability in both qualitative and quantitative characters in M_2 and M_3 generations. Mutation treatments included were 350 Gy, 400 Gy, EMS (0.2%), 350 Gy+EMS (0.2%) and 450 Gy+EMS (0.2%). M_2 and M_3 generation material was evaluated during *Rabi* 2015-16 and *Rabi* 2016-17, respectively at RARS, Vijayapur. The details on material used for evaluation is given in Table 1. The salient features of the varieties DSV-5, DSV-4 and CSV 216R are furnished in Table 2.

3.2. Experimental layout

3.2.1. M_2 generation

The experiment was laid out in the year 2015 during *rabi* season at RARS, Vijayapur. M_2 generation seeds of different varieties that were advanced from M_1 were collected from AICSIP, Vijayapur. Assessment and advancement of M_2 was done during *Rabi*-2015. The experimental material consisting of 2951 M_2 progenies derived from induced mutation using

Table 1. Details of experimental material used for the Induced mutation study in *Rabi* sorghum

Variety	Mutation treatment (Dosage)	2015-16			2016-17	
		M_2 progenies (no.)	Total number of plants (M2)	Plot no.s/entry code	M_3 progenies (no.)	Entry codes
DSV 5	350 Gy	15	375	1001-1015	23	DSV5M-1 to DSV5M-23
	400 Gy	6	150	1016-1021	5	DSV5M-24 to DSV5M-28
	EMS (0.2%)	13	325	1022-1034	13	DSV5M-29 to DSV5M-41
	350 Gy+EMS (0.2%)	2	50	1035-1036	1	DSV5M-42
	400 Gy+EMS (0.2%)	4	100	1037-1040	5	DSV5M-43 to DSV5M-47
DSV 4	350 Gy	12	300	1041-1052	11	DSV4M-49 to DSV4M-59
	400 Gy	8	200	1053-1060	16	DSV4M-60 toDSV4M75
	EMS (0.2%)	13	325	1061-1073	21	DSV4M-76 to DSV4M-96
	350 Gy+EMS (0.2%)	5	125	1074-1078	7	DSV4M-97 to DSV4M-103
	400 Gy+EMS (0.2%)	3	75	1079-1081	7	DSV4M-104 to DSV4M-110
CSV 216R	350 Gy	2	50	1095-1096	7	CSVM-112 to CSVM-118
	400 Gy	4	100	1097-1100	1	CSVM-119
	EMS (0.2%)	8	200	1101-1108	10	CSVM-120 to CSVM-129
	350 Gy+EMS (0.2%)	4	100	1109-1112	10	CSVM-130 to CSVM-139
	400 Gy+EMS (0.2%)	10	250	1113-1122	22	CSVM-140 to CSVM-161
		Total	2951		159	

Table 2. Salient features and other details of varieties used in the present study

Sl.	Entries	Pedigree	Salient features and other details
1.	DSV-5	Selection from Natte Maldandi variety of Gulbarga locality (developed by Dharwad centre)	DSV-5 is resistant to charcoal rot coupled with high grain and fodder yields. In addition, the variety has high grain and fodder quality. Distinct features include **tall, semi-compact head, panicle with tapering at the end and charcoal rot tolerant.** Under pure rainfed situation, the moisture conservation practices like compartment bunding, ridges and furrows, etc., need to be practiced to harness full potentiality of this variety. Wherever possible one protective irrigation at crop stage of 60-70 days will yield the maximum grain and fodder yields. The average grain and fodder yields are 12-15 q/ha and 35-45 q/ha, respectively, compared to M 35-1. The main benefit the farmers getting from this variety is charcoal rot free fodder and good silvery white bold grains, which fetches high price in the market.
2	DSV-4	E 36-1 × SPV 1047 (Developed by Dharwad centre)	DSV-4 is a high grain and fodder yielding *rabi* sorghum variety resistant to charcoal rot. **Distinct features include tall, loose panicle, charcoal rot tolerant.** It produces good quality fodder than M 35-1. In addition, it has stay- green trait, hence the green fodder is available even after maturity of the crop. DSV-4 does not lodge and fodder quality is better than M 35-1. Threshing quality of grain is better than M 35-1. But this variety matures one week later than M 35-1. DSV-4 is resistant to charcoal rot and rust compared to M 35-1. Grain yield of DSV-4 is 30-35 q/ha which is higher than M 35-1. Fodder yield of DSV-4 (80-90 q/ha) is quite higher than M 35-1. Due to its resistance to rust, the variety is best suited to irrigated tract also.
3	CSV 216R	The variety was identified at MPKV, Rahuri during 1998 from the land races of Dhulia region	Tall, semi compact head, lustres bold grains, susceptible to charcoal rot. It was released in the year 2000. It is non-tan type with purple coleoptiles pigmentation, cylindrical semi- compact panicle, white mid-rib leaf, pearly white medium bold grains, and tolerant to shoot fly and susceptible to charcoal rot. CSV 216R gives grain yield of 20-25 q/ha and dry fodder yield of 70-80 q/ha. It has a plant height of 240-270cm and matures in 120 to 125 days.

three *rabi* sorghum varieties (DSV-5, DSV-4 and CSV 216 R) was planted in an Augmented design without replication. The experimental material was sown on 25th September 2015. The varieties were planted with single row each in four meter length with a row spacing of 60 × 15 cm. Fertilizer applied was 8.7 g of urea per m^2 and 5.4 g of DAP per m^2.

3.2.2. M_3 generation

Evaluation of M_3 generation material was carried out in the year 2016 during *rabi* season at RARS, Vijayapur. M_3 generation seeds of three *rabi* sorghum varieties (DSV 5, DSV 4 and CSV 216R) were advanced from M_2 during 2015-16. Each M_2 plant was advanced to M_3 by selfing. Evaluation of M_3 in replicated trial was done during in a Randomized Block Design (RBD) with three replications. The experimental material was sown on 25th September 2016. The varieties were planted in a single row each with four meter length and with a row spacing of 60 × 15 cm. Fertilizer applied was 8.7 g of urea per m^2 and 5.4 g of DAP per m^2 .

3.3. Mutation treatments

M_2 generation seeds of different varieties that were advanced from M_1 treated with different mutagen and dosage combinations. M_2 plants were derived from five mutagen treatment combinations in each of the *rabi* sorghum varieties viz, DSV-5, DSV-4 and CSV 216R and they were planted during *Rabi* 2015. The observations were made on individual plants. Each M_2 plant advanced to M_3 by selfing. The details on varieties and treatment combinations used for in the present study are given below.

Name of the varieties used	:	DSV-5, DSV-4, CSV 216R
Control (without treatment)	:	DSV-5, DSV-4, CSV 216R
Mutagens used	:	i. Gamma rays (γ rays) ii. Ethyl Methane Sulphonate (EMS) iii. Gamma rays + Ethyl Methane Sulphonate (EMS)
Dosage of mutagens used	:	γ rays: 350Gy, 400Gy EMS: 0.2% γ rays + EMS: 350Gy+0.2% and 400Gy+0.2%

3.4. Handling of advancing generations

3.4.1. Handling of M_2 generation material

M_2 generation seeds of different varieties that were advanced from M_1 were collected from AICRP on sorghum, RARS, Vijayapur. These were derived from treatment with different mutagen and dosage combinations. M_2 plants were derived from five mutagen treatment combinations in each of the rabi sorghum varieties *viz*, DSV-5, DSV-4, and CSV 216R and they were planted during *Rabi* 2015. The observations were made on individual plants in each of the M_2 progeny. Selections were made both based on observations recorded and visual observations for various characters. M_2 plants with early flowering, branching, large panicle size, change in panicle compactness, high seed weight, change in seed size etc., were selected by comparing with their corresponding control variety and advanced to M_3 for evaluation during *rabi* 2016. The details on M_2 generation material used in the present study is given in Table 1.

3.4.2. Handling of M_3 generation material

Out of total of 2951 plants from M_2 advanced to M_3 generation, a total of 159 plants were selected for evaluation during *rabi* 2016. The details on M_3 material used is presented in Table 1. The observations were made on five randomly selected plants.

3.5 Observations

In M_2 generation, the visual observations were made on each individual plant for various traits Where as in M_3, observations were recorded on five randomly selected plants in each of the progeny derived from each of the three varieties were tagged for recording observations. The observations yield traits, tolerance to biotic stresses (charcoal rot, shoot fly and shoot bug), and terminal drought (SPAD readings) were recorded on each of the tagged plants. The procedures followed for recording these observations are as follows.

3.5.1. M_2 generation

3.5.1.1 Days to 50% flowering

When 50% flowering noticed in panicle of individual plants, the date was recorded and days were counted from date of sowing. Early flowering plants were identified and tagged.

3.5.1.2 Plant height (cm)

It was taken for all individual plants at physiological maturity. It was measured from ground level to the tip of the panicle of the plant.

3.5.1.3 Panicle length (cm)

It was measured from the base of the panicle to the tip of the panicle.

3.5.1.4 Panicle breadth (cm)

It was measured at the broadest point of the panicle in centimeters.

3.5.1.5 Panicle weight (g)

Panicle of each of the selected plant was weighed and expressed in grams.

3.5.1.6 Grain weight (g/plant)

Grains separated from the panicle of each of the selected plant were weighed and expressed in grams.

3.5.1.7 100 Grain weight (g/100 seeds)

100-seeds separated from panicle of each of the selected plants were weighed in grams.

3.5.2. M_3 generation

3.5.2.1 Chlorophyll mutants

The chlorophyll mutants were classified as per the system proposed by Gustafsson (1940) and Blixt and Gottascalk (1975). The chlorophyll mutants include the following.

Mutant	Description
Albino	White
Xantha	Yellow
Chlorina	Light green
Albomaculata	White dots on green leaves
Alboviridis	Initially white and later becomes normal plants
Xanthaviridis	Initially yellow and later become normal plants

In the present study, the colour of the first formed leaf was taken for scoring the chlorophyll mutants. To compute the spectrum (relative percentage of different types) of mutants, the different types of seedling mutants for chlorophyll deficiency were scored separately from seventh to fifteenth day.

3.5.2.2Leaf glossiness (score)

The intensity of leaf glossiness was recorded (on plot basis) on 9th day after seedling emergence (DAE) using 1-5 scale, where in 1 = high intensity of glossiness and 5 = non-glossy. Leaf glossiness was scored in the morning hours (between 6-8 a.m.) when there was maximum reflection of light.

3.5.2.3 Reaction to sorghum shoot fly

Total number of shoot fly affected plants and the total number of plants were counted in each of the progeny and recorded. Data were recorded on plants with shoot fly dead hearts at 28 DAE, and expressed as the percentage of plants with shoot fly dead hearts. To record data on DH%, the total number of plants was initially recorded, and the numbers of plants with dead hearts were subsequently recorded on 28 DAE. The mean values of DH% (ratio of the number of dead hearts/total number of plants x 100) recorded were used for identification of shoot fly resistant lines (Balakrishna *et al.,* 2015).

3.5.2.4 Seedling height (cm) (30 DAS)

It is measured from the ground level to the tip of the plant at 30 days after sowing (DAS) and expressed in cm. The observations were made on five randomly selected plants.

3.5.2.5 Reaction to Shoot bug

Intensity of shoot bug was scored in each entry as per the standards given by Bhagwat and Shyam Prasad (2016). Plant damage symptoms were recorded at 60-75 days after seedling emergence on 1 to 9 scale. (1 = A few shoot bugs present on the plant, and no apparent damage to the leaves, 2 = shoot bugs present in the leaf whorls and leaf sheaths with a few feeding specks, 3 = 10% leaf or leaf sheath area showing feeding symptoms, 4 = 10% leaf or leaf sheath area showing feeding symptoms, 5= 30 to 40 % leaf/leaf sheath area showing feeding/oviposition damage, 6 = 40 to 50% damage to leaves/leaf sheaths, and 4 to 5 leaves showing symptoms of twisting and oozing of cell sap, 7 = 5-6 leaves showing extensive feeding, twisting, and oozing of cell sap, 8 = 7-8 leaves showing extensive feeding, twisting, and oozing of cell sap, and 9 = plants heavily infested with shoot bugs and most of the leaves twisted, and no panicle exertion).

3.5.2.6 Days to 50% flowering

When 50% flowering noticed in panicle of individual plants, the date was recorded and days were counted from date of sowing. Early flowering plants were identified and tagged.

3.5.2.7 SPAD readings (at flowering)

Chlorophyll content of leaf was measured in terms of chlorophyll context index by using an instrument SPAD meter. A reading was taken after one week of days to 50 % flowering (SPAD 1) in third leaf from the top of the plant (including flag leaf) in each of the five randomly selected plants.

3.5.2.8 SPAD readings (at physiological maturity)

Chlorophyll content of leaf was measured in terms of chlorophyll context index by using an instrument SPAD meter. A reading was taken at physiological maturity (SPAD 2) in third leaf from the top of the plant (including flag leaf) in each of the five randomly selected plants.

3.5.2.9 Days to maturity

Date of maturity was recorded when grain of at least 50% of plants in a plot attained black hilum and number of days were then calculated from planting to maturity.

3.5.2.10 Plant height (cm)

It was taken five randomly selected plant at physiological maturity. It was measured from ground level to the tip of the panicle of the plant.

3.5.2.11 Number of nodes

The total number of nodes present per plant was recorded in each of the five randomly selected plants.

3.5.2.12 Internodal length (cm)

The length between each internode of a plant was taken in each of the five randomly selected plants.

3.5.2.13 Peduncle length (cm)

Length of stalk of an inflorescence in each of the five randomly selected plants was measured.

3.5.2.14 Charcoal rot resistance

Charcoal rot affected plants and the total number of plants in each M3 progeny. The mean values of CR% (ratio of the number of charcoal rot affected plants/total number of plants x 100) recorded were used for identification of charcoal rot resistant lines (0% - Highly resistance, <10% - Resistance, 10-30% - Moderately resistance, 30-50% - Susceptible and >50% - Highly susceptible) (Patil, 1982).

3.5.2.15 Panicle length (cm)

It was measured from the base of the panicle to the tip of the panicle on five randomly selected plants

3.5.2.16 Panicle breadth (cm)

It is measured at the broadest point of the panicle in centimeters on five randomly selected plants.

3.5.2.17 Panicle weight (g)

The fully dried panicle of each of the five randomly selected plants was weighed and expressed as grams per plant.

3.5.2.18 Panicle density (score)

Scoring was done as compact, semi compact and loose.

3.5.2.19 Panicle harvest index (PHI)

It was recorded as ratio of grain mass to total panicle mass.

3.5.2.20 Grain weight (g/plant)

Grains separated from the panicle of each of the five randomly selected plant were weighed and expressed in grams.

3.5.2.21 100 Grain weight (g/100 seeds)

100-seeds separated from each panicle of five randomly selected plants were weighed in grams.

3.6 Statistical analysis

3.6.1 Mean and Range

On the basis of individual plant observations, the population mean for each character was computed as below.

$$\text{Mean } (\overline{X}) = \frac{\text{Sum of values for a trait of all treatments (genotypes)}}{\text{Total no. of treatments (genotypes)}}$$

The minimum and maximum values on the basis of individual plant observations were used to indicate the range of given character.

3.6.2 Analysis of variance

The mean of the five plants in M_3 were used for analysis of variances. The differences among these were tested by 'F' test as given below. For each character and for all varieties, analysis of variance was carried out separately and the analysis of variance table was constructed as follows.

Table: Analysis of Variance

Source of variation	**Degrees of freedom**	**MSS**	**Calculated F**
Replication	(r-1)	RMSS	
Treatment	(t-1)	TMSS	TMSS/EMSS
Error	(r-1) (t-1)	EMSS	

Where in,

r = Number of replications

t = Number of treatments

The standard error was calculated as,

$$SEm = \sqrt{EMSS/r}$$

3.6.3 Components of variance

Phenotypic and genotypic components of variance were calculated according to the formula given by Lush (1940) and Chaudhary and Prasad (1968).

$$\text{Genotypic variance} = \sigma^2 g = \frac{TMSS-EMSS}{r}$$

Error variance - $\sigma^2 e$ = EMSS

Phenotypic variance = $\sigma^2 p = \sigma^2 g + \sigma^2 e$

Where,

TMSS = MSS for treatment

EMSS = MSS for error

' r' = Number of replications

3.6.4 Coefficient of variation

The method suggested by Burton and Devane (1952) was followed for computation of the following parameters.

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\sigma p}{\overline{X}} \times 100$$

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sigma g}{\overline{X}} \times 100$$

Where,

σp = Phenotypic standard deviation

σg = genotypic standard deviation

$\overline{X}$ = Grand mean

GCV and PCV values were categorized as low, moderate and high values as indicated by Siva Subramanian and Menon (1973) as follows:

1-10 % : Low

11-20 % : Moderate

21 % and above : High

3.5.5 Heritability

Heritability in broad sense was computed for each character using the following formula (Lush, 1940).

$$\text{Heritability (\%)} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times 100$$

Heritability was classified as follows (Robinson, 1966)

Above 60 per cent - High

30 to 60 per cent - Moderate

Below 30 per cent - Low

3.6.6 Genetic advance

Genetic advance for a particular trait was estimated adopting the method as suggested by Johnson *et al.* (1955).

$$GA = h^2 \text{ x } \sigma_{ph} \text{ x } K$$

Where,

h^2 - Heritability

σ_{ph} - Phenotypic standard deviation

K - Selection differential (2.06) at 5 per cent selection intensity

$$\text{Genetic advance as percentage of mean} = \frac{GA}{\text{General mean}} \times 100$$

Genetic advance was classified as follows (Robinson, 1966)

Above 20 per cent - high

10 to 20 per cent - moderate

Below 10 per cent - low

3.6.7 Analysis of M_2 generation material

Augmented designs are evaluating hundreds of germplasm lines in the same experiment, utilizing a minimal measure of experimental stuff, which are enough for one replicate only. Due to the limited quantity of M_2 experiment materials (test treatment) in the present study were not replicated in this design, but the optimum number of checks (control treatments) were replicated in each block so as to maximize the efficiency per observations for test treatment vs. control treatment comparison. Some symbols used to make easy to understand. u (number of control treatment), w (number of test treatment) and b (number of blocks in experiment). For data are put to online to make a design layout by SAS or layout can be made manually. First the user enters the design parameter in, and replication of control treatment(s) to maximize the efficiency per observation is automatically computed.

Experimental Results

4. EXPERIMENTAL RESULTS

The experiment was carried out to study the effects of mutagenic treatments on different traits were studied in both M_2 and M_3 generations for three varieties *viz*., DSV-5, DSV-4 and CSV 216R. The data obtained on various traits were subjected to statistical analysis and the results obtained are presented for M_2 and M_3 generations separately under the following headings.

4.1 M_2 Generation

4.1.1 Analysis of variance

The data recorded in a total of 47 M_2 families in *rabi* sorghum variety DSV 5, 58 in DSV 4 and 48 in CSV 216R were subjected for Analysis of variance (ANOVA) for the different yield traits by using the augmented design. Treatment values including checks and variances among genotypes for the different component traits are presented in Table 3. It was observed from the table that variances among the treatments including checks are significant for plant height and panicle weight, and within genotypes panicle weight and grain yield are significant for a variety DSV-5. Regarding variety DSV 4, variances among the treatments including checks and also within genotypes were significant for plant height and hundred grain weight In case of CSV 216R, for the traits days to 50% flowering, plant height, panicle weight, grain yield and 100 grain weight were variances were found to be significant among the treatments including checks. Within genotypes it was significant for all the traits except for panicle breadth.

4.1.2 Mean and range

4.1.2.1 Variety: DSV-5

Mean and range values of genotypes for the different traits have been tabulated in Table 4a. In general, wide range was observed for all the traits in mutation treatments 350 Gy, 400 Gy and EMS (0.2%). Among these, range was wider in 350 Gy compared to 400 Gy and EMS (0.2%). For days to 50% flowering, lowest mean values were observed in 400 Gy (79 days) followed by 350 Gy (81 days) compared to that of control (zero dosage) (84 days). For plant height, mean values were higher in 400 Gy (274.2) followed by 350 Gy (247.39 cm) with lowest observed in 350 Gy (147 cm) and highest in 400 Gy (295 cm) compared to control (232.33). Whereas treatments 350 Gy and 400 Gy were recorded with highest mean

Table 3. ANOVA for yield traits in M_2 generation of three *Rabi* sorghum varieties evaluated during *rabi* 2015-16 at Vijayapur

Variety		Df	DFF	PH	Pa L	PB	PW	GY	HGW
DSV-5	Block (ignoring treatments)	5	73.27	385.26	14.41	1.74**	443.14	136.19	0.79
	Treatment (eliminating blocks)	50	42.99	905.82*	5.47	0.52	580.74*	356.45	0.25
	Checks	2	220.16	571.06	14.11	0.63	110.68	113.15	0.59
	Checks+Var vs. Var.	48	35.61	919.77*	5.11	0.52	600.32*	366.58	0.24
	ERROR	10	360.24	324.95	24.42	0.26	215.29	140.07	0.58
	Block (eliminating checks + var.)	5	249.14	634.33	18.09	0.40	92.73	42.78	0.64
	Entries (ignoring blocks)	50	25.41	880.91*	5.11	0.66	615.78*	365.79	0.27
	Checks	2	220.16	571.06	14.11	0.63	110.68	113.15	0.59
	Varieties	47	12.33	755.83	4.26	0.66	643.46*	384.04*	0.23
	Checks vs. Varieties	1	250.25	7379.77**	26.90	0.58	325.2	13.21	1.47
	ERROR	10	360.24	324.95	24.42	0.26	215.29	140.07	0.58
	Ci-Cj	1	24.42	23.19	6.36	0.66	18.88	15.23	0.98
	BiVi-BiVj	1	59.81	56.80	15.57	1.61	46.24	37.29	2.41
	BiVi-BjVj	1	69.06	65.59	17.98	1.86	53.39	43.06	2.78
	Ci-VI	1	52.75	50.10	13.73	1.42	40.78	32.89	2.12
DSV-4	Block (ignoring treatments)	5	165.24	2434.54**	38.66**	2.39	1513.44*	1237.35**	1.25**
	Treatment (eliminating blocks)	62	41.22	1119.10**	8.95	0.99	443.36	332.02	0.35*
	Checks	2	273.29	193.56	4.73	0.35	1200.72	1681.83**	0.49*
	Checks+Var vs. Var.	60	33.48	1149.95**	9.09	1.01	418.12	287.02	0.34*
	ERROR	10	296.69	271.62	6.51	1.2	356.32	202.12	0.09
	Block (eliminating checks + var.)	5	336.02	228.73	10.36	0.39	159.29	176.36	0.16
	Entries (ignoring blocks)	62	27.44	1296.99**	11.23	1.15	552.57	417.58	0.43**
	Checks	2	273.29	193.56	4.73	0.35	1200.72	1681.83**	0.49*
	Varieties	59	18.42	1356.17**	11.57	1.2	532.75	373.13	0.43**
	Checks vs. Varieties	1	68.04	12.21	3.93	0.12	425.56	511.5	0.73*
	ERROR	10	296.69	271.62	6.51	1.2	356.32	202.12	0.09
	Ci-Cj	1	22.16	21.2	3.28	1.41	24.28	18.29	0.39

Table 3. Contd…..

Variety		Df	DFF	PH	Pa L	PB	PW	GY	HGW
	BiVi-BiVj	1	54.28	51.93	8.04	3.45	59.48	44.8	0.96
	BiVi-BjVj	1	62.67	59.97	9.28	3.99	68.68	51.73	1.11
	Ci-VI	1	47.87	45.8	7.09	3.04	52.46	39.51	0.85
CSV216R	Block (ignoring treatments)	4	163.91**	1192.20**	7.34*	4.22**	2807.61**	1279.83**	0.19*
	Treatment (eliminating blocks)	52	17.80*	1302.31**	3.78	1.32	647.68**	419.5**	0.28**
	Checks	2	1.4	29.31	0.6	0.76	22.46	22.82	0.02
	Checks+Var vs. Var.	50	18.46*	1353.23**	3.91	1.34	672.69**	435.44**	0.29**
	ERROR	8	4.05	142.13	1.37	0.51	66.88	18.73	0.05
	Block (eliminating checks + var.)	4	6.06	397.57	1.68	1.24	280.96*	134.43**	0.19*
	Entries (ignoring blocks)	52	29.94**	1363.44**	4.21*	1.546*	842.03**	507.67**	0.28**
	Checks	2	1.4	29.31	0.6	0.76	22.46	22.82	0.02
	Varieties	49	31.64**	1438.68**	4.44*	1.54	892.67**	533.99**	0.30**
	Checks vs. Varieties	1	3.88	344.82	0.04	3.24*	0.24	187.72*	0.01
	ERROR	8	4.05	142.13	1.37	0.51	66.88	18.73	0.05
	Ci-Cj	1	2.93	17.39	1.71	1.04	11.93	6.31	0.31
	BiVi-BiVj	1	6.56	38.88	3.82	2.33	26.67	14.12	0.70
	BiVi-BjVj	1	7.57	44.89	4.41	2.69	30.80	16.30	0.81
	Ci-VI	1	5.87	34.77	3.42	2.09	23.86	12.63	0.63

* : Significant at 5% level (1.96)

**: Significant at 1% level (2.575)

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm), PW- Panicle weight (g), GY- Grain yield per plant(g), HGW-100 grain weight(g)

Table 4a. Mean and range values in M_2 generation of *rabi* sorghum variety DSV-5 for yield and yield components across different mutation treatment combinations

Traits	Zero dose	350Gy		400Gy		0.2% EMS		350Gy+0.2%EMS		400Gy+0.2%EMS	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
DFF	84.00	78-85	81	77-84	79	78-86	83	83	83	78-94	84
PH	232.33	147-280	247.39	247-295	274.2	187-276	249.77	278	278	200-265	236.4
Pa L	21.70	17-26	21.76	19-21	20.4	17-26	20.85	20	20	21-23	21.8
PB	5.22	5.0-7.0	6.17	5.0-6.0	5.4	4-6.5	5.31	6	6	5.0-6	5.2
PW	89.00	49-157	97.17	60-128	92.6	30-109	75.62	86	86	50-102	86
GY	69.11	31.9-125.73	73.58	46.88-73.58	72.43	23.34-83.73	58.83	70.93	70.93	37.73-76.54	66.21
HGW	3.70	3.26-5.20	4.02	3.79-4.97	4.48	3.78-4.56	4.22	3.77	3.77	3.89-4.74	4.30

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant (g), HGW-100 grain weight(g)

values for Panicle weight (g) (97.17 and 92.6, respectively), grain yield (g/plant) (73.58 and 72.43, respectively) and 100 seed weight (g) (4.02 and 4.48, respectively) compared to control (89, 69, and 3.7, respectively). For panicle length (cm) and panicle breadth (cm), the range was wider in 350 Gy (23-30, 5-6) and EMS (0.2%) (17-32, 4-6.5) compared to other treatments with mean values on par with control (21.7, 5.22, respectively).

4.1.2.2 Variety : DSV-4

With respect to variety, DSV 4, mean and range values of genotypes for the different traits have been tabulated in Table 4b. In general, wide range was observed in all the mutation treatments for all the traits except for days to 50% flowering in 400Gy+ EMS (0.2%). High mean values were observed for the traits plant height, panicle length, panicle weight, grain yield per plant and 100 seeds weight among the genotypes across different mutation treatments. For plant height (cm) higher mean values (260.29, 249.69 and 235.36) were observed in treatments 400 Gy+EMS (0.2%), 400 Gy and 350 Gy, respectively over control (227). With respect to panicle length (cm), higher mean values of 27.27, 27.25 and 26.71 were observed in mutation treatments 350 Gy, 400 Gy, 350 Gy+ EMS (0.2%), respectively over control (26.71). For panicle weight (g) and grain yield (g/plant), high values were recorded in treatments 400 Gy (101.63 and 70.29, respectively) and 400 Gy+EMS (0.2%) (117.43 and 91.40, respectively) compared control (61.94). For trait 100 seeds weight (g), highest mean value of 4.59 was recorded in treatment 400 Gy+EMS (0.2%) compared to control (4.19). Mean values were lower than control in treatments 350 Gy+EMS (0.2%) and 400 Gy+EMS (0.2%) for all the traits except for panicle length in 350 Gy+EMS (0.2%).

4.1.2.3 Variety : CSV 216R

For the variety, CSV 216R, mean and range values of genotypes for the different traits have been tabulated in Table 4c. Wide range was observed for all the traits across all the mutation treatments with genotypes having recorded with lower and higher values than the control except for days to 50% flowering. Lowest mean values for days to 50% flowering were observed in treatment 400 Gy+EMS (0.2%) (69 days) followed by 350 Gy (70 days). Mean values higher than control were recorded for the traits panicle breadth, panicle weight and grain yield. For panicle breadth (cm), higher mean values of 7.21 and 7.00 were recorded in treatments 350 Gy and 400 Gy, respectively compared to control (6.17). For panicle weight (g) and grain yield (g/plant), highest values of 136 and 98.93, respectively were recorded by

Table 4b. Mean and range values in M_2 generation of *rabi* sorghum variety DSV-4 for yield and yield components across different mutation treatment combinations

Traits	Zero dose	350Gy		400Gy		0.2% EMS		350Gy+0.2%EMS		400Gy+0.2%EMS	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
DFF	79.00	79-82	81	78-83	80	70-84	77	71-82	76	80-83	81
PH	227.00	174-266	235.36	216-295	249.69	156-289	222.14	134-259	196.43	198-293	260.29
Pa L	25.17	23-30	27.27	23-32	27.25	17-32	23.29	23-30	26.71	20-27	23.86
PB	6.83	6.0-7.0	6.52	5-8.5	6.69	3.5-7.5	6.02	4.5-7	5.71	4.5-8.5	6.86
PW	89.67	60-105	84.27	46-203	101.63	21-139	72.86	23-100	58.29	25-160	117.43
GY	61.94	44.48-76.85	60.96	28.66-146.31	70.29	15.17-103.05	51.09	9.02-76.4	39.59	19.31-124.43	91.40
HGW	4.19	3.189-4.02	3.61	3.50-4.63	3.89	2.76-4.47	3.58	1.92-3.87	2.92	3.48-5.35	4.59

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant (g), HGW-100 grain weight(g)

Table 4c. Mean and range values in M_2 generation of *rabi* sorghum variety CSV 216R for yield and yield components across different mutation treatment combinations

Traits	Zero dose	350Gy		400Gy		0.2% EMS		350Gy+0.2%EMS		400Gy+0.2%EMS	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
DFF	74.00	69-71	70	80	80	69-86	80	72-78	73.00	67-72	69.00
PH	231.67	170-288	219.86	139.00	139.00	177-240	217.6	154-260	227.70	172-270	229.41
Pa L	20.17	18-23	20.00	23.00	23.00	15-21	18.6	18-23	20.90	15-23	19.77
PB	6.17	5.0-10.0	7.21	7.00	7.00	5.0-8.0	6.65	5.0-9	6.50	4.0-8.0	5.59
PW	114.50	55-196	116.57	136.00	136.00	57-135	104.9	74-208	116.70	38-165	89.09
GY	92.17	23.37-137.92	82.11	98.93	98.93	32.76-104.94	76.37	47.68-152.12	85.95	31.31-119.25	67.55
HGW	4.39	2.57-4.59	4.01	3.94	3.94	3.72-4.93	4.33	2.89-4.90	4.06	2.86-4.96	4.17

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant (g), HGW-100 grain weight (g)

400 Gy over control (114.5 and 92.17, respectively). Lower mean values over control were observed for all the traits in treatment 400 Gy+EMS (0.2%).

4.1.3 Effect of induced mutation on various traits

4.1.3.1 Qualitative traits

M_2 individuals derived from three *rabi* sorghum varieties were screened for induced changes for various qualitative traits. The induced changes were noticed for earliness, branching, panicle size, panicle shape, seed characters (size, color and number), and partial sterility. The frequency and spectrum of these variable mutants are tabulated in Table 5.

4.1.3.1.1 Variety: DSV-5

A total of 1000 M_2 individuals derived from DSV 5 were screened for induced changes for various qualitative traits. The total frequency of mutation observed was 0.62% and the mutants were found only with the partial sterility in a dosage of 0.2%EMS.

4.1.3.1.2 Variety: DSV-4

A total of 1025 M_2 individuals derived from DSV 4 were screened for induced changes for various qualitative traits. The total frequency of mutation observed was 13.31% across mutation treatments. A of total 5.00% mutants were found in a dosage of 400Gy with a 0.5% mutants for earliness, 1.50% for panicle size, 1.5% for panicle shape, 1.00% in seed characteristics, and 0.5% for partial sterility. A total 4.31% mutation was found in a dosage of 0.2%EMS with 2.77% for early mutants, 0.92% for panicle size and 0.62% for panicle shape. A total of 4.00% mutations were found in a dosage of 350Gy+2%EMS with a 0.80% in panicle size, 0.80% in panicle shape, 2.40% in seed characteristics.

4.1.3.1.3 Variety: CSV 216R

A total of 700 M_2 individuals derived from CSV 216R were screened for induced changes for various qualitative traits. The total frequency of mutation observed was 33.2% across five mutation treatments. Total frequency of 8.00% mutations were found in a dosage of 350Gy with a 6.00% for early mutants and 2.0% regarding panicle size. The frequency of 1% mutations were found only for the panicle size in a dosage of 400Gy. Total frequency of 4.00% mutations were found in a dosage of 0.2%EMS with a 1.5% in branching, 0.50% in panicle size, 1.50% in seed characteristics and 0.5% for partial sterility. Total frequency of 11.00% mutations were found in a dosage of 350Gy+0.2%EMS with a 6.00% early mutants,

Table 5. Frequency and spectrum of variable mutations in M_2 generation in *rabi* sorghum

Variety	Treatment	Population size (M_2)	Spectrum of mutation						Total frequency of mutation (%)
			Early mutants	Branching	Panicle size	Panicle shape	Seed characterstics (size, colour, no.)	Partial sterile	
DSV-5	350Gy	375	0	0	0	0	0	0	0
	400Gy	150	0	0	0	0	0	0	0
	0.2%EMS	325	0	0	0	0	0	0.62	0.62
	350Gy+0.2%EMS	50	0	0	0	0	0	0	0
	400Gy+0.2%EMS	100	0	0	0	0	0	0	0
	Total	1000	0	0	0	0	0	0.62	0.62
DSV-4	350Gy	300	0	0	0	0	0	0	0
	400Gy	200	0.50	0	1.50	1.50	1.00	0.50	5.00
	0.2%EMS	325	2.77	0	0.92	0.62	0	0	4.31
	350Gy+0.2%EMS	125	0	0	0.80	0.80	2.40	0	4.00
	400Gy+0.2%EMS	75	0	0	0	0	0	0	0
	Total	1025	3.27	0	3.22	2.92	3.40	0.50	13.31
CSV216R	350Gy	50	6.00	0	2.00	0	0	0	8.00
	400Gy	100	0	0	1.00	0	0	0	1.00
	0.2%EMS	200	0	1.50	0.50	0	1.50	0.50	4.00
	350Gy+0.2%EMS	100	6.00	0	2.00	1.00	2.00	0	11.00
	400Gy+0.2%EMS	250	6.80	0.40	0.80	0	1.20	0	9.20
	Total	700	18.80	1.90	6.30	1.00	4.70	0.50	33.20

2.00% in panicle size, 1.00% in panicle shape and 2.00% in seed characteristics. Total frequency of 9.20% mutations were found in a dosage of 400Gy+0.2%EMS with a frequency of 6.80% for early mutants, 0.4% in branching, 0.80% in panicle size and 2.00% in seed characteristics.

4.1.3.2 Yield traits

4.1.3.2.1 Variety: DSV-5

Performance of selected M_2 mutants of *rabi* sorghum variety DSV-5 for yield traits has been tabulated in Table 6a. In this variety, mutants were found for partial sterility. Partial sterile was having lesser grain yield 25.6 g compared check 77 g.

4.1.3.2.2 Variety: DSV-4

Performance of selected M_2 mutants of *Rabi* sorghum variety DSV-4 for yield traits has been tabulated in Table 6b. In this variety, grain weight of check was 70.5 g. There were 3 early mutants with high grain weight compared to check. Six mutants in panicle size and four in panicle shape were recorded with higher yield. Two mutants in seed type were recorded with higher yield and one partial sterile mutant with lesser grain yield of 28.66 g was observed.

4.1.3.2.3 Variety: CSV 216R

Performance of selected M_2 mutants of *Rabi s*orghum variety CSV 216R for yield traits has been tabulated in Table 6c. In this variety grain weight of check was 84.5 g/plant. There were nine early mutants, one in branching, five in panicle size, one in panicle shape and five in seed type mutants recorded with high grain yield (g/plant) compared to checks. One partial sterile mutant recorded with lesser grain yield of 32.76 g/plant compared to check.

4.1.4 Genetic components

The results pertaining to genetic parameters *viz*., mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad sense heritability (h^2) and genetic advance over mean (GAM) were computed using the data generated in M_2 populations to know the extent of variability for yield traits (Table 7).

Table 6a. Performance of selected M_2 mutants of *rabi* sorghum variety DSV-5 for yield traits

Mutants	Doses	Treatments	Plant height (cm)	Panicle length (cm)	Panicle breadth (cm)	Panicle weight (g)	Grain yield (g/pl)	100 seed weight (g)
Early	0	0	0	0	0	0	0	0
Branching	0	0	0	0	0	0	0	0
Panicle size	0	0	0	0	0	0	0	0
Panicle shape	0	0	0	0	0	0	0	0
Partial sterile	0	Check	**238**	**22.3**	**4.9**	**87**	**77**	**4.35**
	0.2% EMS	1024-4	238	17	4.5	30	23.34	4.27
	0.2% EMS	1026-3	263	26	4	39	25.6	3.78

Table 6b. Performance of selected M_2 mutants of *rabi* sorghum variety DSV-4 for yield traits

Mutants	Doses	Treatments	Plant ht (cm)	Panicle length (cm)	Panicle breadth (cm)	Panicle weight (g)	Grain yield (g/pl)	100 seed weight (g)
Early	0	Check	**220**	**24.5**	**6**	**101**	**70.5**	**4.2**
	400 Gy	1058-2	285	28	8.5	203	146.31	4.21
	0.2%EMS	1070-1	255	26	7	114	88.22	3.4
	0.2%EMS	1070-3	198	27	5.5	50	28	3.61
	0.2%EMS	1070-5	260	25	6	100	52.07	3.75
	0.2%EMS	1070-8	220	21	6	75	53.92	2.95
	0.2%EMS	1070-11	200	21	5	40	23.13	3.61
	0.2%EMS	1071-7	237	25	5.5	51	32.88	3.41
	0.2%EMS	1072-9	252	23	6	76	55.19	4.4
	0.2%EMS	1072-12	250	24	5.5	83	61.78	3.71
	0.2%EMS	1072-15	200	26	6.5	116	82.586	3.72
Branching	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Panicle size	0	Check	**220**	**24.5**	**6**	**101**	**70.5**	**4.2**
	400Gy	1058-2	285	28	8.5	203	146.31	4.21
	400Gy	1058-12	270	27	6.5	102	71.4	3.99
	400Gy	1059-17	254	30	7	134	93	3.93
	0.2%EMS	1068-5	188	17	4.5	21	15.91	2.76
	0.2%EMS	1069-16	211	32	7	107	78.47	3.15
	0.2%EMS	1072-15	200	26	6.5	116	82.586	3.72
	350+0.2%EMS	1077-1	231	30	7	61	32.29	3.55
Panicle shape	0	Check	**220**	**24.5**	**6**	**101**	**70.5**	**4.2**
	400Gy	1053-1	295	28	8	120	105.46	3.69
	400Gy	1058-2	285	28	8.5	203	146.31	4.21
	400Gy	1058-12	270	27	6.5	102	71.4	3.99
	0.2%EMS	1061-10	214	22	6.5	71	43.58	2.92
	0.2%EMS	1067-16	156	23	7.5	104	82.23	4.44
	350+0.2%EMS	1111-2	232	18	8	122	90.43	4.91
	350+0.2%EMS	1077-1	231	30	7	61	32.29	3.547
Seed type	0	Check	**220**	**24.5**	**6**	**101**	**70.5**	**4.2**
	400Gy	1058-2	285	28	8.5	203	146.31	4.21
	400Gy	1058-12	270	27	6.5	102	71.4	3.99
	350+0.2%EMS	1074-1	142	28	4.5	23	10.71	2.15
	350+0.2%EMS	1074-9	141	26	6.5	50	37.05	2.12
	350+0.2%EMS	1077-1	231	30	7	61	32.29	3.55
Partial sterile	0	Check	**220**	**24.5**	**6**	**101**	**70.5**	**4.2**
	400Gy	1059-16	230	28	5.5	46	28.66	4.11

Table 6c. Performance of selected M_2 mutants of *rabi* sorghum variety CSV 216R for yield traits

Mutants	Doses	Treatments	Plant ht (cm)	Panicle length (cm)	Panicle breadth (cm)	Panicle weight (g)	Grain yield (g/pl)	100 seed weight (g)
Early	0	Check	**220**	**19.5**	**5**	**105.5**	**84.5**	**4.25**
	350Gy	1095-2	186	18	7.5	66	49.64	2.57
	350Gy	1095-3	191	19	7	96	74.55	3.63
	350Gy	1095-6	188	18	8	137	100.2	4.54
	350+0.2%EMS	1112-1	228	19	6.5	74	47.68	3.05
	350+0.2%EMS	1112-2	249	23	7.5	208	152.12	4.88
	350+0.2%EMS	1112-3	236	22	6	91	65.26	3.87
	350+0.2%EMS	1112-6	208	20	5	124	91.98	4.21
	350+0.2%EMS	1112-10	239	19	6	78	59.06	3.91
	350+0.2%EMS	1112-12	154	22	5	105	80.73	3.90
	400+0.2%EMS	1113-3	215	22	6	135	97.75	4.59
	400+0.2%EMS	1113-4	212	20	8	165	119.25	3.69
	400+0.2%EMS	1113-6	243	22	5	88	61.95	4.47
	400+0.2%EMS	1115-3	253	22	5	121	93.95	4.00
	400+0.2%EMS	1115-5	258	19	6	74	66.5	2.86
	400+0.2%EMS	1115-6	257	20	6	93	74.17	3.99
	400+0.2%EMS	1115-8	233	18	5.5	74	58.29	3.23
	400+0.2%EMS	1115-16	260	19	5.5	77	54.25	4.26
	400+0.2%EMS	1115-21	204	23	6	110	83.98	4.78
	400+0.2%EMS	1116-6	197	20	6	109	87.72	4.52
	400+0.2%EMS	1118-4	240	21	6	116	85.53	4.96
	400+0.2%EMS	1118-6	242	22	4	11	84.32	4.86
	400+0.2%EMS	1118-8	270	19	6	68	50.67	4.12
	400+0.2%EMS	1118-12	252	20	5	59	44.78	4.25
	400+0.2%EMS	1121-5	172	18	7	69	50.21	4.80
	400+0.2%EMS	1122-15	240	18	6	80	63.51	4.35
	400+0.2%EMS	1122-16	185	15	4	94	72.2	3.83
Branching	0	Check	**220**	**19.5**	**5**	**105.5**	**84.5**	**4.25**
	0.2%EMS	1102-6	203	18	6	57	32.76	3.72
	0.2%EMS	1104-1	240	20	6.5	114	79.92	4.86
	0.2%EMS	1108-2	210	21	6	114	86.85	4.10
	400+0.2%EMS	1119-1	236	21	6	75	49.54	4.12

Table 6c. Contd…..

Mutants	Doses	Treatments	Plant ht (cm)	Panicle length (cm)	Panicle breadth (cm)	Panicle weight (g)	Grain yield (g/pl)	100 seed weight (g)
Panicle size	0	Check	**220**	**19.5**	**5**	**105.5**	**84.5**	**4.25**
	350Gy	1095-4	170	22	10	196	137.92	4.43
	400Gy	1099-1	139	23	7	136	98.93	3.94
	0.2%EMS	1108-2	210	21	6	114	86.85	4.10
	350+0.2%EMS	1110-3	260	21	9	182	135.4	4.27
	350+0.2%EMS	1112-3	236	22	6	91	65.26	3.87
	400+0.2%EMS	1113-4	212	20	8	165	119.25	3.69
	400+0.2%EMS	1113-6	243	22	5	88	61.95	4.47
Panicle shape	0	Check	**220**	**19.5**	**5**	**105.5**	**84.5**	**4.25**
	350+0.2%EMS	1111-2	232	18	8	122	90.43	4.91
Seed type	0	Check	**220**	**19.5**	**5**	**105.5**	**84.5**	**4.25**
	0.2%EMS	1104-1	240	20	6.5	114	79.92	4.86
	0.2%EMS	1108-1	216	21	8	135	104.94	4.32
	0.2%EMS	1108-2	210	21	6	114	86.85	4.10
	350+0.2%EMS	1110-3	260	21	9	182	135.4	4.27
	350+0.2%EMS	1111-2	232	18	8	122	90.43	4.91
	400+0.2%EMS	1115-3	253	22	5	121	93.95	4.00
	400+0.2%EMS	1119-1	236	21	6	75	49.54	4.12
	400+0.2%EMS	1121-5	172	18	7	69	50.21	4.804
Partial sterile	0	Check	**220**	**19.5**	**5**	**105.5**	**84.5**	**4.25**
	0.2%EMS	1102-6	203	18	6	57	32.76	3.72

Table 7. Variability parameters for yield traits in the M_2 generation of three *rabi* sorghum varieties

Variety		DFF	PH	PL	PB	PW	GY	HGW
DSV-5	Mean	80.72	243.38	20.94	5.67	88.74	69.23	4.06
	PCV (%)	11.99	11.54	14.13	13.51	25.68	25.43	14.53
	GCV (%)	2.17	4.01	3.91	5.43	12.07	13.15	5.80
	h^2	3.30	12.10	7.70	16.10	22.10	26.70	16.00
	GA @ 5%	0.65	6.98	0.47	0.26	10.37	9.69	0.19
	GA @ 1%	0.84	8.94	0.60	0.33	13.28	12.42	0.25
DSV4	Mean	78.62	233.33	25.40	6.33	80.96	61.72	3.77
	PCV (%)	11.57	14.22	12.65	16.57	27.40	30.71	16.34
	GCV (%)	3.92	8.22	8.34	4.86	13.08	14.44	8.93
	h^2	11.50	33.40	43.50	8.60	22.80	22.10	29.90
	GA @ 5%	2.16	22.84	2.88	0.19	10.41	8.64	0.38
	GA @ 1%	2.76	29.27	3.69	0.24	13.34	11.07	0.49
CSV216R	Mean	72.55	219.52	19.77	6.10	99.38	77.74	4.16
	PCV (%)	6.98	15.36	10.16	19.51	26.54	26.38	12.07
	GCV (%)	4.94	10.37	4.40	8.68	6.45	7.97	4.30
	h^2	50.10	45.60	18.80	19.80	5.90	9.10	12.70
	GA @ 5%	5.22	31.65	0.78	0.49	3.21	3.85	0.13
	GA @ 1%	6.69	40.56	0.99	0.62	4.11	4.94	0.17

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant (g), HGW-100 grain weight (g)

4.1.4.1 Variety: DSV-5

4.1.4.1.1 Days to 50 % flowering

The mean number of days to flowering was 80.72 days. Low estimates of heritability (h^2 = 3 %), moderate of PCV (11.54 %), low GCV (4.01 %) and GAM (0.65 %) were recorded for the trait (Table 7).

4.1.4.1.2 Plant height (cm)

The mean panicle length was 243.38 cm. Low estimates of heritability (h^2= 12 %), moderate magnitude of PCV (11.54 %), low GCV (4.01 %), and low estimates of GAM (6.98 %) were recorded (Table 7).

4.1.4.1.3 Panicle length (cm)

The mean number panicle length was 20.94 cm. Low estimates of heritability (h^2= 8 %), moderate magnitude of PCV (14.13 %), low GCV (3.91 %), and low estimates of GAM (0.47 %) were recorded for panicle length (Table 7).

4.1.4.1.4 Panicle breadth (cm)

Mean panicle breadth was 5.67 cm. Low estimates of heritability (h^2=16%), moderate magnitude of PCV (13.51 %) and low of GCV (5.43 %), and low estimates of GAM (0.26%) were recorded for panicle breadth (Table 7).

4.1.4.1.5 Panicle weight (g)

For panicle weight M_2 population showed a mean value of 88.74 g. Low estimates of heritability (h^2 = 22 %), high magnitude of PCV (25.68 %), moderate magnitude of GCV (12.07 %) and moderate GAM (10.37 %) were recorded (Table 7).

4.1.4.1.6 Grain weight (g/plant)

For grain weight/plant M_2 population showed a mean value of 69.23 g. Low estimates of heritability (h^2 = 27%), high magnitude of PCV (25.43 %), moderate magnitude of GCV (13.15 %) and low GAM (9.69 %) were recorded (Table 7).

4.1.4.1.7 100 seed weight (g)

The mean for 100 seed weight was 4.06 g. Low estimates of heritability (h^2=16 %), moderate magnitude of PCV (14.53 %), low GCV (5.80 %), and low estimates of GAM (0.19 %) were recorded for 100 seed weight (Table 7).

4.1.4.2 Variety: DSV-4

4.1.4.2.1 Days to 50 % flowering

The mean number of days to flowering was 78.62 days. Low estimates of heritability (*h^2* =12 %), moderate of PCV (11.57 %), low GCV (3.92 %) and GAM (2.16 %) were recorded for the trait (Table 7).

4.1.4.2.2 Plant height (cm)

The mean plant height recorded was 233.33 cm. Moderate estimates of heritability (*h^2*= 33 %), moderate magnitude of PCV (14.22 %) and low GCV (8.22 %) and high estimates of GAM (22.84 %) were recorded (Table 7).

4.1.4.2.3 Panicle length (cm)

The mean number panicle length was 25.40 cm. Moderate estimates of heritability (*h^2*= 44 %), moderate magnitude of PCV (12.65 %), low GCV (8.34 %), and low estimates of GAM (2.88 %) were recorded for panicle length (Table 7).

4.1.4.2.4 Panicle breadth (cm)

Mean panicle breadth was 6.33 cm. Low estimates of heritability (*h^2*=19%), moderate magnitude of PCV (16.57 %) and low of GCV (4.86 %), and low estimates of GAM (0.19%) were recorded for panicle breadth (Table 7).

4.1.4.2.5 Panicle weight (g)

For panicle weight M_2 population showed a mean value of 80.96 g. Low estimates of heritability (*h^2* = 23 %), high magnitude of PCV (27.40 %), moderate magnitude of GCV (13.08 %) and moderate GAM (10.41 %) were recorded (Table 7).

4.1.4.2.6 Grain weight (g/plant)

For grain weight/plant, M_2 population showed a mean value of 61.72 g. Low estimates of heritability (*h^2* = 22%), high magnitude of PCV (30.71 %), moderate magnitude of GCV (14.44 %) and low GAM (8.64 %) were recorded (Table 7).

4.1.4.2.7 100 seed weight (g)

The mean of 100 seed weight was 3.77 g. Moderate estimates of heritability (*h^2*=30 %), moderate magnitude of PCV (16.34 %), low GCV (8.93 %), and low estimates of GAM (0.30 %) were recorded for 100 seed weight (Table 7).

4.1.4.3 Variety: CSV 216R

4.1.4.3.1 Days to 50 % flowering

The mean number of days to flowering was 72.55. Moderate estimates of heritability (h^2 = 50%), low of PCV (6.98 %), GCV (4.94 %) and GAM (5.22 %) were recorded for the trait (Table 7).

4.1.4.3.2 Plant height (cm)

The mean plant height recorded was 219.52 cm. Moderate estimates of heritability (h^2= 46 %), moderate magnitude of PCV (15.36 %) and GCV (10.37 %) and high estimates of GAM (31.65 %) were recorded for the trait (Table 7).

4.1.4.3.3 Panicle length (cm)

The mean panicle length was 19.77 cm. Low estimates of heritability (h^2= 19 %), moderate magnitude of PCV (10.16 %), low GCV (4.40 %), and low estimates of GAM (0.78 %) were recorded for panicle length (Table 7).

4.1.4.3.4 Panicle breadth (cm)

Mean panicle breadth was 6.10 cm. Low estimates of heritability (h^2=20%), moderate magnitude of PCV (19.51 %) and low of GCV (8.68 %), and low estimates of GAM (0.0.49%) were recorded for panicle breadth (Table 7).

4.1.4.3.5 Panicle weight (g)

For panicle weight M_2 population showed a mean value of 99.38 g. Low estimates of heritability (h^2 = 6 %), high magnitude of PCV (26.54 %), low magnitude of GCV (6.45 %) and low GAM (3.21 %) were recorded (Table 7).

4.1.4.3.6 Grain weight (g/pl)

For grain weight (g/pl), M_2 population showed a mean value of 77.74 g. Low estimates of heritability (h^2 = 9%), high magnitude of PCV (26.38 %), low magnitude of GCV (7.97 %) and low GAM (3.85%) were recorded (Table 7).

4.1.4.3.7 100 seed weight (g)

The mean of 100 seed weight was 4.16 g. Low estimates of heritability (h^2=13 %), moderate magnitude of PCV (12.07 %), low GCV (4.30 %), and low estimates of GAM (0.13 %) were recorded for 100 seed weight (Table 7).

4.2 M_3 Generation

4.2.1 Analysis of variance

Analysis of variance (ANOVA) was carried out for yield and yield component traits by using the replicated data on the same 'F' test was conducted to examine the significance of variances. Mean sum of squares for the various yield traits are presented in Table 8. Significant mean sum of square values were not observed for yield traits as indicated by the non-significant variances for these traits. Replication sum of squares were found non significant for all the yield component traits.

4.2.2 Mean and range

4.2.2.1 Variety: DSV-5

Mean and range values in M3 generation of Rabi sorghum variety DSV-5 for yield and yield components across different mutation treatment combinations have been tabulated in table 9a.

4.2.2.1.1Seedling height (cm) (30DAS)

Mean value for the trait for zero dosage (control) was 66.20 cm. Wide range of values were observed for the trait. Highest mean value for seedling height (68.63 cm) was recorded in a dosage of 400Gy+0.2EMS% (Table 9a). Across mutation treatments, lowest and highest values were recorded for the trait in 350 Gy.

4.2.2.1.2 Days to 50% flowering

Mean value for zero dosage (control) is (85 days). Lower mean value (83.33 days) was recorded in a dosage of 400Gy+0.2EMS%. (Table 9a). Among the treatments, wide range was observed for the trait in treatment 350 Gy covering the genotypes with lowest and highest values.

4.2.2.1.3 SPAD readings (at flowering)

Mean value for zero dosage (control) was 52.18. Highest mean value (50.95) for SPAD readings at flowering was recorded in a dosage of EMS (0.2%) (Table 9a).

4.2.2.1.4 Days to maturity

Mean value for zero dosage (control) was 125 days). Among the treatments lowest mean value (123.47 days) was recorded in a dosage of 400Gy+0.2EMS% (Table 9a).

Table 8. Mean sum of square values for various traits in M_3 families of three varieties in *rabi* sorghum

Source of Variation	Replication	Treatment	Error	SEM	C. D. at 5 %
Characters/ Degrees of freedom	2	161	322		
Seedling height	251.37	129.57	68.83	4.77	13.32
Days to 50% flowering	29.59	112.36	4.59	1.23	3.44
SPAD at 50% flowering	44.79	28.24	11.78	1.97	5.51
Days to maturity	30.68	112.68	4.31	1.19	3.33
SPAD at physiological maturity	4.30	3.00	1.92	0.79	2.22
Plant height	115.57	600.42	247.76	9.05	25.28
Number of nodes	3.65	1.15	0.72	0.49	1.37
Internodal length	14.42	5.59	2.87	0.97	2.72
Peduncle length	95.55	13.43	11.57	1.95	5.46
Panicle length	17.17	5.75	2.1	0.83	2.32
Panicle breadth	31.74	0.98	0.54	0.42	1.18
Panicle weight	160.52	118.22	52.3	4.16	11.61
Grain weight per plant	135.94	75.44	35.44	3.42	9.56
100 seeds weight	0.72	0.52	0.12	0.2	0.56
Panicle harvest index	0.17	0.015	0.01	0.05	0.16

Table 9a. Mean and range values in M_3 families of *rabi* sorghum variety DSV-5 for yield and yield components across different mutation treatment combinations

Traits	Zero dose	350Gy		400Gy		0.2% EMS		350Gy+0.2%EMS		400Gy+0.2%EMS	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
SH	66.2	63.20-73.26	68.52	60.80-69.26	66.11	61.33-71.93	66.35	67.73	67.73	62.86-70.47	68.63
DFF	85	77.33-88.33	84.17	84.67-90.33	86.67	82-90	85.77	84.67	84.67	81.33-85.67	83.33
SPAD 1	52.18	47.61-55.61	50.86	47.91-51.78	50.45	47.27-54.02	50.95	50.04	50.04	49.3-51.83	50.76
DM	125	117.33-128.33	124.17	126.67-130.33	126.67	122-130	125.77	124.67	124.67	121.33-125.67	123.47
SPAD 2	10.4	4.11-20.11	11.37	6.31-11.14	8.61	6.13-9.80	7.99	11.14	11.14	7.23-12.85	10.18
PH	161.6	141.67-169.26	157.96	136.27-161.6	153.63	143.26-161.4	150.1	150.6	150.6	143.93-159.07	149.89
NN	8	7.40-8.53	8	7.67-8.6	8	7.2-8.86	8	8	8	8-8.47	8
INL	9.4	11.28-13.88	12.6	10.56-13.75	12.53	11.30-12.62	11.85	12.27	12.27	10.93-12.86	11.86
Pe L	27.4	22.47-29.73	26.29	21.20-28.2	25.73	20.2-32.26	26.69	27	27	22.13-33	26.81
Pa L	17.6	14.60-17.93	15.98	11.07-16.6	14.83	13.86-16.4	15.36	14.47	14.47	15.06-17.267	15.91
PB	4	3.77-5.46	4.51	2.93-4.93	4.03	3.66-4.8	4.21	4.53	4.53	3.76-4.33	3.98
PW	39	30.67-51.26	38.43	12.00-44.86	31.05	24.8-40.46	33.2	33.67	33.67	24.86-40.07	31.73
GW	29.4	21.20-39.93	29.93	7.33-32.33	23.11	16.93-33.73	25.1	27.4	27.4	16.46-31.2	23.88
HGW	3.33	2.87-3.77	3.34	2.45-3.78	3.12	2.91-3.76	3.36	3.11	3.11	3.10-4.0	3.41
PHI	0.74	0.64-0.90	0.77	0.54-0.75	0.69	0.62-0.82	0.74	0.81	0.81	0.65-0.95	0.75

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.2.1.5 SPAD readings (at physiological maturity)

Mean value for zero dosage (control) was 10.40. Among the treatments, highest mean value (11.37) and wide range (4.11-20.11) was observed for SPAD readings at physiological maturity in a dosage of 350 Gy. (Table 9a).

4.2.2.1.6 Plant height (cm)

Mean value for zero dosage (control) was 161.60 cm. Lowest mean value for plant height (149.89 cm) was recorded in a dosage of 400Gy+0.2EMS% (Table 9a).

4.2.2.1.7 Number of nodes

Mean value for zero dosage (control) 8 nodes. Mean value of 8 nodes was also recorded in all treatment combinations (Table 9a).

4.2.2.1.8 Internodal length (cm)

Mean value for zero dosage (control) 9.40 cm. Highest mean value for number of nodes was recorded in a dosage of 350Gy with a mean of 12.60 cm. (Table 9a).

4.2.2.1.9 Peduncle length (cm)

Mean value for zero dosage (control) was 27.4 cm. Highest mean value (26.69) and wider range (20.2-32.26) for peduncle length was recorded in a dosage of 0.2%EMS (Table 9a).

4.2.2.1.10 Panicle length (cm)

Mean value for zero dosage (control) for the trait panicle length was 17.60 cm (Table 9a). All the treatment combinations were recorded with mean values lower than control. Wide range (11.07-16.6) was recorded in 400 Gy (Table 9a).

4.2.2.1.11 Panicle breadth (cm)

Mean value for zero dosage (control) 4 cm. Highest mean value for panicle breadth was recorded in a dosage of 350Gy+0.2%EMS with a mean of 4.53 cm followed by dosage 350 Gy with mean value (4.51 cm).Range was also wider (3.77-5.46) in 350 Gy (Table 9a).

4.2.2.1.12 Panicle weight (g)

Mean value for zero dosage (control) 39 g. All the treatment combinations recorded mean values lower than control with highest mean value (38.43 g) and wide rang (30.67-51.26) recorded in a dosage of 350Gy (Table 9a).

4.2.2.1.13 Grain weight (g/plant)

Mean value for zero dosage (control) 29.40 g. Highest mean value (29.93 g) and wide range (21.20-39.93) was recorded in a dosage of 350Gy (Table 9a).

4.2.2.1.14 100 Grain weight (g/100 seeds)

Mean value for zero dosage (control) was 3.33 g. Highest mean value for 100 grain weight (3.41 g) was recorded in a dosage of 400Gy+0.2%EMS (Table 9a).

4.2.2.1.15 Panicle harvest index

Mean value for zero dosage (control) for the trait was 0.74. Highest mean value for panicle harvest index was recorded in a dosage of 350Gy+0.2%EMS with a mean of 0.81. Wide range of values, 0.64-0.90 and 0.65-0.95 were recorded in 350 Gy and 400 Gy+EMS (0.2%), respectively (Table 9a).

4.2.2.2 Variety: DSV-4

Mean and range values in M_3 families of Rabi sorghum variety DSV-4 for yield and yield components across different mutation treatment combinations have been tabulated in table 9b.

4.2.2.2.1 Seedling height (cm) (30DAS)

Mean value for zero dosage (control) 70 cm. In general, mean values across mutation treatments were lower than control with highest mean value (69.08 cm) for seedling height was recorded in a dosage of 400Gy+0.2EMS%. Wide range (57.06-106.33) was recorded in 400 Gy (Table 9b).

4.2.2.2.2 Days to 50% flowering

Mean value for zero dosage (control) was (82 days). Early flowering was recorded in a dosage of 350Gy+0.2EMS% with a mean of 77 days. Wide range of values (71.66-89.33) recorded in 0.2% EMS treatment (Table 9b).

4.2.2.2.3 SPAD readings (at flowering)

Range value for zero dosage (control) is (39.80-57.2), with a mean of 45.74. Highest mean (51.34) and wide range value (45.74-57.94) for SPAD readings at flowering were recorded in a dosage of 350Gy+0.2EMS% (Table 9b).

Table 9b. Mean and range values in M_3 families of *rabi* sorghum variety DSV-4 for yield and yield components across different mutation treatment combinations

Traits	Zero dose	350Gy		400Gy		0.2% EMS		350Gy+0.2%EMS		400Gy+0.2%EMS	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
SH	70	61.93-72.86	65.5	57.06-106.33	66.37	46.60-74	64.74	58.26-68	61.95	65.73-70.66	69.08
DFF	82	74.00-82.33	78.97	77.33-82.33	79.48	71.66-89.33	79.38	70.33-85	77.29	79-86	83.81
SPAD 1	45.74	43.22-51.02	47.51	44.82-51.26	47.83	44.28-57.33	49.23	45.74-57.94	51.34	45.82-53.84	50.22
DM	122	114.00-122.33	118.97	117.33-122.33	119.67	111.66-129.33	119.38	110.33-125	117.29	119-126	123.81
SPAD 2	5.04	6.40-12.41	9.47	5.9-11.87	7.92	5.41-12.15	8.8	5.92-12.01	8.29	6.28-12.06	8.41
PH	149.8	121.27-147.6	133.65	131.6-155.66	142.78	119.86-165.33	144.36	102.33-149.8	125.15	138.86-160.06	146.17
NN	8	6.87-8	8	7-7.93	7	6.46-8	7	4.93-7.7333	6	7.06-7.86	7
INL	8.6	10.18-12.17	10.84	9.98-12.24	11.13	9.17-14.32	11.87	8.72-13.2067	10.84	11.35-16.66	12.82
Pe L	25.6	24.53-31.4	28.22	24.93-33.4	28.23	21.8-38.86	28.12	26.26-35.2667	30.14	24.6-31	27.8
Pa L	15.8	15.67-17.2	16.37	15.2-18.73	17.09	13.73-18.53	15.94	14.66-20.2	17.1	14.53-17.13	15.47
PB	4	3.63-4.93	4.45	3.93-5.06	4.52	3.46-5.13	4.38	2.93-5	3.83	3.8-5.26	4.46
PW	28.2	20.20-40.13	30.63	25.46-45.66	32.35	20.53-47.13	34.19	18.4-36.2	28.26	25.53-48.66	35.13
GW	19.4	11.87-32.53	21.97	14.73-35.26	22.63	9.8-37.4	24.04	9.5-25.4	19.88	19.8-38	26.41
HGW	3.62	2.36-3.03	2.69	2.46-3.17	2.88	2.47-3.64	2.95	2.4-3.2687	2.8	2.77-3.94	3.34
PHI	0.6	0.59-0.87	0.7	0.15-0.90	0.69	0.45-0.80	0.67	0.45-0.8637	0.67	0.63-0.80	0.75

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.2.2.4 Days to maturity

Mean value for zero dosage (control) 122 days. Early maturity was recorded in a dosage of 350Gy+0.2EMS% with a mean of 117 days (Table 9b).

4.2.2.2.5 SPAD readings (at physiological maturity)

Mean value for zero dosage (control) was 5.04. Highest mean value (9.47) of SPAD readings at physiological maturity were recorded in a dosage of 350Gy (Table 9b).

4.2.2.2.6 Plant height (cm)

Mean value for zero dosage (control) was 149.80 cm. Lowest mean value (125.15 cm) and wide range (102.33-149.8) for plant height was recorded in a dosage of 350Gy+0.2EMS% (Table 9b).

4.2.2.2.7 Number of nodes

Mean value for zero dosage (control) was 8 nodes. Lowest mean value (6 nodes) and wide range (4.9-7.7) for number of nodes was recorded in a dosage of 350Gy+0.2EMS% (Table 9b).

4.2.2.2.8 Internodal length (cm)

Mean value for zero dosage (control) was 8.60 cm. Highest value for number of nodes was recorded in a dosage of 400Gy+0.2% with a mean of 12.82 cm (Table 9b).

4.2.2.2.9 Peduncle length (cm)

Mean value for zero dosage (control) was 25.60 cm. Highest value for peduncle length was recorded in a dosage of 350Gy+0.2%EMS with a mean of 30.14 cm (Table 9b). Wide range of values for the trait 21.8-38.86 cm was recorded in treatment EMS (0.2%) (Table 9b).

4.2.2.2.10 Panicle length (cm)

Mean value for zero dosage (control) was 15.80 cm. Highest mean value (17.09) and wide range (14.66-20.2) for panicle length were recorded in a dosage of 350 Gy+EMS (0.2%) (Table 9b).

4.2.2.2.11 Panicle breadth (cm)

Mean value for zero dosage (control) was 4 cm. Highest value for panicle breadth was recorded in a dosage of 400Gy with a mean of 4.52 cm. (Table 9b).

4.2.2.2.12 Panicle weight (g)

Mean value for zero dosage (control) was 28.20 g. Highest mean value of 35.13 g and wide range (20.53-47.13) for panicle weight was recorded in a dosage of 400Gy+0.2%EMS and EMS (0.2%), respectively (Table 9b).

4.2.2.2.13 Grain weight (g/plant)

Mean value for zero dosage (control) was 19.40 g. Highest mean value (35.13 g) and wide range (19.8-38) for grain weight was recorded in a dosage of 400Gy+0.2%EMS (Table 9b).

4.2.2.2.14 100 Grain weight (g/100 seeds)

Mean value for zero dosage (control) was 3.34 g. Highest value for 100 grain weight was recorded in a dosage of 400Gy+0.2%EMS with a mean of 3.34 g (Table 9b).

4.2.2.2.15 Panicle harvest index

Mean value for zero dosage (control) was 0.60. Highest value for panicle harvest index was recorded in a dosage of 400Gy+0.2%EMS with a mean of 0.75 (Table 9b).

4.2.2.3 Variety: CSV 216R

Mean and range values in M3 families of Rabi sorghum variety CSV 216R for yield and yield components across different mutation treatment combinations have been tabulated in table 9c.

4.2.2.3.1 Seedling height (cm) (30DAS)

Mean value for zero dosage (control) was 72 cm. Highest mean value (74.55 cm) and wide range (46.20-79.53) for seedling height was recorded in a dosage of 400Gy+0.2EMS% and 350 Gy, respectively (Table 9c).

4.2.2.3.2 Days to 50% flowering

Mean value for zero dosage (control) was 76 days. Early flowering was recorded in a dosage of 400Gy+0.2EMS% with a mean of 70.65 days and wide range (69.67-80) was recorded in 350 Gy (Table 9c).

4.2.2.3.3 SPAD readings (at flowering)

Mean value for zero dosage (control) was 49.32. Highest mean value (53.60) for SPAD readings at flowering were recorded in a dosage of 400Gy+0.2EMS% (Table 9c).

Table 9c. Mean and range values in M_3 families of *rabi* sorghum variety CSV 216R for yield and yield components across different mutation treatment combinations

Traits	Zero dose	350Gy		400Gy		0.2% EMS		350Gy+0.2%EMS		400Gy+0.2%EMS	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
SH	72	46.20-79.53	71.86	66.27	66.27	67.40-77.46	72.89	69.73-77.93	73.43	67.66-79.87	74.55
DFF	76	69.67-80	72.29	82.67	82.67	70.33-76.33	72.9	70.33-77.66	72.4	68-75	70.65
SPAD 1	49.32	48.38-53.57	50.8	46.51	46.51	49.45-55.08	51.57	46.35-56.36	52.29	50.49-56.28	53.6
DM	119	109.67-120	112.29	122.67	122.67	110.33-116.33	112.9	110.33-117.66	112.4	108-115	110.64
SPAD 2	4.46	6.11-15.16	8.61	12.37	12.37	5.39-10.32	7.2	4.59-14.39	7.88	5.4-12.31	8.61
PH	164.4	110.13-177	152.91	166.67	166.67	142.67-156.46	148.45	144-181.53	164.41	138.13-179.13	158.59
NN	8	6.07-7.53	7	7	7	7.00-8	7	6.80-8.13	7	6.4-8.07	7
INL	11.8	11.97-15.02	13.4	13.12	13.12	9.82-15.53	12.87	12.97-15.32	13.9	12.25-15.92	13.89
Pe L	26.8	20.73-33.8	27.81	26.07	26.07	21.33-32.06	26.33	25.40-32.8	28.67	24.2-33.53	28.65
Pa L	16.8	12.87-15.86	14.39	15.6	15.6	12.23-15.86	13.59	13.33-17.26	15.92	13.33-17	15.03
PB	6.8	4.03-5.23	4.7	5.6	5.6	4.07-5.86	5.02	4.53-5.73	5.2	4.4-5.47	5.01
PW	94.6	35.47-55.6	42.2	42.73	42.73	36.07-52.86	45.13	37.73-61.93	48.66	32.33-58.07	43.62
GW	75.8	24.87-44	31.48	34.73	34.73	28.20-43.53	36.31	25.20-49.66	37.35	23.86-44.40	32.7
HGW	3.41	2.65-3.71	2.94	2.91	2.91	2.21-4.08	3.15	2.06-3.75	2.88	1.92-3.6	2.75
PHI	0.79	0.63-0.83	0.75	0.83	0.83	0.78-0.82	0.81	0.67-0.80	0.76	0.65-0.81	0.75

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.2.3.4 Days to maturity

Mean value for zero dosage (control) was 119 days. Early maturity was recorded in a dosage of 400Gy+0.2EMS% with a mean of 110.64 days (Table 9c).

4.2.2.3.5 SPAD readings (at physiological maturity)

In general SPAD readings were lower in both control and M3 families across all mutation treatment dosages. Mean value for zero dosage (control) was 4.46. Highest mean value SPAD readings at physiological maturity were recorded in a dosage of 400Gy (12.37) (Table 9c).

4.2.2.3.6 Plant height (cm)

Mean value for zero dosage (control) was 164.40 cm. Lowest value for plant height was recorded in a dosage of EMS (0.2%) with a mean of 148.45 cm (Table 9c).

4.2.2.3.7 Number of nodes

Mean value for zero dosage (control) was 8 nodes. Mean value of 7 nodes was recorded in all treatment combinations (Table 9c).

4.2.2.3.8 Internodal length (cm)

Mean value for zero dosage (control) was 11.8 cm. Highest mean value of 13.87 cm for internodal length was recorded in a dosage of 400Gy+0.2EMS% (Table 9c).

4.2.2.3.9 Peduncle length (cm)

Mean value for zero dosage (control) was 26.80 cm. Highest mean value of 28.67 cm for peduncle length was recorded in a dosage of 350Gy0.2%EMS (Table 9c).

4.2.2.3.10 Panicle length (cm)

Mean value for zero dosage (control) was 16.80 cm. Highest mean value of 15.92 cm for panicle length among M_3 families was recorded in a dosage of 350Gy+0.2%EMS (Table 9c).

4.2.2.3.11 Panicle breadth (cm)

Mean value for zero dosage (control) was 6.8 cm. Highest mean value 5.60 cm for panicle breadth was recorded among M_3 families in a dosage of 400Gy (Table 9c).

4.2.2.3.12 Panicle weight (g)

Mean value for zero dosage (control) was 94.6 g. Highest mean value of 48.66 g for panicle weight was recorded in a dosage of 350Gy+0.2%EMS. None of the entry was recorded with values higher than control for the trait (Table 9c).

4.2.2.3.13 Grain weight (g/plant)

Mean value for zero dosage (control) was 75.8 g. Highest mean value of 37.35 g for grain weight was recorded in a dosage of 350Gy+0.2%EMS (Table 9c).

4.2.2.3.14 100 Grain weight (g/100 seeds)

Mean value for zero dosage (control) was 3.41 g. Highest mean value of 3.15 g and wide range of 2.21-4.08 g within M3 families for 100 grain weight were recorded in a dosage of 0.2%EMS (Table 9c).

4.2.2.3.15 Panicle harvest index

Mean value for zero dosage (control) was 0.79. Highest mean value of 0.83 for panicle harvest index was recorded in a dosage of 400Gy (Table 9c).

4.2.3 Genetic components

The results pertaining to genetic parameters *viz*., mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad sense heritability (h^2) and genetic advance over mean (GAM) were computed using the data generated in M_3 populations of each variety to know the extent of variability for yield traits. The results are presented below.

4.2.3.1 Variety: DSV-5

Wide range of values were observed among M_3 families for all the traits except for SPAD 1 and number of nodes. The results on estimates of genetic components obtained DSV 5 are presented in Table 10a.

4.2.3.1.1 Seedling height (cm) (30DAS)

The mean number of seedling height was 67.57 cm. Low estimates of heritability (h^2 = 2%), low of PCV (8.26 %), low GCV (1.20 %) and low GAM (0.36 %) were recorded for the trait (Table 10a).

Table 10a. Genotypic and Phenotypic coefficients of variation, heritability and genetic advance for various traits in M_3 families of *rabi* sorghum variety DSV-5

Character	RANGE		Mean	PCV (%)	GCV (%)	*h2*	GAM
	Min.	Max.				%	%
SH	60.80	73.27	67.57	8.26	1.20	2.0	0.36
DFF	77.33	90.33	84.78	3.23	2.49	59.0	3.97
SPAD 1	47.27	55.61	50.83	6.59	1.36	4.0	0.58
DM	117.33	130.33	124.79	2.19	1.69	59.0	2.68
SPAD 2	4.11	20.12	10.00	49.87	11.69	5.0	5.64
PH	136.27	169.27	154.33	8.75	1.42	2.0	0.47
NN	7.20	8.87	8.03	6.63	2.31	12.0	1.66
INL	10.56	13.89	12.3	9.17	3.90	18.0	3.42
Pe L	20.2	33.00	26.55	15.95	6.17	15.0	4.93
Pa L	11.07	17.93	15.67	9.28	5.23	31.0	6.06
PB	2.93	5.46	4.32	15.04	6.32	17.0	5.48
PW	12.00	51.26	35.43	29.11	11.35	15.0	9.11
GW	7.33	39.93	27.19	34.34	14.15	17.0	12.02
HGW	2.45	3.99	3.31	12.54	7.71	37.0	9.77
PHI	0.54	0.95	0.75	14.91	6.63	19.0	6.08

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.3.1.2 Days to 50% flowering

The mean number of days to 50% flowering was 84.78 days. Moderate estimates of heritability (h^2 =59%), low of PCV (3.23 %), low GCV (2.49 %) and low GAM (3.97 %) were recorded for the trait (Table 10a).

4.2.3.1.3 SPAD readings (at flowering)

The mean of SPAD reading at flowering was 50.83. Low estimates of heritability (h^2 = 4%), low of PCV (6.59 %), low GCV (1.36 %) and low GAM (0.58 %) were recorded for the trait (Table 10a).

4.2.3.1.4 Days to maturity

The mean number of days to maturity was 124.79 days. High estimates of heritability (h^2 =59 %), low of PCV (2.19 %), low GCV (1.69 %) and low GAM (2.68 %) were recorded for the trait (Table 10a).

4.2.3.1.5 SPAD readings (at physiological maturity)

The mean of SPAD reading at physiological maturity was 10.0. Low estimates of heritability (h^2 =5%), high magnitude of PCV (49.87 %), moderate GCV (11.69 %) and low GAM (5.64 %) were recorded for the trait (Table 10a).

4.2.3.1.6 Plant height (cm)

The mean plant height was 154.33 cm. Low estimates of heritability (h^2= 2 %), low magnitude of PCV (8.75%), low GCV (1.42 %), and low estimates of GAM (0.47 %) were recorded for plant height (Table 10a).

4.2.3.1.7 Number of nodes

The mean number of nodes was 8.03. Low estimates of heritability (h^2 = 12%), low magnitude of PCV (6.63 %), low GCV (2.31 %) and low GAM (1.66 %) were recorded for the trait (Table 10a).

4.2.3.1.8 Internodal length (cm)

The mean Internodal length was 12.30 cm. Low estimates of heritability (h^2= 18 %), low magnitude of PCV (9.17 %), low GCV (3.90 %) and low estimates of GAM (3.42 %) were recorded for internodal length (Table 10a).

4.2.3.1.9 Peduncle length (cm)

The mean peduncle length was 26.55 cm. Low estimates of heritability (h^2= 15%), moderate magnitude of PCV (15.95 %), low GCV (6.17 %), and low estimates of GAM (4.93 %) were recorded for peduncle length (Table 10a).

4.2.3.1.10 Panicle length (cm)

The mean panicle length was 15.67 cm. Moderate estimates of heritability (h^2= 31%), low magnitude of PCV (9.28 %), low GCV (5.23 %) and low estimates of GAM (6.06 %) were recorded for panicle length (Table 10a).

4.2.3.1.11 Panicle breadth (cm)

Mean panicle breadth was 4.32 cm. Low estimates of heritability (h^2=17%), moderate magnitude of PCV (15.03 %) and low of GCV (6.32 %), and low estimates of GAM (5.48 %) were recorded for panicle breadth (Table 10a).

4.2.3.1.12 Panicle weight (g)

For panicle weight M_3 families showed a mean value of 35.43 g. Low estimates of heritability (h^2 = 15%), high magnitude of PCV (29.11 %), moderate magnitude of GCV (11.35 %) and low GAM (9.11%) were recorded (Table 10a).

4.2.3.1.13 Grain weight (g/plant)

For grain weight in M_3 families showed a mean value of 27.19 g. Low estimates of heritability (h^2 = 17 %), high magnitude of PCV (34.34%), moderate magnitude of GCV (14.15%) and low GAM (12.02 %) were recorded (Table 10a).

4.2.3.1.14 100 Grain weight (g)

The mean of 100 seed weight was 3.31 g. Moderate estimates of heritability (h^2=37 %), moderate magnitude of PCV (12.54 %), low GCV (7.71%), and low estimates of GAM (9.77%) were recorded for 100 seed weight (Table 10a).

4.2.3.1.15 Panicle harvest index

The mean panicle harvest index was 0.75. Low estimates of heritability (h^2= 19 %), moderate magnitude of PCV (14.91 %), low GCV (6.63%), and low estimates of GAM (6.08%) were recorded for panicle harvest index (Table 10a).

4.2.3.2 Variety: DSV4

Wide range of values were observed among M_3 families of variety DSV 4. The results on estimates of genetic components are presented in Table 10b.

4.2.3.2.1 Seedling height (cm) (30DAS)

The mean value of seedling height was 65.11 cm. Low estimates of heritability (h^2 =5%), Moderate of PCV (19.45 %), low GCV (4.26 %) and low GAM (1.96 %) were recorded for the trait (Table 10b).

4.2.3.2.2 Days to 50% flowering

The mean number of days to 50% flowering was 79.20 days. Low estimates of heritability (h^2 =12%), high of PCV (33.30 %), low GCV (3.45 %) and low GAM (2.55 %) were recorded for the trait (Table 10b).

4.2.3.2.3 SPAD readings (at flowering)

The mean of SPAD reading at flowering was 48.61. Low estimates of heritability (h^2 = 27 %), high of PCV (43.50%), low GCV (6.01 %) and low GAM (6.45 %) were recorded for the trait (Table 10b).

4.2.3.2.4 Days to maturity

The mean number of days to maturity was 119.04 days. Low estimates of heritability (h^2 =6 %), moderate of PCV (18.03 %), low GCV (2.12%) and low GAM (1.10 %) were recorded for the trait (Table 10b).

4.2.3.2.5 SPAD readings (at physiological maturity)

The mean of SPAD reading at physiological maturity was 8.52. Low estimates of heritability (h^2 =0 %), high magnitude of PCV (23.27 %), low GCV (2.96 %) and low GAM (0.43 %) were recorded for the trait (Table 10b).

4.2.3.2.6 Plant height (cm)

The mean plant height was 139.31 cm. Low estimates of heritability (h^2=21%), moderate magnitude of PCV (14.20 %), low GCV (6.58 %), and low estimates of GAM (6.28 %) were recorded for plant height (Table 10b).

Table 10b. Genotypic and Phenotypic coefficients of variation, heritability, and genetic advance for various traits in M_3 families of *rabi* sorghum variety DSV-4

Character	Range		Mean	PCV (%)	GCV (%)	h^2	GAM
	Min.	Max.				%	%
SH	43.2	106.33	65.11	19.45	4.26	5	1.96
DFF	55	89.33	79.2	33.3	3.45	12	2.55
SPAD 1	29.9	57.94	48.61	43.5	6.01	27	6.45
DM	81.66	129.33	119.04	18.03	2.12	6	1.1
SPAD 2	4.4	12.41	8.52	23.27	2.96	0	0.43
PH	91.46	165.33	139.31	14.2	6.58	21	6.28
NN	4.93	8	7.17	14.47	2.91	4	1.2
INL	7.89	16.66	11.42	18	7.64	18	6.69
Pe L	17.33	38.86	28.18	21.7	4.66	4	2.06
Pa L	10.2	20.2	16.29	13.18	5.41	16	4.57
PB	2.66	5.26	4.34	19.45	6.11	9	3.95
PW	18.4	48.66	32.36	33.3	4.12	1	1.05
GW	9.53	38	23.03	43.5	8.72	4	3.6
HGW	1.88	3.94	2.89	18.02	8.11	20	7.51
PHI	0.45	0.9	0.68	23.27	4.45	3	1.75

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.3.2.7 Number of nodes

The mean number of nodes was 7.17. Low estimates of heritability (h^2=4 %), moderate magnitude of PCV (14.47 %), low GCV (2.91 %) and low GAM (1.20 %) were recorded for the trait (Table 10b).

4.2.3.2.8 Internodal length (cm)

The mean internodal length was 11.42 cm. Low estimates of heritability (h^2= 18 %), moderate magnitude of PCV (18 %), low GCV (7.64 %), and low estimates of GAM (6.69 %) were recorded for internodal length (Table 10b).

4.2.3.2.9 Peduncle length (cm)

The mean peduncle length was 28.18 cm. Low estimates of heritability (h^2= 4%), high magnitude of PCV (21.70 %), low GCV (4.66 %), and low estimates of GAM (2.06 %) were recorded for peduncle length (Table 10b).

4.2.3.2.10 Panicle length (cm)

The mean panicle length was 16.29 cm. Low estimates of heritability (h^2= 16%), Moderate magnitude of PCV (13.18 %), low GCV (5.41 %), and low estimates of GAM (4.57 %) were recorded for panicle length (Table 10b).

4.2.3.2.11 Panicle breadth (cm)

Mean panicle breadth was 4.34 cm. Low estimates of heritability (h^2=9.0 %), moderate magnitude of PCV (19.45 %) and low of GCV (6.11 %), and low estimates of GAM (3.95 %) were recorded for panicle breadth (Table 10b).

4.2.3.2.12 Panicle weight (g)

For panicle weight M_3 families showed a mean value of 32.36 g. Low estimates of heritability (h^2 = 1 %), high magnitude of PCV (33.30 %), low magnitude of GCV (4.12%) and low GAM (1.05 %) were recorded (Table 10b).

4.2.3.2.13 Grain weight (g/plant)

For grain weight, M_3 families showed a mean value of 23.03 g. Low estimates of heritability (h^2 = 4 %), high magnitude of PCV (43.50%), low magnitude of GCV (8.72%) and low GAM (3.60 %) were recorded (Table 10b).

4.2.3.2.14 100 Grain weight (g)

The mean of 100 seed weight was 2.89 g. Low estimates of heritability (h^2=20 %), moderate magnitude of PCV (18.02 %), low GCV (8.11%), and low estimates of GAM (7.51 %) were recorded for 100 seed weight (Table 10b).

4.2.3.2.15 Panicle harvest index

The mean panicle harvest index was 0.68. Low estimates of heritability (h^2= 3 %), high magnitude of PCV (23.27 %), low GCV (4.45 %), and low estimates of GAM (1.75 %) were recorded for panicle harvest index (Table 10b).

4.2.3.3 Variety: CSV 216R

Wide range of values were observed among M_3 families of variety CSV 216R. The results on estimates of genetic components are presented in Table 10c.

4.2.3.3.1 Seedling height (cm) (30DAS)

The mean value of seedling height was 73.42 cm. Low estimates of heritability (h^2 =18%), low of PCV (10.17 %), low GCV (4.31 %) and low GAM (3.76 %) were recorded for the trait (Table 10c).

4.2.3.3.2 Days to 50% flowering

The mean number of days to 50% flowering was 72.03. High estimates of heritability (h^2 =74 %), low of PCV (4.42%), low GCV (3.82 %) and low GAM (6.79%) were recorded for the trait (Table 10c).

4.2.3.3.3 SPAD readings (at flowering)

The mean of SPAD reading at flowering was 52.32. Low estimates of heritability (h^2 = 21 %), low of PCV (6.44 %), low GCV (2.96 %) and low GAM (2.81 %) were recorded for the trait (Table 10c).

4.2.3.3.4 Days to maturity

The mean number of days to maturity was 112.02 days. High estimates of heritability (h^2 =74 %), low of PCV (2.85 %), low GCV (2.45 %) and low GAM (4.36 %) were recorded for the trait (Table 10c).

Table 10c. Genotypic and Phenotypic coefficients of variation, heritability, and genetic advance for various traits in M_3 families of *rabi* sorghum variety CSV 216R

Character	Range		Mean	PCV (%)	GCV (%)	h^2	GAM
	Min.	Max.				%	%
SH	46.20	79.86	73.42	10.17	4.31	18.0	3.76
DFF	68.00	82.66	72.03	4.42	3.82	74.0	6.79
SPAD 1	46.34	56.36	52.32	6.44	2.96	21.0	2.81
DM	108.00	122.66	112.02	2.85	2.45	74.0	4.36
SPAD 2	4.58	15.16	8.20	49.05	10.38	4.0	4.52
PH	110.13	181.53	157.39	11.27	7.09	39.0	9.19
NN	6.06	8.13	7.15	10.05	4.97	24.0	5.07
INL	9.82	15.92	13.60	13.70	2.26	2.0	0.76
Pe L	20.73	33.80	28.07	25.20	10.08	16.0	8.32
Pa L	12.23	17.26	14.85	11.44	6.30	30.0	7.14
PB	4.03	6.13	5.03	15.49	3.87	6.0	0.10
PW	32.33	62.93	45.06	23.06	7.68	11.0	2.37
GW	23.86	49.66	34.50	26.95	10.91	16.0	3.14
HGW	1.92	4.08	2.88	20.34	14.05	47.0	0.57
PHI	0.63	0.83	0.76	8.83	4.60	27.0	0.03

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.3.3.5 SPAD readings (at physiological maturity)

The mean of SPAD reading at physiological maturity was 8.20. Low estimates of heritability (h^2 =4 %), high magnitude of PCV (49.05 %), low GCV (10.38%) and low GAM (4.52 %) were recorded for the trait (Table 10c).

4.2.3.3.6 Plant height (cm)

The mean plant height was 157.39 cm. Moderate estimates of heritability (h^2=39 %), moderate magnitude of PCV (11.27%), low GCV (7.09 %), and low estimates of GAM (9.19 %) were recorded for plant height (Table 10c).

4.2.3.3.7 Number of nodes

The mean number of nodes was 7.15. Low estimates of heritability (h^2=24 %), Moderate magnitude of PCV (10.05 %), low GCV (4.97 %) and low GAM (5.07 %) were recorded for the trait (Table 10c).

4.2.3.3.8 Internodal length (cm)

The mean internodal length was 13.60 cm. Low estimates of heritability (h^2= 2 %), moderate magnitude of PCV (13.70 %), low GCV (2.26 %), and low estimates of GAM (0.76 %) were recorded for internodal length (Table 10c).

4.2.3.3.9 Peduncle length (cm)

The mean peduncle length was 28.07 cm. Low estimates of heritability (h^2= 16 %), high magnitude of PCV (25.20 %), low GCV (10.08 %), and low estimates of GAM (8.32 %) were recorded for peduncle length (Table 10c).

4.2.3.3.10 Panicle length (cm)

The mean panicle length was 14.85 cm. Moderate estimates of heritability (h^2= 30 %), moderate magnitude of PCV (11.44 %), low GCV (6.30 %), and low estimates of GAM (7.14 %) were recorded for panicle length (Table 10c).

4.2.3.3.11 Panicle breadth (cm)

Mean panicle breadth was 5.03 cm. Low estimates of heritability (h^2=6 %), moderate magnitude of PCV (15.49 %) and low of GCV (3.87 %), and low estimates of GAM (0.10%) were recorded for panicle breadth (Table 10c).

4.2.3.3.12 Panicle weight (g)

For panicle weight M_3 families showed a mean value of 45.06 g. Low estimates of heritability (h^2 = 11 %), high magnitude of PCV (23.06 %), low magnitude of GCV (7.68 %) and low GAM (2.37 %) were recorded for panicle weight (Table 10c).

4.2.3.3.13 Grain weight (g/plant)

For grain weight M_3 families showed a mean value of 34.50 g. Low estimates of heritability (h^2 = 16 %), high magnitude of PCV (26.95 %), moderate magnitude of GCV (10.91 %) and low GAM (3.14 %) were recorded for the trait (Table 10c).

4.2.3.3.14 100 Grain weight (g)

The mean value of 100 seed weight was 2.88 g. Moderate estimates of heritability (h^2=47 %), high of PCV (20.34 %), moderate GCV (14.05 %), and low estimates of GAM (0.57%) were recorded for 100 seed weight (Table 10c).

4.2.3.3.15 Panicle harvest index

The mean panicle harvest index was 0.76. Low estimates of heritability (h^2= 27 %), low magnitude of PCV (8.83 %), low GCV (4.60 %), and low estimates of GAM (0.03 %) were recorded for panicle harvest index (Table 10c).

4.2.4 Correlation coefficients

The correlation coefficients between the yield and yield components were estimated using date generated in M_3 families of three *rabi* sorghum varieties. Both genotypic and phenotypic correlation co-efficients were estimated and are presented in Table 11 and Table 12, respectively.

4.2.4.1 Genotypic correlation

Estimates of genotypic correlation coefficients obtained for all the traits in M_3 families is tabulated in Table 11. It was found that correlation coefficients were non-signifcant for all the pairs of traits.

4.2.4.2 Phenotypic correlation

Estimates of phenotypic correlation coefficients obtained for all the traits in M_3 families is tabulated in Table 12. The correlation coefficients between the characters are given below.

Table 11. Genotypic correlation coefficients between yield and yield components in M_3 families of three *rabi* sorghum varieties

Character	SH	DFF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
SH	1.00	-0.63	0.62	-0.63	0.07	0.70	0.09	1.00	0.49	-0.43	0.78	0.83	0.67	-0.05	0.40
DFF		1.00	-0.58	1.00	0.23	-0.07	0.90	-0.47	-0.88	0.09	-0.64	-0.51	-0.39	0.36	-0.09
SPAD 1			1.00	-0.58	0.12	0.22	-0.37	0.63	0.38	-0.13	0.29	0.49	0.51	0.16	0.20
DM				1.00	0.23	-0.08	0.89	-0.48	-0.88	0.10	-0.65	-0.52	-0.39	0.36	-0.07
SPAD 2					1.00	0.22	0.13	0	-0.14	0.13	0.01	0.37	0.31	0.22	0.19
PH						1.00	0.49	0.84	-0.54	-0.49	0.72	0.66	0.55	0.33	0.15
NN							1.00	-0.03	-1.73	-0.13	-0.40	-0.02	0.01	0.58	-0.47
INL								1.00	-0.1	-0.65	1.00	0.94	0.79	0.13	0.42
Pe L									1.00	0.48	0.06	-0.32	-0.45	-0.49	-0.61
Pa L										1.00	-0.40	-0.52	-0.37	-0.12	-0.15
PB											1.00	0.89	0.84	-0.16	0.44
PW												1.00	0.97	0.11	0.56
GW													1.00	0.17	0.71
HGW														1.00	0.14
PHI															1.00

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

Table 12. Phenotypic correlation coefficients between yield and yield components in M_3 families of three *rabi* sorghum varieties

Character	SH	DFF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
SH	1.00	-0.33**	0.12**	-0.33**	-0.04	0.23**	0.02	0.23**	0.06	-0.06	0.23**	0.25**	0.22**	0.04	0.07
DOF		1.00	-0.34**	0.99**	0.06	-0.15**	0.28**	-0.29**	-0.23**	0.01	-0.34**	-0.29**	-0.21**	0.24**	-0.04
SPAD 1			1.00	-0.34**	0.04	0.22**	-0.03	0.24**	0.14**	0.10*	0.24**	0.32**	0.26**	0.09	0.03
DM				1.00	0.06	-0.15**	0.28**	-0.29**	-0.23**	0.01	-0.34**	-0.29**	-0.21**	0.24**	-0.04
SPAD 2					1.00	0.15**	0.18**	0.10*	-0.02	0.05	0.05	0.04	0.05	0.02	0.03
PH						1.00	0.44**	0.64**	0.23**	0.04	0.35**	0.34**	0.29**	0.14*	0.11*
NN							1.00	0.06	-0.09	0	0.10*	0.02	0.06	0.16**	0.12**
INL								1.00	0.17**	-0.04	0.33**	0.34**	0.29**	0.03	0.06
Pe L									1.00	0.09*	0.05	0.02	0.02	-0.07	0.06
Pa L										1.00	0.23**	0.17**	0.16**	-0.04	-0.03
PB											1.00	0.58**	0.51**	0.03	0.19**
PW												1.00	0.88**	0.09*	0.27**
GW													1.00	0.11**	0.50**
HGW														1.00	0.09*
PHI															1.00

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

4.2.4.2.1 Seedling height (cm) (30DAS)

Seedling height was significantly and negatively correlated with days to 50 % flowering (-0.33) and days to maturity (0.33). Seedling height was found to be significantly and positively correlated with SPAD1 (0.12), plant height (0.23), internodal length (0.23), panicle breadth (0.23), panicle weight (0.25), and grain weight (0.22) at 1 % level (Table 12).

4.2.4.2.2 Days to 50% flowering

Days to 50 % flowering was found to be significantly and negatively correlated with seedling height (-0.33), SPAD1 (-0.34), plant height (-0.15), internodal length (-0.29), peduncle length (-0.23), panicle breadth (-0.34), panicle weight (-0.29) and grain weight (-0.21). It was significantly and positively correlated with days to maturity (0.99), number of nodes (0.28) and 100 grain weight (0.24) (Table 12).

4.2.4.2.3 SPAD readings (at flowering)

SPAD readings at flowering was found to be significantly and negatively correlated with days to flowering (-0.34) and days to maturity (-0.34). It was significantly and positively correlated with seedling height (0.12), plant height (0.22), internodal length (0.24), peduncle length (0.14), panicle breadth (0.24), panicle weight (0.32), and grain weight (0.26) at 1% level and panicle length (0.10) at 5 % level (Table 12).

4.2.4.2.4 Days to maturity

Days to maturity was found to be significantly and negatively correlated with seedling height (-0.33), SPAD1 (-0.34), plant height (-0.15), internodal length (-0.29), peduncle length (-0.23), panicle breadth (-0.34), panicle weight (-0.29) and grain weigh (-0.21). It was significantly and positively correlated with days to flowering (0.99), number of nodes (0.28) and 100 grain weight (0.24) (Table 12).

4.2.4.2.5 SPAD readings (at physiological maturity)

SPAD readings at physiological maturity was found to be significantly and positively correlated with plant height (0.15), and number of nodes (0.18) at 1% level and internodal length (0.10) at 5 % level (Table 12).

4.2.4.2.6 Plant height (cm)

Plant height was significantly and negatively correlated with days to flowering (-0.15) and days to maturity (-0.15). It was significantly and positively correlated with seedling height (0.23), SPAD1 (0.22), SPAD2 (0.15), number of nodes (0.44), internodal length (0.64), peduncle length (0.23), panicle breadth (0.35), panicle weight (0.34), grain yield per plant (0.29) and 100 grain weight (0.14) at 1 % level and panicle harvest index (0.11) at 5% level (Table 12).

4.2.4.2.7 Number of nodes

Number of nodes was significantly and positively correlated with days to flowering (0.28), days to maturity (0.28), SPAD2 (0.18), plant height (0.44), 100 grain weight (0.16) and panicle harvest index (0.12) at 1 %level and panicle breadth (0.10) at 5 % level (Table 12).

4.2.4.2.8 Internodal length (cm)

Internodal length was significantly and negatively correlated with days to flowering (-0.29) and days to maturity (-0.29). It is significantly and positively correlated with seedling height (0.23), SPAD1 (0.24), plant height (0.64), peduncle length (0.17), panicle breadth (0.33), panicle weight (0.34), grain yield per plant (0.29) at 1 % level and SPAD2 (0.10) at 5% level (Table 12).

4.2.4.2.9 Peduncle length (cm)

Peduncle length was significantly and negatively correlated with days to flowering (0.23) and days to maturity (0.23). It was significantly and positively correlated with, SPAD1 (0.14), plant height (0.23), internodal length (0.17) at 1 % level and panicle length (0.09) at 5% level (Table 12).

4.2.4.2.10 Panicle length (cm)

Panicle breadth (0.23), panicle weight (0.17) and grain yield per plant (0.16) at 1 % level were significantly and positively correlated with panicle length. Panicle length was positively and significantly correlated with SPAD1 (0.10) and peduncle length (0.09) at 5 % level of significance (Table 12).

4.2.4.2.11 Panicle breadth (cm)

Panicle breadth was found to be significantly and positively correlated with seedling height (0.23), SPAD1 (0.24), plant height (0.35), internodal length (0.33), panicle length (0.23), panicle weight (0.58), grain yield per plant (0.51) and panicle harvest index (0.19) at 1

% level and number of nodes at 5 % level. It was significantly and negatively correlated with days to flowering (0.34) and days to maturity (0.34) (Table 12).

4.2.4.2.12 Panicle weight (g)

Seedling height (0.25), SPAD1 (0.32), plant height (0.34), internodal length (0.34), panicle length (0.17), panicle breadth (0.58), grain yield per plant (0.88) and panicle harvest index (0.27) were found to be significantly and positively correlated with panicle weight at 1 % level. 100 grain weight (0.265) at 5 % level. It is significantly and negatively correlated with days to flowering (0.29) and days to maturity (0.29) (Table 12).

4.2.4.2.13 Grain weight (g/plant)

Grain yield was found to be significantly and positively correlated with seedling height (0.22), SPAD1 (0.26), plant height (0.29), internodal length (0.29), panicle length (0.16), panicle breadth (0.51), panicle weight (0.88), 100 grain weight (0.11) and panicle harvest index (0.50) at 1 % level. It was significantly and negatively correlated with days to flowering (0.21) and days to maturity (0.21) (Table 12).

4.2.4.2.14 100 Grain weight (g)

100 seed weight was found to be significantly and positively correlated with days to flowering (0.24), days to maturity (0.24), plant height (0.14), number of nodes (0.16) and grain yield per plant (0.11) at 1 % level, panicle weight (0.09) and panicle harvest index (0.09) at 5 % level (Table 12).

4.2.4.2.15 Panicle harvest index

Panicle harvest index was found to be significantly and positively correlated with number of nodes (0.12), panicle breadth (0.19), panicle weight (0.27) and 100 grain weight (0.50) at 1 % level, Plant height (0.11) and 100 grain weight (0.09) at 5 % level (Table 12).

4.2.5 Reaction to pest and diseases

The observations made on reaction of M_3 families of three varieties in to shoot fly resistance, charcoal rot resistance, and shoot fly incidence under field conditions have been tabulated in Table 13a, Table 13b and Table 13c.

4.2.5.1 Variety: DSV-5

4.2.4.1.1 Dead heart (%)

It was found that out of 48 lines 24 M_3 lines had lower incidence of dead hearts when compared to control of 11.76 %. So shoot fly incidence was moderate (Table 13a).

4.2.5.1.2 Leaf glossiness (score)

Score for glossiness of control was 1 (high intensity of glossiness) and it was recorded that one mutant line was showing score 4 (non-glossy) (Table 13a).

4.2.5.1.3 Charcoal rot (%)

Frequency of charcoal rot incidence in control was 33.33 % and it was found that out of 48 lines, 36 mutant lines were showing lower incidence of charcoal rot when compared to control (Table 13a).

4.2.5.1.4 Lodging (%)

Lodging % for control was 34.24. It was found that out of 48 lines, 18 lines were showing lower lodging (%) compared to control (Table 13a).

4.2.5.1.5 Shoot bug (score)

Score of shoot bug incidence for control was 1, and out of 48 lines only five lines were showing high incidence to shoot bug when compared to control (Table 13a).

4.2.5.2 Variety DSV-4

4.2.5.2.1 Dead heart (%)

It was found that out of 63 lines, 15 mutant lines recorded lower incidence of dead hearts when compared to control of 6.25 %. So shoot fly incidence was moderate (Table 13b).

4.2.3.2.2 Leaf glossiness (score)

Score for glossiness in control was 1.0 and it was recorded that 4 mutant lines were showing score of 4.0 (Table 13b).

4.2.5.2.3 Charcoal rot (%)

Frequency of charcoal rot incidence in control was 33.33 % and it was found that out of 63 lines, 48 mutant lines were showing resistance to charcoal rot when compared to control (Table 13b).

Table 13a. Reaction of M_3 families of *rabi* sorghum variety DSV-5 to shoot fly resistance, charcoal rot resistance, and shoot bug incidence under field conditions (RARS, Vijayapur, *Rabi* 2016)

Sl. no.	Entry code	Sorghum mutants	DH %	Leaf glossiness (score)	Seedling height (28 DAE)	CR %	Lodging (%)	Shoot bug (score)
	Control	DSV-5	11.76	1	63.33	33.33	34.24	1
	Control	DSV-4	6.25	1	66.53	33.33	30.91	2
	Control	CSV 216 R	16.67	3	72.47	40	39.76	3
1	DSV5M-1	350 Gy	25	2	67.2	46.67	32.89	1
2	DSV5M-2	350 Gy	22.22	2	71.13	26.67	46.43	1
3	DSV5M-3	350 Gy	16.67	2	63.2	33.33	36.8	1
4	DSV5M-4	350 Gy	10	2	67.4	26.67	25.2	1
5	DSV5M-5	350 Gy	12.5	2	67.73	26.67	39.2	1
6	DSV5M-6	350 Gy	9.09	2	73.27	53.33	23.78	1
7	DSV5M-7	350 Gy	12.5	2	68.53	33.33	54.92	2
8	DSV5M-8	350 Gy	11.11	1	69.2	40	59.21	1
9	DSV5M-9	350 Gy	9.09	2	67.8	20	51.31	1
10	DSV5M-10	350 Gy	16.67	3	69.47	33.33	61.18	1
11	DSV5M-11	350 Gy	18.75	2	71.6	26.67	48.35	1
12	DSV5M-12	350 Gy	6.67	2	66.87	40	28.84	1
13	DSV5M-13	350 Gy	20	4	65.87	13.33	29.81	2
14	DSV5M-14	350 Gy	0	3	71.47	20	21.83	1
15	DSV5M-15	350 Gy	33.33	2	66.33	13.33	42.17	1
16	DSV5M-16	350 Gy	13.33	1	72	33.33	53.92	1
17	DSV5M-17	350 Gy	18.18	2	70.67	33.33	55.56	1
18	DSV5M-18	350 Gy	20	3	65.8	20	73.92	1
19	DSV5M-19	350 Gy	0	3	64.47	26.67	43.54	2
20	DSV5M-20	350 Gy	25	2	66.2	26.67	42.31	1
21	DSV5M-21	350 Gy	6.67	1	71.87	6.67	56.62	3
22	DSV5M-22	350 Gy	8.33	1	66	26.67	58.01	1
23	DSV5M-23	350 Gy	7.69	2	71.93	20	59.01	1
24	DSV5M-24	400 Gy	12.5	2	68.2	6.67	19.44	1
25	DSV5M-25	400 Gy	0	2	68.13	20	7.87	1
26	DSV5M-26	400 Gy	18.18	3	69.27	6.67	26.28	1

Table 13a. Contd…..

Sl. no.	Entry code	Sorghum mutants	DH %	Leaf glossiness (score)	Seedling height (28 DAE)	CR %	Lodging (%)	Shoot bug (score)
27	DSV5M-27	400 Gy	16.67	2	60.8	20	30.44	1
28	DSV5M-28	400 Gy	7.69	3	64.13	26.67	36.61	1
29	DSV5M-29	0.2% EMS	15.38	3	65.2	26.67	24.54	1
30	DSV5M-30	0.2% EMS	20	3	71.93	26.67	36.07	2
31	DSV5M-31	0.2% EMS	21.43	2	65.87	33.33	29.25	1
32	DSV5M-32	0.2% EMS	8.33	3	70.93	26.67	39.44	1
33	DSV5M-33	0.2% EMS	25	2	71.8	46.67	66.34	1
34	DSV5M-34	0.2% EMS	12.5	2	63.2	40	24.22	1
35	DSV5M-35	0.2% EMS	6.67	3	64.07	33.33	55.47	1
36	DSV5M-36	0.2% EMS	5	1	66.07	20	57.07	1
37	DSV5M-37	0.2% EMS	16.67	2	65.8	26.67	33.04	1
38	DSV5M-38	0.2% EMS	15.38	2	66.73	46.67	35.03	1
39	DSV5M-39	0.2% EMS	11.76	2	61.13	26.67	10.61	1
40	DSV5M-40	0.2% EMS	12.5	2	65	33.33	22.76	1
41	DSV5M-41	0.2% EMS	8.33	2	64.8	26.67	24.36	1
42	DSV5M-42	350Gy+0.2%EMS	0	2	67.73	33.33	34.49	1
43	DSV5M-43	400Gy+0.2%EMS	7.69	3	69.73	40	44.19	2
44	DSV5M-44	400Gy+0.2%EMS	9.09	2	70.13	53.33	43.72	1
45	DSV5M-45	400Gy+0.2%EMS	9.09	3	69.93	26.67	23.1	1
46	DSV5M-46	400Gy+0.2%EMS	6.67	2	62.87	26.67	16.99	2
47	DSV5M-47	400Gy+0.2%EMS	12.5	1	70.47	53.33	13.25	1
48	DSV5M-48	0	11.76	1	63.33	33.33	34.24	1

Table 13b. Reaction of M_3 families of *rabi* sorghum variety DSV 4 to shoot fly resistance, charcoal rot resistance, and shoot bug incidence under field conditions (RARS, Vijayapur , *Rabi* 2016)

Sl. no.	Entry code	Sorghum mutants	DH %	Leaf glossiness (score)	Seedling height (28 DAE)	CR %	Lodging (%)	Shoot bug (score)
	Control	DSV-5	11.76	1	63.33	33.33	34.24	1
	Control	DSV-4	6.25	1	66.53	33.33	30.91	2
	Control	CSV 216 R	16.67	3	72.47	40	39.76	3
1	DSV4M-1	350 Gy	5.88	2	63.93	33.33	48.47	2
2	DSV4M-2	350 Gy	12.5	2	64.53	33.33	25.12	1
3	DSV4M-3	350 Gy	11.11	3	56.4	40	25	2
4	DSV4M-4	350 Gy	16.67	3	67.93	40	24.24	2
5	DSV4M-5	350 Gy	10	3	64.33	40	27.23	1
6	DSV4M-6	350 Gy	22.22	3	74.4	40	54.46	3
7	DSV4M-7	350 Gy	25	3	64.53	26.67	63.75	2
8	DSV4M-8	350 Gy	15.38	3	62.8	26.67	43.88	2
9	DSV4M-9	350 Gy	25	4	74.47	40	60.92	4
10	DSV4M-10	350 Gy	33.33	3	61.87	26.67	15.6	1
11	DSV4M-11	350 Gy	0	3	62.93	33.33	21.82	1
12	DSV4M-12	400 Gy	11.11	2	62.87	20	37.66	2
13	DSV4M-13	400 Gy	6.67	1	65.47	33.33	43.67	2
14	DSV4M-14	400 Gy	27.27	2	52.6	46.67	43.57	2
15	DSV4M-15	400 Gy	16.67	3	61.47	40	20.88	1
16	DSV4M-16	400 Gy	16.67	3	67.93	26.67	20.32	1
17	DSV4M-17	400 Gy	0	3	66.47	20	58.97	1
18	DSV4M-18	400 Gy	20	3	62.27	26.67	69.82	1
19	DSV4M-19	400 Gy	6.67	1	63.93	20	65.24	1
20	DSV4M-20	400 Gy	10	2	71.07	26.67	40.48	2
21	DSV4M-21	400 Gy	10	1	65.47	20	60.08	2
22	DSV4M-22	400 Gy	18.18	2	62.4	26.67	62.63	1
23	DSV4M-23	400 Gy	16.67	3	66.4	26.67	58.01	2
24	DSV4M-24	400 Gy	9.09	2	106.33	26.67	79.64	1
25	DSV4M-25	400 Gy	9.09	3	63.47	20	56.79	1
26	DSV4M-26	400 Gy	6.67	3	61.33	40	63.47	3
27	DSV4M-27	400 Gy	13.33	3	63.07	26.67	68.45	3
28	DSV4M-28	0.2%EMS	0	2	66.67	26.67	34.44	1
29	DSV4M-29	0.2%EMS	7.14	1	63.8	20	9.43	2

Table 13b. Contd…..

Sl. no.	Entry code	Sorghum mutants	DH %	Leaf glossiness (score)	Seedling height (28 DAE)	CR %	Lodging (%)	Shoot bug (score)
30	DSV4M-30	0.2%EMS	0	2	61	26.67	30	1
31	DSV4M-31	0.2%EMS	0	3	61.73	26.67	79.13	1
32	DSV4M-32	0.2%EMS	33.33	3	59.13	26.67	45.64	1
33	DSV4M-33	0.2%EMS	0	2	66.73	33.33	59.61	1
34	DSV4M-34	0.2%EMS	0	2	64.47	53.33	17.92	2
35	DSV4M-35	0.2%EMS	0	2	44.6	26.67	25.4	2
36	DSV4M-36	0.2%EMS	12.5	1	61.4	26.67	21.93	1
37	DSV4M-37	0.2%EMS	11.11	3	63.07	26.67	21.36	1
38	DSV4M-38	0.2%EMS	0	1	58.13	26.67	46.94	1
39	DSV4M-39	0.2%EMS	7.14	2	71.87	33.33	29.52	1
40	DSV4M-40	0.2%EMS	12.5	3	68.2	26.67	26.96	1
41	DSV4M-41	0.2%EMS	0	2	62.73	33.33	35.4	1
42	DSV4M-42	0.2%EMS	6.67	2	67.13	20	63.67	1
43	DSV4M-43	0.2%EMS	8.33	3	67.6	26.67	26.2	1
44	DSV4M-44	0.2%EMS	0	3	64.27	33.33	22.99	1
45	DSV4M-45	0.2%EMS	0	2	72.33	46.67	20.53	1
46	DSV4M-46	0.2%EMS	25	3	69.13	33.33	60.71	2
47	DSV4M-47	0.2%EMS	15.38	2	74.93	20	49.22	2
48	DSV4M-48	0.2%EMS	33.33	2	71.07	40	48.09	2
49	DSV4M-49	350Gy+0.2%EMS	20	4	61.67	13.33	70.28	1
50	DSV4M-50	350Gy+0.2%EMS	14.29	4	57.47	33.33	84.97	1
51	DSV4M-51	350Gy+0.2%EMS	11.76	4	61.2	20	77.02	2
52	DSV4M-52	350Gy+0.2%EMS	6.67	2	65.07	33.33	49.63	1
53	DSV4M-53	350Gy+0.2%EMS	25	3	63	46.67	41.36	1
54	DSV4M-54	350Gy+0.2%EMS	33.33	2	64.67	33.33	33.61	1
55	DSV4M-55	350Gy+0.2%EMS	20	3	58.93	26.67	25.26	1
56	DSV4M-56	400Gy+0.2%EMS	6.25	3	68.53	46.67	53.3	1
57	DSV4M-57	400Gy+0.2%EMS	20	2	72	26.67	24.13	1
58	DSV4M-58	400Gy+0.2%EMS	18.18	2	64.4	40	61.95	1
59	DSV4M-59	400Gy+0.2%EMS	30	1	69.8	33.33	29.82	1
60	DSV4M-60	400Gy+0.2%EMS	10	2	67.07	26.67	41.43	1
61	DSV4M-61	400Gy+0.2%EMS	25	2	72.53	33.33	48.94	1
62	DSV4M-62	400Gy+0.2%EMS	15.38	1	69.4	40	49	1
63	DSV4M-63	0	6.25	1	66.53	33.33	30.91	2

4.2.5.2.4 Lodging (%)

Lodging % for control was 34.24. It was found that out of 63 lines, 23 lines were recorded with reduced lodging compared to control (Table 13b).

4.2.5.2.5 Shoot bug (score)

Score of shoot bug incidence for control was 2 and out of 63 M3 families, only one line was with high incidence of shoot bug when compared to control (Table 13b).

4.2.5.3 Variety CSV 216R

4.2.5.3.1 Dead heart (%)

It was found that out of 51 lines, 33 mutant lines had lower values of dead heart (%) when compared to control of 16.67 %. So shoot fly incidence was moderate (Table 13c).

4.2.5.3.2 Leaf glossiness (score)

Score for glossiness in control was 3 and it was recorded that one mutant line was showing 4 (Table 13c).

4.2.5.3.3 Charcoal rot (%)

Charcoal rot incidence in control was 40.00 % and it was found that out of 51 lines, all lines were showing lower incidence of charcoal rot when compared to control (Table 13c).

4.2.5.3.4 Lodging (%)

Lodging % for control was 39.76. It was found that out of 51 lines, 16 lines were lower incidence of lodging when compared to control (Table 13c).

4.2.5.3.5 Shoot bug (score)

Score for shoot bug incidence in the control was 3, and out of 51 lines only one line was recorded with high incidence of shoot bug when compared to control (Table 13c).

Table 13c. Reaction of M_3 families of *rabi* sorghum variety CSV 216R to shoot fly resistance, charcoal rot resistance, and shoot bug incidence under field conditions (RARS, Vijayapur, *Rabi* 2016)

Sl. no.	Entry code	Sorghum mutants	DH %	Leaf glossiness (score)	Seedling height (28 DAE)	CR %	Lodging (%)	Shoot bug (score)
	Control	DSV-5	11.76	1	63.33	33.33	34.24	1
	Control	DSV-4	6.25	1	66.53	33.33	30.91	2
	Control	CSV 216 R	16.67	3	72.47	40	39.76	3
1	CSVM-1	350Gy	0	3	73.87	26.67	73.61	1
2	CSVM-2	350Gy	11.11	3	75	33.33	70.48	3
3	CSVM-3	350Gy	16.67	3	75.13	26.67	80.98	2
4	CSVM-4	350Gy	22.22	2	74.8	26.67	74.96	1
5	CSVM-5	350Gy	14.29	2	46.2	13.33	47.69	1
6	CSVM-6	350Gy	16.67	1	79.53	26.67	44.04	1
7	CSVM-7	350Gy	18.18	2	78.47	26.67	40.37	1
8	CSVM-8	400Gy	0	3	66.27	26.67	45	2
9	CSVM-9	0.2%EMS	14.29	3	74.67	26.67	66.35	1
10	CSVM-10	0.2%EMS	18.18	3	72	40	70.05	1
11	CSVM-11	0.2%EMS	33.33	3	74.73	33.33	51.67	1
12	CSVM-12	0.2%EMS	10	3	73.73	33.33	51.14	1
13	CSVM-13	0.2%EMS	25	2	70.93	26.67	70.56	1
14	CSVM-14	0.2%EMS	0	3	76.93	33.33	80.45	2
15	CSVM-15	0.2%EMS	25	3	77.47	26.67	80.95	1
16	CSVM-16	0.2%EMS	18.18	3	69.33	26.67	63.14	2
17	CSVM-17	0.2%EMS	15.38	3	71.67	13.33	62.63	1
18	CSVM-18	0.2%EMS	15.79	2	67.4	6.67	49.8	3
19	CSVM-19	350GY+0.2%EMS	16.67	3	74.73	13.33	32.68	1
20	CSVM-20	350GY+0.2%EMS	20	2	74	6.67	50	1
21	CSVM-21	350GY+0.2%EMS	20	3	70.6	33.33	29.29	1
22	CSVM-22	350GY+0.2%EMS	12.5	3	75.53	26.67	56.52	1
23	CSVM-23	350GY+0.2%EMS	0	3	69.73	6.67	32.59	2
24	CSVM-24	350GY+0.2%EMS	8.33	1	70.47	26.67	33.98	1
25	CSVM-25	350GY+0.2%EMS	0	2	73.33	20	47.58	1
26	CSVM-26	350GY+0.2%EMS	7	2	74.73	20	43.33	1

Table 13c. Contd…..

Sl. no.	Entry code	Sorghum mutants	DH %	Leaf glossiness (score)	Seedling height (28 DAE)	CR %	Lodging (%)	Shoot bug (score)
27	CSVM-27	350GY+0.2%EMS	0	3	77.93	13.33	42.38	1
28	CSVM-28	350GY+0.2%EMS	10	3	73.2	26.67	28.04	1
29	CSVM-29	400Gy+0.2%EMS	15.38	2	68.13	13.33	41.39	1
30	CSVM-30	400Gy+0.2%EMS	25	2	72.67	33.33	30.28	1
31	CSVM-31	400Gy+0.2%EMS	7.14	1	77.33	33.33	53.17	3
32	CSVM-32	400Gy+0.2%EMS	16.67	1	75.73	6.67	56.67	1
33	CSVM-33	400Gy+0.2%EMS	0	2	77	13.33	36.11	1
34	CSVM-34	400Gy+0.2%EMS	0	2	72.67	26.67	20.83	1
35	CSVM-35	400Gy+0.2%EMS	0	3	79.87	26.67	55.56	1
36	CSVM-36	400Gy+0.2%EMS	16.67	2	75	26.67	49.44	1
37	CSVM-37	400Gy+0.2%EMS	11.11	1	76.93	40	54.17	2
38	CSVM-38	400Gy+0.2%EMS	12.5	2	67.67	20	49.07	2
39	CSVM-39	400Gy+0.2%EMS	10	3	78.2	40	49.21	1
40	CSVM-40	400Gy+0.2%EMS	25	3	79	20	4.76	4
41	CSVM-41	400Gy+0.2%EMS	0	3	72.13	33.33	28.8	2
42	CSVM-42	400Gy+0.2%EMS	20	3	77.13	33.33	16.61	2
43	CSVM-43	400Gy+0.2%EMS	22.22	3	75.07	40	26.71	2
44	CSVM-44	400Gy+0.2%EMS	20	3	75.6	33.33	45.9	2
45	CSVM-45	400Gy+0.2%EMS	18.18	3	72.13	33.33	26.85	2
46	CSVM-46	400Gy+0.2%EMS	66.67	4	76.4	33.33	21.76	2
47	CSVM-47	400Gy+0.2%EMS	14.29	3	71.2	33.33	48.72	3
48	CSVM-48	400Gy+0.2%EMS	20	3	73.73	33.33	47.39	3
49	CSVM-49	400Gy+0.2%EMS	16.67	3	73.87	20	24.02	1
50	CSVM-50	400Gy+0.2%EMS	0	3	72.53	13.33	30.36	1
51	CSVM-51	0	16.67	3	72.47	40	39.76	3

Discussion

5. DISCUSSION

Sorghum is a staple food for millions of poor people throughout the world due to its versatile use, hardiness and stability of yield, and its adaptation to wide range of climates. It is well adapted to tropical as well as temperate climates, although it is well known for its good adaptation to the drought prone semi-arid tropical (SAT) regions of the world. Sorghum being an often cross pollinated crop, amenable for breeding procedures which are applicable to both self and cross pollinated crops, enabling the exploitation of both additive as well as non-additive gene effects.

Sorghum (*Sorghum bicolor* L.) is grown mainly in the semi-arid area of the tropics and sub-tropics and fifth in term of importance among the world's cereals (Dogget *et al*., 1988). It is also known to have wide adaptability, ranging from lowland, medium and highland altitude. It is an important staple food for more than 300 million people and feed for cattle in Asia and Africa (Anand and Kajjidoni, 2014). The grain can be used for flour to make bread, porridge and for brewing beer. As a food crop, sorghum was reported to have high nutrition so that it can be used for substituting rice (Depker, 1991; Soeranto, 2001). The large juicy sweet stems are utilized for chewing and making syrup, ethanol and sugar (Prakash *et al*., 2006).

In India, sorghum ranks fourth as food and first as forage. It is cultivated over an area of 6.30 million ha with an annual production of 5.28 million tonnes of grain with a productivity of 854 kg/ha (FAOSTAT, 2013). The first three largest sorghum producing states are Maharashtra, Karnataka and Madhya Pradesh. In Karnataka, it is cultivated in 1.26 million ha with an annual production of 1.32 million tonnes of grain (20.99% of total global production) with a productivity of 1041 kg/ha.

Sorghum in India is cultivated in two seasons: June to October (rainy/*kharif*) and October to February (post rainy/*rabi*). The *rabi* sorghum accounts for 56.3 per cent of the total area under cultivation and 46.4 per cent of the total production. Sorghum grown in *rabi* is used for human consumption (98%) due to superiority of the grain, largely owing to its maturation under dry and cloud free conditions (Seetharama *et al.*, 1990), and stover as feed. Thus, post rainy sorghum provides food and stover security for millions of people in the drought-prone regions.

Terminal moisture stress is most common in *rabi* sorghum areas as it is largely grown under stored soil moisture situations. Terminal drought during the cropping season leads to (a) premature leaf senescence, (b) reduced grain filling and (c) predisposing plants to root/stalk rots leading to severe lodging. Thus reduces productivity and quality of grain and stover. Hence, moisture stress is a major constraint limiting the *rabi* sorghum productivity. Genetic improvement in *rabi* sorghum is based on existing genetic variability for yielding ability, maturity and drought tolerance. The variety *Maldandi* is widely grown by the farmers in *Rabi* sorghum areas of North Karnataka due to its moderate tolerance to moisture stress, tolerance to shoot fly and its excellent grain quality. Although several high yielding varieties have been released, but due to their late maturity (compared to M 35-1), are susceptible to terminal moisture stress.

Unlike *kharif* sorghum, the breeding progress in rabi sorghum is slow. One of the major reason is narrow genetic variability present in the available breeding material. Hybrid technology using *rabi* based material has not been successful because of poor heterotic advantage for yield. Although significantly high heterosis achieved using *kharif* based breeding material, which led to release of hybrids for *rabi* season. However, none became popular because of their poor grain quality and susceptible to shoot fly. Under this situation it needs to be given priority for improvement of existing varieties by new breeding approaches.

Major area of Rabi sorghum has been covered under medium soil and occupied by *Maldandi* and its relatives because of their tolerance to drought stress, which is frequent in *rabi* sorghum growing areas. Although several high yielding varieties released for cultivation in *rabi* season, but their high yielding ability can only be best harnessed under deep soil with assured moisture situations. It is necessary to diversify the cultivars in farmers field, by developing high yielding, early maturing varieties with grain quality on par with Maldandi, which can escape drought stress under medium soil situations.

For the improvement of a crop, the extent of genetic variability is more important than the total variability. Mutation breeding is one of the plant breeding techniques used for creating genetic variability in traits and to improve the yield of crop plants (Anluwalia and Malusznski, 2004). The inheritance of important economic traits such as yield, quality, adaptation, pest and stress resistance, upon which much of the future of plant improvement depends, can be understood through the analysis of a wide range of induced mutations. Mutation breeding has been used in recent years as a valuable supplement to the method of plant breeding in the development of better crop cultivars (Awan, 1991). The availability of narrow genetic variability with *rabi* sorghum necessitates creation of new variability through mutation breeding.

Several workers have attempted for induction of mutation using either physical or chemical mutagens for evolving new genotypes (Bravo, 1988; Hassan & Khan, 1991a, b; Shamsuzzaman & Shaikh, 1991; Kharkwal, 1983; Kharkwal *et al*., 1988; Haq *et al*., 1988; 1989). The most popular mutagen used for creating genetic variability is Gamma irradiation (Reddy, 1977). The widespread use of induced mutants in plant breeding programmes throughout the world has led to the official release of more than 2,700 plant mutant varieties. For sorghum, only 15 mutant varieties have been released.

The study on variability and heritability for desirable characters is a pre-requisite in the development of new varieties/hybrids with increased yield potential. Knowledge of interrelationship between yield and yield attributing components enables the breeders to plan the breeding programme accordingly.

Therefore, in this background present study was carried out to study the induced mutations in M_2 and M_3 generations derived from three *Rabi* sorghum varieties using five dosage combinations inducing viable mutations. The study was aimed to compare and assess the effect of different mutagen treatment combinations on genetic variability for yield and yield components; to study induced changes with reference to genetic parameters for yield and yield components; to identify desirable mutants for reduced height, earliness and other yield related traits.

The varieties viz., DSV 5, DSV 4 and CSV 216R, and the dosage combinations viz., 350 Gy, 400 Gy, EMS (%), 350 Gy+0.2%EMS, 400 Gy+0.2%EMS were used in the present study on induced mutations in Rabi sorghum. All these varieties are late maturing and high yielding compared to Maldandi. DSV 5 and DSV 4 are charcoal resistant varieties where as CSV 216R is susceptible to terminal stress and charcoal rot incidence. All these differ for morphological characters like Panicle shape and panicle density. DSV 5 is having long and semi-compact panicle, DSV 4 with long and loose panicle and CSV 216R having semi-compact and wide panicles. DSV 5 and CSV 216R are landrace selections where as DSV 4 is derivative of a cross involving E 36-1 as one of the parent, which is an exotic line with early maturity and charcoal rot resistance. The mutant selections for reduced height, early maturity coupled with high yield are desirable to escape from terminal stress.

M_2 progenies advanced from M_1 plants were planted during *Rabi* 2015, and selections were made based on induced changes for visual characters. The observations were recorded for various yield traits in these mutants as well as other M_2 selections. The individual plant selections in each dosage combinations were advanced to M_3. These M_3 plant to progenies were planted in a replicated trial during *Rabi* 2016. The observations were recorded on yield traits *viz*., seedling height (cm), days to 50 % flowering, plant height (cm), number of nodes, nodal length(cm), peduncle length (cm), panicle length (cm), panicle breadth (cm), panicle weight (g), 100 seed weight (g), grain yield per plant (g) and panicle harvest index. Reaction to pest and diseases (Shoot fly, charcoal rot and shoot bug) was also recorded.

The results obtained are discussed below in the light of available literature under following headings:

5.1 Analysis of variance for different component traits

5.2 Genetic parameters

5.3 Correlation studies

5.4 Frequency and spectrum of variable mutations

5.5 Reaction to pest and diseases

5.6 Performance of early mutant selections.

5.7 Promising M_3 families for various traits.

5.1 Analysis of variance for different component traits

5.1.1 M_2 generation

A total of 47 M_2 families in the variety DSV 5, 58 in DSV 4 and 48 in CSV 216R were subjected for analysis of variance (ANOVA) for yield traits involving their respective parental varieties (control). Significant differences were observed for plant height and panicle weight among treatments of the variety DSV-5, for plant height and 100 grain weight among treatments of DSV 4 and for all the traits studied except panicle breadth (days to 50 % flowering, plant height, panicle weight, grain weight and 100 grain weight) with respect to variety CSV 216R (Table 3). Highly significant treatment variances indicated the presence of variability for these traits in the material used for the study.

5.1.1.1 Mean performances

The means and range values can help to deduce variation induced by mutation on agronomic traits of the crop plants. The mean values of seven agronomic traits in M_2 generation are showed in Table 4a, 4b and 4c. Wide range of values were observed for majority of the traits across treatment combinations indicating the effect of mutagen treatment dosage combinations in creating variation for these traits.

5.1.1.1.1 Days to 50% flowering

In DSV-5, it was observed that for the trait days to 50% flowering, lowest mean values were observed in 400 Gy (79 days) followed by 350 Gy (81 days) compared to that of control (zero dosage) (84 days) (Table 4a). In DSV-4 mean of control (zero dosage) was 79 days, and it was 76 days in a dosage of 350Gy+0.2% (Table 4b). And in CSV 216R mean of control (zero dosage) was 74 days, and it was 69 days in a dosage of 400Gy+0.2% (Table 4c). The results indicated the scope of isolating early maturing genotypes in CSV 216R at higher dosage combination of both gamma irradiation and EMS among the treatment combinations used in the present study. It was stated by Rao (1970) that for days to flowering the gene action was essentially additive. However, the predominance of non additive gene action was reported by Biradar (1995).

5.1.1.1.2 Plant height (cm)

For the trait plant height, in all the treatments mean value was higher than control except in a dosage of 400Gy+0.2%EMS in DSV-5 (Table 4a). Lowest height was found in 350 Gy. Regarding DSV 4, means for the trait were higher in 350 Gy, 400 Gy and 400 Gy+0.2% EMS compared to control. Reduction in height was noticed in 350Gy+EMS (0.2%) (Table 4b).

Mean value is 231.67 cm for control and a mean of 217.60 cm. reduced height was found in a dosage of 0.2%EMS in CSV 216R (Table 4c). The genotypes with significantly reduced height were also found in other dosage combinations. The analysis of variance for the effects of different doses of gamma irradiation separately and with the application of gibberellic acid on plant height in M_2 population of chickpea also revealed high fluctuations of induced variability in genotypes across different treatments. (Khan *et al.,* 2005). According to Rao (1970), the gene action for plant height was essentially additive. Similarly, Chavan and

Nerkar (1978) also reported additive gene action in a diallel cross of *kharif* and *rabi* varieties and also by Shankaregouda *et al*. (1972) in a line x tester.

5.1.1.1.3 Panicle length (cm)

For panicle length control mean was 21.70 cm. and a mean of 20.85 cm was observed in a dosage of 0.2%EMS in DSV-5 (Table 4a). The results indicate the effect of this dosage treatment in inducing changes in panicle length. With respect to DSV 4, the mean of control was 25.17 cm and a mean of 23.29 cm and 23.86 cm were observed in dosage treatments 0.2% EMS and 400 Gy+ 0.2% EMS, respectively. The results indicate the effect of these treatments in reducing panicle length in DSV-4 (Table 4b). Similar results were observed regarding CSV 216R in which reduced panicle length (18.6 and 19.77 cm) were observed in the dosage treatment combinations 0.2%EMS and 400 Gy+0.2%EMS.The results indicated the effect of these dosage combinations on panicle length was evident in CSV 216R also (Table 4c). With respect to inheritance of this trait, Chiang and smith (1967) and Paisan (1975) showed that panicle length was controlled by additive gene action.

5.1.1.1.4 Panicle breadth (cm)

For panicle breadth control mean was 5.22 cm. and cm increased breadth (6.17 cm) over control was found in a dosage of 350Gy in DSV-5 and in rest of the treatments the mean values were on par with control (Table 4a). Mean of control was 6.83 cm. and a mean of 6.02 cm was found in a dosage of 0.2%EMS in DSV-4 indicating the effect of this treatment in reducing the panicle breadth (Table 4b). Regarding CSV 216R, mean of control was 6.17 cm. and a mean of 7.21 cm was found in a dosage of 350Gy in CSV 216R indicating the effect of this mutation treatment (Table 4c).

5.1.1.1.5 Panicle weight (g)

For panicle weight mean was 89 g for control and for dosage 350Gy and 400 Gy increased mean of 97.17 g and 92.6, respectively was observed in DSV-5 (Table 2a). Whereas for DSV-4, increased mean values 117.43 g were recorded in dosage 400Gy+0.2%EMS compared to control (89.67 g) (Table 4b). In case of CSV 216R, increased mean value (136 g) was observed for dosage 400Gy over the control (114.50 g) (Table 4c). The results indicate the effect of mutation treatment and fluctuation of dosage combinations in increasing panicle weight in all these varieties.

5.1.1.1.6 Grain weight (g/plant)

For grain yield control mean is 69.1 g and increased yield was found in dosages of 350Gy and 400 Gy with a mean of 73.58 g and 72.43 g, respectively in DSV-5 (Table 4a). Whereas increased yield was found in a dosage of 400Gy+0.2%EMS with a mean of 91.40g followed by 400 Gy with mean of 70.29 in DSV-4 compared to control (61.94 g)(Table 4b). In case of CSV 216R, mean of control was 92.17 g and increased yield over control was found in a dosage of 400Gy with a mean of 98.93g (Table 4c) indicating the effect mutation treatment noticed for the trait and importance of gamma irradiation (400 Gy) for inducing changes for yield in all the 3 varieties.

5.1.1.1.7 100 Grain weight (g/100 seeds)

Mean of hundred grain weight for control was 3.70 g and it was increased in a dosage of 400Gy with a mean of 4.48 g in DSV-5 (Table 4a). Regarding DSV 4, mean of hundred grain weight for control was 4.19 g and it was increased in a dosage of 400Gy+0.2%EMS with a mean of 4.59 g (Table 4b). Increased hundred grain weight for control was 4.39 g and it was decreased in a dosage of 0.2%EMS with a mean of 4.33 g in CSV 216R (Table 2c) Thus indicating the effect of mutation treatment for the trait and fluctuation of mutation treatment dosage combinations in inducing changes in positive direction for the trait.

5.1.2 M_3 generation

Analysis of variance (ANOVA) was carried out for the different yield component traits by using the replicated data. ‘F’ test was conducted to examine the significance of variances. Mean sum of squares for the different yield component traits are presented (Table 8). Significant mean sum of square values were not observed for yield traits as indicated by the non-significant variances for these traits. Replication sum of squares were found non significant for all the yield component traits. Although significant change in values induced through mutation were observed in M_2 but non-significant mean sum of squres observed for yield traits in M_3 indicate segregation of polygenes and influence of environment on inheritance of yield traits studied.

5.1.2.1 Mean performances

The means and can help to deduce variation induced by mutation on yield traits of the crop plants. The mean and range of values of 15 yield traits in M_3 generation were showed in Table 9a, 9b and9c.

5.1.2.1.1 Seedling height (cm) (30DAS)

Highest mean value for seedling height was recorded in a dosage of 400Gy+0.2EMS% in M_3 families of the varieties DSV 5 (66.2 cm) and CSV 216R (72 cm) compared to a mean of 68.63 cm 69.08, respectively compared to zero dosage/control(Table 9a and Table 9b). Where as in case of CSV 216R none of the treatments recorded mean value higher than control in their M_3 families (Table 9c). The results indicate the effect of mutation treatments on either decreasing or increasing the mean values over their respective control.

5.1.2.1.2 Days to 50% flowering

Early flowering (77-88 days) was recorded in M_3 families of DSV 5 for the mutation treatment 350 Gy (Mean value for control was 85 days). (Table 9a). Whereas early flowering was recorded in all the dosage combinations except 400 Gy+0.2%EMS in M_3 families of DSV 4 (Table 9b). In CSV 216R early flowering was noticed in a dosage of 400Gy+0.2EMS% (Table 9c). The results indicate the scope of isolating early genotypes upon mutation treatment in *rabi* sorghum varieties to escape from terminal stress.

5.1.2.1.3 SPAD readings (at flowering)

None of the mutation treatments were recorded with mean value for trait higher than Control DSV 5 (Table 9a), all treatments in DSV 4 (Table 9b), in dosage combinations of gamma and EMS (350 Gy+0.2% and 400 Gy+0.2%EMS) for CSV 216R (Table 9c). The results indicate differential response of varieties to different mutation treatments. However, induced change was only marginal indicating more than one gene controlling the trait, and influence of environment.

5.1.2.1.4 Days to maturity

Mean values in M_3 families of variety DSV 5 were on par with control across all the mutation treatments, only marginal reduction in M_3 of DSV 4. However, in CSV 216R, majority of treatments resulted significant reduction in values for days to maturity. Lowest mean value for days to maturity was recorded in a dosage of 400Gy+0.2EMS% with a mean of 110.64 days in M_3 of CSV 216R compared to control (119 days) (Table 9c). The results indicated differential response of varieties for various mutation treatment combinations, and scope of isolating early types in CSV 216R.

5.1.2.1.5 SPAD readings (at physiological maturity)

Across varieties, none of the treatment combinations induced significant effect in increasing the values. Among all the treatments highest mean value SPAD readings at physiological maturity were recorded only in a dosage of 400Gy with a mean of 12.37 in CSV 216R (Table 9c).

5.1.2.1.6 Plant height (cm)

Mean value for zero dosage (control) was161.60 cm and lowest mean value for plant height was recorded in a dosage of 400Gy+0.2EMS% with a mean of 149.89 cm in DSV-5 (Table 9a). Lowest mean value for plant height was recorded in a dosage of 350Gy+0.2EMS% with a mean of 125.15 cm in DSV-4 Mean compared to control (149.80 cm) (Table 9b). In CSV 216R, lowest mean value for plant height was recorded in a dosage of 0.2EMS% with a mean of 148.45 cm compared to control (164.40 cm)(Table 9c). The results indicate effect of mutation treatments on reducing the plant height.

5.1.2.1.7 Number of nodes

Across varieties, none of the treatments showed significant effect for inducing changes in number of nodes except in the dosage combination of 350 Gy+0.2%EMS for variety DSV 4 (Tables 9a, 9b, 9c).

4.2.1.1.3.8 Internodal length (cm)

Across varieties, all the treatments recorded inducing change of increasing internodal length and none of the treatment combination was found effective in reducing the internodal length (Tables 9a, 9b, 9c).

5.1.2.1.9 Peduncle length (cm)

Across all the treatments, marginal induced change in peduncle length in M3 compared control in DSV 5, increased mean value for DSV 4 and increased mean values in treatments of 350 Gy+0.2%EMS and 400 Gy+0.2%EMS in variety CSV 216R was observed. The results indicated differential response of varieties to various mutation dosage combinations.

5.1.2.1.10 Panicle length (cm)

Highest mean value for panicle length was recorded in a dosage of 400Gy+0.2%EMS with a mean of 26.69 cm in DSV-5 (Table 9a) compared to control (17.60 cm). In DSV 4, the dosage of 400Gy was found effective for increasing the values (17.09) compared to control (15.80 cm) (Table 9b). Across all the treatment combinations, none of the treatments were found to be effective towards increasing panicle length, and in general, mean values were lower than control (Table 9c).

5.1.2.1.11 Panicle breadth (cm)

In case of DSV 5, the dosage of 350 Gy+0.2%EMS was found to be effective for increasing panicle breadth compared to control (Table 9a). Whereas in both the DSV 4 and CSV 216R, the dosage of 400 Gy was found effective for increased values (Table 9b and Table 9c).

5.1.2.1.12 Panicle weight (g)

None of the treatment combinations recorded mean values higher than control in DSV 5 and CSV 216R (Table 9a and Table 9c). Where as highest mean value for panicle weight was recorded in a dosage of 400Gy+0.2%EMS with a mean of 35.13 g in DSV-4 than control (28.2 g) (Table 9b)

5.1.2.1.13 Grain weight (g/plant)

For DSV 5, in all the treatment combinations mean values of grain weight were reduced except in lower dosage of irradiation 350 Gy (Table 9a). In DSV 4, highest mean value for grain weight was recorded in a dosage of 400 Gy+0.2%EMS (Table 9b), in CSV 216R for 350Gy+0.2%EMS compared to their respective controls (Table 9c). However, Rao (1988) reported that gamma irradiation had adverse affect on grain yield in chickpea.

5.1.2.1.14 100 Grain weight (g/100 seeds)

Across all the varieties, it was noticed that none of the treatments had induced effect on increase in weight of 100 seeds compred to their respective control parents (Tables 9a, 9b and Table 9c).

5.1.2.1.15 Panicle harvest index

Mean values of M3 in DSV 5 and CSV 216R were on par with their respective control varieties across all the treatment combinations, where as mean values were higher than control in DSV 4. The results indicate the effect of mutation on improving seed set in DSV 4 (Tables 9a, 9b and 9c)

5.2 Genetic components

5.2.1 M_2 generation

The genetic parameters can help to deduce variation induced by mutation on agronomic traits of the crop plants. The results on genetic parameters estimated for yield traits in M_2 generation of three varieties DSV 5, DSV 4 and CSV 216R are presented in Table 10a, Table 10b and Table 10c, respectively. Genetic variability plays an important role in selection and isolation of superior genotypes for improvement of crop plants. Estimation of genotypic and phenotypic coefficient of variation, heritability and genetic advance as percentage of mean for 15 agronomic traits of 5 mutagenic treatments were also presented in above mentioned tables. In the present study, GCV and PCV showed a wide range of variation for most of the traits studied in M_2 generation. A consistently greater PCV was observed than GCV in all yield traits among five mutagenic treatments. It indicated that there was the influence of environment on the expression of these traits as the observed phenotypic variability includes both genotypic and environmental variation.

In general, the high PCV were observed for, panicle weight and grain yield per plant in all the three varieties. Moderate PCV were observed for rest of the traits days to 50 % flowering, plant height, panicle length, panicle breadth and 100 grain weight per plant in all the three varieties. Moderate GCV were observed for, plant height, panicle weight and grain yield per plant in all the three varieties. Low GCV was observed for days to 50 % flowering, panicle length, panicle breadth and 100 grain weight per plant in all the three varieties. These results are concurrent with the report of Unche *et al*. (2008) and Anand & Kajjidoni (2014) who reported that high GCV and PCV were exhibited for grain yield per plant in sorghum.

Heritability in broad sense is a measure of the extent of phenotypic variation caused by the action of genes. Heritability plays an important role in deciding the suitability and strategy for selection of a character (Navin *et al*, 2014). In the present investigation, the estimate of heritability also showed wide variation for studied traits in M_2 generation. The low heritability values were observed for all the traits in DSV-5. The low heritability values were observed for all the traits except plant height and panicle length which recorded moderate value in DSV-4. In CSV 216R low heritability values were observed for all the traits except days to 50% flowering and plant height which recorded moderate value. These results for plant height are in accordance with the reports of Biradar *et al*. (1996), Deepalaxmi *and*

Ganeshmurthy (2007) and Anand & Kajjidoni (2014). For all the traits across varieties, low heritability was noticed. Where as moderate values of heritability are noticed for panicle length and panicle length in DSV 4, days to 50% flowering and plant height in CSV 216R. If the heritability of that particular trait is high, it favors effective selection on single plant basis but if the trait concerned has lower heritability estimate, breeder has to rely on progeny mean rather than on single plant (Saimullah and Sonu, 2009). However, heritability alone provides no indication of amount of genetic improvement that would result from selection of individual genotype; hence knowledge about genetic advance coupled with heritability is most useful (Anshuman *et al*, 2013).

In the present study, the moderate heritability values noticed for plant height in both the varieties DSV 4 and CSV 216R, which also recorded high genetic advances as percentage of mean (GAM). These results agree with Veerabadhiran & Kennedy (2001), Unche *et al*. (2008) and Anand & Kajjidoni, (2014) who reported that high heritability coupled with high genetic advance as percent of mean was observed for grain yield per plant. High heritability accompany with high genetic advance indicates that preponderance of additive gene effect (Panse and Sukhalme, 1967). Therefore, these results indicate that most likely the heritability is due to additive gene effect and as a result there is scope of improving these traits through selection procedure. The traits for which low heritability values were recorded they also had low GAM.

5.2.2 M_3 generation

The genetic parameters can help to deduce variation induced by mutation on agronomic traits of the crop plants. The estimates of genetic parameters for all 15 agronomic traits in M_3 generation are presented in Table 10a. Success in selecting a desirable plant type largely depends upon the genetic variability present in the base population, and mutation breeding offers the unique possibility of creation of new variation for crop improvement (Konzak, 1987).

Wide range was observed among M_3 families of DSV 5 for majority of the traits indicating the effect of mutation treatments. The estimates of PCV were higher than GCV for all the traits. High heritability was observed for days to 50% flowering, SPAD (at Physiological maturity) and 100 seeds weight, moderate heritability observed for panicle length. Genetic advance was high for grain weight per plant (Table 10a).

Regarding DSV 4, wide range of values were observed for all the traits. In general PCV values were higher than estimates of GCV for all the traits. Estimates of heritability and genetic advance were low for all the characters. Thus indicating selection will not be effective in the variation generated through mutation treatment in this variety (Table 10b).

Wide range was observed for all the traits among M_3 families of variety CSV 216R indicating the effect of mutation treatments (Table 10c). The estimates of PCV were higher than GCV for all the traits. However, marginal differences were observed between PCV and GCV, and high heritability were noticed for both the traits days to 50% flowering and days to maturity. These results indicate the less influence of environment and high effectiveness of mutation treatments in inducing heritable changes for these traits in this variety. Heritability estimates were moderate for plant height, panicle length and 100 seed weight in the M_3 material generated in CSV 216R. In general, the estimates of genetic advance were low for the traits studied in this variety.

PCV values were slightly higher than corresponding values of GCV for all the traits in M_3 of all the varieties. These results are in conformity with finding of earlier workers Mehetre *et al.* (1995) in soybean, Borah and khan (2000) in fodder cowpea. Similar observations have been reported earlier by Abu-El-Gasim and Kambal (1975), Keim and Rosenow (1984), Kumar and Singh (1986), Biradar (1995), Rao and Patil (1996), Reddy *et al.* (1996), Can and Yoshida (1999), Prabhakar (2001), Veerabadhiran and Kennedy (2001), Umakanth *et al.* (2004), Godbharle *et al.* (2010), Seetharam and Ganesamurthy (2013). Moderately high results were reported by Shinde and Nayeem (1979), Salilkumar and Singhania (1984), Desai *et al.* (1983), Kumar and Singh (1986), Phul and Allarang (1986), Rao and Patil (1996), Prabhakar (2001), Deepalakshmi and Ganesamurthy (2007), Godbharle *et al.* (2010), Seetharam and Ganesamurthy (2013), Dhutmal *et al.* (2014), Chittapur e*t al.* (2015).

With the genetic coefficient of variation alone, it is difficult to determine the relative amount of heritable and non-heritable components of variations present in the population. Estimates of heritability and genetic gain would be supplement to this parameter. The highest heritability estimate in broad sense (h^2) were noted for the characters days to 50 % flowering and days to maturity, moderate heritability was noted for 100 grain weight similar result obtained by Rajput *et al.* (1987). Low heritability was noted for seedling height, SPAD at 50 % flowering, SPAD at physiological maturity, plant height, number of nodes, internodal length, peduncle length, panicle length, panicle breadth, panicle weight, grain weight and plant harvest index. Sinha and Bharati (1990) also reported similar results wide range for all the characters obtained in mutant population of urdbean.

Heritability estimates alone is not of any use in predicting the results about the selection unless it is accompanied by genetic advance. High heritability accompanied with high genetic advance observed for grain weight per plant in the M_3 generation of DSV 5 suggest that the inheritance of character is mainly governed by additive gene effects and therefore selection based on phenotypic performance proved useful. Talukdar and Biswas (2008) recorded high heritability values for days to 50 per cent flowering (M_2 and M_3); 100 seed weight (M_3) and seed yield plant-1 (M_3). High heritability together with significant genetic advance were noted for plant height (M_2 and M_3); branches plant-1 and pods plant-1 (M_2) and seed yield plant-1 (M_2 and M_3) in soybean.

5.3 Correlation

The phenotype of a plant is the result of interaction of a large number of factors. Final yield is the sum of effect of several component factors. Amelioration of yield is the ultimate aim of the plant breeder in any crop improvement programme and this has to be achieved through gaining insight into the behaviour of component characters that are associated with grain yield. Correlation studies provide information on the nature and extent of association between any two pairs of metric characters. Grafius (1959) opined that there may not be any gene for yield as such but operates only through its components. Correlation studies will surely help to identify the character to make selections for higher yield with a view to determine the extent and nature of relationship among the yield contributing characters.

The correlation coefficient helps a breeder in determining the direction of selection and number of characters to be considered in improving the grain yield. Correlation coefficients not only denote the total association existing between a pair of characters which themselves are the result of the interaction between various features of the plant but also it measures the relationship existing between pair of characters.

Genotypic and phenotypic correlation coefficients for all the traits in M_3 generation are tabulated in Tables 11 and 12. Genotypic correlation for all the traits in M_3 generation is tabulated in Table 11 and it was found that all the estimates of correlation coefficients were non-significant for all the trait. The results on phenotypic correlation coefficients are discussed below.

5.3.1 Seedling height (cm) (30DAS)

Seedling height was significantly and negatively correlated with days to 50 % flowering, days to maturity. It was found to be significantly and positively correlated with SPAD1, plant height, internodal length, panicle breadth, panicle weight, and grain weight.

5.3.2 Days to 50% flowering

Days to 50 % flowering was found to be significantly and negatively correlated with seedling height, SPAD1, plant height, internodal length, peduncle length, panicle breadth, panicle weight and grain weight. It was significantly and positively correlated with days to maturity, number of nodes and 100 grain weight.

5.3.3 SPAD readings (at flowering)

SPAD readings at flowering was found to be significantly and negatively correlated with days to flowering. It was significantly and positively correlated with seedling height plant height, internodal length, peduncle length, panicle length, panicle breadth, panicle weight, and grain weight.

5.3.4 Days to maturity

Days to maturity was found to be significantly and negatively correlated with seedling height, SPAD1, plant height, internodal length, peduncle length, panicle breadth, panicle weight and grain weight. It was significantly and positively correlated with days to flowering, number of nodes and 100 grain weight.

5.3.5 SPAD readings (at physiological maturity)

SPAD readings at physiological maturity was found to be significantly and positively correlated with plant height, number of nodes and internodal length.

5.3.6 Plant height (cm)

Plant height was significantly and negatively correlated with days to flowering and days to maturity. It was significantly and positively correlated with seedling height, SPAD1, SPAD2, number of nodes, internodal length, peduncle length, panicle breadth, panicle weight, grain yield per plant, 100 grain weight and panicle harvest index.

Plant height showing significant and positive correlation with grain yield per plant, was also reported by Srihari and Nagur (1980), Nimbalkar *et al.* (1988), Pasha (1974), Thombre and Patil (1985), El Hifney *et al*. (1972), Potdukhe *et al*. (1994), Patil *et al*. (1995), Jeyaprakash *et al*. (1997), Taurchi and Rezai (1997), Setimala *et al*. (1998), Desai *et al*. (1999) , Sunku *et al*.(2002), Awari *et al* (2003) Umakanth *et al*. (2004) and Deepak kumar *et al*. (2011).

5.3.7 Number of nodes

Number of nodes was significantly and positively correlated with days to flowering, days to maturity, SPAD2, plant height, panicle breadth, 100 grain weight and panicle harvest index.

5.3.8 Internodal length (cm)

Internodal length was significantly and negatively correlated with days to flowering and days to maturity. It was significantly and positively correlated with seedling height, SPAD1, SPAD2, plant height, peduncle length, panicle breadth, panicle weight and grain yield per plant.

5.3.9 Peduncle length (cm)

Peduncle length was significantly and negatively correlated with days to flowering and days to maturity. It was significantly and positively correlated with SPAD1, plant height, internodal length and panicle length.

5.3.10 Panicle length (cm)

SPAD1, peduncle length, panicle breadth, panicle weight and grain yield per plant were significantly and positively correlated with panicle length.

Significant and positive correlation between panicle length and grain yield per plant were reported by Pasha (1974), Srihari and Nagur (1980), Goud and Sastry (1974), Potdukhe *et al.* (1994), Patil *et al.* (1995), Jeyaprakash *et al.* (1997), Taurchi and Rezai (1997), Ivanar *et al.* (2001), Umakanth *et al.* (2004), Deepakkumar *et al.* (2011), Vijayakumar *et al.* (2012), Seetharam and Ganesamurthy (2013) and Patil *et al*, (2014).

5.3.11 Panicle breadth (cm)

Panicle breadth was found to be significantly and positively correlated with seedling height, SPAD1, plant height, internodal length, panicle length, panicle weight, grain yield per plant, panicle harvest index and number of nodes. It was significantly and negatively correlated with days to flowering and days to maturity.

Significant and positive correlation between panicle breadth and grain yield per plant was also reported by Baviskar *et al.* (2005).

5.3.12 Panicle weight (g)

SPAD1, plant height, internodal length, panicle length, panicle breadth, grain yield per plant, 100 grain weight and panicle harvest index were found to be significantly and positively correlated with panicle weight. It was significantly and negatively correlated with days to flowering and days to maturity.

Observations made by a Pasha (1974), Nimbalkar *et al.* (1988), Cheralu and Rao (1989), Geremew and Gebeyehu (1993), Potdukhe *et al.* (1994), Pawar and Jadhav (1996), Jeyaprakash *et al*. (1997), Ivanar *et al.* (2001), Umakanth *et al.* (2004), Baviskar *et al.* (2005), Deepalakshmi and Ganesamurthy (2007), Vijayakumar *et al.* (2012), and Seetharam and Ganesamurthy (2013) showed positive significant correlation between panicle weight and grain weight per plant.

5.3.13 Grain weight (g/plant)

Grain yield was found to be significantly and positively correlated with seedling height, SPAD1, plant height, internodal length, panicle length, panicle breadth, panicle weight, 100 grain weight and panicle harvest index. It was significantly and negatively correlated with days to flowering and days to maturity.

Mallinath *et al.* (2003) reported in correlation studies that grain yield per plant was found to be significantly and positively associated with panicle weight and fodder yield per plant.

5.3.14 100 Grain weight (g/100 seeds)

100 seed weight was found to be significantly and positively correlated with days to flowering, days to maturity, plant height, number of nodes, grain yield per plant, panicle weight and panicle harvest index. Results of 100 seed weight showing significant and positive correlation with grain yield per plant were also obtained by Bakheti (1990) and Godbharle *et al.* (2010).

5.3.15 Panicle harvest index

Panicle harvest index was found to be significantly and positively correlated with number of nodes, panicle breadth, panicle weight, 100 grain weight, and plant height. It was significantly and negatively correlated with days to flowering and days to maturity.

5.4 Frequency and spectrum of variable mutations (M_2)

The usefulness of any mutagen in plant breeding depends not only on its mutagenic effectiveness, but also on its mutagenic efficiency Efficient mutagenesis being the product of the maximum desirable changes accompanied by the least possible undesirable changes. Effectiveness and efficiency are two distinct properties of mutagens that have been extensively discussed elsewhere (Kawai, 1975, 1986; Shah *et al.*, 2008; Girija and Dhanavel, 2009).

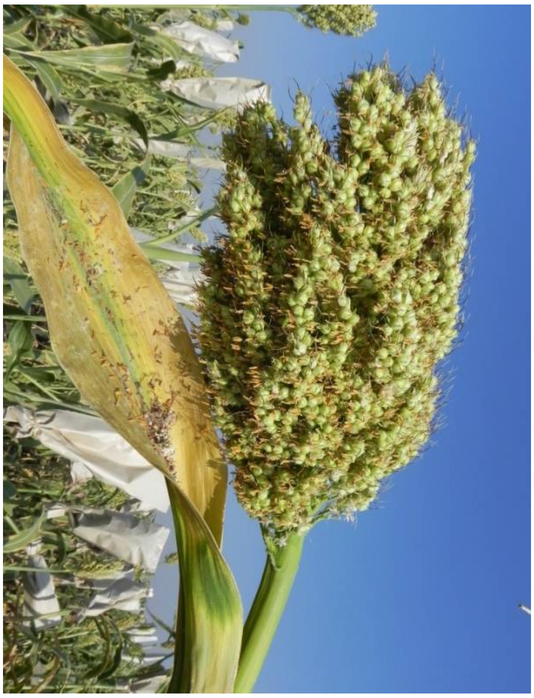
Frequency and spectrum of viable mutations were studied in M_2 generation of three varieties induced using five dosage combinations of mutagenic treatments. A total plant populations of 2951 (across all three varieties) were planted in M_2, out of which 159 plants were selected and advanced to M_3 generation. In order to induce variability and utilize useful mutations for efficient plant breeding, the systematic study of induced viable morphological mutations in M_2 and M_3 generation is the most dependable index (Knarkwal, 2000). In the present study, morphological changes in panicle size, panicle shape, seed color, seed size, seed shape, branching and day to flowering (earliness), partial sterility, were scored in M_2 generation (Table 5). These mutants were characterized and named on the basis of specific characters for spectrum of viable mutations. A high frequency and spectrum of viable mutations was observed in M_2 generation (Table 5). Early mutants consisted of plants which are in flowering compared to check. The families showing early mutants were represented in Plate 1. Panicle and seed type mutation contained twin panicle mutants, compact panicle mutants, white seed mutants and bold seed mutants.

A total 56 mutants were obtained in the M_2. The highest frequency of mutation was found in 2 dosages *viz.*, 0.2%EMS and 400Gy+0.2%EMS (19 mutants in each dose). Followed by 9 mutants in a dose of 350Gy+0.2%EMS, 6 mutants in 400Gy and 5 mutants in 350GyDose 300Gy. 400Gy+0.2%EMS dose induced the highest frequency of early maturity mutations (Table 5). The highest frequencies of panicle and seed type mutations were observed at both dosages 0.2%EMS and 350Gy+0.2%EMS. Dose 350Gy showed the least

CHECK-DSV-4

DSV4M-90

CHECK-CSV 216R



CSVM-141

Plate 1. Early mutant (M_3 generation) observed of DSV-4 and CSV 216R

spectrum and lowest frequency of viable mutations. According to Konzak *et al.* (1961), significant changes in the spectrum and the frequency of recoverable mutations could be brought by a single gene difference.

Yield contributing traits of selected mutants were compared mean values of control in M_2 generation (Table 14). Both positive and negative occurred as compared to the control. The mean of days to flowering in early mutants was 71 days as compared to 84 days in the control in DSV-4 and it was 68 days as compared to 74 days in CSV 216R. One early mutant has higher yield compared to control in DSV-4 and 6 mutants in CSV 216R. No early mutants were found in DSV-5. Yield of panicle size mutants in all three varieties were significantly higher than the control with significant increase in panicle length and breadth. Branching was observed only in CSV 216R. Bold seed size mutants were found in CSV 216R, and they have higher yield and also higher 100 grain weight compared to control. Partial sterility was observed in a dose of 0.2%EMS in both DSV-5 and CSV 216R. White seed mutant was observed in CSV 216R. Among all mutants, the largest panicle length and width was observed in high yielding mutant.

It was also observed some mutants related to panicle density. Panicle of DSV-5 is a semi-compact type. All 48 lines were semi compact only, no mutants were found in DSV-5. Panicle character of DSV-4 is loose. Out of 63 lines, 17 mutant lines were of semi-compact. Panicle character of CSV 216R is semi-compact. Out of 51 lines 7 mutant lines were of compact type and 2 mutant lines were loose type (Table 15a).

Among the treatments across varieties, highest total mutation frequency was observed in CSV 216R under treatments of 350Gy+0.2%EMS and 400 Gy+0.2%EMS, and highest frequency in the variety CSV 216R. The results indicated that, among the test varieties, CSV 216R was well responded to mutagenic treatments, and combination of gamma irradiation and EMS were found to be effective for inducing high frequency of early mutants in CSV 216R. These observations indicate the scope of isolating desirable mutants in high yielding variety of *rabi* sorghum CSV 216R for earliness to escape from terminal moisture stress, which is of common occurrence in *rabi* sorghum growing areas.

5.5 Reaction to pest and diseases

In the dry land agriculture, the yield and quality of sorghum produced is affected by a wide array of biotic and abiotic constraints. Several insect pests damage sorghum from

Table 14. Yield contributing traits among selected M_2 mutants of three *rabi* sorghum varieties

Trait	Dose	No. of mutants	Entry no.s (in M_3)	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle breadth (cm)	Panicle weight (g)	Grain weight/plant (g)	100 seed weight (g)
DSV 4 (control)	0	-	-	84	227	25.17	6.83	89.67	61.94	4.19
Panicle size (large)	350 Gy	1	57	82	252	29	7	105	76.9	3.39
Partial sterility	400 Gy	1	74	78	230	28	5.5	46	28.7	4.11
Earliness	400 Gy	1	68	82	285	28	8.5	203	146.3	4.21
DSV 5 (control)	0	-	-	84	232.33	21.70	5.22	89	69.11	3.70
Panicle size (large)	400 Gy	3	68,70, 75	81	270	28	7.3	146.3	103.6	4.04
	0.2%EMS	1	86	81	211	32	7	107	78.5	3.15
Partial sterility	0.2%EMS	2	31, 33	81	251	22	4.3	34.5	24.5	4.03
Earliness	0.2%EMS	9	87-92, 94-96	71	234	24	5.1	73.6	67.1	3.61
CSV 216R (control)	0	-	-	74	231.67	20.17	6.17	114.50	92.17	4.39
Branching	0.2%EMS	3	123, 125, 128	81	218	20	6.2	95	66.5	4.23
	400Gy+0.2% EMS	1	154	72	236	21	6	75	49.5	4.12
Panicle size (large)	350 Gy	1	114	71	170	22	10	196	137.9	4.43
	400 Gy	1	119	80	139	23	7	136	98.9	3.94
	0.2%EMS	1	128	83	210	21	6	114	86.9	4.1
	350 Gy+0.2%EMS	2	130, 136	72	248	22	7.5	136.5	100.3	4.07
Bold seed size	0.2%EMS	2	125, 127,	78	228	21	7.3	124.5	92.4	4.59
	350 Gy+0.2%EMS	1	132	78	232	18	8	122	90.4	4.91
Partial sterility	0.2%EMS	1	123	86	203	18	6	57	32.8	3.72
White seed	400Gy+0.2% EMS	1	158	69	172	18	7	69	50.2	4.8
Earliness	350 Gy	3	112, 113, 115	69	188	18	7.5	99.7	74.8	3.58
	350 Gy+0.2%EMS	6	134-139	72	219	21	6	113.3	82.8	3.97
	400Gy+0.2% EMS	17	140-153, 157, 159-160	68	220	19	5.4	87.6	71.3	4.17
	Total	58								

Table 15a. Performance of mutants of three *rabi* sorghum varieties in M_3 generation for Panicle density

Score	Variety	Entries	Total
Semi compact	**DSV-5**	DSV5M-1 to 48	48
	DSV-4	DSV4M-70, 80-81, 87, 89, 96, 98, 100, 102-110	17
	CSV 216 R	CSVM-112 to 118, 126-133, 135-162.	42
Compact	**DSV-5**	-	0
	DSV-4	-	0
	CSV 216 R	CSVM-119 to 125.	7
Loose	**DSV-5**	-	0
	DSV-4	DSVM-49 to79, 82-86, 88, 90-95, 97, 99, 101, 111.	46
	CSV 216 R	CSVM-134, 150.	2

seedling stage to maturity. Around 150 insect pests attack sorghum (Jotwani *et al*, 1980; Sharma, 1993), of which sorghum shoot fly, *Atherigona soccata* is a serious pest that reduces sorghum production in the semi-arid tropics. Due to shoot fly damage, a loss of 80–90% of grain, and 68% of fodder yield was recorded in India (Balikai and Bhagwat, 2009; Kahate *et al.*, 2014). Identifying sorghum genotypes with stable shoot fly resistance is highly important as it will help to reduce the cost of cultivation and stabilize the yields.

Data were recorded on shoot fly in terms of dead hearts (%), seedling height and leaf glossiness in M_3 families of three rabi sorghum varieties, DSV 5, DSV 4 and CSV 216R Data were recorded on plants with shoot fly dead hearts at 21DAE, and expressed as the percentage of plants with shoot fly dead hearts. To record data on DH%, the total number of plants was initially recorded, and the numbers of plants with dead hearts were subsequently recorded on 28 DAE. The mean values of DH% (ratio of the number of dead hearts/total number of plants x 100) recorded on 28 DAE were used for identification of shoot fly resistant lines (Balakrishna *et al.,* 2015). Over all resistance score was recorded on a 1-9 scale before harvesting (1= plants with <10% dead hearts and uniform tillers and harvestable panicles, and 9= plants with >80% dead hearts, and a few or no productive tillers) (Sharma *et al*., 1992).

Leaf glossiness was evaluated visually on a 1–5 scale (1 = highly glossy, and 5 = non-glossy) at 10–12 DAE (fifth leaf stage), when the expression of this trait is most apparent in the early morning hours (Sharma and Nwanze, 1997). The families showing leaf glossiness mutants were represented in Plate 2.

Charcoal rot of sorghum caused by the fungus *Macrophomina phaseolina* is a root and stalk rot disease of great destructive potential in most sorghum growing regions. *Macrophomina phaseolina* is a common soil borne, non-aggressive and plurivorous pathogen that attacks plants whose vigor has been reduced by unfavorable growing conditions (Das *et al*., 2008). Improved, high-yielding cultivars under good management tend to be very susceptible to the disease (Mughogho and Pande, 1984). Drought stress is the primary factor that predisposes sorghum to charcoal rot. In diseased roots and stalks, *M. phaseolina* is often associated with other fungi, suggesting that the disease is of complex etiology.

Of the insect pests of sorghum *[Sorghum bicolor* (L.) Moench], shoot bug (*Peregrinus maidis* Ashmead) (Delphacidae: Homoptera) has attained serious pest status due to the introduction of hybrids that mature at different times. In India shoot bugs can cause 41 %

Check- DSV-5(Glossy)

DSV5M-13 (Non glossy)

Check- DSV-4 (Glossy)

DSV4M-57(Non glossy)

Check- CSV216R (Glossy)

CSVM-157 (Non glossy)

Plate 2. Sorghum seedlings with glossy and non glossy leaves (M_3)

losses (Hosmani and Chittapur, 1997). Both nymphs and adults suck the sap of young leaves, resulting in leaf chlorosis that in severe cases causes stunted growth and shriveled, chaffy grains (Prabhakar *et al*. 1981). Severe infestation at the boot stage results in the top leaves twisting and preventing the emergence of the panicles (Agarwal *et al.*, 1978).

Chlorophyll mutants are employed as markers for the evaluation of gene action of mutagenic factors in inducing mutation studies (Gaul, 1964). The spectrum and frequency of chlorophyll mutants are assessed in M_3 population easily and is being used as primary index of effectiveness of mutagens and mutability of the genotypes towards the mutagens which in turn would be useful to generate the wide array of desirable mutants in the treated population. Different types of chlorophyll mutants were obtained when seedlings were 8-20 days old. The spectrum of chlorophyll mutations included: albina, chlorina, and xantha in all the varieties. All mutants died at seedling stage only. In the present study, chlorophyll deficient seedlings were counted and recorded as chlorophyll mutant segregation in M_3 generation. A wide spectrum of chlorophyll mutants segregation was observed in the mutagenic treatments. Similar results were expressed by Singh and Sanjeev Singh (2001) and Vennila (2005). Data has been tabulated in Table 15b, 15c, 15d, 16e, 15f.a and 15f.b. The families showing chlorophyll mutants were represented in Plate 3.

5.5.1 Variety: DSV-5

Shoot fly incidence was ranged from 10 % to70 %. Out of 48 lines 20 lines were shown less than 10% incidence, 22 lines were of 11-20% incidence, 5 lines were of 21-30%, 1 line was shown 31-40% incidence (Table 15b).

The data generated in M_3 generation mutants on glossiness ranged from 1 - 4 on a scale of 1-5, with an average of 2. Out of 48 lines forty-seven mutant lines recorded lower score for glossiness; only one line was found to be susceptible compared to check (Table 15d).

Charcoal rot incidence was ranged from 10% to 70%. Out of 48 lines 3 lines were resistant (<10%), 28 lines were moderately resistance, 10 lines were susceptible and 3 lines were highly susceptible (Table 15c).

Shoot bug incidence was very low because of high temperature; out of 48 lines 36 lines will come under score 1, which shows very less incidence of shoot bug, and 9 lines were

DSV5M-19

DSV5M-24

DSV5M-14

DSV5M-24

Plate 3. Segregation for chlorophyll mutants in variety DSV-5

Table 15b. Reaction of Sorghum mutants (M_3) of *rabi* sorghum varieties for shoot fly resistance induced under different mutagen treatment conditions

DH %	Variety	Mutagenic treatments					Total
		350Gy	**400Gy**	**0.2%EMS**	**350Gy+0.2% EMS**	**400Gy+0.2%EMS**	
< 10%	**DSV-5**	DSV5M-4, 6, 9, 12, 14, 19, 21-23	DSV5M-25, 28.	DSV5M-32, 35-36, 41.	DSV5M-42	DSV5M-43 to 46	20
	DSV-4	DSV4M-49, 53, 59.	DSV4M-61, 65-69, 72-74.	DSV4M-76 to 79, 81- 83, 86-87, 89 to 93	DSV4M-100	DSV4M-104, 108, 111.	29
	CSV 216 R	CSVM-112	CSVM-119	CSVM-123, 125.	CSVM-134 to 139.	CSVM-142, 144-146, 150, 152, 161.	17
11-20%	**DSV-5**	DSV5M-3, 5, 7, 8, 10-11, 13, 16-18.	DSV5M-24, 26, 27.	DSV5M-29, 30, 34, 37-40.	-	DSV5M-47, 48.	22
	DSV-4	DSV4M-50 to 52, 56.	DSV4M-60, 63-64, 66, 70, 71, 75.	DSV4M-84, 85, 88, 95.	DSV4M-97 to 99, 103.	DSV4M-105, 106, 108.	22
	CSV 216 R	CSVM-113-114, 116-118.	-	CSVM-120-121, 127 to 129.	CSVM-130 to 133.	CSVM-140, 143, 147 to 149, 153, 155, 156, 158 to 160, 162.	26
21-30%	**DSV-5**	DSV5M-1, 2, 20.	-	DSV5M-31, 33.	-	-	5
	DSV-4	DSV4M-54, 55, 57.	DSV4M-62	DSV4M-94	DSV4M-101	DSV4M-107, 109.	10
	CSV 216 R	CSVM-115	-	CSVM-124, 126.	-	CSVM-141, 151, 154.	6
31-40%	**DSV-5**	DSV5M-15	-	-	-	-	1
	DSV-4	DSV4M-58	-	DSV4M-80, 96.	DSV4M-102	-	4
	CSV 216 R	-	-	CSVM-122	-	-	1
41-50%	**DSV-5**	-	-	-	-	-	0
	DSV-4	-	-	-	-	-	0
	CSV 216 R-	-	-	-	-	-	0
51-60%	**DSV-5**	-	-	-	-	-	0
	DSV-4	-	-	-	-	-	0
	CSV 216 R	-	-	-	-	-	0
60-70%	**DSV-5**	-	-	-	-	-	0
	DSV-4	-	-	-	-	-	0
	CSV 216 R	-	-	-	-	CSVM-157	1

Table 15c. Reaction of Sorghum mutants (M_3) of *rabi* sorghum varieties for charcoal rot resistance induced under different mutagen treatment conditions

Frequency	Variety	Mutagenic treatments					Total
		350Gy	400Gy	0.2%EMS	350Gy+0.2%EMS	400Gy+0.2%EMS	
0%	DSV-5	-	-	-	-	-	0
	DSV-4	-	-	-	-	-	0
	CSV 216 R	-	-	-	-	-	0
<10%	DSV-5	DSV5M-21	DSV5M-24, 26.	-	-	-	3
	DSV-4	-	-	-	-	-	0
	CSV 216 R	-	-	CSVM-129	CSVM-131, 134.	CSVM-143	4
10-30%	DSV-5	DSV5M-2, 4, 5, 9, 11, 13 to 15, 18 to 20, 22-23.	DSV5M-25, 27-28.	DSV5M-29, 30, 32, 35, 36, 37, 39, 40, 41.	DSV5M-42	DSV5M-45, 46.	28
	DSV-4	DSV4M-55, 56, 58.	DSV4M-60, 64 to 73, 75.	DSV4M-76 to 80, 83 to 86, 88-90, 91, 95.	DSV4M-97, 99, 103.	DSV4M-105, 108.	35
	CSV 216 R	CSVM-112, 114 to 116.	CSVM-119	CSVM-120, 124, 126 to 128.	CSVM-130, 133, 135 to 139.	CSVM-140, 144 to 147, 149, 151, 160-161.	26
30-50%	DSV-5	DSV5M-1, 3, 7, 8, 10, 12, 16, 17.	-	-	-	DSV5M-43, 48.	10
	DSV-4	DSV4M-49 to 54, 57, 59.	DSV4M-61 to 74.	DSV4M-81, 87, 89, 92, 93, 94, 96.	DSV4M-98, 100 to 102.	DSV4M-106, 107, 109 to 111.	28
	CSV 216 R	-	CSVM-113, 117, 118.	CSVM-121 to 123, 125.	CSVM-132	141-142, 148, 150, 152 to 159, 162.	21
>50%	DSV-5	DSV5M-6	-	-	-	DSV5M-44, 47.	3
	DSV-4	-	-	DSV4M-82	-	DSV4M-104	2
	CSV 216 R		-	-	-	-	0

Table 15d. Performance of mutants of three *rabi* sorghum varieties for leaf glossiness in M_3 generation

Score	Variety	Entries	Total
1	**DSV-5**	DSV5M-8, 16, 21-22, 36, 47-48.	7
	DSV-4	DSV4M-61, 67, 69, 77, 84, 86, 107, 110-111.	9
	CSV 216 R	CSVM-117, 135, 142-143, 148.	5
2	**DSV-5**	DSV5M-1 to 7, 9, 11-12, 15, 17, 20, 23 to 25, 27, 31, 33, 34,37 to 42, 44, 46.	28
	DSV-4	DSV4M-49, 50, 60, 62, 68, 70, 72, 76, 78, 81 to 83, 87, 89-90, 93, 95-96, 100, 102, 105-106, 108-109.	24
	CSV 216 R	CSVM-115, 116, 118, 124, 129, 131, 136-137, 140-141, 144-145, 147, 149.	14
3	**DSV-5**	DSV5M-10, 14, 18-19, 26, 28 to 30, 32, 35, 43, 45.	12
	DSV-4	DSV4M-51 to 56, 58, 59, 63 to 66, 71, 73 to 75, 79-80, 85, 88, 91-92, 94, 101, 103-104.	26
	CSV 216 R	CSVM-112 to 114, 119 to 123, 125 to 128, 130, 132 to 134, 138-139, 146, 150, 151 to 156, 158 to 162.	31
4	**DSV-5**	DSV5M-13	1
	DSV-4	DSV4M-57, 97 to 99.	4
	CSV 216 R	CSVM-157	1

recorded under score 2, 2 lines were under score 3 and only 1line was shown susceptible to shoot bug which comes under score 4 (Table 15e).

Highest frequency of chlorophyll mutants were found in DSV-5 only. Out of 48 lines 5 lines were showed (13.04 % in 350Gy and 40% in 400Gy) chlorophyll mutants in segregating panicles. Among segregating progenies highest frequency (30.74) was recorded in a mutant line number 28 in a dose of 400Gy (Table 15f.a and 15f.b).

5.5.2 Variety: DSV-4

Shoot fly incidence was ranged from 10 % to 70 %. Out of 63 lines 29 lines were shown less than 10% incidence, 22 lines were of 11-20% incidence, 10 lines were of 21-30%, 4 lines were shown 31-40% incidence (Table 15b).

The data generated in M3 generation mutants on glossiness ranged from 1 - 4 on a scale of 1-5, with an average of 2. Out of 63 lines 59 mutant lines recorded lower score for glossiness; only 4 lines were found to be susceptible compared to check (Table 15d) indicating the effect of mutation treatment for intensity of leaf glossiness.

Charcoal rot incidence was ranged from 10% to 70%. Out of 63 lines none of lines were resistant (<10%), 35 lines were moderately resistance, 28 lines were susceptible and 2 lines were highly susceptible (Table 15c).

Shoot bug incidence was very low because of high temperature; out of 63 lines 40 lines will come under score 1, which shows very less incidence of shoot bug, and 19 lines were recorded under score 2, 3 lines were under score 3 and only 1line was shown susceptible to shoot bug which comes under score 4 (Table 15e).

Medium frequency of chlorophyll mutants were found in DSV-4. Out of 63 lines 3 lines were showed (9.52 % in 0.2%EMS and 14.29% in 350Gy+0.2%EMS) chlorophyll mutants in segregating panicles. Among segregating progenies highest frequency (38.58) was recorded in a mutant line number 103 in a dose of 350Gy+0.2%EMS (Table 15f.a and 15f.b).

5.5.3 Variety: CSV 216R

Shoot fly incidence was ranged from 10 % to70 %. Out of 51 lines 17 lines were shown less than 10% incidence, 26 lines were of 11-20% incidence, 6 lines were of 21-30%, 1 line was shown 31-40% incidence (Table 15b).

Table 15e. Performance of mutants of three *rabi* sorghum varieties for in M_3 generation for reaction to shoot bug incidence

Score	Variety	Entries	Total
1	**DSV-5**	DSV5M-1 to 5, 8-10,12, 14-15, 17-18, 20, 22-29, 31-39, 41-42, 44, 45, 47.	36
	DSV-4	DSV4M-50, 53, 55, 58-59, 63-64, 66-67, 70, 72-73, 76-81, 84-93, 97-98, 100-110,	40
	CSV 216 R	CSVM-112, 115-118, 120-124, 126, 128, 130-133, 135-141, 143-147, 150, 160, 161.	31
2	**DSV-5**	DSV5M-6, 7, 11, 13, 16, 19, 30, 43, 46.	9
	DSV-4	DSV4M-49, 51-52, 55-56, 60-62, 65, 68, 69, 71, 77, 82, 83, 95, 96, 99, 111.	19
	CSV 216 R	CSVM-114, 119, 125, 127, 134, 148, 149, 152-157.	13
3	**DSV-5**	DSV5M-21, 48.	2
	DSV-4	DSV4M-54, 74, 75.	3
	CSV 216 R	CSVM-113, 129, 142, 158-159, 162.	6
4	**DSV-5**	DSV5M-40	1
	DSV-4	DSV4M-57	1
	CSV 216 R	CSVM-151	1

The data generated in M_3 generation mutants on glossiness ranged from 1 - 4 on a scale of 1-5, with an average of 3. Out of 51 lines 50 mutant lines recorded lower score for glossiness; only one line was found to be susceptible compared to check (Table 15d).

Charcoal rot incidence was ranged from 10% to 70%. Out of 51 lines 4 lines were resistant (<10%), 26 lines were moderately resistance and 21 lines were susceptible (Table 15c).

Shoot bug incidence was very low because of high temperature; out of 51 lines 31 lines will come under score 1, which shows very less incidence of shoot bug, and 13 lines were recorded under score 2, 6 lines were under score 3 and only 1line was shown susceptible to shoot bug which comes under score 4 (Table 15e).

Low frequency of chlorophyll mutants were found in CSV 216R. Out of 51 lines only one line was shown (10 % in 350Gy+0.2%EMS) chlorophyll mutant in segregating panicles. Among segregating progenies highest frequency (21.58) was recorded in a mutant line number 131 in a dose of 350Gy+0.2%EMS (Table 15f.a and 15f.b).

5.6 Performance of early mutant selections

Early mutants were obtained only in DSV-4 and CSV 216R. Comparative performance of early mutants of both M_2 and M_3 generation was done. The results are compiled and presented in Table 15g.a and 15g.b. Mutants related to panicle traits were represented in Plate 4a(M_2) and Plate 4b(M_3).

5.6.1 Variety: DSV-4

Out of 63 lines, 10 lines were early in flowering compared to check. Among these mutants the lines which were early in M_2, were early in M_3 also. But for grain yield segregation was observed. Line number 68 has shown a highest yield 146.31 g (M_2), and 40.33 g (M_3) followed by line number 87 with 88.22g (M_2), and 30.31g (M_3) and line number 96 with 82.59 g (M_2), and 31.23 g (M_3) (Table 15.g.a).

5.6.2 Variety: CSV 216R

Out of 51 lines, 26 lines were early in flowering compared to check. Among these mutants the lines which were early in M_2, were early in M_3 also. But for grain yield segregation was observed. Line number 138 was shown a highest yield 59.06g (M_2), and

1054-10

1058-2

1095-4

1112-3

Plate 4a. Induced changes in panicle characteristics in M_2 generation

CSVM-136

CSVM-141

Plate 4b. Induced changes in panicle characteristics in M_3 generation

Table 15f.a. Frequency of Chlorophyll mutants (segregating panicles) of *rabi* sorghum varieties in M_3 generation

Treatment	DSV-5			DSV-4			CSV 216 R		
	Total no. of M3 progeny	Segregating mutants	Frequency %	Total no. of M3 progeny	Segregating mutants	Frequency %	Total no. of M3 progeny	Segregating mutants	Frequency %
Control	0	0	0.00	0	0	0.00	0	0	0.00
350Gy	23	3	13.04	11	0	0.00	7	0	0.00
400Gy	5	2	40.00	16	0	0.00	1	0	0.00
0.2%EMS	13	0	0.00	21	2	9.52	10	0	0.00
350Gy+0.2%EMS	1	0	0.00	7	1	14.29	10	1	10.00
400Gy+0.2%EMS	5	0	0.00	7	0	0.00	22	0	0.00

Table 15f.b. Frequency of Chlorophyll mutant plants in segregating progenies (M_3) of three *rabi* sorghum varieties

Sl. No.	Variety	Entry code	Entry no.	Dosage	Frequency of mutation (%)		
					Total plants	Mutants	%
1	DSV-5	1008-9	DSV5M-14	350Gy	86	20	22.96
2	DSV-5	1011-12	DSV5M-19	350Gy	76	23	30.70
3	DSV-5	1012-7	DSV5M-20	350Gy	78	18	23.61
4	DSV-5	1017-4	DSV5M-24	400Gy	74	17	22.97
5	DSV-5	1021-6	DSV5M-28	400Gy	77	24	30.74
6	DSV-4	1065-7	DSV4M-79	0.2%EMS	40	5	12.50
7	DSV-4	1070-5	DSV4M-89	0.2%EMS	65	17	26.80
8	DSV-4	1078-6	DSV4M-103	350Gy+0.2%EMS	23	9	38.58
9	CSV 216 R	1111-1	CSVM-131	350Gy+0.2%EMS	46	10	21.58

40.86 g (M_3) followed by line number 135 with 152.12 g (M_2), and 39.35 g (M_3) and line number 141 with 119.25 g (M_2), and 37.76 g (M_3) (Table 15.g.b).

5.7 Promising M_3 families for various traits

Considering all the traits some of the families have been identified as promising lines based on their performances.

5.7.1 Variety: DSV-5

Promising lines for yield were line no.s DSV5M-1, DSV5M-18 and DSV5M-39. Promising lines for charcoal rot were DSV5M-21, DSV5M-24 and DSV5M-26. Promising lines for Shoot fly resistance were DSV5M-4, DSV5M-6, DSV5M-9, DSV5M-12, DSV5M-14, DSV5M-19, DSV5M-21-23, DSV5M-25, DSV5M-28, DSV5M-32, DSV5M-35-36, DSV5M-41-46.

5.7.2 Variety: DSV-4

Promising lines identified for earliness were DSV4M-68, DSV4M-87-92 and DSV4M-94-96. For yield are DSV4M-55 and DSV4M-95. For Earliness and Yield promising line was line DSV4M-95. Promising lines for Shoot fly resistance were DSV4M-49, DSV4M-53, DSV4M-59, DSV4M-61, DSV4M-65, DSV4M-67-69, DSV4M-72-74, DSV4M-76-79, DSV4M-81-83, DSV4M-86-87, DSV4M-89-93, DSV4M-100, DSV4M-104, DSV4M-108 and DSV4M-111.

5.7.3 Variety: CSV 216R

Promising lines for earliness were CSVM-112, CSVM-113, CSVM-115, CSVM-134-139, CSVM-140-153, CSVM-157 and CSVM-159-160. For yield were CSVM-114-115, CSVM-122-125, CSVM-127-132 and CSVM-141. For Earliness and yield, promising lines were CSVM-115 and CSVM-141. Promising lines for Shoot fly resistance were CSVM-49, CSVM-53, CSVM-59, CSVM-61, CSVM-65, CSVM-67-69, CSVM-72-74, CSVM-76-79, CSVM-81-83, CSVM-86-87, CSVM-89-93, CSVM-100, CSVM-104, CSVM-108 and CSVM-111. Promising lines for charcoal rot CSVM-129, CSVM-131, CSVM-134 and CSVM-143. Promising lines for Yield and Charcoal rot resistance were CSVM-129, CSVM-131 and CSVM-134. For Shoot fly resistance promising lines were CSVM-112, CSVM-119, CSVM-123, CSVM-125, CSVM-134-139, CSVM-142, CSVM-144-146, CSVM-150, CSVM-152 and CSVM-161. Promising lines for Shoot fly resistance and yield was line CSVM-125.

Table 15g.a. Comparative performance of early mutants of Rabi sorghum variety DSV-4 (DSV4M) for yield traits in M_2 and M_3 generations evaluated during *rabi* 2015, Rabi 2016, respectively at RARS Vijayapur

Entries		Treatment	Days to 50% flowering		Plant height (cm)		Panicle length (cm)		Panicle breadth (cm)		Panicle weight (g)		Grain weight/plant (g)		100 seed weight (g)	
M_2	M_3	Dose	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3
Control		0	78.00	82.33	220.00	135.80	24.50	15.46	6.00	4.26	101.00	31.26	70.50	23.06	4.20	3.08
1058-2	68	400 Gy	72.00	78.66	285.00	140.00	28.00	16.00	8.50	5.60	203.00	51.80	146.31	40.33	4.21	2.72
1070-1	87	0.2%EMS	70.00	78.33	255.00	155.60	26.00	16.20	7.00	5.40	114.00	38.25	88.22	30.31	3.47	2.98
1070-3	88	0.2%EMS	70.00	81.66	198.00	154.33	27.00	16.33	5.50	3.60	50.00	31.26	28.00	22.90	3.61	2.55
1070-5	89	0.2%EMS	70.00	78.33	260.00	154.06	25.00	13.80	6.00	4.40	100.00	37.80	52.07	28.53	3.75	3.83
1070-8	90	0.2%EMS	70.00	76.66	220.00	155.46	21.00	15.33	6.00	4.26	75.00	32.33	53.92	21.53	2.95	2.84
1070-11	91	0.2%EMS	77.00	69.00	200.00	132.46	21.00	15.60	5.00	3.50	40.00	25.77	23.13	18.26	3.61	3.03
1071-7	92	0.2%EMS	71.00	79.66	237.00	136.33	25.00	15.26	5.50	3.50	51.00	30.86	32.88	27.88	3.41	2.47
1072-9	94	0.2%EMS	71.00	78.66	252.00	144.60	23.00	16.66	6.00	4.13	76.00	38.53	55.19	31.40	4.40	3.40
1072-12	95	0.2%EMS	71.00	79.33	250.00	144.60	24.00	16.06	5.50	4.23	83.00	39.86	61.78	33.26	3.71	3.53
1072-15	96	0.2%EMS	71.00	74.00	200.00	143.80	26.00	17.26	6.50	4.70	116.00	36.90	82.59	31.23	3.72	2.77
	Range	Max	87.5	89.33	282.5	165.33	30.5	20.2	8.25	5.26	119.5	48.66	100.16	38	5.28	3.94
		Min	70	68	137.5	91.46	19	10.2	4.85	2.66	51.5	18.4	37.98	9.53	2.02	1.88
		Mean	78.62	79.2	233.33	139.31	25.40	16.29	6.33	4.34	80.96	32.36	61.72	23.03	3.77	2.89
		CV	10.87	9	11.60	12.59	9.50	12.02	15.84	18.46	24.07	33.04	27.10	42.62	13.68	16.1
		CD at 5%	-	11.52	54.80	3.01	4.88	3.16	-	-	-	-	-	-	1.04	0.75

Table 15g.b. Comparative performance of early mutants of Rabi sorghum variety CSV 216R (CSVM) for yield traits in M_2 and M_3 generations evaluated during *rabi* 2015, *rabi* 2016, respectively at RARS Vijayapur

Entries		Treatment	Days to 50% flowering		Plant height (cm)		Panicle length (cm)		Panicle breadth (cm)		Panicle weight (g)		Grain weight/plant (g)		100 seed weight (g)	
M_2	M_3	Dose	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3
Control		0	74	77	220	172	19.5	15.8	5	6.13	105.5	48.26	84.5	36.58	4.25	3.03
1095-2	112	350Gy	69	71.33	186	129.73	18	12.86	7.5	4.46	66	35.46	49.64	28.6	2.574	2.95
1095-3	113	350Gy	69	71	191	110.13	19	13.13	7	4.03	96	39.26	74.55	27.4	3.62	2.81
1095-6	115	350Gy	69	69.66	188	163.06	18	15.86	8	5.23	137	46.1	100.2	35.82	4.54	3.09
1112-1	134	350Gy+0.2% EMS	72	72	228	163.4	19	15.4	6.5	5.33	74	37.73	47.68	25.2	3.05	2.1
1112-2	135	350Gy+0.2% EMS	72	71.33	249	164.26	23	15.86	7.5	0.73	208	48.26	152.12	39.35	4.88	3
1112-3	136	350Gy+0.2% EMS	72	70.33	236	181.53	22	15.66	6	4.53	91	40.93	65.26	30.93	3.86	3.69
1112-6	137	350Gy+0.2% EMS	72	72.33	208	151.53	20	16.73	5	5.33	124	50.26	91.98	37.06	4.21	2.27
1112-10	138	350Gy+0.2% EMS	72	70.66	239	174.73	19	16.4	6	5.46	78	48.33	59.06	40.86	3.912	3.75
1112-12	139	350Gy+0.2% EMS	72	70.66	154	150.66	22	16.06	5	4.86	105	37.6	80.73	29.93	3.899	3.34
1113-3	140	400Gy+0.2% EMS	68	69.66	215	150	22	17	6	5.46	135	44.36	97.75	34.93	4.585	2.7
1113-4	141	400Gy+0.2% EMS	68	69.33	212	155.73	20	16.73	8	5.4	165	44.86	119.25	37.76	3.689	2.36
1113-6	142	400Gy+0.2% EMS	68	70	243	156.46	22	15.06	5	4.93	88	42.83	61.95	33.26	4.465	2.94
1115-3	143	400Gy+0.2% EMS	69	71.33	253	170.93	22	15.66	5	4.73	121	41.33	93.95	33.53	4	3.24
1115-5	144	400Gy+0.2% EMS	69	71	258	166.4	19	15.33	6	4.86	74	39.06	66.5	29.86	2.863	2.65
1115-6	145	400Gy+0.2% EMS	69	70.66	257	168.4	20	15.26	6	4.73	93	32.33	74.17	23.86	3.993	2.6
1115-8	146	400Gy+0.2% EMS	69	70.66	233	168.06	18	13.6	5.5	5	74	35.66	58.29	26.26	3.232	2.86
1115-16	147	400Gy+0.2% EMS	69	70.33	260	156.73	19	14	5.5	5.13	77	40.8	54.25	31.26	4.264	3.23
1115-21	148	400Gy+0.2% EMS	69	71	204	163.73	23	14.93	6	5	110	39.26	83.98	26.46	4.781	2.75
1116-6	149	400Gy+0.2% EMS	69	71.66	197	150.66	20	15.33	6	5.33	109	44	87.72	31.13	4.522	2.56
1118-4	150	400Gy+0.2% EMS	71	71	240	164.6	21	14.66	6	4.4	116	34.4	85.53	23.2	4.96	2.26
1118-6	151	400Gy+0.2% EMS	71	70.33	242	179.13	22	14.86	4	5.2	11	38.12	84.32	29.73	4.86	3.11
1118-8	152	400Gy+0.2% EMS	71	70.33	270	175.66	19	14.46	6	4.73	68	42.73	50.67	29.93	4.123	2.66
1118-12	153	400Gy+0.2% EMS	71	71.66	252	168.73	20	14.66	5	5.06	59	42.07	44.78	34.57	4.252	3.59
1121-5	157	400Gy+0.2% EMS	71	69	172	138.13	18	15.2	7	4.93	69	42.6	50.21	34.46	4.804	2.54
1122-15	159	400Gy+0.2% EMS	71	71.66	240	156.93	18	14.26	6	5	80	50.93	63.51	40.53	4.353	2.87
1122-16	160	400Gy+0.2% EMS	71	75	185	147.4	15	13.86	4	5.33	94	40.96	72.2	33.03	3.825	3.03
	Range	**Max**	86	82.66	269	181.53	22.5	17.26	8.5	6.13	137.5	62.93	110.37	49.66	4.91	0.83
		Min	66.5	68	134.75	110.31	15	12.23	4.5	4.03	63.5	32.33	46.26	23.86	2.97	0.63
		Mean	72.55	72.03	219.52	157.39	19.77	14.85	6.1	5.03	99.38	45.06	77.74	34.5	4.16	0.76
		CV	4.9326	2.23	11.33	8.76	9.15	9.55	17.46	15.96	25.74	21.74	25.14	24.64	11.27	14.7
		CD at 5%	7.28	2.61	50.67	22.34	-	2.3	-	-	-	-	-	13.77	-	0.68

Table 15h. List of promising entries for Earliness, Yield, Shoot fly resistance, and Charcoal rot resistance in M_3 generation of 3 *rabi* sorghum varieties

SL. No.	Traits	Promising entries		
		DSV-5	DSV-4	CSV 216R
1	Earliness	0	DSV4M-68, 87-92, 94-96	CSVM-112, 113, 115, 134-139, 140-153, 157, 159-160.
2	Yield	DSV5M-1, 18, 39.	DSV4M-55, 95.	CSVM-114-115, 122-125, 127-132, 141.
3	Earliness- Yield	0	95	CSVM-115, 141.
4	Charcoal rot resistance	DSV5M-21, 24, 26	0	CSVM-129, 131, 134, 143.
5	Yield-Charcoal rot resistance	0	0	CSVM-129, 131, 134.
6	Earliness- Yield-Charcoal rot resistance	0	0	0
7	Shoot fly resistance	DSV5M-4, 6, 9, 12, 14, 19, 21-23, 25, 28, 32, 35-36, 41-46.	DSV4M-49, 53, 59, 61, 65, 67-69, 72-74, 76-79, 81-83, 86-87, 89-93, 100, 104, 108, 111.	CSVM-112, 119, 123, 125, 134-139, 142, 144-146, 150, 152, 161.
8	Shoot fly resistance - Yield	0	0	CSVM-125
9	Earliness- Charcoal rot resistance-Shoot fly resistance -Yield	0	0	0

Future line of work

1. Early mutants identified in CSV 216R may be evaluated for yield in replicated trials to identify promising ones to escape from terminal stress.
2. Early mutants of DSV-4 and CSV 216 may be utilized as donors in improving for earliness in other high yielding and late maturing varieties.
3. M_3 families of CSV 216R which were recorded with reduced height may be critically evaluated, stabilized and utilized.
4. The promising M_3 families derived from CSV 216R for earliness, charcoal rot resistance and yield may be critically evaluated, stabilized and utilized.
5. The effectiveness of dosage combinations gamma and EMS may be assessed for other varieties and applied to create new variability for various traits.

Summary and Conclusions

6. SUMMARY AND CONCLUSIONS

The research on induced mutation studies in *Rabi* sorghum [*Sorghum bicolor* (L.) Moench] was conducted at Regional Agricultural Research Station, Vijayapur. The present study on induced mutagenesis in rabi sorghum was designed to study mutagenic effects of physical (γ-irradiation) and chemical (EMS) mutagens and combination of physical and chemical mutagen treatment for yield and yield components, to study induced changes with particular reference to genetic parameters of various characters, and to identify desirable mutants for reduced height, earliness and other yield related traits.). The experimental material used was M_2 and M_3 generation material derived from five mutation treatment combinations (EMS and Gamma) induced in three *rabi* sorghum varieties. Three *rabi* sorghum varieties namely, DSV-5, DSV-4 and CSV 216R were chosen to study the effect of the physical and chemical mutagens on the induction of variability for both qualitative and quantitative characters.. Mutation treatments included were 350 Gy, 400 Gy, EMS (0.2%), 350 Gy+EMS (0.2%) and 450 Gy+EMS (0.2%). M2 generation seeds of different varieties that were advanced from M_1 were collected from AICSIP, Vijayapur.

The experimental material consisting of a total of 47 M2 families in variety DSV 5, 58 in DSV 4 and 48 in CSV 216R was laid out in an Augmented design without replication during *Rabi* 2015. In M_2 generation, individual plant observations were recorded on days to 50 per cent flowering, plant height, panicle length, panicle breadth, panicle weight, grain yield and 100 grain weight were recorded.

Selections in M_2 generation were made based on induced changes for visual characters, The individual plant selections in each dosage combinations were advanced to M_3. A total of 159 plants were advanced to M_3 by selfing were selected for evaluation. Evaluation of 159 M_3 families was done in replicated trial along with respective control varieties during 2016-17 in a Randomized Block Design (RBD) with three replications. The observations were recorded on yield traits *viz*., seedling height (cm), days to 50 % flowering, plant height (cm), number of nodes, nodal length(cm), peduncle length (cm), panicle length (cm), panicle breadth (cm), panicle weight (g), 100 seed weight (g), grain yield per plant (g) and panicle harvest index. Reaction to pest and diseases (Shoot fly, charcoal rot and shoot bug) was also recorded.

The experimental results obtained are summarized under following headings.

6.1 ANOVA (M_2)

In M_2 generation analysis of variance has showed that variances among the treatments including checks were significant for plant height and panicle weight, and within genotypes for panicle weight and grain yield were significant for a variety DSV-5. Regarding variety DSV 4, variances among the treatments including checks and also within genotypes were significant for plant height and hundred grain weight. In case of CSV 216R, variances were found to be significant among the treatments including checks for the traits days to 50% flowering, plant height, panicle weight, grain yield and 100 grain weight..

6.2 Mean and range (M_2)

Mean and range values of DSV-5 showed a wide range for all the traits in mutation treatments 350 Gy, 400 Gy and EMS (0.2%). Among these, range was wider in 350 Gy compared to 400 Gy and EMS (0.2%). And in case of DSV-4, wide range was observed in all the mutation treatments for all the traits except for days to 50% flowering in 400Gy+ EMS (0.2%). High mean values were observed for the traits plant height, panicle length, panicle weight, grain yield per plant and 100 seeds weight among the genotypes across different mutation treatments. In CSV 216R, wide range was observed for all the traits across all the mutation treatments with genotypes having recorded with lower and higher values than the control except for days to 50% flowering.

6.3 Effect of induced mutation on various traits (M_2)

The total frequency of mutation observed was 0.62% and the mutants were found only with the partial sterility in a dosage of 0.2%EMS, in DSV-5. The total frequency of mutation observed was 13.31% across mutation treatments in case DSV-4. And it was 33.2% in CSV 216R.

In DSV-5, mutants were found for partial sterility. In DSV-4 grain weight of check was 70.5 g. and there were three early mutants with high grain weight compared to check. Six mutants in panicle size and four in panicle shape were recorded with higher yield. Two mutants in seed type were recorded with higher yield and one partial sterile mutant with lesser grain yield of 28.66 g was observed. In CSV 216R there were nine early mutants, one in branching, five in panicle size, one in panicle shape and five in seed type mutants recorded with high grain yield (g/plant) compared to checks. One partial sterile mutant recorded with lesser grain yield of 32.76 g/plant compared to check.

6.4 Genetic components (M_2)

The estimates of PCV, GCV, heritability and genetic advance were obtained in all the three varieties using data generated in M_2 generation for various traits. In DSV-5 highest PCV values were observed for the traits panicle weight and grain yield, moderate GCV values for panicle weight and grain yield. For all the traits heritability and GAM values were very low. for DSV-4 highest PCV values were observed for the traits panicle weight and grain yield, moderate GCV values for panicle weight and grain yield. Moderate heritability for plant height, panicle length and highest GAM was observed in plant height. In variety CSV 216R highest PCV for panicle weight and grain yield, moderate GCV for plant height, moderate heritability for fays to 50% flowering and plant height, and highest GAM for plant height was observed.

6.5 ANOVA (M_3)

Significant mean sum of square values were not observed for yield traits as indicated by the non-significant variances for these traits. Replication sum of squares were found non - significant for all the yield component traits.

6.6 Mean and range (M_3)

In DSV-5 highest mean value (29.93 g) and wide range (21.20-39.93 g) was recorded in a dosage of 350Gy. Highest mean value (35.13 g) and wide range (19.8-38) for grain weight was recorded in a dosage of 400Gy+0.2%EMS in DSV-4. Highest mean value of 37.35 g for grain weight was recorded in a dosage of 350Gy+0.2%EMS in CSV 216R.

6.7 Genetic components (M_3)

Highest PCV values were observed for panicle weight and grain weight vand lowest GCV for all the traits in all the varieties. Highest heritability was observed for days to 50% flowering and days to maturity in DSV-5. Low heritability for all the traits in DSV-4 and highest heritability for SPAD2 and 100 grain weight in CSV 216R. Low values of GAM were observed for all the traits in all the varieties and mutation treatment combinations.

6.8 Correlation coefficients (M_3)

Grain yield was found to be significantly and positively correlated with seedling height (0.22), SPAD1 (0.26), plant height (0.29), internodal length (0.29), panicle length (0.16), panicle breadth (0.51), panicle weight (0.88), 100 grain weight (0.11) and panicle harvest index (0.50) at 1 % level. It was significantly and negatively correlated with days to flowering (0.21) and days to maturity (0.21).

6.9 Reaction to pest and diseases (M_3)

Some of the lines were exhibited susceptibility to shoot fly and shoot bug. And some lines were found to be with charcoal rot resistance in all the three varieties. Promising lines with high yield and charcoal rot resistance were identified.

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Appendices

Appendix I: Meteorological data for the year 2015 at Regional Agricultural Research, Station: Vijayapur.

Month	Air Temperature		Relative humidity		Wind Speed	Sunshine	Total Rainfall	Rainy	Pan Evaporation
	Max (C)	Min (C)	AM (%)	PM (%)	(KMPH)	Duration (h)	(mm)	Days	(mm/day)
January	29.5	13.1	76	34	3.9	8.5	4.6	1	3.8
February	33.2	15	64	21	5.3	10	0	0	6.1
March	35.3	20.3	64	28	5.9	8.2	36.2	2	6.8
April	37.3	22.1	67	25	7.4	8.9	32.4	3	8.1
May	39.7	23.8	72	26	11.2	8.2	38.4	4	8.8
June	33.8	22.3	82	48	16.8	6.3	100.7	5	6.1
July	33.4	22.1	83	45	16.3	6.5	0.8	0	6.7
August	32.7	21.5	87	54	12.6	5.1	73.9	7	5.3
September	32.2	21.3	90	57	8.2	6	257.2	10	4.7
October	33.3	20.3	83	42	4.2	7.5	97	2	5.1
November	31.6	18	78	40	4.5	7.2	9.9	1	4.8
December	31.7	15.5	75	35	3.6	8.1	0	0	4.7

Appendix II: Meteorological data for the year 2016 at Regional Agricultural Research, Station: Vijayapur

Month	Air Temperature		Relative humidity		Wind Speed	Sunshine	Total Rainfall	Rainy	Pan Evaporation
	Max (C)	Min (C)	AM (%)	PM (%)	(KMPH)	Duration (h)	(mm)	Days	(mm/day)
January	31	14	64	29	3.9	8.8	0.2	0	5
February	35	18.9	58	26	5.5	9.5	0	0	6.7
March	37.7	21.9	54	22	6.6	9.1	17	2	8.5
April	40.9	25	56	21	8.5	8.2	19.6	3	10.7
May	39.7	24.1	72	29	11.2	9.1	46	4	9.1
June	33.1	22.7	86	55	13.6	3	51.8	4	5.6
July	30	21.7	91	65	13.8	2.2	169.2	10	3.7
August	30.6	21.3	90	60	13.9	5.6	48.2	6	3.7
September	29.8	20.8	92	64	10.8	3.8	133.7	6	3.3
October	31.6	18.2	76	44	6.2	7.7	12	1	4
November	31.2	14	73	32	3.9	8.6	0	0	4.7
December	30.5	12.8	72	34	4	8.5	0	0	4.5

Appendix III. Mean data of M_2 generation material for three varieties of *rabi* sorghum, *Rabi* 2105.

1) Variety: DSV-5

Entry code	DFF	PH	Pa L	PB	PW	GW	HGW
1001-2	83	210.00	22.00	7.00	93.00	70.46	3.97
1002-1	84	210.00	26.00	7.00	129.00	97.54	3.94
1003-9	82	255.00	24.00	6.00	111.00	86.07	3.84
1004-1	85	257.00	23.00	7.00	99.00	69.32	3.29
1004-4	85	247.00	22.00	7.00	109.00	81.19	3.76
1005-3	85	260.00	22.00	6.00	79.00	61.49	3.34
1006-6	80	266.00	20.00	5.00	81.00	59.88	3.27
1006-13	80	248.00	21.00	6.00	108.00	82.12	4.00
1007-2	79	280.00	25.00	5.00	51.00	31.90	3.56
1007-15	79	265.00	23.00	6.00	110.00	87.23	4.40
1007-16	79	244.00	20.00	6.00	100.00	82.13	4.77
1008-1	80	147.00	26.00	7.00	106.00	75.48	3.39
1008-6	80	262.00	17.00	6.00	60.00	47.43	3.60
1008-9	80	249.00	21.50	7.00	136.00	100.90	4.40
1009-12	78	266.00	23.00	6.00	100.00	76.08	3.90
1009-13	78	252.00	20.00	7.00	116.00	90.24	4.48
1010-6	80	262.00	20.00	6.00	92.00	58.74	4.22
1010-15	80	230.00	19.00	5.00	49.00	38.59	3.43
1011-12	82	247.00	19.00	5.00	63.00	49.23	3.85
1012-7	78	225.00	20.00	5.00	64.00	50.16	3.93
1013-15	84	276.00	23.00	7.00	140.00	107.40	5.12
1014-17	81	275.00	23.00	7.00	157.00	125.73	5.21
1015-9	81	257.00	21.00	6.00	82.00	63.04	4.84
1017-4	77	272.00	21.00	6.00	116.00	88.89	4.75
1017-11	77	295.00	21.00	5.00	128.00	98.97	4.98
1018-24	81	276.00	21.00	5.00	60.00	46.88	4.66

Appendix III. Contd…..

Entry code	DFF	PH	Pa L	PB	PW	GW	HGW
1020-6	84	247.00	19.00	5.00	70.00	55.56	3.80
1021-6	77	281.00	20.00	6.00	89.00	71.85	4.26
1022-6	85	187.00	23.00	5.00	76.00	56.97	4.36
1023-14	86	276.00	20.00	6.00	83.00	65.15	4.49
1024-4	80	238.00	17.00	4.50	30.00	23.34	4.27
1025-2	85	272.00	23.00	6.00	95.00	77.18	4.55
1026-3	81	263.00	26.00	4.00	39.00	25.60	3.78
1027-4	82	222.00	20.00	6.00	74.00	55.48	4.56
1028-4	84	261.00	22.00	6.00	109.00	81.53	4.07
1028-11	84	272.00	20.00	6.50	105.00	83.73	4.15
1029-1	78	253.00	21.00	5.00	90.00	70.76	3.79
1030-9	84	236.00	19.00	5.00	88.00	68.12	4.33
1031-12	85	263.00	21.00	5.00	72.00	59.32	3.99
1033 -13	84	234.00	18.00	5.00	56.00	44.67	4.32
1034-11	85	270.00	21.00	5.00	66.00	52.99	4.14
1035-12	83	278.00	20.00	6.00	86.00	70.93	3.78
1037-2	78	227.00	22.00	5.00	95.00	74.68	4.02
1037-7	78	200.00	22.00	5.00	102.00	76.54	4.32
1038-15	80	265.00	23.00	6.00	100.00	76.53	4.74
1039-9	90	230.00	21.00	5.00	50.00	37.73	3.89
1040-2	94	253.12	20.39	5.04	76.18	60.29	4.40

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant(g), HGW-100 grain weight(g)

Appendix III. Contd…..

2) Variety: DSV-4

Entry code	DFF	PH	Pa L	PB	PW	GW	HGW
1041-10	82	258.00	28.00	7.00	80.00	58.25	3.87
1041-15	82	248.00	30.00	7.00	73.00	51.10	4.02
1042-7	80	266.00	27.00	6.50	81.00	58.80	3.57
1043-3	81	215.00	24.00	6.00	60.00	44.48	3.40
1043-12	81	174.00	28.00	6.50	77.00	48.19	3.19
1044-6	82	244.00	23.00	6.50	74.00	63.29	3.86
1045-1	81	237.00	26.00	7.00	104.00	76.14	3.68
1045-3	81	250.00	29.00	6.00	79.00	56.86	3.73
1046-15	82	252.00	29.00	7.00	105.00	76.85	3.39
1047-2	79	245.00	28.00	6.00	91.00	67.18	3.43
1048-7	82	200.00	28.00	6.25	103.00	69.39	3.61
1053-1	83	295.00	28.00	8.00	120.00	105.46	3.62
1053-2	83	227.00	28.00	8.50	146.00	86.31	4.08
1054-1	78	230.00	29.00	5.50	55.00	31.33	3.69
1054-10	78	238.00	29.00	6.00	73.00	33.18	4.01
1055-6	82	262.00	32.00	7.00	157.00	108.40	3.78
1056-7	81	266.00	28.00	6.50	100.00	73.09	4.01
1057-2	80	248.00	27.00	7.50	120.00	86.75	3.65
1057-8	80	272.00	26.00	8.00	128.00	92.33	3.71
1058-2	82	285.00	28.00	8.50	203.00	146.31	4.21
1058-9	82	216.00	25.00	6.00	60.00	35.02	4.64
1058-12	82	270.00	27.00	6.50	102.00	71.40	3.99
1058-13	82	252.00	23.00	5.00	57.00	43.86	3.51
1059-1	78	220.00	25.00	6.00	69.00	48.28	3.73
1059-7	78	230.00	23.00	5.50	56.00	41.22	3.63
1059-16	78	230.00	28.00	5.50	46.00	28.66	4.11
1059-17	78	254.00	30.00	7.00	134.00	93.00	3.93
1061-10	82	214.00	22.00	6.50	71.00	43.58	2.92
1062-13	83	239.00	23.00	6.00	68.00	47.30	3.69

Appendix III. Contd…..

Entry code	DFF	PH	Pa L	PB	PW	GW	HGW
1064-8	80	195.00	19.00	5.00	28.00	15.17	3.47
1065-7	84	192.00	19.00	3.50	28.00	19.31	3.42
1066-7	84	233.00	19.00	7.00	62.00	55.94	3.36
1066-13	84	194.00	20.00	7.50	63.00	43.15	3.32
1067-16	84	156.00	23.00	7.50	104.00	82.23	4.44
1068-5	76	188.00	17.00	4.50	21.00	15.91	2.76
1069-1	81	251.00	27.00	5.50	62.00	40.06	4.05
1069-4	81	231.00	23.00	6.50	72.00	50.92	3.57
1069-16	81	211.00	32.00	7.00	107.00	78.47	3.15
1070-1	70	255.00	26.00	7.00	114.00	88.22	3.47
1070-3	70	198.00	27.00	5.50	50.00	28.00	3.61
1070-5	70	260.00	25.00	6.00	100.00	52.07	3.75
1070-8	70	220.00	21.00	6.00	75.00	53.92	2.95
1070-11	70	200.00	21.00	5.00	40.00	23.13	3.61
1071-7	77	237.00	25.00	5.50	51.00	32.88	3.41
1072-1	71	289.00	27.00	7.00	139.00	103.05	4.48
1072-9	71	252.00	23.00	6.00	76.00	55.19	4.40
1072-12	71	250.00	24.00	5.50	83.00	61.78	3.71
1072-15	71	200.00	26.00	6.50	116.00	82.59	3.72
1074-1	71	142.00	28.00	4.50	23.00	10.71	2.15
1074-9	71	141.00	26.00	6.50	50.00	37.05	2.12
1074-14	71	134.00	27.00	5.50	70.00	54.24	1.93
1075-3	79	259.00	27.00	6.50	100.00	76.40	3.49
1076-15	78	232.00	23.00	5.50	78.00	57.40	3.87
1077-1	82	231.00	30.00	7.00	61.00	32.29	3.55
1078-6	79	236.00	26.00	4.50	26.00	9.02	3.31
1079-5	83	248.00	25.00	5.50	129.00	99.85	3.85
1079-10	83	264.00	27.00	8.00	150.00	105.94	3.84
1080-1	83	198.00	20.00	4.50	25.00	19.31	3.48
1081-1	80	282.00	26.00	8.50	144.00	109.57	5.35
1081-3	80	293.00	27.00	8.00	160.00	124.43	5.26
1081-6	80	272.00	22.00	7.50	119.00	103.93	5.31
1081-10	80	265.00	20.00	6.00	95.00	76.75	5.07

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant(g), HGW-100 grain weight(g)

Appendix III. Contd…..

3) Variety: CSV 216R

Entry code	DFF	PH	Pa L	PB	PW	GW	HGW
1095-2	69	186.00	18.00	7.50	66.00	49.64	2.57
1095-3	69	191.00	19.00	7.00	96.00	74.55	3.63
1095-4	69	170.00	22.00	10.00	196.00	137.92	4.43
1095-6	69	188.00	18.00	8.00	137.00	100.20	4.54
1096-1	71	266.00	22.00	7.00	55.00	23.37	3.95
1096-2	71	288.00	23.00	5.00	108.00	68.79	4.60
1096-3	71	250.00	18.00	6.00	158.00	120.27	4.39
1099-1	80	139.00	23.00	7.00	136.00	98.93	3.94
1101-1	69	177.00	17.00	5.00	84.00	60.02	3.99
1102-1	86	218.00	18.00	6.00	113.00	80.55	4.34
1102-2	86	227.00	20.00	8.00	127.00	96.40	4.44
1102-6	86	203.00	18.00	6.00	57.00	32.76	3.72
1102-7	86	205.00	15.00	7.00	115.00	87.99	4.04
1104-1	73	240.00	20.00	6.50	114.00	79.92	4.86
1104-2	73	240.00	20.00	7.00	106.00	70.37	4.94
1108-1	83	216.00	21.00	8.00	135.00	104.94	4.32
1108-2	83	210.00	21.00	6.00	114.00	86.85	4.10
1108-4	83	240.00	16.00	7.00	84.00	63.95	4.62
1110-3	72	260.00	21.00	9.00	182.00	135.40	4.27
1111-1	78	233.00	23.00	5.00	102.00	75.35	4.69
1111-2	78	232.00	18.00	8.00	122.00	90.43	4.91
1111-3	78	238.00	22.00	7.00	81.00	61.52	2.89
1112-1	72	228.00	19.00	6.50	74.00	47.68	3.05
1112-2	72	249.00	23.00	7.50	208.00	152.12	4.88
1112-3	72	236.00	22.00	6.00	91.00	65.26	3.87
1112-6	72	208.00	20.00	5.00	124.00	91.98	4.21

Appendix III. Contd…..

Entry code	DFF	PH	Pa L	PB	PW	GW	HGW
1112-10	72	239.00	19.00	6.00	78.00	59.06	3.91
1112-12	72	154.00	22.00	5.00	105.00	80.73	3.90
1113-3	68	215.00	22.00	6.00	135.00	97.75	4.59
1113-4	68	198.00	21.00	8.00	165.00	119.25	3.69
1113-6	68	243.00	22.00	5.00	88.00	61.95	4.47
1115-3	69	253.00	22.00	5.00	121.00	93.95	4.00
1115-5	69	258.00	19.00	6.00	74.00	66.50	2.86
1115-6	69	257.00	20.00	6.00	93.00	74.17	3.99
1115-8	69	233.00	18.00	5.50	74.00	58.29	3.23
1115-16	69	260.00	19.00	5.50	77.00	54.25	4.26
1115-21	69	204.00	23.00	6.00	110.00	83.98	4.78
1116-6	69	197.00	20.00	6.00	109.00	87.72	4.52
1118-4	71	240.00	21.00	6.00	116.00	85.53	4.96
1118-6	71	242.00	22.00	4.00	11.00	84.32	4.86
1118-8	71	270.00	19.00	6.00	68.00	50.67	4.12
1118-12	71	252.00	20.00	5.00	59.00	44.78	4.25
1119-1	72	236.00	21.00	6.00	75.00	49.54	4.12
1119-3	72	225.00	18.00	5.00	45.00	34.94	4.08
1120-3	70	247.00	21.00	5.00	88.00	66.38	3.91
1121-1	69	188.00	17.00	5.00	38.00	31.31	3.87
1121-5	69	172.00	18.00	7.00	69.00	50.21	4.80
1122-5	67	232.00	19.00	5.00	71.00	54.81	4.12
1122-15	67	240.00	18.00	6.00	80.00	63.51	4.35
1122-16	67	185.00	15.00	4.00	94.00	72.20	3.83

DFF- Days to 50% flowering (Days), PH- Plant height(cm), Pa L- Panicle length(cm), PB- Panicle breadth(cm),
PW- Panicle weight (g), GY- Grain yield per plant(g), HGW-100 grain weight(g)

Appendix IV. Mean data of M_3 generation material for three varieties of *rabi* sorghum, *Rabi* 2106

1) Variety: DSV-5

Entry code	SH	DFF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
DSV5M-1	67.2	84.33	55.61	124.33	11.73	150.2	7.73	11.74	26.53	15.8	4.93	48.13	39	3.59	0.82
DSV5M-2	71.13	85	49.4	125	11.89	156.67	7.4	12.1	29.13	14.6	4.07	32.2	23	3.2	0.71
DSV5M-3	63.2	87	48.37	127	12.25	141.67	8	11.28	24.4	15.47	4.33	30.67	21.2	3.62	0.67
DSV5M-4	67.4	85	49.11	125	12.22	154.6	7.93	11.98	26.27	15.67	3.77	36.07	23.67	2.96	0.67
DSV5M-5	67.73	86.33	47.61	126.33	12.87	156	8.33	12.44	25.8	15.13	4.33	34.13	27.53	2.87	0.8
DSV5M-6	73.27	86.67	48.69	126.67	11.61	162.87	8.27	13.16	26	16	4.57	37.73	30.4	3.45	0.81
DSV5M-7	68.53	84.67	48.09	124.67	10.91	153.53	8.2	12.9	25.07	15.87	4.73	38.33	30.13	3.77	0.78
DSV5M-8	69.2	84	48.95	124	9.35	153.33	7.67	12.63	25.6	17.17	4.2	33.67	26.67	3.27	0.78
DSV5M-9	67.8	85.33	50.31	125.33	16.35	155.73	8.13	11.96	25.93	16.6	4.47	36.07	31.8	3.55	0.88
DSV5M-10	69.47	88.33	49.93	128.33	18.48	151.8	7.6	12.34	25.87	15.8	4.33	32	25.13	3.55	0.76
DSV5M-11	71.6	83.67	53.09	123.67	11.67	158.73	8.13	12.11	26.6	15	4.47	35.47	22.73	3.5	0.64
DSV5M-12	66.87	85	50.06	125	20.12	141.87	7.47	12.08	22.8	17.93	4.13	39.2	35.53	3.19	0.9
DSV5M-13	65.87	83.33	49.42	123.33	12.33	150.27	8	11.88	22.47	14.87	4.13	32	21.53	3.56	0.65
DSV5M-14	71.47	83.33	52.36	123.33	8.63	168.07	7.73	13.16	27.13	16.53	5.07	43.27	35.6	3.24	0.82
DSV5M-15	66.33	84	51.23	124	10.44	165.4	8.07	13.1	26.73	16.23	4.4	38	32.53	3.17	0.86
DSV5M-16	72	83.67	51.81	123.67	10.97	166.67	7.73	12.12	27.4	15.6	4.73	35.27	26.07	3.07	0.74
DSV5M-17	70.67	77.33	52.85	117.33	4.11	168.6	8.53	12.08	28.73	16.73	4.8	47.27	36.8	3.03	0.77
DSV5M-18	65.8	78.67	48.07	118.67	8.61	169.27	8.07	13.6	29.73	15.33	5.47	51.27	39.93	3.59	0.78
DSV5M-19	64.47	83.33	54.21	123.33	7.7	162.87	8.33	13.89	27.07	16.8	4.57	48.53	38.07	3.16	0.78
DSV5M-20	66.2	84	51.93	124	6.11	158	7.67	13.86	25.93	16.53	4.27	38.33	29.73	3.63	0.77
DSV5M-21	71.87	84	51.99	124	9.43	166.67	8.07	13.44	27.07	15.73	4.6	37.4	30.4	3.36	0.8
DSV5M-22	66	85	52.23	125	11.13	163.6	7.8	12.78	26.73	15.73	4.8	39.67	31	3.2	0.79
DSV5M-23	71.93	84	54.5	124	12.61	156.6	8.13	13.1	25.73	16.33	4.47	39.2	29.93	3.23	0.76
DSV5M-24	68.2	84.67	51.78	124.67	8.65	154.67	7.87	13.14	27.2	16.6	3.97	32.47	24.27	3.74	0.76
DSV5M-25	68.13	84.67	51.48	124.67	11.14	161.6	8.6	12.78	26.67	16.27	4.2	33.8	26.6	3.79	0.75

Appendix IV. Contd…..

Entry code	SH	DFF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
DSV5M-26	69.27	86	51.59	126	8.22	160.87	7.67	13.75	28.2	15.73	4.93	44.87	32.33	2.63	0.69
DSV5M-27	60.8	90.33	49.48	130.33	6.31	136.27	8.47	10.56	21.2	11.07	2.93	12	7.33	2.45	0.54
DSV5M-28	64.13	87.67	47.91	127.67	8.74	154.73	7.8	12.42	25.4	14.47	4.13	32.13	25	2.99	0.73
DSV5M-29	65.2	82.67	52.02	122.67	7.65	159.67	8.87	11.98	26.33	16.4	4	36.87	24.87	3.7	0.63
DSV5M-30	71.93	82	51.78	122	6.35	161.4	8.27	12.02	29.27	15.4	4.47	37.33	26.93	3.22	0.72
DSV5M-31	65.87	85.33	50.97	125.33	8.53	144.8	8.2	11.91	20.2	16.27	4.8	38.73	28.6	3.12	0.72
DSV5M-32	70.93	86.33	49.16	126.33	8.35	148.73	7.73	11.91	26.47	15.8	4	39.4	30.73	3.24	0.78
DSV5M-33	71.8	90	47.27	130	8.59	152.87	8.33	12	24.4	14.6	3.67	25.8	16.93	3.38	0.62
DSV5M-34	63.2	86	52.45	126	8.3	144.73	7.67	11.68	27.73	14.67	3.83	24.8	17.47	3.02	0.69
DSV5M-35	64.07	87	48.41	127	6.13	143.27	8.27	11.81	26.53	15.93	4.4	31.8	23.93	3.76	0.75
DSV5M-36	66.07	84	53.55	124	8.18	150.73	7.2	12.63	32.27	14.73	4.07	31.73	24.53	3.25	0.78
DSV5M-37	65.8	86	52.49	126	7.11	152	8.6	11.3	25.67	15.47	3.73	34.27	26	3.4	0.74
DSV5M-38	66.73	84.67	52.59	124.67	7.48	145.13	7.73	11.74	27.6	13.87	4.4	33.2	26.27	3.37	0.78
DSV5M-39	61.13	87.67	49.89	127.67	9.81	153.4	8.13	11.49	29.33	16.27	4.73	40.47	33.73	3.72	0.83
DSV5M-40	65	86	54.02	126	9.75	148.07	8.07	11.88	24.47	15.33	4.57	29.53	23.67	2.91	0.8
DSV5M-41	64.8	87.33	47.75	127.33	7.63	146.53	7.8	11.69	26.73	15	4	27.67	22.6	3.64	0.79
DSV5M-42	67.73	84.67	50.04	124.67	11.14	150.6	7.8	12.27	27	14.47	4.53	33.67	27.4	3.11	0.81
DSV5M-43	69.73	83	50	123.67	12.05	145.07	8.13	11.87	22.87	17.27	4	40.07	31.2	3.14	0.75
DSV5M-44	70.13	82.67	49.3	122.67	8.53	159.07	8.2	12.52	33	16.4	3.87	30.33	20.4	3.11	0.65
DSV5M-45	69.93	81.33	51.09	121.33	7.23	143.93	8.33	11.03	23.13	15.33	3.93	31.47	28.27	3.19	0.95
DSV5M-46	62.87	84	51.83	124	10.23	154.73	8	12.86	32.93	15.07	3.77	24.87	16.47	4	0.66
DSV5M-47	70.47	85.67	51.57	125.67	12.85	146.67	8.47	10.99	22.13	15.47	4.33	31.93	23.07	3.63	0.73
DSV5M-48	63.33	83.67	51.58	123.67	9.38	155.47	8.27	12.23	32.87	16.8	4.4	37.67	28.13	3.06	0.74

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

Appendix IV. Contd…..

2) Variety: DSV-4

Entry code	SH	DOF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
DSV4M-49	62.33	80.33	44.31	120.33	12.41	133.6	7.33	11.04	30.8	17.2	4.57	27.27	18.67	2.64	0.69
DSV4M-50	63.07	80	47.48	120	9.23	121.27	7.33	10.44	24.53	15.87	4.1	20.2	11.87	2.72	0.59
DSV4M-51	62.6	81.67	47.56	121.67	9.03	133.33	7.67	11.35	27.33	16.33	4.67	33.93	22.07	2.51	0.64
DSV4M-52	64.8	82.33	47.54	122.33	8.01	124.93	7.67	10.66	28.53	17.13	4.93	32.27	23.67	2.51	0.73
DSV4M-53	67.53	78.33	50.47	118.33	7.89	129.07	6.87	10.92	28.47	16.13	4.03	26.8	19.33	2.66	0.72
DSV4M-54	72.87	74.33	50.9	114.33	8.69	135.6	7.4	10.63	31.4	16	4.6	39.6	28.67	3.03	0.69
DSV4M-55	62.47	78	43.22	118	9.26	133.2	7.73	10.7	28	16.33	4.73	30.53	22.07	3.02	0.66
DSV4M-56	67.13	77.67	48.61	117.67	11.13	133.33	7.47	10.18	27.6	15.67	3.63	24.47	14.87	2.64	0.61
DSV4M-57	71.8	74	51.02	114	10.18	134.87	7.73	10.52	29.67	16.73	4.8	40.13	32.53	2.36	0.83
DSV4M-58	61.93	81.33	44.95	121.33	6.4	147.6	7.53	12.17	25.73	15.87	4.27	29.4	24.87	2.83	0.87
DSV4M-59	63.93	80.67	46.6	120.67	11.93	143.4	8	10.6	28.4	16.8	4.6	32.33	23.07	2.63	0.71
DSV4M-60	62	80.33	48.84	120.33	9.83	152.67	7.87	11.45	30.8	16.07	4.4	27.93	23.2	3.15	0.83
DSV4M-61	62.07	80.33	48.31	120.33	11.44	143.4	7.67	10.62	26.8	17	4.93	34.13	24.27	3.18	0.7
DSV4M-62	57.07	79.67	49.9	119.67	5.9	146.27	7.2	12	26.47	18.73	4.33	28.47	14.73	3.08	0.53
DSV4M-63	62.47	82.33	51.27	122.33	7.21	131.6	7.2	9.98	29.2	18.47	3.93	30.33	17.07	2.73	0.52
DSV4M-64	65.07	80.33	49.41	120.33	7.16	155.67	7.4	11.54	27.33	17	4.53	31.47	21.93	2.46	0.66
DSV4M-65	68.67	79.33	44.82	119.33	6.28	146.53	7.73	11.35	30.47	17.07	4.6	29.67	21.67	2.59	0.73
DSV4M-66	59.6	80.67	45.57	120.67	7.65	138.8	7.47	11.54	26.8	15.2	4.47	27.93	19.33	3.08	0.68
DSV4M-67	66.87	79.67	45.38	119.67	6.22	136.27	7	10.46	29.2	18.27	4.87	37.2	26.33	2.92	0.7
DSV4M-68	69	77.33	46.65	117.33	6.73	143.53	7.47	12.24	25	16.4	5.07	45.67	35.27	2.75	0.76
DSV4M-69	65.27	77.67	48.87	117.67	9.9	152.87	7.93	11.4	24.93	16.8	4.8	39.4	27.53	2.79	0.71
DSV4M-70	63.4	79.67	50.35	119.67	7.56	141.2	7.13	11.38	25.8	17.4	4.4	32.2	27.8	2.89	0.9
DSV4M-71	106.33	77.33	46.39	120.33	6.12	139.07	7.07	10.92	30.93	18.33	4.93	40.8	27.47	3.13	0.66
DSV4M-72	65	79.67	49.67	119.67	9.62	139.8	7.2	11.82	29.4	17.4	3.93	25.47	16.2	2.81	0.64
DSV4M-73	62.2	79	46.87	119	6.98	138.27	7.33	10.25	33.4	15.6	4.53	29.2	20.4	3.14	0.71
DSV4M-74	65.07	78	45.75	118	6.31	133.13	7.27	10.5	25.4	17.27	4.33	27.87	18.93	2.87	0.65
DSV4M-75	61.8	80.33	47.29	120.33	11.87	145.47	7.8	10.6	29.73	16.4	4.27	29.87	19.93	2.49	0.62
DSV4M-76	66.87	81.33	46.25	121.33	9.61	130.93	7.33	10.2	23.67	15.53	4.87	28.8	18.47	2.56	0.64
DSV4M-77	64.73	85.33	46.37	125.33	5.79	137.73	8	10.31	25.53	16.2	3.87	33.2	21.87	3.04	0.64
DSV4M-78	59.2	80.67	50.04	120.67	8.79	142.13	7.27	11.41	25.33	15.47	4.7	30.07	20.93	2.68	0.65
DSV4M-79	59.73	74.67	56.32	114.67	11.69	154.07	6.73	13.22	31.87	16.27	4.8	37.13	28.8	2.79	0.77
DSV4M-80	62.53	75.67	49.13	115.67	8.76	165.33	7.2	13.27	30.67	14.87	4.8	36.67	26.6	2.63	0.72

Appendix IV. Contd…..

Entry code	SH	DOF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
DSV4M-81	66.8	80.67	53.83	120.67	9.39	142.4	7.27	10.08	21.8	13.73	4.67	39.2	30.07	3.17	0.76
DSV4M-82	53.73	87.33	50.31	127.33	10.11	161.33	6.87	14.32	29.13	16.47	4.2	30.87	23.47	3.12	0.74
DSV4M-83	47.6	89.33	46.85	129.33	9.66	119.87	6.47	9.17	38.87	15.8	4.4	33.33	22.6	2.64	0.63
DSV4M-84	64	80.67	47.35	120.67	7.97	158.53	7	13.5	30.67	16.47	5.07	34.8	26.47	2.94	0.75
DSV4M-85	64.27	79.67	48.39	119.67	9.36	140.8	7.07	11.41	30.33	15.93	4.4	32.6	21.8	3.14	0.63
DSV4M-86	62.8	79.67	48.09	119.67	9.83	129.6	6.87	12.52	24.8	15.73	4.4	32.33	18.07	2.71	0.57
DSV4M-87	68.67	80.33	45.58	120.33	11.07	155.4	7.4	12.86	27	16.73	4.83	38.53	27.27	2.95	0.63
DSV4M-88	67.73	79	47.15	119	10.48	155.93	6.93	12.02	31.93	14.8	3.8	29.87	17.07	2.75	0.51
DSV4M-89	64.67	75.33	49.49	115.33	8.49	163.73	7.67	13.54	25.4	15.6	4.53	43.4	30.33	3.65	0.7
DSV4M-90	70.73	77.67	49.69	117.67	10.53	141.2	6.6	12.67	30.33	14.8	3.87	25.6	16.47	2.47	0.64
DSV4M-91	65.27	71.67	47.85	111.67	7.43	136	6.93	11.15	24.73	15	3.47	20.53	9.8	2.85	0.46
DSV4M-92	66.47	79.67	47.49	119.67	6.06	134.87	6.67	11.08	29.53	17	4.4	33.67	21.07	2.92	0.62
DSV4M-93	71.07	78.67	51.98	118.67	5.47	147.27	7.53	12.2	26.67	17.4	3.67	33.6	25.27	3.21	0.72
DSV4M-94	69	78.33	44.28	118.33	5.41	139.53	6.93	11.99	29.67	16.07	4.03	39.2	32.27	3.36	0.8
DSV4M-95	74	79.33	50.05	119.33	6.74	144.73	7.13	11.44	26.07	16.4	4	37.53	28.8	3.17	0.75
DSV4M-96	69.6	72	57.33	112	12.16	130.13	6.73	10.93	26.6	18.53	5.13	47.13	37.4	3.27	0.8
DSV4M-97	60	70.67	57.81	110.67	8.07	108.8	5.6	8.72	35.27	20.2	3.67	29.47	25.4	2.87	0.86
DSV4M-98	58.27	70.33	57.94	110.33	12.01	102.33	4.93	9.21	30.73	18.87	3.43	30.2	22.73	2.4	0.75
DSV4M-99	59.6	71.33	52.17	111.33	9.34	117.53	5.93	10.66	35.27	17.07	4	31	21.8	2.97	0.71
DSV4M-100	68	81.67	48.69	121.67	8.29	131.93	6.6	12.32	26.27	15.8	3.73	29.6	19.53	3.27	0.66
DSV4M-101	62.87	80.33	48.11	120.33	5.92	140.33	7.53	11.73	26.93	17.33	5	36.2	24.6	2.98	0.68
DSV4M-102	61.47	85	45.74	125	6.19	125.33	6.4	10.05	29	14.67	2.93	18.4	9.53	2.57	0.46
DSV4M-103	63.47	81.67	48.9	121.67	8.19	149.8	7.73	13.21	27.53	15.8	4.03	22.93	15.53	2.53	0.55
DSV4M-104	70.67	79	46.71	119	8.67	139.33	7.4	12.34	24.6	14.53	4.47	32.4	23.93	2.77	0.74
DSV4M-105	69.07	86	45.82	126	7.57	138.87	7.2	11.55	30.87	14.8	3.8	25.53	20.07	2.9	0.78
DSV4M-106	65.73	84.33	48.73	124.33	6.58	143.07	7.6	11.36	27.33	14.8	3.8	27.53	19.8	3.13	0.73
DSV4M-107	69.93	84	52.05	124	10.98	151.27	7.87	12.17	25.33	16.33	4.87	40	30.47	3.95	0.77
DSV4M-108	68.93	85.67	52.68	125.67	6.73	148.67	7.2	13.31	30.27	15.93	5.27	38.27	30.93	3.25	0.81
DSV4M-109	69.67	84.67	53.84	124.67	12.07	160.07	7.8	16.66	25.2	17.13	4.93	48.67	38	3.53	0.78
DSV4M-110	69.53	83	51.74	123	6.29	141.93	7.07	12.36	31	14.73	4.07	33.53	21.67	3.87	0.63
DSV4M-111	43.2	55	29.9	81.67	4.41	91.47	4.93	7.89	17.33	10.2	2.67	22.8	18.47	1.88	0.53

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

Appendix IV. Contd…..

3) Variety: CSV 216R

Entry code	SH	DOF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
CSVM-112	73.87	71.33	49.53	111.33	6.43	129.73	6.4	13.36	23.6	12.87	4.47	35.47	28.6	2.96	0.81
CSVM-113	75	71	53.57	111	6.11	110.13	6.07	11.97	20.73	13.13	4.03	39.27	27.4	2.82	0.7
CSVM-114	75.13	70.33	50.67	110.33	9.71	151.73	6.67	13.76	31.87	14.2	4.6	43	35.53	2.69	0.84
CSVM-115	74.8	69.67	53.08	109.67	6.46	163.07	7.53	12.89	25.47	15.87	5.23	55.6	44	3.09	0.79
CSVM-116	46.2	80	49.65	120	6.8	165.2	6.07	12.63	26.2	14.73	4.8	39.93	24.87	3.71	0.63
CSVM-117	79.53	71.33	48.38	111.33	15.17	177	7	14.15	33	15.07	5.07	37.53	26.87	2.67	0.72
CSVM-118	78.47	72.33	50.68	112.33	9.61	173.53	6.87	15.02	33.8	14.87	4.7	44.6	33.07	2.65	0.74
CSVM-119	66.27	82.67	46.51	122.67	12.37	166.67	6.93	13.12	26.07	15.6	5.6	42.73	34.73	2.91	0.83
CSVM-120	74.67	73.67	52.37	113.67	8.74	147.73	6.8	13.79	21.87	14.13	5.87	52.87	43.53	3.51	0.82
CSVM-121	72	74.67	50.95	114.67	8.39	156.47	6.8	13.43	29.47	13.13	4.7	46.53	38.2	3.29	0.82
CSVM-122	74.73	72.67	49.53	112.67	10.32	145.33	6.73	9.82	21.8	13.4	4.73	48.07	39.27	3.09	0.81
CSVM-123	73.73	75.67	49.45	115.67	8.67	148.33	6.8	12.63	30.73	12.23	4.07	36.07	28.2	4.08	0.78
CSVM-124	70.93	76.33	50.79	116.33	7.53	142.67	6.87	12.71	21.33	12.6	5.27	48.67	38.27	3.25	0.78
CSVM-125	76.93	70.33	51.01	110.33	5.4	149	6.6	13.12	25.73	14.13	4.67	42.4	34.33	2.47	0.83
CSVM-126	77.47	70.67	51.73	110.67	5.92	151.07	7	12.74	32.07	12.33	4.93	42.87	34.67	3.21	0.81
CSVM-127	69.33	71.33	55.09	111.33	5.94	148.27	6.6	12.61	24	15.87	5.73	45.87	36.8	3.06	0.8
CSVM-128	71.67	72.67	53.01	112.67	5.69	150.8	6.93	15.54	24.87	13.73	4.8	43.27	33.73	3.32	0.78
CSVM-129	67.4	71	51.75	111	5.39	144.8	7.07	12.35	31.4	14.33	5.47	44.67	36.13	2.21	0.82
CSVM-130	74.73	77.67	46.35	117.67	6.79	181.13	7.67	13.83	25.4	16	5.13	46.27	35.07	2.62	0.76
CSVM-131	74	71.67	51.13	111.67	7.31	168.47	7.27	14.04	25.47	17.27	5.53	61.93	49.67	2.83	0.81
CSVM-132	70.6	75.67	51.13	115.67	4.59	144	6.93	12.97	30.13	13.33	5.13	50.67	40.07	3.08	0.8
CSVM-133	75.53	71.67	50.68	111.67	8	155.4	7.2	14.46	26.47	16.47	4.93	43.27	31.27	2.06	0.72
CSVM-134	69.73	72	53.31	112	14.39	163.4	7.47	13.35	30.47	15.4	5.33	37.73	25.2	2.1	0.67
CSVM-135	70.47	71.33	56.37	111.33	7.27	164.27	7.6	13.79	29.2	15.87	5.73	61.6	48.8	3.01	0.79
CSVM-136	73.33	70.33	51.66	110.33	10.18	181.53	8.13	13.8	32.8	15.67	4.53	40.93	30.93	3.7	0.77

Appendix IV. Contd…..

Entry code	SH	DOF	SPAD 1	DM	SPAD 2	PH	NN	INL	Pe L	Pa L	PB	PW	GW	HGW	PHI
CSVM-137	74.73	72.33	52.99	112.33	6.15	151.53	6.8	14.33	27.8	16.73	5.33	50.27	37.07	2.27	0.74
CSVM-138	77.93	70.67	54.37	110.67	5.19	174.73	7.4	15.33	31.2	16.4	5.47	50.67	40.87	3.76	0.81
CSVM-139	73.2	70.67	54.87	110.67	8.92	159.67	7.73	13.09	27.73	16.07	4.87	43.27	34.6	3.35	0.78
CSVM-140	68.13	69.67	54.45	109.67	5.44	150	6.4	15.92	25.87	17	5.47	46.73	35.93	2.31	0.77
CSVM-141	72.67	69.33	54	109.33	7.39	155.67	7.47	13.61	25.2	16.73	5.4	58.07	44.4	2.03	0.76
CSVM-142	77.33	70	52.7	110	7.41	155.73	7.2	13.01	24.2	15.07	4.93	47.13	35.93	1.93	0.76
CSVM-143	75.73	71.33	50.49	111.33	6.18	156.47	7.33	13.56	26.67	15.67	4.73	45.67	35.2	3.15	0.77
CSVM-144	77	71	55.66	111	9.95	170.93	7.47	14.68	30.2	15.33	4.87	43.07	30.87	2.65	0.73
CSVM-145	72.67	70.67	52.19	110.67	6.39	166.4	7.6	14.35	32.2	15.27	4.73	32.33	23.87	2.6	0.74
CSVM-146	79.87	70.67	54.84	110.67	9.36	168.07	7.67	13.83	28.13	13.6	5	35.67	26.27	2.87	0.74
CSVM-147	75	70.33	52.21	110.33	7.75	156.73	7	12.88	30.27	14	5.13	40.8	31.27	3.24	0.77
CSVM-148	76.93	71	54.6	111	6.39	163.73	7	13.38	28.67	14.93	5	39.27	26.47	2.76	0.67
CSVM-149	67.67	71.67	53.79	111.67	6.83	150.67	7.33	12.26	24.93	15.33	5.33	44	31.13	2.57	0.71
CSVM-150	78.2	71	51.87	111	8.73	164.6	7.33	13.98	32.33	14.47	4.4	37.73	26.53	2.26	0.66
CSVM-151	79	70.33	55.09	110.33	9.03	179.13	7.8	15.44	29.93	14.87	5.2	42.13	30.73	2.48	0.73
CSVM-152	72.13	70.33	53.04	110.33	9.35	175.67	7.53	15.74	29.53	14.47	4.73	42.73	29.93	2.66	0.69
CSVM-153	77.13	71.67	55.08	111.67	10.25	168.73	7.53	14.23	29.67	14.67	5.07	45.73	34.27	3.6	0.76
CSVM-154	75.07	68	51.99	108	11.23	169.8	8.07	13.91	30.67	15.4	5.2	39.4	28.53	2.9	0.72
CSVM-155	75.6	69	54.52	109	5.4	147.73	6.47	13.94	30.2	15.13	4.67	46.8	35.33	3.1	0.76
CSVM-156	72.13	69.33	55.24	109.33	8.89	154.93	6.8	13.98	33.53	15.6	5	42.2	30.53	3.13	0.72
CSVM-157	76.4	69	52.57	109	12.31	138.13	6.53	13.77	29.93	15.2	4.93	42.6	34.47	2.54	0.81
CSVM-158	71.2	68.67	56.28	108.67	9.85	146.53	6.93	13.16	29.13	16.4	5.13	44.07	32.8	2.9	0.74
CSVM-159	73.73	71.67	54.33	111.33	7.98	156.93	7.87	13.64	27.2	14.27	5	50.93	40.53	2.88	0.8
CSVM-160	73.87	75	51.51	115	12.27	147.4	8	12.94	25.8	13.87	5.33	47.6	38.13	3.03	0.78
CSVM-161	72.53	74.67	52.71	114.67	11.07	144.93	7.4	13.37	26.13	13.33	4.87	44.93	36.33	2.87	0.81
CSVM-162	72.47	77.67	48.92	117.67	5.66	172.53	8	13.68	30.73	15.8	6.13	62.93	48.33	3.04	0.77

SH-Seedling height(cm), DFF-Days to 50% flowering, SPAD1-SPAD at 50% flowering, DM-Days to maturity, SPAD2-SPAD at physiological maturity, PH-Plant height(cm), NN- Number of nodes, INL-Internodal length(cm), Pe L-Peduncle length(cm), Pa L-Panicle length(cm), PB-Panicle breadth(cm), PW-Panicle weight(g), GW-Grain weight per plant(g), HGW-100 grain weight(g) and PHI-Plant harvest index.

INDUCED MUTATION STUDIES IN *RABI* SORGHUM [*Sorghum bicolor* (L.) Moench]

PREETI M. LADDI **2017** **Dr. G. M. SAJJANAR**
Major advisor

ABSTRACT

An investigation was carried out in *Rabi* Sorghum at Regional Agricultural Research Station (RARS), Vijayapur during *rabi* 2015 and 2016 designed to study mutagenic effects of physical (γ-irradiation-350Gy and 400Gy) and chemical (EMS-0.2%) mutagens and their combination for yield and yield components, genetic parameters and to identify desirable mutants for reduced height, earliness and other yield related traits in three varieties of *rabi* sorghum *viz.,* DSV-4, DSV-5 and CSV216R. In M_2 generation, individual plant selections made in each dosage combinations were advanced to M_3.

Genetic variability was significant for yield and yield contributing traits among the M_2 progenies and M_3 families. Results indicated relatively higher mean performance in M_2 and M_3 families of 350Gy and EMS (0.2%) doses for most of the characters studied. Highest PCV values were observed for panicle weight and grain weight and lowest GCV for all the traits in all the varieties. Highest heritability was observed for days to 50% flowering and days to maturity in DSV-5; SPAD2 and 100 grain weight in CSV 216R respectively. Low values of GA were observed for all the traits in all the varieties. The total frequency of mutation observed was 0.62% in DSV-5; 13.31% in DSV-4 and 33.2% in CSV 216R respectively.

The overall comparison of estimates of correlation coefficients obtained in each M_3 families of DSV-4, DSV-5 and CSV-216R suggests that many characters were highly correlated with grain yield and are needed to be considered for selection. Some of the lines were exhibited susceptibility to shoot fly and shoot bug and tolerant to charcoal rot. Promising lines with high yield and charcoal rot resistance were identified in CSV216R, Early mutants in DSV4 and CSV216R.