EFFECT OF GAMMA IRRADIATION ON SEED QUALITY, INSECT INFESTATION AND FUNGAL INFECTION IN SORGHUM

(*Sorghum bicolor*L.Moench)

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BY

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2016

CERTIFICATE

Mr. RAM SWAROOP MEENAhas satisfactorily prosecuted the course of research and that the thesis entitled**"EFFECT OF GAMMA IRRADIATION ON SEED QUALITY, INSECT INFESTATION AND FUNGAL INFECTION IN SORGHUM *(Sorghum bicolor* L. Moench*)*"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

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Chairperson

CERTIFICATE

This is to certify that the thesis entitled"**EFFECT OF GAMMA IRRADIATION ONSEED QUALITY, INSECT INFESTATION AND FUNGAL INFECTION IN SORGHUM *(Sorghum bicolor* L.Moench*)*"**submitted in partial fulfillment of the requirements for the degree of **'**Master of science in agriculture**'** of the Professor Jayashankar Telangana State Agricultural University, Hyderabad is a record of the bonafide research work carried out by**Mr. RAM SWAROOP MEENA**under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. The published part has been fully acknowledged. All the assistance and help received during the course of investigation have been duly acknowledged by the author of the thesis.

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DECLARATION

I, **RAM SWAROOP MEENA,** hereby declare that the thesis entitled **EFFECT OF GAMMA IRRADIATION ON SEED QUALITY, INSECT INFESTATION AND FUNGAL INFECTION IN SORGHUM *(Sorghum bicolor* L.Moench*)***submitted to the **Professor Jayashankar Telangana State Agricultural University** for the degree of **Master of Science in agriculture** is a result of the original research work done by me. I also declare that the thesis or part thereof has not been published earlier elsewhere in any manner.

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Date: I. D. No: RAM/14-59

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Date: **(RAM SWAROOP MEENA)**

Place:Hyderabad

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SYMBOLS AND ABBREVIATIONS

µ	Micro
%	Per cent
ANOVA	Analysis of variance
Cm	Centimeter
CD	Critical difference
CV	Coefficient of variation
et al.	And others
Fig.	Figure
G	Gram
Ha	Hectare
HDPE	High density polyethylene
i.e.,	That is
Mg	Milli gram
M ha	Million hectare
m.t	Million tonnes
Mol	Molar
No.	Number
CRD	Completely randomised design
SE	Standard error
viz.,	Namely
Gy	Gray

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ABSTRACT

Influence of five gamma radiation doses generated from ^{60}Cosource of Gamma chamber 5000 in combination with control on seed quality parameters of sorghum variety C43, CSH14 and CSV 29R was investigated. Seed quality parameters viz., germination percentage, field emergence, speed of germination, root, shoot and seedling length, vigour index, electrical conductivity, seed moisture and seed health parameters were evaluated immediately after irradiation and up to nine months under storage at ambient conditions. The experiment was laid out in a Completely Randomised Design with factorial concept.

Marked significance of interaction effects was recorded for various seed quality parameters studied immediately after exposing the seed to selected doses of gamma rays. The results indicated that gamma doses up to 750 Gy were found to exercise positive influence in enhancing all the germination, seedling and biochemical parameters. However, this gamma radiation differed significantly in their response and registered variable values for seed quality parameters. The doses beyond 750 Gy had detrimental effect by interfering with various seed quality attributes.

The analysis of bimonthly data at four intervals on seed storage potential up to nine months indicated significant influence of storage period on all the seed quality parameters including seed health. The interaction effects between storage period, gamma doses were also highly significant. Marked decline in germination percentage, seedling dimensions and corresponding vigour index was noticed over a period of nine months. Among germination and seedling traits studied, vigour index and root and shoot length were the most sensitive seed quality parameters affected by ageing due to storage under ambient conditions,which registered higher reduction at the end of nine months.These traits can serve as reliable parameters for assessing seed quality under the influence of gamma radiation.

The electrical conductivity values were also increase significantly at the end of nine months of storage. The study revealed that, among the interactions CSV 29R and C 43 variety at 500 Gy and 750 Gy performed better than other gamma irradiation of 0, 250, 1000, 2000 Gy in the all seed quality and health parameters during nine months of storage. As far as seed health parameters are concerned, both CSH 14 and C 43 varieties at 1000 and 2000 Gy gamma irradiation performed well.

From the results of the study it could be concluded that, gamma doses 500 and 750 Gy showed superiority in influencing all the seed quality parameters positively during storage. Irradiation effect during storage in terms of maintenance of seed quality particularly the germination percentage above Minimum Seed Certification Standards prescribed for the crop, indicated that at 500 Gy CSV 29R, C 43 and CSH 14 could maintain minimum germination standards above 70 % and 75% for 7 and 5 months respectively. The superior combinations identified in this storability study can be further validated for commercial application.

Chapter I

INTRODUCTION

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most consumed staple cereal globally and over 80% of its cultivation lies in resource poor ecosystems. Sorghum is inherently high in protein and yields well in subsistence farming environments. The crop is capable of tolerating lower inputs and more marginal field conditions. World area under sorghum is 42.12 M ha with a production of 61.38 M t and productivity of 2.66 tha^{-1} (Anonymous, 2013). India leads the world in average with 1/3 of global area comprising of 10.9 M ha with a production of 8.0 M t and average yield of 0.73 t ha^{-1}(Anonymous, 2013). Given its natural tolerance to heat and drought stress, sorghum is a key crop in providing food security for millions of people in the developing world. Recent projections of sorghum based foods by health care professionals as an alternative to check life style diseases, have further enhanced the importance of this crop. The nutrient composition of sorghum indicates that it is a good source of energy, proteins, carbohydrates, vitamins and minerals. As demand for sorghum is increasing, it is essential to increase the productivity. Quality seed is key input for realizing of high yield in sorghum.

In tropics, 60-80 % of harvested sorghum seed is stored on farms or in villages by the farmers (Compton *et al.* 1993). The qualitative loss in stored seed is attributed to change in bio-chemical components such as carbohydrates, starch and proteins. The commercial value of the seed is reduced by contamination with uric acid, insect body fragments, dead body of insects and other toxic substances (Borikar and Tayde, 1979) and also, it exposes the seeds to attack by storage fungi (Subramanyan *et al*. 1992). These predisposing conditions have made the storage aspect of jowar seed as an emerging challenge.

Seed quality is a complex concept comprising several physical, chemical and biological components. Seed being a biological entity, deterioration in its quality is inevitable, irreversible and actually commences immediately after attaining physiological maturity even on the mother plant itself (Helmer *et al.* 1962).

Among other constraints influencing the storability of sorghum seed, pest incidence is of paramount importance. Rice weevil *(Sitophilus oryzae)* is a primary pest capable of feeding on seed, reducing not only germination capacity but also

nutritional and commercial value (Gwinner *et al*. 1998). The weight loss in stored sorghum is caused by both larval and adult feeding, with the major damage being done by larvae eating inside the kernel. In granaries, this weevil can induce up to 75 % of losses to the stored seed (Dal Bello *et al*. 2001). The annual losses of seed due to weevils in storage are estimated to be 25 to 40 % after 6 months of storage.

Maintenance of seed viability and vigour during storage is a matter of prime concern in tropical and subtropical countries. Owing to the prevailing tropical climate, seeds of most crop species show rapid deterioration and jowar is no exception. With the development of organized seed production and marketing system, seedmen are becoming aware of the problems of seed storage and there by systematic research needs to be initiated. However, when the awareness and infrastructure develops, substantial quantity of seed may be stored for few planting seasons as a safeguard against monsoon failure, natural calamities, market demands and other exigencies.

In this context, effective and environmentally friendly storage methodologies with minimum interference with seed quality and storability parameters would be of immense practical utility. In many countries both fumigation with chemicals and heat sterilization have been applied with varying degree of success. However, such applications are hidden with disadvantages like toxic residue accumulation leading to potential environmental hazards and altering storage potential of seed. Hence, gamma radiation administered at selective sub lethal doses can be projected as an effective technology to sanitize the seed before storage and to minimize deterioration of seed quality and storability. Gamma rays possess high penetrating characteristics and prevent re-contamination or re-infection of sterilized sample. Effectiveness of selected sub lethal gamma dose in maintaining the sorghum seed quality parameters during an extended period of ambient storage under farmer’s condition need to be ascertained.

Further, to improve the efficiency of gamma rays in terms of extending shelf life, the side effects of stress created by radiation exposure needs to be countered. The free radical generation associated with radiation stress may have to be curtailed by appropriate seed enhancement technology.

Therefore, the present study is proposed to investigate changes in both seed quality and storability parameters of promising jowar varieties at different doses of gamma radiation stored under ambient conditions with following objectives.

OBJECTIVES

1. To study the effect of selected doses of gamma radiation on seed quality of selected sorghum cultivars.
2. To study the effect of selected doses of gamma radiation on insect and fungal infection in selected sorghum cultivars.

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Chapter II

REVIEW OF LITERATURE

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REVIEW OF LITERATURE

Presently, gamma exposure is useful in solving various agricultural problems like reduction of post-harvest losses through suppressing sprouting and contamination, eradication or control of insect pests, reduction of food-borne diseases and extension of shelf life (Emovon, 1996). Ionizing radiations are also used to sterilize some agricultural products in order to increase the storage time or to reduce insect / pathogen propagation (Melki and Salami, 2008).

In recent years gamma radiation has been employed as an excellent tool for application in sterilization and preservation of food (Maity *et al*. 2008, Hyun-Pa *et al*., 2006 and Bari *et al*., 2003). Gamma rays belong to ionizing radiation and are the most energetic form of such electromagnetic radiation. Therefore, they are more penetrating than other types of radiation such as alpha and beta rays (Kovacs and Keresztes, 2002). Considering the practical difficulties in current approaches of bulk seed storage and their associated issues concerning cost involved and environmental pollution, application of gamma irradiation provides a tangible technology for developing safe seed storage protocols on a long term basis. Adoptions of cost effective and environmentally safe seed storage protocols are essential for sustaining production and distributionof quality seed.

Further, if such technological advancement is integrated with another frontier technology like seed treatment the goal of achieving efficient long term seed storage protocols particularly in crops like sorghum is likely to become a reality. As the research results in the Gamma irradiation particularly in sorghum are scanty, previous research efforts in this direction in cereals and other important field crops where seed storability poses a challenge are reviewed in this chapter under following heads and were referred to.

2.1Effect of gamma radiation on insect and fungal infection

Byun *et al.* (1988) evaluated the effect of gamma irradiation on controlling infestation of insects on irradiated rice grain. The egg and larval stages of rice weevil (*Sitophilus oryzae*) were radiosensitive. The complete mortal dose of the

egg and larva stages was 0.05 KGy. In Indian-meal moth (*Plodia interpunctella*), the sterile doses of egg, larva, pupa and adult were 0.04 to 0.05, 0.05 to 0.06 and 0.2 to 0.25 KGy respectively.

Singh and Singh (2005) reported that the change in fungal infestion due to seed treatment with different doses (0.05, 0.10 and 0.50 KGy) of gamma irradiation studied in four rice cultivars (Moirangphou, Tombung, KD-26-3 and RCM-5). The percent fungal infection on untreated seed of the four rice cultivars were 58, 64, 66, and 69% for RCM-5,Moirangphou, Tombung and KD-26-3 respectvely. The minimum fungal infections after radiation treatment were found to be 18% in RCM-5 and KD-2-6-3, 27% in Moirangphou and 32% in Tombung. These observations were made in the seeds treated with irradiation level between 0.10 and 0.50 KGy.

Vyas and Mishra (2010) reported that population growth of rice weevil, *Sitophilus oryzae*(L.) on sorghum genotypes, among the seven varieties studied, it was found that CSV 15 and PFGS 98 supported lesser number of *S. oryzae* than other five varieties and were therefore, relatively less susceptible to rice weevil**.**

Maity *et al*. (2011) evaluated the effect of gamma radiation on seed born fungi (*in vitro*) Swarna rice genotype (accession no.-5656), by irradiating with 1, 2, 2.5 and 3 KGy doses. The inactivation of individual fungal-viability was noted between 1.0-2.0 KGy for *Alternaria alternata*and *Aspergillus flavus* and 0.5-1.0 KGy for *Trichoderma viride* and *Curvularia geniculata*. Complete inhibition was observed at 2.0 KGy. (*A. flavus* reqired a higher dose to reduce viability to 10% (D_{10}) value in comparison to other selectd fungi).Different fungi exhibited different radio sensivity. The radiation doses between 2-2.5 KGy were found to be effective in killing all selected fungi.

In a study on influence of gamma irradiation on pest incidence in rice, it was observed that reduction in percent pupation, adult emergence, fecundity and fertility of the resulting adults depended upon the dose and larval age at the time of treatment. The severe reduction in fecundity and fertility was observed in 25days old larvae treated with a gamma dose of 80 Gy.(Kareem and Baki, 2013).

Subbarayudu *et al.* (2013) reported on sorghum resistance to rice weevil, *Sitophilus oryzae*through antibiosis and antixenosis.Twenty sorghum cultivars

along with a maintainer line 296B were screened for susceptibility to *Sitophilus oryzae*at the Directorate of Sorghum Research (DSR), Hyderabad, India. The grain traits such as hardness,fat and protein content imparting resistance to rice weevil were studied and correlated with weevil damage.Considering the adult weevil population, colonization, oviposition and seed damage, the genotypes viz., CSV 15,SPV 1330, SPV 462, SPV 1231, CSV 13, 296 B and Local Yellow jowar sorghum were found to be the least susceptible varieties to *S. oryzae*

The higher quantities of protein imparting resistance to rice weevil oviposition and its adult colonies with SPV 1330, SPV 462, SPV 1231, SPV 1328, CSV 13, CSV 11, CSH 5, CSH 16, SPH 821 indicating antibiosis for dominant component of resistance among the sorghum genotypes. The higher doses of fat significantly reduced the oviposition and rice weevil adults in SPV 1231, SPV 462, CSV 13, CSV 15 and CSH 9. The studies demonstrated that antixenosis and antibiosis to *S. oryzae*in the development of varieties, hybrids and in locals to ensure greater non-chemical protection over long term sorghum storage.

Jayashree *et al*. (2013) reported on management of *Sitophilus oryzae* (L.) under modified atmospheric condition in stored sorghum. Incidence of *Sitophilus oryzae* under modified atmospheric (MA) condition in stored sorghum containing various concentrations of carbon dioxide (CO_2), oxygen (O_2) and nitrogen (N_2) was studied. Adult emergence and egg loss (%) was recorded after exposure periods of 90, 135, 180, 225, 270 and 315 days. Fifteen and 20 % CO_2 concentrations exposed up to 315 days and resulted in cent per cent mortality of insects. Further, there was no adult emergence, egg loss (%) was nil and also there was no loss in germination of seed.

Kudachi and Balikai (2014) evaluated25*rabi*sorghum genotypes against rice weevil, *Sitophilus oryzae* (L.) based on parameters like % of damaged seeds, % germination, % loss in weight of seed and population build up recorded at 30, 90 and 180 days after storage. Results revealed that, cumulative seed damage at 180 days after storage was minimum in DJ 6514 (17.0%) followed by RS 585, CSV 216R, SPV570, BRJ 356 with minimum % damage ranging from 21.0 to 24.0 % indicating their high degree of resistance.Maximum viability was noticed in RS 585 (78.00%) followed by BRJ 356 (76.50%). Grain weight loss was significantly low in IS 2312 (4.80%) followed by IS 2205 (5.60%) and DJ 6514 (6.30%) and

maximum in Y 75 (23.06%), RSE 03 (20.32%) and DSV 4 (20.08%) at 180 days after storage. The genotype, CSV 8R showed high degree of resistance with minimum population buildup of 55.0 followed by RS 585 (56.0) and CSV 216R (56.0) and more number of adult weevils emerged in the RSE 03 (180.00), 5-4-1 (152.50) and Y 75(154.50) followed by Dagadi Solapur (133.00).

Shyam Prasad (2015) stated that sorghum is the fifth most important cereal and suffers heavy damage from rice weevil *Sitophilus oryzae*(L.) reducing their quality and quantity. Studies were conducted to identify the association of seed characteristics and their relationship with resistance to the rice weevil. The researchers discussed the associations between sorghum seed parameters, insect oviposition, insect development data and grain weight loss. The important seed characteristics, *viz.*, 100 seed weight was significantly positively correlated with seed hardness (0.55**) and median development period (0.47**) and significantly negatively correlated with grain weight loss (- 0.43*). However, the grain hardness was significantly negatively correlated with oviposition (- 0.49**), adult emergence (- 0.75**) and grain weight loss (- 0.82**) and was significantly positively correlated with median development period (0.85**). The pest parameter, *viz*., oviposition was significantly positively correlated with adult emergence (0.43*) and grain weight loss (0.55**).

2.2 Effect of gamma radiation on seed quality

2.2.1 Germination parameters

Yeh and Handerson (1963) observed reduction in the germination, after irradiation with both gamma rays and neutrons. They reported that gamma rays with a doserange of 15 to 50 Krypton (Kr), the relationship was approximately linear, with a drop of 10 per cent for each increase of 10 Kr.

Goud *et a1*. *(*1967) compared six varieties of rice after irradiation of the seeds with different doses of gamma rays. They observed delayed germination with increase in dosage in all the varieties except in Taichung Native -1.

Woodstock and Justice (1967) reported that radiation-induced changes in respiration of corn, wheat, sorghum and radish seeds during initial stages of germination in relation to subsequent seedling growth

Clark *et al*. (1968) reported on germination and survival of conifers following chronic gamma irradiation of seeds. Dry seeds of the Jack pine, Black spruce, Red pine, Scotch pine, White spruce and White pine were exposed to chronic ^{60}Co gamma irradiation for a period of 1–250 days. A dose-rate of 0·035 R/min for total doses to 12·6 Kr was employed. Two parameters to assess radiation effects were studied, 30-day germination under laboratory conditions and 1st year survival in the field. Germination was higher for all species under laboratory conditions than in the field. The higher dose of exposures producing no inhibition of germination (LD_0) varied from approx 400 to 3700 R. The lower dose of exposures preventing all germination (LD_{100}) varied from 1500 to 11,200 R. Survival of seedlings from irradiated seed 1st year post irradiation showed White pine and White spruce to be most sensitive with an LD_{50} of 575 R and Jack pine the most radioresistant with an LD_{50} of 2950 R. The LD_0 ranged from approx 80 to 1160 R and the LD_{100} from 950 to 4300 R.

Raj *et al*. (1972) treated the seeds of SLO-13, a long duration paddy variety with different doses of gamma rays at 20, 30, 40, 60, 70, 80 and 100 Kr. They observed germination was reasonably good in all treatments. In control the germination was 98 per cent while in treatments it varied from 89 to 97 per cent. Not much difference was seen regarding germination between control and 20 Kr treatments. Germination was 89 per cent in 60 Kr whereas, 95 per cent in the 100 Kr.

El-Keredy and Abd - Alla (1976) concluded that of the nine rice varieties, IR 22 is the most sensitive showed less germination and TKM-6 showed more germination which is the most resistant to the gamma rays when irradiated with different doses.

Pathak and Patel (1988) observed that germination percentage was not appreciably reduced by gamma radiation when three genotypes of upland rice were irradiated (i.e. Sathi 34-36, a local high-yielding, late and tall genotype; IET 2473, dwarf mid-early and coarse-grained; and Culture 102-5, semi dwarf with medium duration and long fine grain)with 5, 10, 15 and 20 Kr doses of gamma rays.

Krishnaswamy and Seshu (1989) opined that the stimulatory effects of gamma radiation on germination parameters could be attributed to its influence on oxygen uptake, dehydrogenase activity by providing energy to the germinating

embryo and overall capacity of the metabolic machinery. While, the inhibitory effect at higher doses could be a result of greater loss of leachates due to enhanced membrane permeability. Decrease in peak value of germination with increase in gamma radiation dose was earlier reported by Bhatnagar (1991).

Salter and Hewitt (1992) reported that gamma irradiation induces oxidative stress with overproduction of reactive oxygen species (ROS) such as superoxide radicals, hydroxyl radicals and hydrogen peroxides, which react rapidly with almost all structural and functional organic molecules including proteins, lipids and nucleic acids causing disturbances of cellular metabolism. Further, Lokesha *et al*. (1992) stated that the inhibitory effect on germination at higher doses of γ-rays could be due to several reasons like histological and cytological changes, disruption and disorganization of seed layer and generation of free radicals resulting in metabolic disorders in the germinating seeds directly proportional to the intensity of exposure to γ-rays.

Chaudhary (2002) reported that in higher radiation dose, germination percentage reduced, while, in lower dose *i.e.,* 0.1 KGy the germination percentage was not significantly different from control.

While estimating the sensitivity to gamma rays in five varieties of basmati rice (i.e. Basmati 370, 385, 2000, Pak and Super Basmati) by exposing them to different doses (150, 200, 250, 300 and 350Gy), Ashraf *et al*. (2003) reported that seedling emergence in field decreased with corresponding increase in doses in all the varieties. There was a significant effect of variety x dose interaction for seedling emergence. Radiations showed significant negative correlation with seedling emergence.

Cheema and Atta (2003) evaluated the seeds of three basmati rice cultivars *viz.,* Basmati 370, Basmati Pak and Super Basmati for varietal differences in radio sensitivity to gamma radiation when irradiated with 150, 200, 250, and 300 Gy of gamma rays. The germination decreased after gamma irradiation, but the decrease was neither proportional to the increase in dosage nor definite pattern was found in all the three rice varieties. The reduction in emergence of seedlings under field conditions occurred with each corresponding increase in gamma ray doses. In case of seedling emergence, 150 and 200 Gy doses did not have drastic effect but emergence decreased significantly at higher doses. Further, decrease in peak value

of germination with increase in gamma dose was earlier reported by Din *et al*. (2003).

Akbar and Babar (2003) evaluated the seeds of three basmati rice cultivars *viz.*, Basmati 370, Basmati Pak and Super Basmati for varietal differences in radio sensitivity to gamma radiation with 150, 200, 250, and 300 Gy of gamma rays. The germination decreased after gamma irradiation, but the decrease was neither proportional to the increase in dosage nor definite pattern was found in all the three rice varieties. Similar results have been reported in rice by other workers (Miah*et al*., 1970, Pathak and Patel, 1988).

Qasim and Ahmad (2004) studied the genetic variation in germination percentage of five irradiated wheat genotypes, which were subjected to 15, 25, 35, and 45 Kr doses of gamma irradiation. The differences in the mean values were highly significant. The data revealed that the range of mean values for radiation doses was 14.60 to 74.26 for germination percentage. The lowest germination percentage (14.6) was recorded at 45 Kr dose and the highest germination of 74.26 % was recorded in control. Generally a significant decrease was observed with an increase in the radiation intensity and the decrease was inversely related to the intensity of gamma ray doses.

Singh and Singh (2005) reported on the changes in seed germination rate and seedling growth due to seed treatment with different doses (0.05, 0.10, 0.25 and 0.50 KGy) of gamma irradiation in four rice cultivars (Moirangphou, Tombung, KD-2-6-3 and RCM-5). Highest rate of seed germination in all the four rice cultivars was recorded among the seeds irradiated with 0.10 KGy. The speed of seed germination was stimulated by low irradiation doses in all the four rice cultivars. The maximum speed of germination was recorded at 0.05 KGy in KD-2-6.

Lower dose irradiation was found to induce the growth stimulation by changing the hormonal signaling network in plant cells or by increasing the anti oxidative capacity of the cells to easily overcome daily stress factors such as fluctuations of light intensity and temperature in the growth condition as per Wi *et al*. (2007).

Increasing frequency of chromosomal damage with increasing radiation dose may be responsible for less germinability. The stimulating causes of gamma ray on germination may be certified to the activation of RNA or protein synthesis, which occurred during the early stage of germination after seeds irradiated (Abdel-Hady *et al*., 2008).

Minn *et al*.(2008) irradiated the seeds of paddy variety Sin thwe Latt (IR53936) With 100,200,300,400 and 500 Gy of gamma rays. The germination percentage has decreased with increase in gamma dose. But the decrease was not proportional to the increase in dosage. The dose 500Gy caused 50 per cent germination reduction.

In general, the germination percentage provides useful information for making decisions regarding storage. Seeds with 70% germination will generally not store as good as one with 95% of germination. But it is apparent that some important aspects of seed storability and vigour may not be reflected in the initial germination percent prior to storage. The solution to problems to the storability of seed lies in the development of tests that will differentiate among seed lots with respect to storage potential. Seed vigour can be viewed as a measure of accumulated damage in seed as viability declines. Testing for vigour becomes more important if seeds were stored under unknown conditions or under unfavorable storage conditions (Mendes and Moraes, 2009).

Miranda *etal*. (2009) evaluated the seeds of rice cultivar BRS-7 Taim' for the effects of different doses of gamma on seed quality. In first test the seeds were subjected to gamma radiation with doses 0, 1, 2.5 and 5 Gy. In second test the seeds were subjected to the ageing test methodology described by AOSA (1983) and irradiated with doses 0, 1, 2.5 and 5 Gy to evaluate the effect of radiation on seed vigour. In the germination test, there was significant difference between seeds with different water content (wet and dry seeds) on all radiation doses studied with the exception of 2.5 Gy. The germination percentage at 5 Gy was more than control. The germination speed index at 5 Gy was more than the control.

Babaei *et al*. (2010) found the morpho-physiological characteristics including seed germination characteristics of pure line seeds of Tarom-hashemi, Sange-tarom and Nemat rice varieties at different γ-ray dosages of 150, 250, 350 and 450 Gy. The results indicated that the seed germination percentage of Nemat,

Tarom-hashemi and Sange-tarom varieties reduced up to 5, 10 and 35per cent in 450 Gy. By increasing γ-ray radiation and their LD_{50} were close to 170, 310 and 350 Gy respectively.

Borzouei *et al*. (2010) observed the effect of gamma radiation on germination. Seeds of *cvs*. Roshan and T-65-58-8 (mutant line) of wheat were selected for irradiation with 100-400Gy by 100 Gy intervals. Seed germination test after gamma radiation (100, 200, 300 and 400 Gy) revealed that Gamma radiation had no significant effect on final germination percentage. Maximum decrease in germination percentage was observed with 300 Gy. These results were in accordance with the germination test done by Melki and Marouani (2009) where, there was no significant difference in germination of irradiated and non-irradiated seedlings of hard wheat.

Sasikala and Kalaiyarasi (2010) exposed six promising rice varieties (CO 43, 47, 48, 49, ADT 43 and improved white ponni) to gamma irradiation with doses of 100Gy, 200Gy, 250Gy, 300Gy and 350Gy of gamma rays in order to study effect of gamma irradiation in seed germination of rice varieties. The germination percentage has decreased with increase in gamma dose. But the decrease was neither proportional to the increase in dosage nor definite pattern was found in all the six rice varieties. At the dose of 350Gy all the six varieties exhibited the low germination percentage especially in the variety ADT 43.

Wu *et al*. (2010) reported that the germination, vigour, rate and index of irradiated rice seed under test increased first and decreased gradually with increase in intensity of ^{60}Co gamma rays. The germinating rate reached the maximum value at 100 Gy. The germination curve showed that rice seed germination was obviously inhibited at 400 Gy.

Tabasum *et al*.(2011)observed for varietal differences in radio sensitivity to gamma radiations in three Basmati rice genotypes *viz.*, 00515, 99417 and Super Basmati which were exposed to variable doses of gamma radiations (*i.e.*, 150, 200, 250, 300, 350 and 400 Gy). The mean germination percentage was significantly different among genotypes and values were in the range of 86.66% to 99.81 % with maximum germination in Super Basmati. Germination showed very little response towards increasing radiation doses and thus giving statistically non significant differences for all treatments. However, the lowest germination

percentage was recorded at 150 Gy dose and the highest germination was recorded at 200 Gy. The genotype X dose interactions were non-significant for germination percentage, indicating stability of performance for characters across different radiation levels.

Silva *et al*.(2011) reported that rice seeds of BRS Querência and BRS Fronteira were irradiated at the following doses: 0, 50, 100, 150 and 200 Gy, The cultivar BRS Querência showed a higher index of emergence speed (IES) in comparison to *cv*. BRS Fronteira in the control treatment (0 Gy) and in the lower radiation doses tested. However, doses higher than 100 Gy significantly affect the index of emergence speed (IES) for cultivar BRS Querência. The cultivar BRS Fronteira, however, showed decreases in seeds IES in all radiation treatments compared to the control, the most drastic reduction being observed at a dose of 200 Gy which was highly significant for all variables The response at a dose of 200 Gy confirms the greater IES.

Taher *et al*. (2011) evaluated two rice genotypes for optimum dose determination and to compare their sensitivity to different doses of 0,150, 180, 200, 220, 250 and 300 Gy gamma rays**.** The germination decreased after gamma irradiation, but the decrease was related to the increase of dosage and definite pattern was not determined in two rice genotypes. Germination percentage had reduced significantly at dose 300 Gy in both of genotypes. Optimum doses for landrace Tarom mohalli and for cultivar Fajr were 220 and 200 Gy, respectively.

Dehpour *et al*. (2011) reported that the rice cultivar Taroom Hashemi seeds irradiatd with three doses *i.e.* 100,200 and 300 Gy. Maximum decrease in germination was observed at 300 Gy.

Harding *et al*. (2012) stated that thirteen rice varieties cultivated in Sierra Leone were used to examine varietal differences in radio sensitivity to gamma radiation by exposing to different doses (50,100, 200, 300, 400, 500, 600, 800 Gy). Germination percentage decreased after gamma irradiation. Increase in doses of gamma irradiation had no significant effect on seed germination. The decrease in germination was not directly proportional to the increase in dosage. However, the effectiveness of gamma irradiation on percentage of germination was evident at 300 and 400 (LD_{50}) and reduces significantly at 500 and 600 Gy. Beyond 600 Gy none of the seedlings for any of the varieties survived.

Grover and khan (2014) reported that gamma irradiation up to 170 Gy increased the percentage emergence but at higher dose of 190 Gy, there was a drastic reduction in physiological characteristics of seedling of wheat in laboratory and field conditions at IARI, New Delhi. The study concluded that gamma radiation at a low dose stimulates, while at high dose (180 Gy and above) inhibits plant growth and development of wheat.

2.2.2 Seedling parameters

Matsumura and Mabuchi (1965) observed delayed seedling growth with the increasing doses of gamma rays when dry grains of the rice variety Norin 8 were irradiated. Similarly, Choi *et a1*. (1967) reported that three Korean rice varieties after irradiation, showed reduction in seedling elongation with increasing dosage.

Ukai (1968) reported that seedling growth and coleoptile elongation showed a differential response among a total of 27 rice varieties following seed treatment withgamma rays. Inhibition of seedling growth and coleopti1e elongation showed significant correlation with reduced root growth with increase in dose.

Bajaj *et al*. (1970) reported that effects of ^{60}Co gamma radiation on seeds, seedlings and callus cultures of *Phaseolus vulgaris*(L.) var. Manitou. Tissues were subjected to various doses (0·5–40 Kr) of gamma radiation at 200 rad/min and subsequently grown for 4–8 weeks. Seeds irradiated with 10–12 Kr produced stunted seedlings which later exhibited delayed flowering, and poor seed set; although the seeds germinated, no normal seedlings were formed at 15 Kr. However, when 8 day old seedlings were irradiated, severe inhibition of growth occurred at 2 Kr. There was a striking difference in the radiosensitivity of seeds, seedlings and callus tissue; the young seedlings are most radiosensitive, followed by seeds, and callus tissue was the most tolerant.

Miah *et al*. (1970) concluded that seedling height decreased with increasing radiation dose in the rice variety IR-8. Woo *et al*. (1971) reported that reduction in rice seedling height with increasing dose by treatment with diethyl sulphate (DES) or gamma rays.

Raj *et al*. (1972) treated the seeds of SLO-13, a long duration paddy variety with different doses of gamma rays at 20, 30, 40, 60, 70, 80 and 100 Kr. They observed that the length of the plumule and radical was reduced with the increase

in dose upto 60 Kr. Length of the plumule and radical in 70 Kr and 80 Kr was found more than 60 Kr.

Bhan and Kaul (1973) reported that seedling root and shoot growth was reduced in the varieties IR-8, Jhona and Basumati when seeds were treated with gamma rays at 10 to 50 Kr doses and chemical mutagens. The root to shoot ratio decreased with increasing dosage.

Pathak and Patel (1988) reported that three genotypes of upland rice were irradiated *i.e.* Sathi 34-36, a local high-yielding, late and tall genotype; IET 2473, dwarf- mid-early and coarse-grained variety and Culture 102-5, semi dwarf with medium duration and long fine grainvarietywith 5, 10, 15 and 20 Kr doses of gamma rays. Gamma radiation did not reduce shoot length except in Culture 102-5. Analysis of variance confirmed that radiation effects on roots and shoot length varied significantly among varieties. When compared to an average of 0.09 cm Kr^{-1} unit for the two other varieties, the root length of Culture 102-5 was reduced 0.30 cm for every Kr increase in radiation. Irradiation increased shoot length of Sathi 34-36, reduced shoot length of Culture 102-5, but had no effect on IET 2473.

Rodrigues and Ando (2003) stated that sixty-five upland rice cultivars (*Oryza sativa* L.) were evaluated in relation to gamma-ray sensitivity. Seeds were subjected to seven doses of gamma-radiation at 60, 120, 180, 240, 300 and 360 Gy, using $^{60}C_0$a source of gamma rays. The Japonica and Indica groups did not differ in(levels of 0 and 60 Gy to the character height). The Japonica group showed the greatest reductions in height compared to the Indica group at doses 300 and 360 Gy.

Ashraf *et al*. (2003) estimated the sensitivity to gamma rays in five varieties of basmati rice (i.e.Basmati 370, 385, 2000, pak and Super Basmati) by exposing them to different doses (150,200,250,300 and 350Gy). Shoot and root lengths declined with increasing doses in all the varieties. There was a highly significant effect of variety X dose interaction. Differences in shoot length showing that the varieties differed in their response to irradiation. Radiations showed highly significant negative correlation with seedling shoot length (-0.998) and root length (-0.941) exhibiting a dose dependent response. Root length was more affected than shoot length.

Seed vigour declines first as seed deteriorates, followed by loss of germination and viability. The highest difference in vigour of sunflower and soybean aged seed and control was found when cold test was applied. Genetic factors and seed chemical composition influence the expression of seed deterioration and vigour decline (Malencic *et al*.2003). Differences in genotypes sensitivity to storage conditions and duration were evident, especially in soybean which is more sensitive than sunflower. However, decline in seed germination after six and twelve months of storage was more pronounced in soybean genotypes, especially under conventional conditions compare with sunflower genotypes. Sunflower was more stable in terms of storage duration, and decrease of germination after 12 months of storage was approximately equal to the decline in germination of soybean genotypes after six months of storage. Initial plant growth is very significant for their further development and survival very often under unfavorable environmental conditions. Quick formation of assimilation surface and root system in early stage of plant life gives the plants certain advantage during later stages of development and growth. High vigour seeds are expected to tolerate high temperature and humidity while retaining their capability to produce normal seedlings. Applied vigour tests revealed that soybean seed was damaged during storage, which adversely affected the seedling growth under unfavorable germination conditions. Reduced capacity of old seed to absorb water seems to be associated with degradative changes in insoluble carbohydrates and protein macromolecules, which are primary components responsible for water absorption. When the initial water content in seed is low due to damage caused by unfavorable environmental conditions the rate of swelling is low, especially when water viscosity is increased.

Toker *et al*. (2005) reported on effects of gamma irradiation on the shoot length of *Cicer* seeds. The effects of radiation on the shoot and root lengths of germinated seedling of irradiated seeds of *Cicer* species, *i.e.* three kabuli types and four desi types of cultivated chickpea *Cicer arietinum* (L.) and 2 annual wild types*C. reticulatum* (L.) and *C. bijugum* K.H. Rech.) were investigated. The seeds were irradiated with a ^{60}Co gamma source using 0, 200, 300 and 400 Gy doses at 1.66 KGy h^{-1}. At 200 Gy minor effects could be observed, but at 400 Gy an obvious depression of shoot length was observed. The kabuli types were more affected than the desi ones. The critical dose that prevented the shoot and root

elongation varied among species and also ranged from genotypes to genotype within species.

Singh and Singh (2005) reported on the changes in seed germination rate and seedling growth due to seed treatment with different doses (0.05, 0.10, 0.25 and 0.50 KGy) of gamma irradiation studied in four rice cultivars (Moirangphou, Tombung, KD-2-6-3 and RCM-5). The higher irradiation doses inhibited shoot and root lengths. Root and shoot length in all the cultivars were found to be stimulated by low irradiation treatments. Maximum root and shoot lengths for *cvs*. KD-2-6-3, Moirangphou and Tombung were recorded at 0.05 KGy while that of *cv*. RCM-5 was observed at 0.10 KGy.

Minn *et al*. (2008) irradiated the seeds of paddy variety Sin thwe Latt (IR53936) with 100,200,300,400 and 500 Gy of gamma rays. The seedling height was decreased with increase in gamma dose. But the decrease was not proportional to the increase in dosage. The dose 400Gy caused 50 per cent seedling height reduction in this variety. Reduction in the root length occurred with each corresponding increase in gamma dose. The dose 320Gy caused 50 per cent seedling height reduction in this variety.

Miranda *etal*. (2009) evaluated the seeds of rice cultivar BRS-7 Taim' for the effects of different doses of gamma on seed quality of rice. In first test the seeds were subjected to gamma radiation source with doses 0, 1, 2.5 and 5 Gy. In second test the seeds were subjected to the ageing test and irradiated with doses 0, 1, 2.5 and 5 Gy to evaluate the effect of radiation on seed vigour. 1 and 2.5 Gy showed no statistical difference for shoot length of seedling, but for dose 5 Gy, seedlings from seeds irradiated with higher water content showed higher shoot growth than seedlings from irradiated seeds dried. For the root system, there were differences between seeds irradiated with different contents water and dose zero (control). There were no differences in length of root system in each radiation dose, when dry seeds compared with moist seeds.

Moradi *et al.* (2009) studied on pre-treatment effect of gamma radiation on germination in rice var.*Tarom hashemi* (Iranian local rice variety). Fully mature and perfect seeds were irradiated with three doses of gamma radiation (100, 200 and 300 Gy). Results revealed that the maximum root length was observed in

gamma 200 Gy treatments. Gamma 200 Gy treatment was significant than other treatments and control.

Borzouei *et al*. (2010) observed the effect of gamma radiation on germination. Seeds of *cvs*. Roshan and T-65-58-8 (mutant line) of wheat were selected for irradiation with 100-400Gy by 100 Gy intervals. Gamma ray imposed a significant impact on the shoot length. The highest length of shoot (3.8cm) was observed at 100 Gy. By increasing radiation dose to 200, 300 and 400 Gy shoot length declined 40, 49 and 46 percent respectively compared to the control. Shoot length decreased in both Roshan and T-65-58-8 genotypes after all doses of gamma radiation. The maximum decrease in shoot length was observed, when wheat genotypes were exposed by gamma ray dose higher than 200 Gy. Results showed that radiation on interaction of radiation and genotypes imposed a significant effect on root length. Maximum root length was measured for control (9.8cm), while root length of 100 Gy seedlings (9.5cm) was in statistically similar group. Treatment of 200 and 300 Gy radiations also had no significant difference in root length and a minimum length of the root was found in 400 Gy. Root length decreased after all doses of irradiation as compared to non-irradiated control. Maximum reduction in root length was observed after 200 Gy dose in both genotypes, but in Roshan the reduction of root length after 200 Gy was higher than that in other genotype.

Majeed and Muhammad (2010) investigated effects of gamma rays on days to germination, days to completion of germination, germination percentage, survival percentage, shoot length/plant, root length/plant, number of branches/plant, number of leaves/plant, fresh weight of shoot/plant and dry weight of shoot/plant of *Lepidium sativum* (L.) Dry seeds were irradiated with 20, 30, 40, 50, 60, 70 and 80 Kr by a ^{60}Cogamma chamber. The study revealed that gamma irradiation significantly affected all the mentioned parameters except germination percentage. Days to initiation of germination and days to completion of germination were significantly delayed at higher doses of gamma rays. However, other growth parameters showed declining tendency with increasing doses of gamma irradiation. Germination percentage was not significantly affected by higher doses of gamma rays.

Sasikala and Kalaiyarasi (2010) exposed six promising rice varieties to gamma irradiation with doses of 100, 200, 250, 300 and 350Gy of gamma rays in order to study the effect of gamma irradiation in seed germination of rice varieties and to study the root and shoot length variation. Root length variation in present study showed that the reduction of root length with the corresponding increase of radiation dose. The inhibition of root development was higher in dose of 300 Gy in all the six varieties. At higher dose of 350Gy root length is very much affected in the varieties of CO 43 (76% reduction) and improved white ponni (70% reduction). The reduction of shoot length with the corresponding increase of radiation dose. But at 100Gy, CO 43 and improved white ponni showed shoot length more than non-irradiated seeds. The gamma ray dose of 300Gy was causing 42-51% seedling height reductions in CO 43, CO 47, CO 48, CO 49 and ADT 43. The seedling height was reduced in decreasing manner with the increase of irradiation dose in CO 47 and improved White Ponni, but decrease was proportional to the increase of irradiation dose.

Wu*et al*. (2010) concluded that the vigour index of irradiated rice seed under test increased first and decreased gradually with increase in intensity of ^{60}Co gamma rays. The vigour index reached the maximum value at 200 Gy. Babaei *et al*. (2010) found the morpho-physiological characteristics including seed germination characteristics of pure line seeds of Tarom-hashemi, Sange-tarom and Nemat rice varieties at different γ-ray dosages at 150, 250, 350 and 450 Gy. Meanwhile, their radical and length at 14 days period significantly reduced in all dosage treatments and ranged from 93 to 12, 156 to 87 and 176 to 57 mm in Tarom-hashemi, Sange-tarom and Nemat rice varieties respectively. The same pattern was also observed in plumule for means 49 to 7, 61 to 48 and 75 to 34 mm.

Silva *et al*. (2011) reported that rice seeds of BRS Querência and BRS Fronteira were irradiated at the following doses: 0, 50, 100, 150 and 200 Gy. The height of the seedlings was negatively affected by the use of radiation for cultivar BRS Querência in the two analyzed periods (*i.e*. 14 DAS and 28 DAS) and the response was linear and decreasing with reductions of 31.4 % at dose 150 Gy, 14 DAS and 27.5% at 200 Gy at 28 DAS. For cultivar BRS Fronteira, in both evaluation dates, there was an increase in this trait at doses of 50, 100 and 150 Gy. The better response was obtained with 50 Gy (25.6% compared to control). The lower doses of gamma radiation are concluded to produce a stimulus on the growth

of the aerial as well as the underground parts of cultivar BRS Fronteira. As a consequence of the obtained results and making an analogy to the ratio between shoots and root system it can be verified that for the cultivar BRS Fronteira dose of 50 and 100 Gy affected the development of the root more expressively, in both evaluations. The same behavior was observed in cultivar BRS Querência with a dose of 100 Gy at 14 DAS and to 200 Gy at 28 DAS. These results demonstrated the existence of a distinct behavior between the two rice cultivars with regards to radiation doses.

Tabasum *et al*.(2011) observed for varietal differences in radio sensitivity to gamma radiations in three Basmati rice genotypes *viz.*, 00515, 99417 and Super Basmati which were exposed to variable doses of gamma radiations (*i.e.*, 150, 200, 250, 300, 350 and 400 Gy). The differences among gamma radiation treatments were highly significant ($p<0.01$) for shoot and root length, Genotypic differences in mean values for shoot and root lengths were significant and were in the range of 11.6 cm to 15.09 cm and 11.6 to 12.6 (cm) respectively. Highest dose of gamma radiation 400 Gy produced significant differences for shoot length in genotype "00515" and super basmati while genotype "99417" did not respond to radiations in spite of producing maximum shoot length. Genotype "00515" got superiority in root length and produced significant differences at 250 Gy while in other genotypes differences appeared at 200 Gy showing more radio sensitivity for this trait. Shoot length did not increase or decrease in definite pattern in response to different doses while; with increasing radiation doses decline in root length values was observed. The mean valuesfor gamma doses indicated lowest values at highest radiation level and maximum values in control for both traits.

Dehpour *et al*.(2011) irradiatd the rice cultivar Taroom Hashemi seeds with three doses *i.e.* 100, 200 and 300 Gy. Maximum decrease in shoot and root length was observed in 300 Gy .

Taher *et al*. (2011) evaluated two rice genotypes (cultivar Fajr and landrace Tarom mohalli) for optimum dose determination and to compare their sensitivity to different doses of 0,150, 180, 200, 220, 250 and 300 Gy gamma rays**.** At higher doses, height of seedlings was reduced. In medium doses (200, 220 and 250 Gy), height of seedlings was reduced to half in some replications and at higher dose

(300 Gy) height of seedlings had been decreased even to less than half of normal height seedling .

Harding*et al*.(2012) observed thirteen rice varieties cultivated in Sierra Leone for varietal differences in radio sensitivity to gamma radiation by exposing to different doses of gamma radiation (50,100, 200, 300, 400, 500, 600, 800 Gy). The results indicated that increasing doses from 0 – 300 Gy had no effect on seedling height even though there were slight decrease in heights with increase in dosage but the decrease was not proportional to the increase in dosage for all rice varieties. These results indicated that the varieties did not differ in radio sensitivity with respect to seedling height as the dose of 300 Gy causing 50% seedling height reductions. However, at 400 Gy and above the effect became significant.

2.2.3 Biochemical parameters

Myttenaere*et al*. (1965) evaluated the effects of gamma radiation on seed moisture content in relation to germination and seedling height in seeds of Italian Japonica Rice varieties; Ardizone, Balilla, Maratelli, Razza 77 and Rinaldo Bersani when irradiated with 0,5,10,20,30,40 and 50 Kr at different seed moisture. The highest germination was observed at moisture content of 11.1, 8.5, 11.1, 10.6, 10.6 and 11.1for 0,5,10,20,30,40 and 50 Kr doses respectively. The germination percentage decreased with increase of moisture content. Significant differences appeared among varieties both in percentage of germination and seedling height in relation to moisture content. Thus varieties Razza 77 and Balilla seemed to be more radio sensitive than the othersthree varieties.

Akbar *et al.* (1976) concluded that when the dry rice seeds of *indica* varieties Jhona 349 and Mangolia exposed to RD_{5O} and LD_{5O} values of gamma irradiation, the sensitivity to radiation was directly related to the amount of endogenous reducing sugars released by alpha amylase activity between 4 and 10 days after germination.

Earlier studies associated with increased membrane permeability with gamma radiation and concluded that enhanced leakage of leachates could be one of its side effects. Predominant effect of ionizing radiation in organisms induces reactive oxygen species (ROS) formation (De-Vita *et al.*1993).

It was earlier reported that, lower gamma doses up to 100 Gy interfered positively with the seed membrane dynamics and arrested the loss of seed substrates, antioxidants and peroxidases which were apparently involved in the compensatory mechanism of inhibiting free radical generation upon irradiation of seeds as reported earlier by Rogozhin *et al*. (2000).

Amjad and Akber (2002) suggested that, the seeds irradiated at higher doses suffered greater losses than those irradiated at the lower dose and therefore, the leachates from the samples irradiated at higher doses had higher conductivities than at lower doses.

Moaed Almeselmani *et al*. (2006) opined that, in general, stress induces significant changes in normal physiological processes such as photosynthesis dark respiration, membrane stability and mitochondrial respiration. Mechanism of injury involves the generation and reactions of reactive oxygen species (ROS). In order to limit oxidative damage under stress condition plants have developed a series of detoxification systems that break down the highly toxic ROS. Plants protect cell and sub cellular systems from the cytotoxic effects of the active oxygen radicals using antioxidant enzymes such as superoxide dismutase, ascorbate peroxidase, glutathione reductase and catalase.The protection of plant from stresses is believed to be achieved by preventing the oxidation of enzymes and membranes.An experiment was conducted to study the effect of high temperature stress on the antioxidant enzyme activity in five wheat genotypes viz., PBW 343, PBW 175, HDR-77, HD 2815 and HD 2865. There was significant increase in the activity of superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase (CAT) in the late and very late planting and at all stages of plant growth, *i.e.*, vegetative phase. In general HD 2815, HDR-77 showed relatively higher SOD, APX, GR, CAT and POX activity in the late plantings compared to PBW 343, PBW 175 and HD 2865.

In an effort to study the seed enzyme activity, Miranda *etal*. (2009) evaluated the seeds of rice cultivar BRS-7 Taim' for the effects of different doses of gamma on seed quality of rice. In first test the seeds were subjected to gamma radiation source with 0, 1, 2.5 and 5Gy, doses. In second test the seeds were subjected to the ageing test and irradiated with doses 0, 1, 2.5 and 5Gy to evaluate the effect of radiation on seed vigour. The total activity of the enzyme alpha

amylase was evaluated higher to zero days and decreased from seven to 14 days of germination. It was observed that the enzyme activity decreased with increasing doses of gamma radiation to zero days. After seven days alpha amylase activity decreased in dose of 2.5 Gy, and 14 days, there was no significant difference in enzymatic activity of alpha amylase, at different doses of gamma radiation.

In general the levels of enzyme activity are correlated with germination and vigour of seed under the influence of storage. Decrease in enzyme activity lowers the respiratory potential which in turn lowers both energy and food supply to the germinating seed. Several changes in enzyme macromolecular structure may contribute to their lower effectiveness. They may undergo compositional changes by losing or gaining certain functional groups by oxidation of sulfhydryl groups or by conversion amino acids within the protein structure. The enzymes may undergo configurational changes such as partial folding or unfolding of the ultra structure. Dehydrogenase activity is also known as tetrazolium reduction ability. The activity of this enzyme is directly correlated with seed vigour (Chauhan *et al*., 2011).

Sreedhar *et al*. (2013) suggested that, Gamma irradiation was reported to induce oxidative stress with overproduction of reactive oxygen species (ROS) such as superoxide radicals, hydroxyl radicals and hydrogen peroxides, which react rapidly with almost all structural and functional organic molecules. To avoid oxidative damage, plants have evolved various protective mechanisms to counteract the effects of ROS in cellular compartments. One of the protective mechanisms was the enzymatic system, which operates with the sequential and simultaneous actions of a number of enzymes including peroxidase. Exposure of plant cells to gamma radiation leads to the formation of ROS and therefore, SOD removes superoxide formed during radiation exposure and also inhibits formation of more reactive pro oxidants. Radiation is a well known factor that affects antioxidant status and increases free oxygen radical generation. In the present study, this was evident due to significant increase in the activity of SOD exposed to ionizing radiation. These findings indicated increased antioxidant activity. The observed increase of SOD of the antioxidant system indicated that increase in oxidative stress caused by radiation may be overwhelmed by this enzymatic system. Enzyme induction was significantly correlated with the dose of irradiation. Results for groundnut *Arachis hypogaea* (L.) cv. Narayani seedlings irradiated with gamma radiation, indicated fluctuation in the activity of superoxide dismutase

(SOD) correspondingly with the irradiation dose. SOD activity increased in the irradiated samples as the absorbance is inversely proportional to SOD activity, fact which concluded that irradiation had a stimulatory effect on the enzyme except at the lower dose 10 Gy,

2.2.4 Causes for seed deterioration

Abdul-Baki and Anderson (1973) observed that leaching of sugars increased with increase seed age and increased injury to endosperm resulted in reduction in seed quality.

Delouche and Baskin (1973) defined seed deterioration as summation of all physical, physiological, biochemical changes occurring in a seed which ultimately leads to its death. They also characterized seed deterioration as inexorable, irreversible, inevitable and minimal at the time of physiological maturity and varies with the kind of seed, varieties and seed lots of same variety.

The seed viability and vigour are maximum at physiological maturity. After physiological maturity seeds begin to deteriorate at varying rates depending on the conditions of storage environment. (Roberts and Ellis,1980)Many researchers agreed that the seed deterioration is a progressive process which has far reaching consequences (Ellis and Roberts, 1981 and Ghosh *et al*., 1981).

Seed deterioration is mainly due to lipid peroxidation and membrane degradation. Biochemical changes associated with seed deterioration are increase in acidity and leaching of sugars and electrolytes (Halder *et al.,* 1983). The leachate of seed as measured by electrical conductivity (Bradnock and Mathews, 1970 and Powell and Mathews, 1986) was shown to be associated with the loss of vigour and viability.

Perl *et al*. (1987) observed the possible involvement of membrane with loss of vigour and could not obtain consistent changes in the amount of electrolytes, aminoacids and inorganic phosphates leached from sorghum seeds subjected to various durations of accelerated ageing.

Copeland (1988) highlighted the consequences of deteriorative changes in seed which include membrane degradation, accumulation of toxic metabolites, decreased enzymatic activity, lipid autooxidation, failure of repair mechanisms, genetic degradation and finally loss of germination or death of the seed.

Crowe *et al*. (1992) reported that decrease in membrane stability is due to non-enzymatic reaction between the carboryl group of CH_2O and amino group of aminoacid and protein. Dighe *et al*. (1995) opined that membrane degradation during deterioration as judged by increased seed leachate and electrical conductivity.

The enzymes play an important role in the progress of seed deterioration and changes in their activity can be an indication of quality loss (Copeland and McDonald, 1995). The relationship between seed deterioration and the enzymes involved in lipid peroxidation, free radical removal, and seed respiratory metabolism also has been studied. All enzyme activity is positively correlated with germination of seed as ageing progressed germination also decreased and enzyme activity also decreased which showed significant deterioration in both accelerated as well as in natural aged seed lot. All seeds undergo ageing process during long-term storage which leads to deterioration in seed quality, especially in the humid tropical regions.

Many hypotheses have been proposed regarding causes of seed ageing such as lipid peroxidation mediated by free radicals, inactivation of enzymes or decrease in proteins, disintegration of cell membranes and genetic damage (McDonald, 1999, Murthy *et al.,* 2003). Degradation and inactivation of enzymes due to changes in their macromolecular structures is one of the most important hypotheses proposed regarding causes of ageing in seeds (Bailly, 2004; Basavarajappa *et al*., 1991, Goel *et al*., 2002 Lehner *et al*., 2008; McDonald, 2004). Most of these studies suggest that decreases occur in the activity of enzymes such as superoxide dismutase, catalase, peroxidase and glutathione reductase in aged seeds. The general decrease in enzyme activity in the seed lowers the respiratory capacity, which in turn lowers both the energy (ATP) and assimilates supply of the germinating seed. Therefore, several changes in the enzyme macromolecular structure may contribute to their lowered germination efficiency.

Singh *et al*. (2001) reported that rate of electrolyte leakage of seed leachate was influenced by the type of paddy cultivars, associated fungal species and storage period. Among the four rice cultivars, RCM-5 was more resistant to leakage of electrolytes which showed the lowest electrical conductivity values both in treated and untreated seeds throughout the storage period.

Scialabba *et al*. (2002) reported that peroxidase activity decreased in aged seeds as compared to fresh seeds in radish. Pallavi *et al*. (2003) studied that sharp decline in peroxidase emzyme during ageing in sunflower. Peroxidase and catalase activities were found higher in younger seeds of *Chenopodium rubrum* (Mitrovic *et al*., 2005). Also, Pallavi *et al*. (2003) revealed that the absorbance of dehydrogenase enzyme was decreased as the period of storage increased in sunflower.

The events relating to physically manifested phenomenon of seed ageing are commensurate with biochemical changes occurring in seed matrix during storage. It is believed that biochemical processes of lipid peroxidation are the major cause of seed deterioration during storage. Intensified activities of enzymes that participate in lipid metabolism, caused especially by increased moisture content in seed and higher storage temperature, increased the usage of lipids in the respiration process, leading to significant reduction of oil content in seed. The types of fatty acids present in an oil, and in particular their number of double bounds, determine the type and extent of chemical reactions which occur during the storage time (Morello *et al*., 2004).

Lipid peroxidation and products resulting from these processes lead to DNA denaturation, prevent translation and protein transcription, and cause oxidation of the most reactive amino acids. When these types of damages occur in seed, they may cause decrease in vigour and seed germination. Mechanism of oxidative damage is very complex and occurs as two different types of fatty acid changes. The first one is linked to the process of ageing during the first week of storage and includes spontaneous oxidation of unsaturated fatty acids, with no changes occurring in saturated fatty acids. In the second type of damage the seed that has lost its ability to germinate, showed oxidation of both saturated and unsaturated fatty acids. Activity of free radicals in seed may depend on water content, seed components, seed lot, species and variety, as well as the ageing treatment (Laloi *et al*., 2004).

The leading attribute causing seed deterioration increasingly appears to be free radical production. It is, primarily initiated by oxygen, has been related to the peroxidation of lipids and other essential compounds found in cells. This causes a host of undesirable events to include decreased lipid content. Lipid peroxidation

begins with the generation of a free radical either by auto oxidation or enzymatically by oxidative enzymes such as lipoxygenase present in many seeds. Seed moisture content due to the absence of free water in dry seeds, non-enzymatic mechanisms such as lipid peroxidation are likely to be involved in ROS accumulation during dry storage, but as soon as seeds imbibe, enzymatic mechanisms participate in ROS production. One of the major sources of ROS in metabolically active seeds is the mitochondrial respiratory chain (Bailly, 2004). Lipid peroxidation occurs in all cells, but in fully imbibed cells, water acts as a buffer between the autooxidatively-generated free radicals and the target macromolecules, thereby reducing damage. Thus, as seed moisture content is lowered, autoxidation is more common and is accelerated by high temperatures and increased oxygen concentrations. Lipid autooxidation may be the primary cause of seed deterioration at moisture contents below 6%. Above 14% moisture content, lipid peroxidation may again be stimulated by the activity of hydrolytic oxidative enzymes such as lipoxygenase, becoming more active with increasing water content.

However, the rate of seed deterioration can vary among various plant species. Aged seeds show decreased vigour and produce weak seedlings that are unable to survive once reintroduced into a habitat (Atici *et al.*, 2007). Some protective mechanisms involving free radical and peroxide scavenging enzymes, such as catalase (CAT), peroxidase (POD) and superoxide dismutase (SOD) have been evaluated within the mechanism of seed ageing (Pukacka and Ratajczak 2007).

2.1.5 Seed viability

Low seed viability is a major constraint in tropical and subtropical areas. Frequent weather fluctuations in southern and western parts of India affect stored crops and make them more prone to invasion by different types of fungi (Reddy *et al.*, 2009). In stored seeds, ageing is an universal physiological phenomenon followed by deterioration resulting in the loss of viability. Usually it progresses at faster rate under stress or unfavorable conditions. The mechanism of deterioration which is the final stage of ageing process is still an enigma. Seeds go through a series of changes before they finally lose viability.

Storing and preserving quality seed until the next season is as important as producing quality seeds. During storage, the seeds are bound to undergo ageing, an inevitable physiological phenomenon showing the pronounced effects on viability and vigour. It is widely accepted that loss in cellular membrane integrity is one of the chief causes for loss of viability and leads to increased leaching of seed constituents and ultimately death of the seed (Ching and Craft, 1968).

Roberts (1972) postulated loss of viability due to intrinsic and extrinsic factors based on internal and external agents causing loss of viability. The most important factors that determine the longevity of seeds in storage are the seed moisture, temperature, relative humidity and the type of container. The potential storage life of seeds varies from species to species (Agrawal, 1979) and within a species and from variety to variety.

During storage, seed deteriorates rapidly (Janardhana *et al*., 1999; Jackowiak *et al*., 2005; Adilakshmi *et al*., 2007; Reddy *et al*., 2009) and as a result substantial loss in terms of vigor and germinability occurs particularly in humid condition. Incidence of seed interacting with fungal pathogen during harvest period is higher in humid condition, which leads to the rapid rate of deterioration of stored seed.

Rickman *et al*. (2006) reported that the quality of the seed was very important to farmers as it measures the potential performance of the seed under optimal conditions. Since high quality seed is free from various diseases and has better seed health, it is expected to produce healthy seedlings with no initial disease inoculums (Nguyen, 2001).

Indira *et al*. (2006) reported on utility of biocontrol agents in the suppression of seed borne pathogenic mycoflora and their effect on seed quality in sorghum *Sorghum bicolor* (L.) Moench. The bacterial bioagent *P. fluorescens* was most efficient in checking the growth of all the test pathogens *viz.,Fusarium moniliforme, Curvularia lunata* and *Alternaria alternata* (66.8, 68.5 and 64.9% inhibition of colony growth respectively) followed by other bioagents for their antagonistic effect. The *in vivo* effectiveness of the bioagents were enhanced when combined with other components like host-resistance, cultural and chemical control strategies, paving the way for a possible Integrated Disease Management. Of all the treatments, *P. fluorescens* resulted in maximum germination (88 %) and

seedling vigor (2635 vigour index), followed by treatment with *T. viride* (86.6% and 2478.47 germination and vigour index respectively).

The use of good quality seeds of adapted and improved varieties is widely recognized as fundamental to increased crop production and productivity. According to Rickman *et al.* (2006) the use of good quality seed increases crop yields, decreases the number of seeds that need to be sown, and reduces the carryover of weeds, insects and diseases. Good quality seeds also allow farmers to attain high quality end products, minimize the cost of production by ensuring high rate of survival, fast growth, and low infection by diseases and pest.Mbora *et al*. (2009) reported that seeds of the best quality will result in produce of best quality in the field which will result to yields of highest value and also indicated that the use of good quality seed enables farmers to make the best use of available land and attain economic returns faster.

Madanzi *et al.* (2007) reported effect of storage length on early stand establishment of four sorghum *Sorghum bicolor* (L.) varieties in the smallholder sector of Zimbabwe. Sub-optimal crop establishment is one of the major constraints to sorghum production in the smallholder sector of Zimbabwe attributed to the use of farm-retained seed subjected to long and poor storage conditions. A study was carried out to determine optimum storage length that results in optimum stand establishment. Standard germination and vigour tests were carried out to determine loss of vigour due to storage length (one to three years after harvest) on four sorghum varieties (Marcia, SV2, SV3, and SV4). A field experiment was also carried out to determine the effects of seed storage length on emergence of sorghum. The interaction ($P<0.001$) between variety and storage length after the vigour test was significant. There was a general decrease in vigour with increased storage length with variety Macia maintaining a high germination after three years of storage. The other varietieshad germination less than 50 % after one year. In the field, there was significant difference ($P<0.05$) due to variety on emergence. Variety SV3 achieved the highest emergence of 56.8 % while Macia, SV4, and SV2 had 52.5 %, 39.3 %, and 34.2 % respectively. Conclusively, Macia and SV3 can be grown beyond one year and give reasonable stand establishment.

Oliveira and Gomes Filho (2011) reported aboutsorghum seedling establishment from primed seeds with different physiological qualities. To evaluate the establishment of the seedlings in the plot, the initial (IS) and final (ES) stands, the emergence speed index (ESI) and mean time (EMT), the root (RDM), shoot (SDM) and total (TDM) dry matter and the SDM/RDM ratio were analyzed. The primed seeds from the non-aged group showed higher values for the variables IS, ES, SDM and TDM, reflecting the beneficial effect of priming on the establishment of seedlings from high quality seeds. Priming high quality seeds increased the emergence percentage and dry matter production of seedlings.

Kavitha *et al.* (2013) observed that effect of seed hardening and film coating on crop growth and yield of sorghum *cv.* CO (S) 28. The hardened and film coated seeds were evaluated initially both under laboratory and pot culture experiments for germination, vigour performance. From the findings obtained from the hardening and film coating treatments, the best treatment was selected and coated using DAP @ 30 g kg^{-1} and micronutrient mixture @ 20 g kg^{-1} of seed. The results indicated that seeds hardened with 2% KH_2PO_4 and film coated with carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + 30 g DAP + 20 g micronutrient mixture + pink polykote @ 3 g kg^{-1} + *Azospirillum* @ 40 g kg^{-1} of seed recorded higher germination (98%), vigour index (3695) under laboratory evaluation.

2.3 Effect of gamma radiation on seed storability

Natarajan and Maric (1961) observed the effects of gamma radiation in barley during 32 days storage. Barley seeds were treated with 10000 r of gamma rays both chronically (1000 r/hr for 10 hr) and acutely (630000 r/hr for 57 sec). The seeds were germinated immediately after treatment as well as after different duration of storage, namely 1, 2, 4, 7, 14, 21 and 32 days after treatment. There is significant difference between the germination and seedling height of the two treatments, when the seeds were sown immediately after treatment, the difference slowly diminishes with increase in the time of storage and after 7-32 days, there is no significant difference between treatments. There is reduction in the germination and seedling height as the time of storage increases. The decrease is steep within 7 days and from 8-32 days the decrease was non-significant.

Ching and Craft (1968) opined that deterioration of seeds with ageing results in loss of viability and vigour during storage which is usually due to the changes in biochemical composition and results in leaching of electrolytes and other low molecular weight substances during imbibition.

Ito *et al*. (1971) evaluated the effects of storage on germination and micro organism in relation to moisture content in gamma irradiated rice varieties of Koshihikari and Tibbasalu when irradiated with 0.02, 0.05, 0.1, 0.2, 0.3 and 0.4 Mrad at moisture contents of 14.5, 16 and 17 per cent and stored in HDPE 0.06 mm bag for one to five months. During storage germination of rice varieties was not affected at 14.5 per cent moisture level for two months, but it was retarded greatly for longer periods of storage. Rice irradiated with a dose of 0.1 Mrad extend the storage life from 2 to 3 months at dose of 0.2 Mrad the storage life was extended for more than 3 to 4 months. At 14.5 per cent moisture level mold growth was high after two months of storage. At 16 per cent germination seeds were maintained for less storage time compared with rice containing 14.5 per cent moisture when irradiated with same dose. No increase was observed in the number of bacteria on the rice during these two months of storage. At 17 per cent germinability of irradiated rice with less than 0.2 Mrad decreased rapidly in one month of storage and thus may be due to the propagation of molds on the germ. The storage life of polyethylene packaged rice containing 14.5 per cent can be moisture extended 3 to 4 times by means of 0.2 Mrad irradiation. When moisture content of rice seed is greater than 16 per cent a dose of 0.3 and 0.4 Mrad extended its storage life. By keeping the moisture content of rice seed stored in polyethylene bag below 14.5 per cent a dose of 0.2 Mrad is probably enough to extend storage life safely more than 1 year.

Harrington (1972) in his studies on seed storage and longevity opined that crop seeds differ considerably for viability and longevity depending on plant species and varieties as well as the conditions of storage. Further, it has been demonstrated that early deteriorative change in seeds under storage was due to various biochemical processes *viz.*, denaturation of biomolecules and accumulation of toxic substances in addition to loss of membrane integrity (Abdul Baki and Anderson. 1973).

Wang *et al*. (1983) observed the effects of gamma-radiation on Taiwan-produced rice grains which has been investigated to find an advantageous application of radiation processing on the storage of rice grains. The results obtained from the three major kinds of rice grains which were gamma irradiated and stored. The activity of alpha-amylase in the rice grains, germination rate of the rice grains and rice insect fertility were studied. Among them, the following factors were considered as the main results. The germination of rice grains was reduced considerably with the irradiated samples exposed to a gamma dose over 50 Kr Gamma irradiation could reduce the contaminated microorganisms remarkably as the gamma dose was raised over 100 Kr, *e. g.,* reduction of the survivals of microorganisms to 19.62 – 39.76 % with 100 Kr to 5.41- 9.09 % with 300 Kr to 0.58-0.81 % with 1 Mrad during the twelve months storage period. Some fluctuations of reducing sugars in the irradiated rice grains were observed in the period of twelve months preservation at 20-30^{0}C. No deleterious effects on rice insect fertility on the irradiated rice grains with a 50 Kr gamma dose occurred during the twenty-four months storage period, unlike those of the non-irradiated ones and the irradiated ones with gamma doses below 30 Kr

As per Lin (1988), germination percentage decreased significantly with increasing length of storage. Loss of seed vigour paralleled the loss of seed germination. Loss of vigour was more rapid than loss of viability. Leakage of electrolytes was highly correlated with seed vigour and germination. Seed moisture content increased during storage, possibly indicating that membrane deterioration under high seed moisture content was involved in the loss of vigour and viability during storage.

Basavarajappa *et al.* (1991) reported reduction in total carbohydrate and reducing sugar during ageing of the seeds. He attributed this decline to respiratory utilization of carbohydrates for energy purposes or due to an increase in amylase activity. He also attributed the decline in protein content during storage to the process of denaturation. Further, increase in scavenging enzymes like peroxidase activity was thought to be one of biochemical changes involved with low doses of gamma irradiation (Croci *et al*., 1991).

In similar studies, Kalpana and Rao (1991) reported that seed deterioration as a result of ageing results in the loss of capacity to germinate and vigour during

storage under ambient conditions which is usually due to alterations in cellular physiology of seeds, fluctuation in moisture content, changes in biochemical composition and increased leaching of electrolytes and other low molecular weight substances during imbibitions.

Gamma exposure can be availed in solving various agricultural problems: reduction of post-harvest losses through suppressing sprouting and contamination eradication or control of insect pests, reduction of food-borne diseases and in extension of shelf life (Emovon, 1996).

The biological effect of gamma rays is based on the interaction with atoms or molecules in the cell, particularly water, to produce free radicals (Kovacs and Keresztes, 2002). These radicals can damage or modify important components of plant cells and have been reported to affect differentially the morphology, anatomy, biochemistry and physiology of plants depending on the radiation dose (Ashraf *et al*., 2003).

Gamma rays belongs to ionizing radiation and are the most energetic form of such electromagnetic radiation, having the energy level from around 10 kilo electron volts (keV) to several hundred keV. Therefore, they are more penetrating than other types of radiation such as alpha and beta rays (Kovacs and Keresztes, 2002). In comparison with other physical modification methods, such as microwave, UV, ultrahigh hydrostatic pressure and hydrothermal treatment, irradiation treatment is rapid, convenient and more extensive because ionizing energy penetrates through the polysaccharide granule rapidly (Bao *et al*., 2005).

Maity *et al*. (2009) treated the seed grains of *O. sativa* (L). *cv.* 2233 with different doses of gamma radiation (*i.e.*1,2,3,4,5 and 6 KGy) and the seed samples were stored for 12 months at room temperature in a gamma sterile air-tight polythene bag (both non-irradiated and irradiated seeds were preserved in the same condition). The percentage of seed germination and fungi were examined for both groups of samples (exposed and non-exposed) at just after gamma treatment and after specific interval of 1.5, 3, 4.5, 6, 7.5, 9 and 12 months. The germination percentage of *O. sativacv.* 2233 remained unchanged just after gamma irradiation within dose range of 1-5 KGy whereas, only 10 % loss was noticed at 6 KGy. However, the germination percentage was noted to be lost significantly (pp0.05) with the increase in storage time in case of control seeds and irradiated seeds at 1,

5 and 6 KGy. Such depletion in germination potential was noted in control sample from 1.5 month but in case of irradiated seeds such depletion was found to differ in time scale. Seeds irradiated at 1 and 5 KGy showed depletion of germination potential from 6 and 4.5 months, respectively. However, the germination potential of seeds irradiated at 6 KGy was found to decrease from 3 months storage time. The loss of germination of seeds irradiated at 1, 5 and 6 KGy after 12 months storage exhibited 23 %, 30 % and 75 %, respectively. No change in germination potential was noted in case of seeds irradiated in the dose range of 2-4 KGy when studied after the same time period of 12 months. Effects of gamma irradiation on seed viability clearly indicated that gamma irradiation did not hamper germination efficiency within the dose range of 2- 4 KGy up to 12 months storage. It was observed that the germination of seed decreased with increasing storage time due to drastic increase in infection of fungi. After 1.5 month at 3 KGy whereas, germination efficiency of treated seed remained unchanged. Interestingly, the germination efficiency decreased from 3 months storage seed at 1 KGy and immediately after irradiation at 5 and 6 KGy, respectively. The doses range of 2- 4 KGy could be the most effective to keep the seed viabilities for long storage.

Yu and Wang (2010) observed the trend of the differences with the germination rates of the irradiated rough rice, at varying irradiation doses (0 KGy, 2 KGy,5 KGy, 8 KGy, and 10 KGy) and storage time (0, 1, 1.5, and 2 years). The germination tests were carried out after storage for 0 (non-stored), 1, 1.5 and 2 years. The 2 KGy irradiated rough rice had a higher vigour after 1.5 year storage. The germination rates of the 5 KGy and the 8 KGy irradiated rough rice samples increased with the increasing storage time because of the increasing life activity. The change of life activity for the irradiated rough rice at different storage time may be due to the interaction between the self-repair function which increases the life activity and the respiration which decreases the life activity of the irradiated organism. The life activity of the rough rice decreased evidently after irradiation and increased to a higher level after 1.5 years and 2 years of storage respectively due to the self-repair during storage. The germination rates of the 10 KGy irradiated rough rice sample were all very low during storage, After 0 and 1 year of storage, the high germination rates (>75%) appeared for the non-irradiated rough rice because of its higher life activity, but the germination rate was very low when the dose was higher than 2 KGy due to the low life activity. This is because of the

effect of irradiation on rice embryo that the embryo is damaged by γ-ray. After one year storage, the self-repair function of the irradiated rough rice did not show. After 1.5 and 2 years of storage, the higher germination rates of the rough rice appeared at 2 KGy and 5 KGy, respectively. It was because that the self-repair of rough rice sample occurred with the increasing storage time and had a higher degree at 2 KGy and 5 KGy after 1.5 and 2 years of storage respectively.

Wang and Yu (2011) reported on the long-term germination characteristics of irradiated rice variety Zhenong 1, at 0, 2, 5, 8 and 10 KGy. The first set of germination tests were conducted immediately and the other set of tests were done at two months intervals up to two years. The results showed that the germination rate of samples irradiated at 2 and 5 KGy have increased to about 90 % at 18^{th} month and 85 % at 24^{th} month, respectively as against 79 % and 70 % in non-irradiated rice sample. After long-term storage, germination rates of some irradiated samples were higher than that of non-irradiated rice sample. After 22 months of storage, the germination rates of irradiated rice at 2 and 5 KGy were 86 % and 84 % respectively which were higher than that of non-irradiated sample (73 %). These changes in germination rates of irradiated samples might be due to the self-repair of irradiated organism. For the 2 KGy irradiated rice sample, with the increasing storage time i.e. from 14 to 18 months, the peak value of germinated seeds increased and the time needed to reach the peak value decreased. The result showed that the germination per cent was increased with the increase in irradiation doses in long term storage.

Chaturvedi *et al.* (2012) while working on the effect of gamma irradiation on germination of rice indicated that storage period in combination with higher doses of gamma radiation had not only resulted in drastic reduction in germination percentage but also prolonged the period for completion of the germination process which has finally resulted in lower germination value that is important from field point of view.

Chapter III

MATERIAL AND METHODS

Chapter III

MATERIAL AND METHODS

The present study entitled “Effect of gamma irradiation on seed quality, insect infestation and fungal infection in sorghum (*Sorghum bicolor* L. Moench)”was carried out at Dept. of Seed Science & Technology, PJTSAU and Indian Institute of Millet Research (IIMR), Rajendranagar, during 2015-2016. The details of experimental material used and methods employed during the course of the present study are given below.

3.1 MATERIAL

3.1.1 Crop variety

Breeder seed of sorghum varieties viz., CSV 29R (*Rabi* variety), C 43 (*Kharif* parental line), and CSH 14(*Kharif* hybrid)were used for the experimental purpose, which was procured from Indian Institute of Millets Research, Rajendranagar.

3. 1. 2 Gamma Chamber

Gamma chamber 5000 (Figure 3.1) was used for giving radiation treatments. It is compact shelf shielded ^{60}Co gamma irradiator providing an irradiation volume of approximately 5000cc. The material for irradiation was placed in an irradiation chamber located in vertical drawer inside the Lead flask. This drawer can be moved up and down with the help of a system of motorized drive, which enables precise positioning of the irradiation chamber at the centre of the irradiation field. Radiation field was provided with service sleeves for grasses, thermocouple, etc. Mechanism for rotating / stirring samples during irradiation is also incorporated. The Lead shield provided around the source was adequate to keep the external radiation field well within permissible limits.

The quantity absorbed radiation dose (KGy) can be defined as the amount of energy absorbed per unit mass of the matter at the point of interest.

1 Gy = 100 rads

1KGy= 1000Gy

Figure 3.1. Gamma Radiation Chamber 5000

3.1.3 Gamma radiation

Seeds of sorghum variety *viz.,* CSV 29R, C 43 and CSH 14 weighing 400 g for each treatment was packed in HDPE bag (400 gauge) was exposed to selected doses of gamma radiation in GC 5000 radiation chamber with ^{60}COsource having 1.96 KGy hr^{-1} dose rate.

3.1.4 Treatments

The details of treatments are depicted below.

Gamma dose: T0 = Control, T1 = 250 Gy, T2 = 500 Gy, T3 =750 Gy, T4 = 1000 Gy andT5= 2000 Gy

Varieties: CSH 14, C 43 and CSV 29R

Interactions:

1. CSH 14/0 Gy	7. C 43/0 Gy	13. CSV 29R/0 Gy
2. CSH 14/250 Gy	8. C 43/250 Gy	14. CSV 29R/250 Gy
3. CSH 14/500 Gy	9. C 43/500 Gy	15. CSV 29R/500 Gy
4. CSH 14/750 Gy	10. C 43/750 Gy	16. CSV 29R/750 Gy
5. CSH 14/1000 Gy	11. C 43/1000 Gy	17. CSV 29R/1000 Gy
6. CSH 14/2000 Gy	12. C 43/2000 Gy	18. CSV 29R/2000 Gy

3.2 METHODS

Initial data on seed quality was generated immediately after irradiation during 1st month and four periodical observations at bi-monthly intervals on storability parameters were generated during 3rd, 5th, 7th and 9th month for a period of nine months after storage and the changes during storage were recorded with respect to following parameters.

3.2.1 Germination (%)

Germination test was conducted on pure seed fraction using 100 seeds in four replicates following between paper (BP) method at 25^{0}C temperature and 93$\pm$2 per cent relative humidity (ISTA, 2005). The germinated of normal seedlings were counted on 4th day (first count) and 10th day (final count) of germination from all the replications. The germination per cent was calculated based on the number of normal seedlings produced.

$$\textbf{Germination (\%)} = \frac{\textbf{Number of seeds germinated}}{\textbf{Total number of seeds kept for germination}} \times 100$$

3.2.2 Field emergence (%)

Field emergence potential of seeds from each treatment was measure as per the method suggested by Shenoy *et al.* (1990). Four hundred seeds in each treatment were sown in four replications of hundred seeds each on raised bed (4 x 1 m) of red loamy soil with a spacing of 10 cm between the rows. The number of seeds germinated in each row was calculated on 10^{th} day and field emergence (%) was computed using the following formula,

$$\textbf{Field emergence (\%)} = \frac{\textbf{Number of seeds germinated}}{\textbf{Total number of seeds sown}} \textbf{x100}$$

3.2.3 Speed of germination

Germination test was conducted in four replicates of 100 seeds each by adopting top paper method at 25^0C temperature and 93$\pm$2 per cent relative humidity. Daily germination counts were performed until no further germination was observed. An index of the speed of germination was then calculated by adding the quotients of the daily counts divided by the number of days of germination (Maguire, 1962).

Speed of germination = $\sum$ (n/t)

Where, n = Number of seeds newly germinating at time‘t’

t = Days from sowing

3.2.4 Root length (cm)

Ten normal seedlings were selected at random from each replication on the 10^{th} day (final count) from germination test and used for measuring root length. The root length measured between collar region and tip of the primary root. The mean root lengths were expressed in centimeters.

3.2.5 Shoot length (cm)

Ten normal seedlings were selected at random from each replication on the 10^{th} day (final count) from germination test and used for measuring shoot length. The shoot length was measured from the collar region to the tip of the apical bud. The mean shoot length was expressed in centimeters.

3.2.6 Seedling vigour index

Vigour index of the seedlings obtained from the germination test was calculated using the formula suggested by Abdul-Baki and Anderson (1973).

Seedling vigour index= Percentage of seed germination x Mean seedling length ()

(cm)

3.2.7 Electrical conductivity of seed (µs cm^{-1})

Electrical conductivity of seed leachate was estimated as described by Presley (1958). Four replications of 25 seeds from each treatment was drawn and pre-washed thoroughly with distilled water to remove the adhering chemicals and then soaked in 50 ml of distilled water for 16 h at room temperature. After soaking, the seed steep water was decanted to obtain the seed leachate. The electrical conductivity of the seed leachate was measured in a digital conductivity meter with a cell constant of one and expressed as µs cm^{-1}.

3.2.8 Seed moisture (%)

Moisture content of seed was determined as per ISTA rules (ISTA, 2005). Five grams of seed was weighed, ground and put in aluminum cups. The aluminum cups along with ground seed material was dried in hot air oven maintained at 130 $\pm$ 1^0C temperature for two hours. The moisture content was determined on dry weight basis using the following formula

$$\textbf{Moisture content (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where, W_1 - Weight of empty container with its cover

W_2 - Weight of container with its cover and ground seeds before drying

W_3 - Weight of container with its cover and ground seeds after drying.

Figure: 3.2. Evaluation of speed of germination

Figure: 3.3. Measurement on Seedling length

3.2.9 Dehydrogenase enzyme activity (µg)

Dehydrogenase enzyme activity was determined as described by Kittock and Law (1968) using 2,3,5-triphenyl tetrazolium chloride solution at 0.1 per cent concentration prepared by using Sorenson's buffer solution as solvent. Five seeds from each treatment were taken randomly and preconditioned by soaking in water for 7 h. Seeds were steeped in tetrazolium solution and kept in dark for 2h at 40 ^{0}C for staining. After staining, the excess solution was drained and the seeds were washed thoroughly with distilled water and transferred to a test tube containing 10 ml of 2-methoxy ethanol (methyl cellosolve). The test was closed air tight and allowed to remain in the incubator in darkness overnight for extracting the red coloured formazon. The coloured solution was decanted and the colour intensity (Fig: 3.3) was measured in an optima UV-VIS spectrophotometer using blue filter (470 nm) and methyl cellosolve as the blank. The dehydrogenase activity was expressed as OD value or µg per 5 seeds per 10 ml.

3.2.10 α- amylase activity [diameter in millimeter (mm)]

The α-amylase activity was analyzed as per method suggested by Simpson and Naylor (1962). Two gram of agar shreds and one gram of potato starch was mixed together in water to form paste and the volume was made up to 100 ml with distilled water. The homogenous solution of agar- starch mixture after boiling was poured into sterilized petri dishes and allowed to settle in the form of gel after cooling. The presoaked (for 8 hours) and half cut seeds (with their half endosperm and embryo portion intact) were placed in the petri dishes in such a way that the endospermic part remained in contact with agar starch gel. The petri dishes were closed and kept in dark at 30^{0}C. After 24 hours the petri dishes were uniformly smeared with potassium iodide solution (0.44 g of iodine crystal + 20.008 g potassium iodide in 500 ml distilled water) and excess solution was drained off after few minutes. The diameter of halo (clear) zone formed around the seed was measured in mile meter and reported as α- amylase activity.

3.2.11 Insect infestation (%)

During storage period of nine month, periodical observation on pest incidence ware recorded in termsof damaged seeds. Observations were recorded at initial and bimonthly intervals from the seeds of all treatments stored in HDPE bags under ambient conditions. During each periodical observed, 50 g of seeds

were drawn from each treatment separately. The seeds were observed for damage caused by storage pest. The percentages of damaged seeds were worked out using the following formula.

$$\textbf{Insect infestation (\%)} = \frac{\text{Total no. of damaged seeds}}{\text{Total no. of seeds observed}} \times 100$$

Note: no data was reported in case of absence of any pest damage.

3.2.12Fungal invasion (%)

During storage period of nine month, periodical observations on pathogen infectivity were recorded in terms of infected seed. Observations were recorded at initial and bimonthly intervals form the seed of all treatments stored in HDPE bags under ambient conditions. Pathogen infectivity in seed sample was determined by using standard blotter method. Discs of blotting paper (90 cm diameter) were dipped in sterile distilled water and placed in Petri plates of same diameter and 25 seeds of each sample were placed equidistantly using forceps (Figure: 3.5). These plates were labeled and kept in incubator at $25+1^0$C for seven days and the infected seeds were counted. Percentages of total infected seeds were calculated for each sample in all the three replication.

$$\textbf{Fungal infectivity (\%)} = \frac{\text{Total no. of infected seed}}{\text{Total no. of seeds kept for germination}} \times 100$$

3.2.13 Starch content of seed (%)

Starch was estimated by enzymatic procedure, as reported by Southgate (1976).

Reagents

1. Ethyl alcohol
2. 2 M Sodium acetate buffer, PH 4.8
3. Enzyme – Amyloglucosidase
4. Phenol (5% w/v)
5. Conc. Sulphuric acid.

Principle

Starch comprising of amylose and amylopectin, on hydrolysis by amyloglucosidase enzyme results in the release of maltose and finally glycols. The

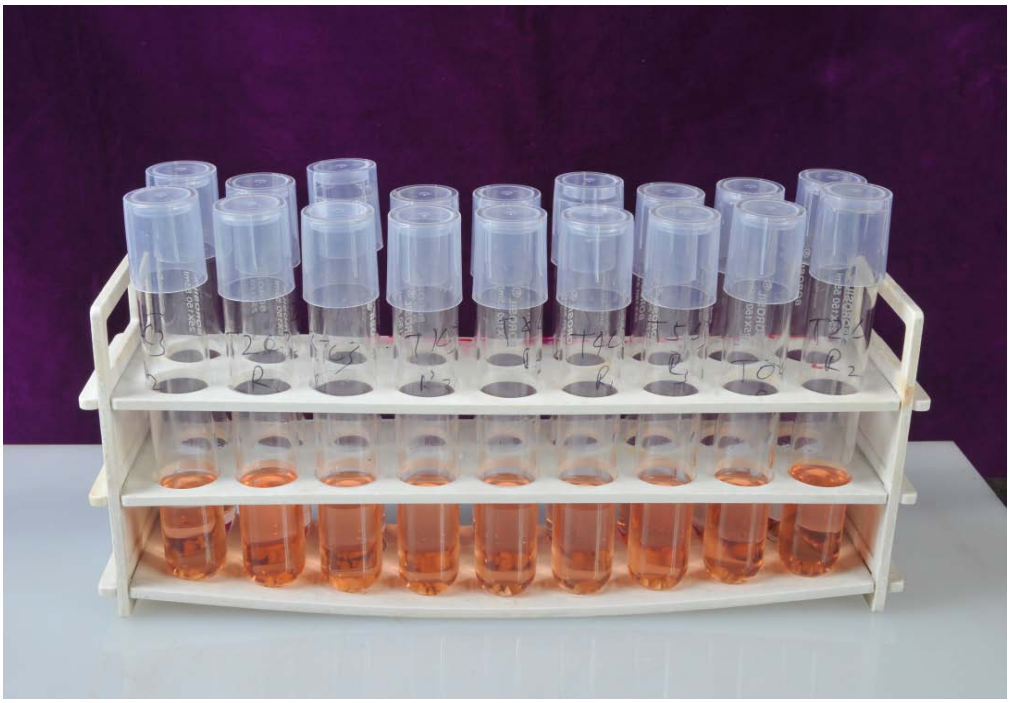

Figure:3.4. Seed samples for estimation of Dehydrogenase

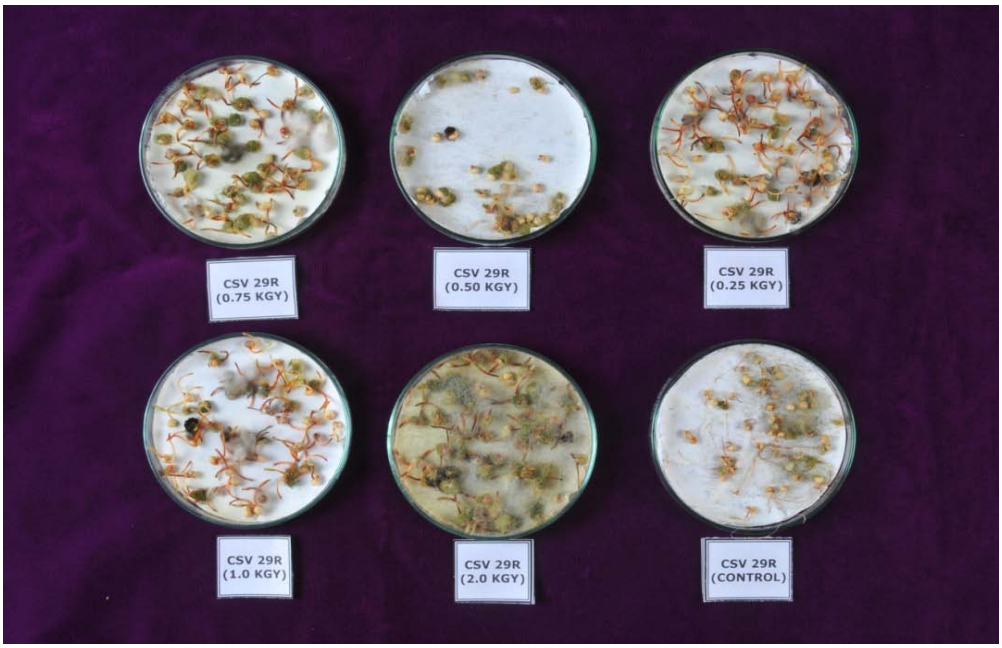

Figure: 3.5 Germinated seeds showing fungal invasion.

sugars thus obtained react with sulphuric acid to form furfural and its derivatives which inturn react with phenol reagent to form colored complexes.

Procedure

Sorghum grain sample flour (75mg) was taken in a 50ml Erlenmayer flask and flour was dispersed with few drops of ethanol. Quartz distilled water (10ml) was added and flasks were covered with aluminium foil. Then the contents were autoclaved for 90 minutes at 19 lbs pressure (126^0C). After cooling, 1 ml of 2 M sodium acetate buffer, 25 mg of amyloglucosidase and 15 ml of quartz distilled water were added. After sealing the flask with parafilm the contents were incubated at 55^0 C for 2 hours in a waterbath shaker (Heto, Germany) for hydrolysis.

After the incubation, volume was made upto 250 ml with quartz distilled water. An aliquot of 10 ml was taken and diluted to 100 ml. To 1 ml of the aliquot 1 ml of 5% phenol and 5 ml 96% sulphuric acid were added slowly and vortexed. After cooling the tubes, absorbance was read at 490 nm against the blank using a UV-VIS spectrophotometer (Thermo, USA). A reagent blank (water, phenol + acid) was also run. Glucose in the range of 10 µg – 50 µg was used as a reference standard.

The following equation was used to calculate the distribution factor.

$$\text{Distribution factor} = \frac{\text{Concentration of the standard (µg)}}{\text{Absorbance of standard}} \times \frac{\text{1 (conversion for g)}}{\text{1000,000}}$$

$$\times \frac{\text{250 ml (sample dilution)}}{\text{1 ml (taken for color development)}} \times \frac{100}{10} \times \frac{\text{100 (percent)}}{\text{0.075 g (sample weight)}} \times 0.9$$

*0.9 is the conversion factor for sugars.

Percent starch = distribution factor X absorbance of the sample volume taken (1 ml)

3.2.14 Protein content of seed (%)

Protein content was estimated by using colorimetric determination of total kjeldhal nitrogen using salicylate (Willis *et al*, 1996).

Principle

Protein content present in the sample is digested with acid and is converted to ammonia also called total kjeldhal nitrogen. The total kjeldhal nitrogen is colorimetrically quantified by salicylate nitro prusside reagent. Total kjeldhal nitrogen reacts with salicylate-nitroprusside reagent to form a green coloured complex and the absorbance is read at 685 nm. The amount of protein is calculated by multiplying the amout of nitrogen obtained with a factor of 6.25 (N x 6.25).

Reagents

1. Salicylate: - Using mild heat, 32 g of sodium salicylate, 40 g of Tri-sodium phosphate and 0.5 g of sodium nitroprusside were dissolved and made upto one litre of quartz distilled water.
2. Hypochlorite Reagent: - Analytical grade sodium hypochlorite (50 ml) was added to quartz distilled water (1 litre). This reagent should be protected from light and freshly made.
3. Nitrogen standard: - Ammonium chloride was used as a reference standard with a concentration range of 1-20 µg ml^{-1} (nitrogen).

Procedure

Digestion of sample:

For block digestion, a 12 tube block digestor (Gerhardt, Germany) was used. Defatted grain sorghum sample flour (100 mg) accurately weighed (Mettler balance, Austria) into a digestion tube to which 2 ml of concentrated sulphuric acid and 1 digestion tablet containing 3.5 g potassium sulphate and 35 mg Selenium were added. The mixture was digested for one hour at 425^0 C. After digestion the reaction mixture was cooled and made upto 100 ml with quartz distilled water.

Colorimetry

An aliquot (200 µl) was taken for colour development and make to 10 ml with quartz distilled water. To this 4 ml of salicylate reagent and 1 ml of hypochlorite reagent were added. After twelve minutes of incubation absorbance was read at 685 nm using a UV-VIS spectrophotometer. (Thermo, USA). Ammonium chloride (1-20 µg ml^{-1}) was used as a reference standard. Milligrams

nitrogen present in the sample was calculated with the standard curve and percent protein was calculated by multiplying with a factor of 6.25 (N x 6.25).

3.2.15 Fat content of seed (%)

Mature grains were ground on a UDY mill (Tecator, Sweden) to a fine powder of 0.4 mm particle size, and it was subjected to defatting by soxhlet procedure. (AOAC, 1995)

Principle:

Fat was extracted in a soxhlet apparatus (Borosil, India) using n-hexane as a solvent.

Reagents: n-Hexane.

Procedure:

Three grams of the finely powdered sample was packed in whatman No.2 filter paper thimble. The thimble was placed into the soxhlet extraction flask and the apparatus was assembled. Hexane (170 ml) was poured till ¾ of the extraction flask. Then it was heated on an electric heating mantle at such a rate that the solvent flows atleast 150 drops per min. The solvent was allowed to flow on the thimble. Extraction was continued for 6 to 8 hours. After the extraction the thimble was dried in an oven at 70^0C for half an hour and then the sample was used for the subsequent chemical analysis.

Estimation of fat

The contents of the extraction flask were transferred into a beaker (250 ml), previously weighed with repeated washings of n-hexane. The hexane was evaporated on a hot sand bath. The beaker was dried in an oven at 105^0C for 30 minutes to evaporate the traces of hexane and moisture. After cooling the beaker, it was desiccated and later the contents were weighed.

Calculation of fat (%):

$$\text{Fat (\%)} = \frac{(A - B) \times 100}{C}$$

[Weight of the beaker + oil = A; Weight of the beaker =B
Weight of the sample = C; Weight of the fat = A-B]

3.2.16 Ash content of seed (%)

The samples were ignited at 600 ^{0}C to burn off all organic material. The organic material which does not volatilize at the temperature is called ash.

Procedure:

Set the temperature of the muffle furnace to 600 ^{0}C and heated crucibles for 1 h and transfer into a dissector, cooled them to room temperature and weigh (W1). Weighed 2 g sample (defatted) into the crucible of known weight (W2). Incinerate the sample at 600 ^{0}C for about 2 h. transferred the crucible into the desicator and cooled them to room temperature and weighed (W3). Weighed immediately to prevent moisture absorption. Repeated the incineration until content weight was obtained. Saved the sample for mineral determinations,as needed.

Calculation of Ash :

Weight of the sample taken = W2-W1
Weight of the ash obtained = W3-W1

$$\textbf{Ash (\%)} = \frac{(W3-W1) \times 100}{(W2-W1)}$$

Figure 3.6: Plates showing ash content of seed

3.4 Statistical analysis

The data generated were subjected to analysis of variance as per factorial experiment laid out in completely randomized design to test the significance of various treatments evaluated in the experiment as per Gomez and Gomez (1984).

Table 3.1. Analysis of Variance for the Two-Factor Experiment with '*N*' Replications for Seed Quality immediately after gamma exposure

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed *f*
Main effect:				
A	SSA	$a-1$	$s_1^2 = \frac{SSA}{a-1}$	$f_1 = \frac{s_1^2}{s^2}$
B	SSB	$b-1$	$s_2^2 = \frac{SSB}{b-1}$	$f_2 = \frac{s_2^2}{s^2}$
Two-factor interactions:				
AB	$SS(AB)$	$(a-1)(b-1)$	$s_3^2 = \frac{SS(AB)}{(a-1)(b-1)}$	$f_3 = \frac{s_3^2}{s^2}$
Error	SSE	$ab(n-1)$	$s^2 = \frac{SSE}{ab(n-1)}$	
Total	SST	$abn-1$		

Table 3.2. ANOVA for the Three-Factor Experiment with '*N* replications for Seed quality during storage

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed *f*
Main effect:				
A	SSA	$a-1$	s_1^2	$f_1 = \frac{s_1^2}{s^2}$
B	SSB	$b-1$	s_2^2	$f_2 = \frac{s_2^2}{s^2}$
C	SSC	$c-1$	s_3^2	$f_3 = \frac{s_3^2}{s^2}$
Two-factor interaction:				
AB	$SS(AB)$	$(a-1)(b-1)$	s_4^2	$f_4 = \frac{s_4^2}{s^2}$
AC	$SS(AC)$	$(a-1)(c-1)$	s_5^2	$f_5 = \frac{s_5^2}{s^2}$
BC	$SS(BC)$	$(b-1)(c-1)$	s_6^2	$f_6 = \frac{s_6^2}{s^2}$
Three-factor interaction:				
ABC	$SS(ABC)$	$(a-1)(b-1)(c-1)$	s_7^2	$f_7 = \frac{s_7^2}{s^2}$
Error	SSE	$abc(n-1)$	s^2	
Total	SST	$abcn-1$		

Chapter IV

RESULTS AND DISCUSSION

Chapter IV

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In tropical regions of sorghum cultivation, major part of harvested sorghum seed is stored traditionally on farms or in villages by the farmers, thus reducing the prospects of reasonably long period of storage without losing seed quality attributes. The qualitative loss in stored seed is attributed to degradation of bio-chemical components such as carbohydrates, starch and proteins, apart from being attacked by various storage biotic stresses. These predisposing conditions have made the storage aspect of jowar seed as an emerging challenge necessitating designing cost effective and efficient storage protocols.

The prevailing trend of access to farm resources, cropping intensity and market demands warrants availability of quality seed during recommended cropping season at right time and in right quantity. Commercially viable seed production strategies ably supported by cost effective and environmentally safe seed storage methodologies are the need of the hour. Utilisation of sub lethal doses of ionising gamma radiation to extend seed storability without interfering with the seed quality is being contemplated in recent times to explore the benefits of chronic radiation exposure in a controlled manner. The effectiveness of gamma radiation in extending the shelf life of biological material is well documented. In the present study GC 5000 gamma irradiator was employed to administer selective sub lethal doses for further evaluation.

The present study was conducted with 18 treatments arranged in factorial completely randomized design to understand and quantify the influence of six gamma radiation doses including control on three sorghum variety *i.e.* CSH 14, C 43 and CSV 29R with varying grain types and their interaction on seed quality parameters immediately after irradiating in the 1^{st} month. Storage studies at bimonthly intervals were carried out at 3^{rd}, 5^{th}, 7^{th} and 9^{th} months to ascertain the influence of storage period in combination with gamma radiation doses and varieties on seed quality. Data on treatment wise storability parameters was generated periodically from the sorghum seed stored in HDPE bag (700 gauge) under ambient conditions. The ambient temperature and the relative humidity prevailed during the storage period starting from October, 2015 to June, 2016. The temperature and moisture content of stored grain in the packaging

Table 4.1. Mean values for seed quality parameters immediately after gamma exposure

Variety x Dosage	Germination (%)	Speed of Germination	Root Length (cm)	Shoot Length (cm)	Seedling vigour index	Field emergence (%)	Electrical conductivity ((µS cm^{-1})	Dehydrogenase activity (µg)	Moisture (%)
CSH 14 : 0 Gy	87**	44.2**	14.3**	15.8**	1343**	75**	33.0	0.16	9.2
CSH 14 : 250 Gy	81	43.3**	4.8	5.8	441	65**	43.0	0.17	9.2
CSH 14 : 500 Gy	88**	45.3**	11.0**	11.5**	1001**	73**	52.4**	0.18	9.2
CSH 14 : 750 Gy	86	44.5**	9.0**	10.5**	894**	71**	45.6	0.17	9.2
CSH 14 : 1000 Gy	76	39.7	2.8	3.5	268	34	48.5	0.16	9.2
CSH 14 : 2000 Gy	71	30.7	1.7	2.5	161	18	41.2	0.15	9.1
C 43 : 0 Gy	89**	42.7**	14.3**	14.8**	1272**	79**	40.5	0.17	9.3**
C 43 : 250 Gy	85	35.3	4.7	5.5	470	66**	46.5	0.16	9.3**
C 43 : 500 Gy	89**	41.9**	9.3**	10.8**	954**	76**	55.4**	0.19**	9.2
C 43 : 750 Gy	87**	40.4	8.5**	9.3**	803**	74**	49.1	0.18	9.2
C 43 : 1000 Gy	80	33.7	2.5	2.5	198	38	42.4	0.16	9.2
C 43 : 2000 Gy	77	31.8	1.9	2.3	178	20	60.3**	0.14	9.1
CSV 29R : 0 Gy	90**	41.2**	15.3**	15.4**	1396**	82**	42.8	0.21**	9.2
CSV 29R : 250 Gy	85	37.8	7.1	7.8	674	68*	32.5	0.21**	9.2
CSV 29R : 500 Gy	90**	42.4**	13.5**	15.4**	1386**	80**	34.3	0.23**	9.2
CSV 29R : 750 Gy	88**	41.7**	12.8**	14.8**	1309**	77**	50.7**	0.22**	9.2
CSV 29R : 1000 Gy	81	38.9	3.6	3.7	302	43	53.4**	0.18	9.1
CSV 29R : 2000 Gy	78	35.9	2.8	2.7	217	22	55.8**	0.15	9.1
General Mean	**83**	**39.3**	**7.6**	**8.7**	**737**	**59**	**47.9**	**0.18**	**9.1**
CV %	2.019	2.062	3.679	3.172	3.531	3.541	2.570	2.802	0.639
SEm±	0.841	0.406	0.107	0.134	13.015	1.038	0.606	0.002	0.029
C.D. 5%	2.388	1.151	0.303	0.381	36.895	2.943	1.719	0.007	0.083
C.D. 1%	3.180	1.533	0.403	0.507	49.135	3.919	2.289	0.009	0.111

** **Significant at 1% level**

Table 4.2. Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Germination (%)				Speed of germination				Root length (cm)			
	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	81	69	63	59	40.9**	32.6**	29.8**	25.6**	13.5**	12.8**	9.6**	8.5**
CSH 14 : 250 Gy	78	75	66	62	41.4**	33.7**	26.7	24.1**	4.6	3.4	2.8	2.5
CSH 14 : 500 Gy	81	77**	70**	66**	44.8**	38.3**	32.5**	30.6**	10.5**	9.8**	7.9**	7.3**
CSH 14 : 750 Gy	79	76	67	64	43.3**	37.8**	31.8**	29.4**	9.5*	8.8**	7.6**	7.8**
CSH 14 : 1000 Gy	73	71	65	61	36.4	31.5	24.3	21.9	2.5	1.7	1.2	0.9
CSH 14 : 2000 Gy	66	63	59	49	29.6	28.6	24.6	21.5	1.3	1.3	0.4	0.4
C 43 : 0 Gy	83**	71	63	60	37.4	30.8	26.6	20.8	14.8**	12.6**	9.6**	9.9**
C 43 : 250 Gy	79	76	67	62	33.8	28.7	24.7	21.7	5.5	4.3	3.8	2.5
C 43 : 500 Gy	84**	78**	72**	68**	40.8**	34.3**	29.5**	26.4**	9.7**	7.9**	7.7**	6.5**
C 43 : 750 Gy	82**	77**	69	66**	39.5**	33.7**	28.6**	24.7**	8.8**	6.7**	6.3**	5.5**
C 43 : 1000 Gy	75	72	67	63	32.7	28.9	24.4	22.3	1.8	1.8	1.3	0.9
C 43 : 2000 Gy	66	65	60	52	30.7	27.8	21.7	18.7	1.7	1.3	0.8	0.8
CSV 29R : 0 Gy	83**	74	66	62	37.3	27.9	25.7	20.5	14.5**	12.8**	10.8**	9.4**
CSV 29R : 250 Gy	81	77**	69	63	35.2	26.9	22.8	19.9	6.5	5.7	5.5	4.3
CSV 29R : 500 Gy	85**	80**	71**	70**	41.4**	37.9**	25.5	23.9	13.7**	11.8**	10.8**	9.5**
CSV 29R : 750 Gy	82**	77**	69	68**	40.9**	36.8**	24.6	22.3	13.5**	10.3**	9.8**	8.8**
CSV 29R : 1000 Gy	78	73	66	64	36.7	23.9	21.6	18.9	2.8	2.8	1.8	1.5
CSV 29R : 2000 Gy	67	65	63	54	32.7	20.9	21.3	18.7	1.8	1.6	1.5	1.3
General Mean	**78**	**73**	**66**	**62**	**37.4**	**30.9**	**25.8**	**22.1**	**7.5**	**6.3**	**5.3**	**4.8**
SEm±	0.935	0.921	0.899	0.903	0.474	0.357	0.398	0.325	0.107	0.082	0.095	0.075
CV %	2.406	2.525	2.718	2.928	2.533	2.303	3.075	2.845	2.848	2.601	3.488	3.117
CD (5%)	2.652	2.611	2.548	2.559	1.343	1.011	1.128	0.920	0.303	0.233	0.268	0.214
CD (1%)	3.532	3.477	3.393	3.408	1.788	1.346	1.502	1.225	0.403	0.311	0.357	0.285

** **Significant at 1% level**

Table 4.2 (contd.) . Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Shoot length (cm)				Seedling Vigour Index I				Field emergence (%)			
	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	15.4**	12.6**	10.4**	8.8**	1267**	886**	661**	503**	74**	69**	62**	58**
CSH 14 : 250 Gy	4.8	4.8	3.8	2.8	346	314	255	175	63**	59**	53**	51**
CSH 14 : 500 Gy	10.6**	9.5**	9.5**	8.8**	868**	768**	649	569**	71**	68**	66**	63**
CSH 14 : 750 Gy	8.3	7.8	7.5	6.5**	673	567**	512**	411	69**	66**	64**	60**
CSH 14 : 1000 Gy	2.8	2.8	1.7	1.5	184	171	117	93	31	28	22	18
CSH 14 : 2000 Gy	1.8	1.3	1.6	1.3	123	108	95	63	17	16	14	14
C 43 : 0 Gy	13.8**	12.8**	10.5**	8.4**	1157**	927**	674**	518**	77**	72**	64**	59***
C 43 : 250 Gy	5.8	4.7	3.9	3.3	421	366	269	207	64**	61**	55**	52**
C 43 : 500 Gy	10.3**	10.3**	8.8**	7.9**	872**	798**	607**	541**	75**	71**	68**	67**
C 43 : 750 Gy	9.8**	7.8**	7.7**	6.7**	766**	603**	543**	447**	74**	69**	67**	64**
C 43 : 1000 Gy	2.8	1.9	1.5	1.8	187	140	104	93	36	31	27	22
C 43 : 2000 Gy	2.5	1.6	1.4	1.2	144	108	87	63	19	18	17	15
CSV 29R : 0 Gy	15.8**	13.7**	11.6**	9.5**	1307**	1026**	777**	601**	79**	73**	60**	57**
CSV 29R : 250 Gy	7.6	7.5	6.5	5.6	620	560	454	357	66**	63**	53**	52**
CSV 29R : 500 Gy	15.6**	13.6**	12.8**	10.8**	1332**	1093**	913**	759**	78**	73**	66**	65**
CSV 29R : 750 Gy	14.8**	12.5**	11.0**	8.5**	1231**	970**	763**	590**	76**	71**	64**	62**
CSV 29R : 1000 Gy	2.8	2.5	2.7	2.8	202	189	180	158	42	36	24	20
CSV 29R : 2000 Gy	2.0	2.3	2.8	2.3	156	153	157	127	20	18	15	13
General Mean	**8.6**	**7.8**	**6.8**	**5.9**	**659**	**542**	**434**	**349**	**57.2**	**53**	**48**	**45**
SEm±	0.171	0.135	0.120	0.124	17.117	11.379	10.431	10.546	0.929	1.071	0.979	0.840
CV %	4.240	3.763	3.747	4.579	5.197	4.203	4.804	6.049	3.251	4.017	4.096	3.739
CD (5%)	0.484	0.383	0.339	0.350	48.525	32.258	29.572	29.897	2.632	3.036	2.775	2.382
CD (1%)	0.645	0.510	0.452	0.466	64.622	42.960	39.382	39.815	3.506	4.043	3.696	3.172

** **Significant at 1% level**

Table 4.2(contd.). Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Electrical conductivity (µS cm^{-1})				Dehydrogenase Activity (µg)				Alfa Amylase activity (mm)			
	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	51.9	95.6	146.6	156.5	0.14	0.11	0.09	0.09**	6.05	5.70	5.15	4.58
CSH 14 : 250 Gy	41.5	81.5	118.8	127.0	0.15	0.11	0.08	0.07**	6.15	5.85	5.25	4.95
CSH 14 : 500 Gy	48.3	93.8	133.8	140.5	0.16	0.15**	0.11**	0.06	6.70**	6.35**	6.00**	5.78**
CSH 14 : 750 Gy	53.7	96.5	154.9**	159.5	0.16	0.14	0.10**	0.05	6.35**	6.00**	5.70**	5.33**
CSH 14 : 1000 Gy	57.8**	100.5	170.8**	430.5**	0.15	0.11	0.07	0.06	5.00	4.65	4.28	3.95
CSH 14 : 2000 Gy	59.5**	102.7**	184.7**	442.0**	0.13	0.10	0.07	0.07**	4.08	3.88	3.48	3.18
C 43 : 0 Gy	56.9**	106.7**	151.5**	145.7	0.15	0.12	0.07	0.09**	6.05	5.85	5.55	5.05
C 43 : 250 Gy	51.7	103.8**	124.0	124.7	0.16	0.14	0.09	0.08**	6.18	5.88	5.58	5.33**
C 43 : 500 Gy	53.3	105.6**	142.1	134.5	0.18**	0.16**	0.11**	0.06	6.98**	6.55**	6.23**	5.93**
C 43 : 750 Gy	57.7**	105.6**	165.7**	169.7	0.17**	0.15**	0.11**	0.06	6.73**	6.35**	5.90**	5.68**
C 43 : 1000 Gy	63.6**	112.8**	183.8**	443.5**	0.15	0.13	0.09	0.09**	5.33	5.08	4.70	4.30
C 43 : 2000 Gy	65.8**	114.7**	201.8**	446.2**	0.12	0.12	0.08	0.09**	4.38	4.08	3.65	3.33
CSV 29R : 0 Gy	48.5	91.9	116.6	135.5	0.19**	0.12	0.08	0.09	6.65**	6.35**	5.95	5.38**
CSV 29R : 250 Gy	36.3	87.3	105.2	132.0	0.18**	0.14	0.11**	0.06	7.03**	6.65**	6.23**	5.93**
CSV 29R : 500 Gy	36.9	89.6	106.7	135.7	0.22**	0.20**	0.15**	0.05	7.68**	7.30**	6.78**	6.45**
CSV 29R : 750 Gy	54.5	92.4	124.3	176.5	0.21**	0.19**	0.15**	0.05	7.38**	7.05**	6.50**	6.10**
CSV 29R : 1000 Gy	66.4**	96.1	138.9	428.7**	0.17	0.14	0.12**	0.09**	5.55	5.15	4.95	4.53
CSV 29R : 2000 Gy	68.4**	98.3	151.7**	432.7**	0.14	0.14	0.11**	0.07**	4.65	4.28	3.95	3.68
General Mean	**54.0**	**97.7**	**145.6**	**241.7**	**0.16**	**0.14**	**0.099**	**0.069**	**6.04**	**5.72**	**5.32**	**4.97**
SEm±	0.430	0.761	1.015	1.152	0.002	0.002	0.002	0.001	0.048	0.057	0.067	0.072
CV %	1.592	1.557	1.393	0.953	2.927	2.974	3.570	3.804	1.587	1.987	2.525	2.913
CD (5%)	1.219	2.158	2.876	3.266	0.007	0.006	0.005	0.004	0.136	0.161	0.190	0.205
CD (1%)	1.623	2.874	3.830	4.350	0.009	0.007	0.07	0.005	0.181	0.215	0.254	0.273

** **Significant at 1% level**

Table 4.2(contd.). Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Protein (%)		Starch (%)		Ash (%)		Fat (%)		Seed moisture (%)			
	2nd Bi-month	4th Bi-month	2nd Bi-month	4th Bi-month	2nd Bi-month	4th Bi-month	2nd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	11.4	8.35	64.72**	58.94	1.39	1.34	3.29	2.67	9.2	9.3	9.3	9.4**
CSH 14 : 250 Gy	11.8	10.59	63.02**	56.95	1.47	1.43	3.16	2.85	9.2	9.3	9.3	9.4**
CSH 14 : 500 Gy	11.6**	11.42**	64.40**	61.69**	1.72**	1.62**	3.35	3.31**	9.2	9.2	9.3	9.3
CSH 14 : 750 Gy	11.6**	11.10**	64.43**	60.99**	1.61	1.51**	3.27	3.21	9.2	9.2	9.3	9.4**
CSH 14 : 1000 Gy	11.1	10.43	57.93	56.69	1.37	1.26	2.98	2.73	9.2	9.2	9.2	9.3
CSH 14 : 2000 Gy	10.8	9.77	57.61	56.28	1.30	1.20	2.56	2.50	9.1	9.2	9.2	9.3
C 43 : 0 Gy	10.6	8.87	65.92**	60.00**	1.54	1.53**	3.41	3.05	9.3	9.4**	9.4**	9.4**
C 43 : 250 Gy	10.9	10.26	57.96	56.43	1.40	1.33	3.21	2.93	9.3	9.3	9.4**	9.4**
C 43 : 500 Gy	11.5**	11.17**	65.42**	62.69**	1.75**	1.67**	3.55**	3.21	9.3	9.3	9.3	9.4**
C 43 : 750 Gy	11.8	10.91	64.16**	62.26**	1.68**	1.67**	3.38	3.11	9.3	9.3	9.3	9.4**
C 43 : 1000 Gy	11.3	10.22	57.80	56.56	1.29	1.25	3.12	2.56	9.2	9.3	9.3	9.4**
C 43 : 2000 Gy	10.5	9.44	57.30	56.58	1.26	1.24	2.70	2.47	9.2	9.2	9.3	9.4**
CSV 29R : 0 Gy	10.7	9.77	64.19**	62.01	1.61	1.46	3.54	2.69	9.2	9.3	9.4	9.4**
CSV 29R : 250 Gy	10.5	10.21	62.33	61.09**	1.58	1.40	3.37	3.21**	9.2	9.3	9.3	9.4**
CSV 29R : 500 Gy	11.2	11.20**	65.46**	62.93**	1.70**	1.61**	3.71**	3.47**	9.2	9.2	9.3	9.3
CSV 29R : 750 Gy	11.09	10.88**	65.17**	62.69**	1.61	1.56**	3.61**	3.34**	9.2	9.3	9.3	9.4**
CSV 29R : 1000 Gy	10.52	10.15	60.35	59.36	1.46	1.41	3.29	2.91	9.2	9.2	9.3	9.3
CSV 29R : 2000 Gy	10.45	10.04	58.86	57.80	1.40	1.37	2.76	2.59	9.2	9.2	9.2	9.3
General Mean	**11.01**	**10.26**	**62.06**	**59.55**	**1.50**	**1.43**	**3.23**	**2.93**	**9.2**	**9.2**	**9.3**	**9.3**
SEm±	0.111	0.104	0.235	0.279	0.028	0.023	0.065	0.061 .185	0.042 0.247	0.018 4.043	0.010	0.015
CV %	2.014	2.033	0.757	0.938	3.688	3.203	4.043	4.172	0.920	0.388	0.219	0.316
CD (5%)	0.314	0.296	0.666	0.791	0.079	0.065	0.185	0.173	0.120	0.051	0.029	0.042
CD (1%)	0.419	0.394	0.887	1.054	0.105	0.087	0.247	0.231	0.160	0.068	0.038	0.056

** **Significant at 1% level**

Table 4.2(contd.). Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Fungal infection (%)				Insect infestation (%)			
	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	11.00**	12.00**	15.00**	16.50**	4.00**	5.00**	7.25**	11.25**
CSH 14 : 250 Gy	4.50	5.50	7.50	8.00	2.25	3.25	4.00	6.50
CSH 14 : 500 Gy	9.50	11.75**	13.00**	14.50**	2.75	3.00	3.50	5.50
CSH 14 : 750 Gy	7.00	8.50	9.25	10.25	1.00	1.50	2.25	4.25
CSH 14 : 1000 Gy	5.50	7.50	8.75	9.25	0.00	0.00	1.00	2.50
CSH 14 : 2000 Gy	1.50	2.00	3.75	4.75	0.00	0.00	0.00	1.75
C 43 : 0 Gy	12.25**	14.50**	17.00**	19.00**	2.50	3.25	5.50**	9.50**
C 43 : 250 Gy	6.50	7.25	8.75	9.50	2.25	2.75	3.50	5.50
C 43 : 500 Gy	11.75**	14.00**	14.75**	16.50**	1.50	2.00	2.25	4.50
C 43 : 750 Gy	9.25	10.50	10.75	11.50	1.00	1.50	2.00	3.75
C 43 : 1000 Gy	6.25	7.50	8.00	9.00	0.00	0.75	2.50	3.25
C 43 : 2000 Gy	2.75	3.00	4.50	6.00	0.00	0.00	0.00	2.50
CSV 29R : 0 Gy	14.75**	15.50**	19.50**	22.50**	6.00**	7.00**	13.50	19.25**
CSV 29R : 250 Gy	7.50	8.50	9.00	9.50	4.00**	5.00**	7.50**	10.50**
CSV 29R : 500 Gy	14.00**	17.00**	18.00**	19.50**	3.50**	4.00**	5.75**	8.00**
CSV 29R : 750 Gy	10.50**	12.50**	14.00**	14.75**	2.75	3.25	4.25	7.00
CSV 29R : 1000 Gy	8.50	9.50	10.50	11.50	0.00	1.75	3.25	4.75
CSV 29R : 2000 Gy	3.00	3.50	5.75	7.75	0.00	0.00	1.75	4.25
General Mean	**8.11**	**9.47**	**10.99**	**12.24**	**1.86**	**2.44**	**3.87**	**6.36**
SEm±	0.376	0.337	0.342	0.434	0.236	0.293	0.228	0.360
CV %	9.266	7.111	6.224	7.099	25.329	23.945	11.779	11.320
CD (5%)	1.065	0.955	0.969	1.231	0.668	0.830	0.647	1.021
CD (1%)	1.419	1.271	1.291	1.640	0.890	1.105	0.862	1.359

** **Significant at 1% level**

Table 4.3. Analysis of variance (Mean square) for seed quality parameters immediately after gamma exposure

Source of variance	df	Germination (%)	Speed of germination	Root length (cm)	Shoot length (cm)	Seedling Vigour Index	Moisture (%)	Electrical conductivity (µS cm^{-1})	Dehydrogenase Activity (µg)	Field emergence (%)
Varieties	2	97.54**	90.51**	25.34**	44.72**	380708.06**	0.01	389.13**	0.01**	225.38**
Dosages	5	349.29**	196.26**	311.68**	326.87**	2762359.75**	0.01**	555.62**	0.00**	7033.42**
Varieties x Dosages	10	3.91	19.58**	2.35**	5.78**	46078.54**	0.00	70.82**	0.00**	5.82
Error (B)	54	2.84	0.66	0.05	0.07	677.43	0.00	1.47	0.00	4.31
Total	71	30.05	19.63	23.03	25.15	212261.70	0.00	61.18	0.00	505.76

** **Significant at 1% level**

material varied with time because of changing weather conditions. The temperature was 31.9 ^{o}C in first month and then gradually increased during summer. The average relative humidity was 74.46 %. The results obtained are discussed under following heads:

4.1 Analysis of variance for seed quality parameters immediately after gamma exposure.

4.2 Influence of gamma radiation doses, varieties and their interactions on quality parameters of seed immediately after gamma exposure.

4.3 Analysis of variance for seed quality parameters under storage.

4.4 Influence of storage period, gamma radiation doses, varieties and their interaction on seed quality during storage period.

4.1 ANALYSIS OF VARIANCE FOR SEED QUALITY PARAMETERS IMMEDIATELY AFTER GAMMA EXPOSURE.

Mean data collected on germination percentage, speed of germination, root length, shoot length, seedling length, seedling vigour index, moisture and electrical conductivity were analyzed as per factorial design and the mean squares are presented in Table 4.1. The results indicated that the treatments were highly significant for all the parameters studied. Examination of ANOVA Table revealed that gamma radiation doses had significant effect on all parameters except seed moisture percentage which was uniform for all treatments under study.

Gamma radiation dose interaction component was significant for germination percentage, field emergence, and speed of germination, root length, shoot length, seedling vigour index, electrical conductivity, dehydrogenase activity and moisture percentage. The influence of interaction between varieties and gamma radiation doses was not significant on the expression of the seed moisture percentage, germination percentage and field emergence. Therefore, interaction Tables for remaining parameters are presented in tables (Table 4.4 to 4.12).

4.2 Influence of gamma radiation doses, varieties and their interactions on qualityparameters of seed immediately after gamma exposure.

The results indicated significant differences among the treatments in comparison to general mean for all the parameters studied (Table 4.1).

4.2.1 Germination parameters

Germination parameters are good indicators of field performance of a seed lot. Laboratory based germination data provides an estimate of seed viability under optimum conditions. In the present investigation, mean germination percentage ranges from 71.0 to 90.0 % among different treatments. Interaction effects between gamma doses and varieties were also significant (Table 4.4 and Fig 4.1b). Maximum values were noticed in CSV 29R irradiated with 0 Gy (90.0 %) followed by CSV 29R: 500 Gy, C 43: 0 Gy and C 43: 500 Gy. Lowest germination percent of 71.0 was recorded in CSH 14 with 2000 Gy irradiation.

Further, germination was significantly influenced by gamma dose and Varieties. Highest germination was noticed at 0 Gy (88.0 %) followed by 500 Gy (88.0%), 750 Gy (87.0%) and 250 Gy (84.0%). However, gamma dose of 2000 Gy recorded significantly lowest germination value of 75.0 per cent (Table 4.4).

Among the varieties, maximum germination percentage was observed in CSV 29R (85.0%) and lowest was recorded in CSH 14 (81.0%).

Further, the results also indicated that the germination percentage at 0 Gy dose was higher than all the gamma doses in all the three varieties. Similar findings were reported by Singh and Singh (2005) who reported that seed treated with different gamma doses (0.05, 0.10, 0.25 and 0.50 kGy) in four rice cultivars (Moirangphou, Tombung, KD-2-6-3 and RCM-5) showed highest percentage of germination at 0.10 kGy or 100 Gy. Further, significant decrease in germination per cent with increasing gamma dose was noticed in the present study. The results were in accordance with research findings of Chaudhary (2002) who reported that at higher radiation dose, germination percentage reduced, while, at lower dose *i.e.,* 0.10 kGy the germination percentage was not significantly different from 0 Gy or control.

It is evident that all sorghum varieties in the present study showed higher germination percentage at gamma doses 0 Gy followed by 500 and 750 Gy which could be attributed to stimulatory effect (Hormesis). Luckey (1980) explained hormesis as a phenomenon of excitation or stimulation by small doses of any agent in any system. The beneficial effect of hormesis has been well documented in many plant species of agricultural importance (Zaka *et al.,* 2004 and Kim *et al.,* 2005). The stimulatory effects of γ-rays on germination could be attributed to the activation of RNA synthesis (Kuzin *et al*., 1975) or protein synthesis (Kuzin *et al*., 1976), which occurred during

Table 4.4. Germination (%) as influenced by interaction between gamma doses andvarieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	87	89	90	**88**
250 Gy	81	85	85	**84**
500 Gy	87	89	89	**88**
750 Gy	85	87	88	**87**
1000 Gy	76	80	81	**79**
2000 Gy	71	77	78	**75**
Mean	**81**	**84**	**85**	**83**
	Gamma dose	**Varieties**		**Interaction**
SEm±	**0.687**	**0.486**		**1.191**
CD (0.05)	**1.37**	**0.97**		**2.38**

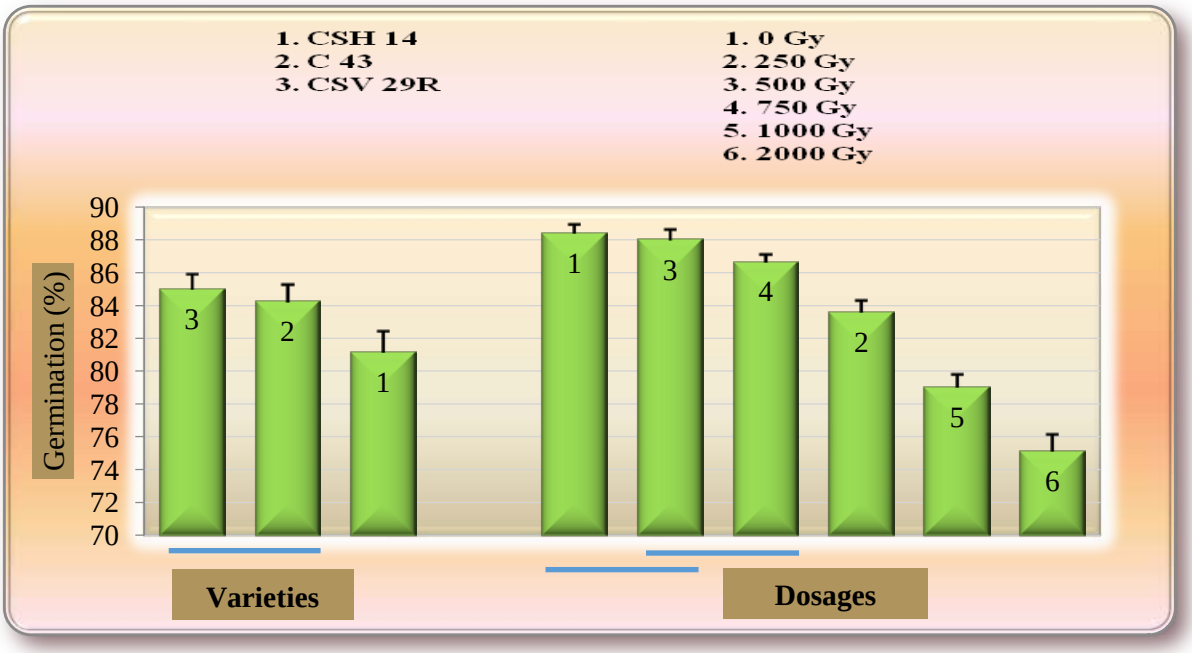

Fig.4.1 a. Germination as influenced by gamma doses and varieties

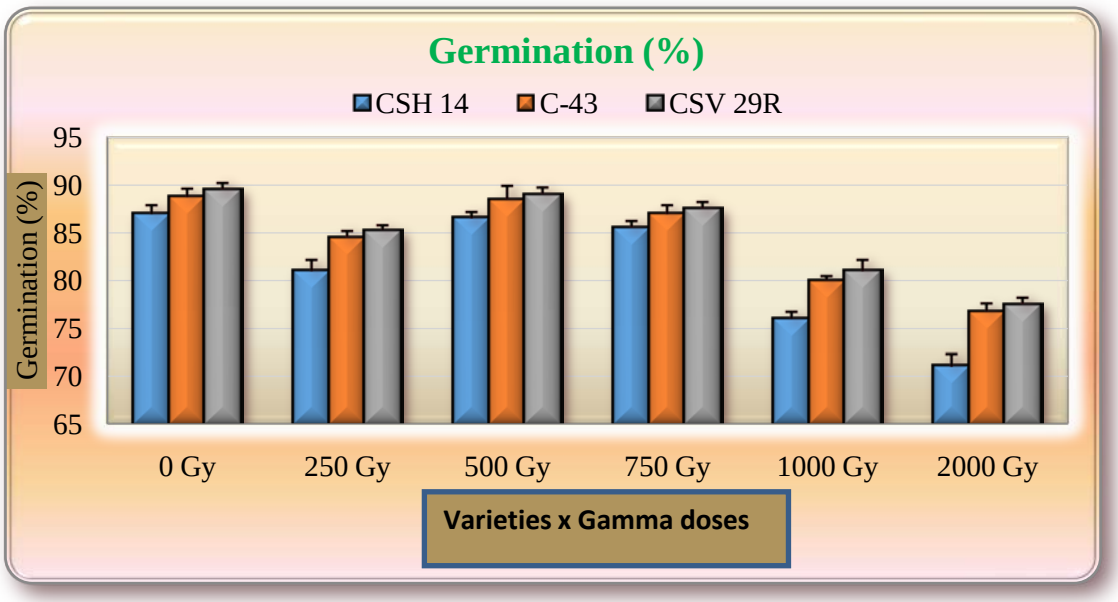

Fig.4.1 b. Germination as influenced by the interaction between gamma doses and varieties

initial stage of germination after seeds were irradiated.

The inhibitory effect on germination at higher doses of γ-rays could be due to several reasons like histological and cytological changes, disruption and disorganization of seed layer and generation of free radicals resulting in metabolic disorders in the germinating seeds which is directly proportional to the intensity of exposure to γ-rays (Lokesha *et al*., 1992).

In the present study also, germination percentage decreased with increasing gamma dose as reported earlier by many research workers (Choi *et al*., 1967, Miah *et al*., 1970, Pathak and Patel, 1988, Cheema and Atta, 2003., Minn *et al*., 2008, Sasikala and Kalayarasi, 2010, Dehpour *et al*., 2011 and Albokari *et al*., 2012). Further, the data on germination was validated with field emergence percentage as it is gives a true reflection of seed's ability to germinate under field conditions overcoming various impedances. Twelve treatments *viz.* CSV 29R/0, 500 Gy, 750 Gy, C 43/ 0 Gy, 250 Gy, 500 Gy, 750 Gy and CSH 14/0 Gy, 250 Gy, 500 Gy, 750Gy recorded significantly higher field emergence than general mean (59%). The treatments ranged from 17.0 per cent (CSH 14/2000 Gy) to 82.0 per cent (CSV 29R/0 Gy) which were significantly different. Results are presented in Table 4.5 and Fig 4.2b.

Speed of germination provides good validation of seed vigour enabling categorisation of strong and weak seedlings. Eleven treatments *viz*., CSH 14/ 0 Gy, 250 Gy, 500 Gy, 750 Gy, 1000 Gy, C 43/ 0 Gy, 500 Gy, 750 Gy, CSV 29R/0 Gy, 500 Gy 750 Gy were significantly superior over general mean of 39.6(Table 4.6). Highest speed of germination (45.3) was recorded in the treatment CSH 14/ 500 Gy and lowest (31.8) was noticed at 2000 Gy in C 43 variety. Results are presented in Table 4.6 and Fig 4.3b.

Significance of gamma doses in influencing speed of germination was evident from the results. Maximum speed of germination 43.8 was recorded at 500 Gy followed by 42.5 at 0 Gy. However 1000 Gy and 2000 Gy recorded much lower speed of germination of 37.4and 32.6respectively (Table 4.6). Similarly, varieties CSH 14 and CSV 29R recorded a speed of germination 41.2 and 39.5 respectively which were significantly higher compared to the speed of germination of 37.4 observed in C 43 variety (Fig. 4.3b)

The speed of germination had positive correlation with germination. The influence of gamma radiation on speed of germination in all genotype was same as it was on

Table 4.5. Field emergence (%) as influenced by interaction between gamma doses and varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	75	79	82	**79**
250 Gy	64	66	67	**66**
500 Gy	73	76	79	**76**
750 Gy	70	74	77	**74**
1000 Gy	33	38	43	**38**
2000 Gy	17	20	21	**20**
Mean	**55**	**59**	**62**	**59**
	Gamma dose	**Varieties**		**Interaction**
SEm±	0.847	0.599		1.468
CD (0.05)	1.699	1.201		2.943

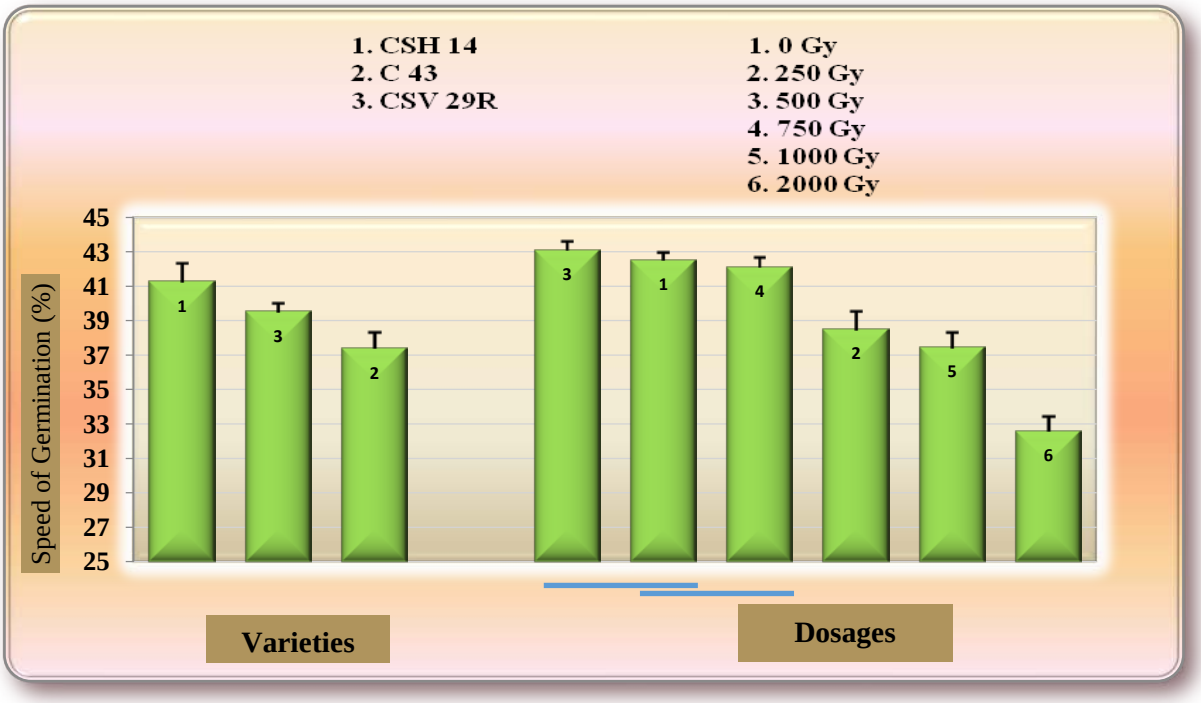

Fig.4.3 a. Speed of Germination as influenced by gamma doses and varieties

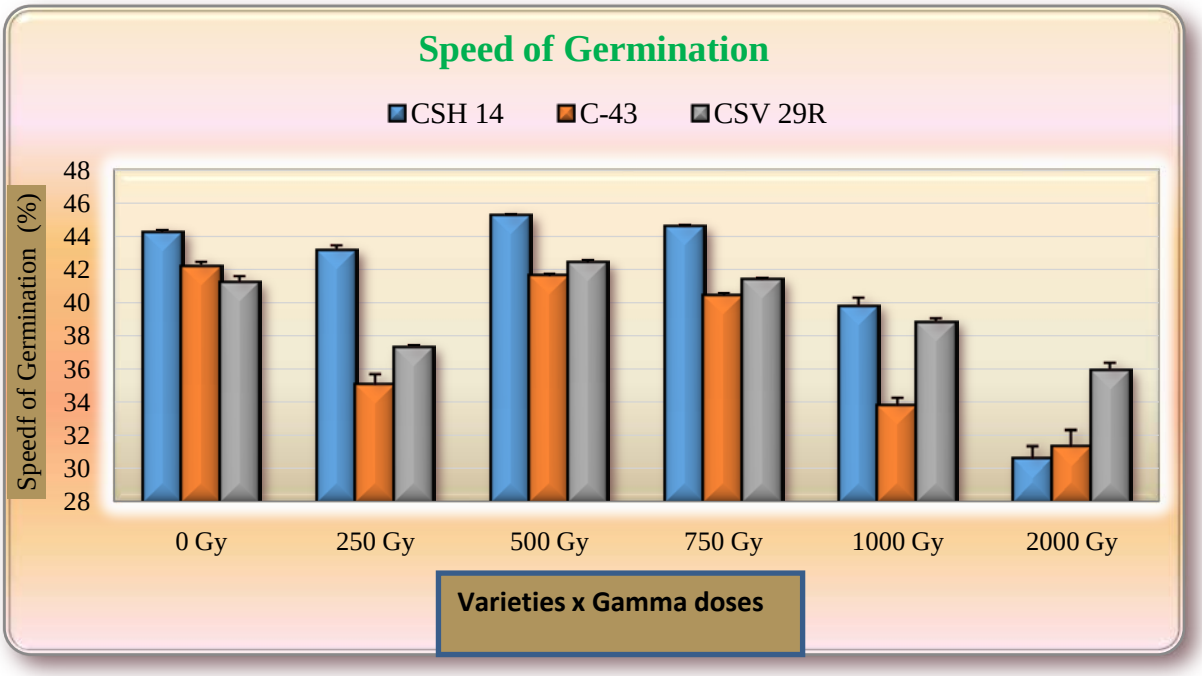

Fig.4.3 b. Speed of Germination as influenced by the interaction between gamma doses and varieties

germination. The results revealed that the speed of germination at 500 Gy was higher than 0 Gy and decreased with increasing dose up to 2000 Gy in all sorghum genotypes. The results were in conformity with research findings of Silva *et al*. (2011) in which rice seeds of BRS Querência and BRS Fronteira were irradiated at the doses of 0, 50, 100, 150 and 200 Gy and the former showed a higher speed of germination in comparison to the latter variety at lower radiation doses (50 and 100 Gy). Further it was reported that, the cultivar BRS Fronteira, however, showed decrease in speed of germination at a dose of 200 Gy which was similar to the result in the present study, this could be due to the enhanced rate of respiration or auxin metabolism in seed.

4.2.2 Seedling parameters

Seedling length is widely used as an index in determining the biological effects of various physical and chemical mutagens (Konzak *et al*., 1965). The results of the present study showed that the seedling length decreased with the increase in the irradiation dose and was directly proportional to dose increment.

Nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy, 750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy,and C 43/ 0 Gy, 500 Gy, 750 Gy, recorded significantly higher root length than general mean of 7.6 cm (Table 4.7). The values ranged from 1.7 cm (CSH 14/ 2000 Gy) to 15.2 cm (CSV 29R / 0 Gy). Interaction effects presented in Table 4.7 and Fig 4.4b were significant for root length.

Significant influence of gamma doses was observed in the expression of root length. But all doses exhibited inhibitory effect on root length, which was less than that of 0 Gy. Maximum root length of 15.2 cm was observed at 0 Gy and lowest mean root length was recorded at 2000 Gy (1.7 cm). Results are collated in Table 4.7. Pathak and Patel (1988) reported that radiation effects on root length varied significantly among varieties. In present study also root length significantly differed among varieties. Lower reduction of root length was observed in case of CSV 29R and CSH 14 compared to C43. Similar results were reported by Bhan and Kaul (1973), Cheema and Atta (2003), Minn *et al*. (2008), Borzouei *et al.* (2010) and Silva *et al*. (2011). Gamma radiation showed inhibitory effect on root length at all gamma doses in comparison to non-irradiated sample. Root length had decreased with increasing dose of gamma in all interactions which could be due to reduced mitotic activity in meristematic tissues and cell arrest at G2 / M phase during somatic cell division as was earlier reported by Preussa and Britta (2003), Shakoor *et al*. (1978) and Khalil *et al*. (1986).

Table 4.7. Root length (cm) as influenced by interaction between gamma doses and Varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	14.3	14.2	15.3	**14.5**
250 Gy	4.6	4.8	7.1	**5.5**
500 Gy	11.0	9.5	13.5	**11.2**
750 Gy	9.7	8.5	12.7	**10.1**
1000 Gy	2.7	2.4	3.5	**2.5**
2000 Gy	1.7	1.9	2.7	**1.9**
Mean	**7.3**	**6.8**	**8.8**	**7.6**
	Gamma dose	**Varieties**		**Interaction**
SEm±	0.087	0.061		0.150
CD (0.05)	0.174	0.123		0.302

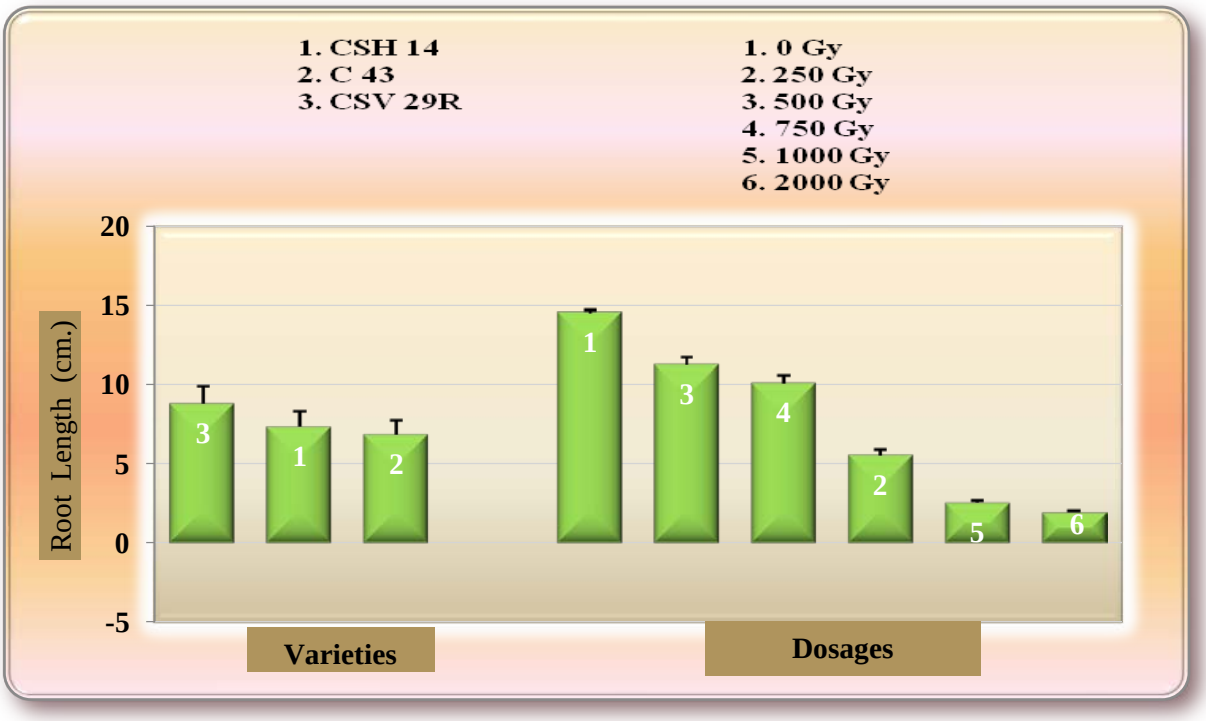

Fig.4.4 a. Root length as influenced by gamma doses and varieties

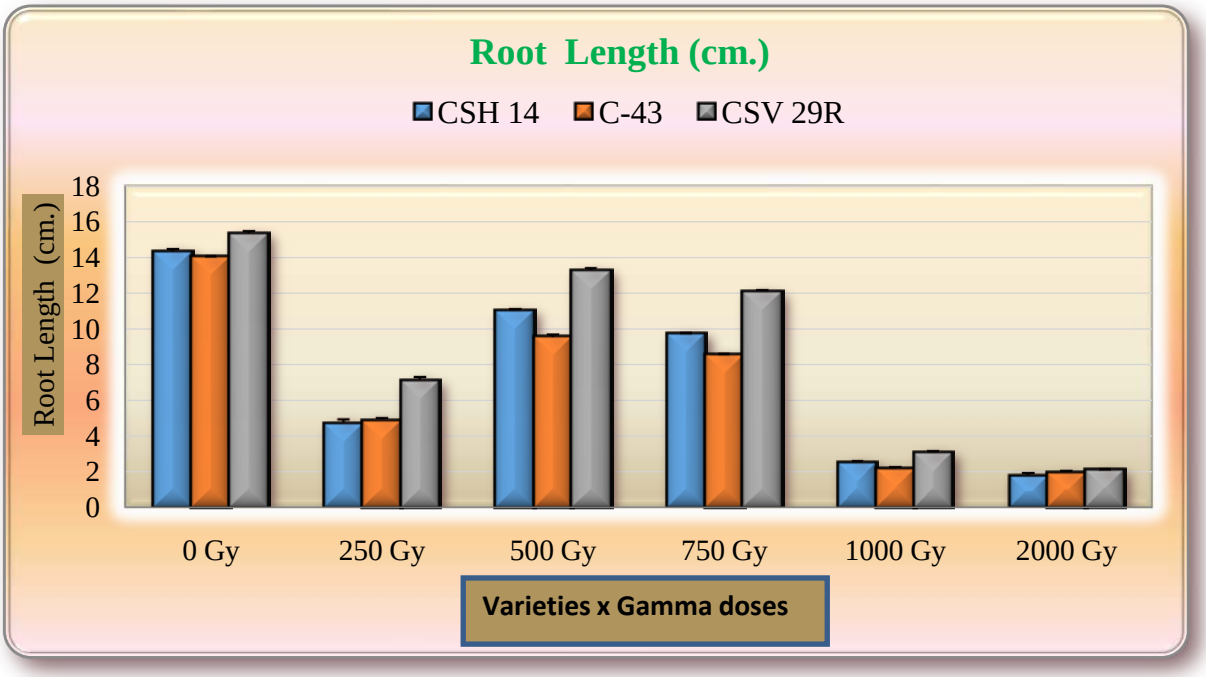

Fig.4.4 b. Root length as influenced by the interaction between gamma doses and varieties

Table 4.8. Shoot length (cm) as influenced by interaction between gamma doses and varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	15.7	14.7	15.4	**14.9**
250 Gy	5.7	5.5	7.8	**6.2**
500 Gy	11.5	10.7	15.4	**12.5**
750 Gy	10.5	9.1	14.8	**11.4**
1000 Gy	3.5	2.4	3.7	**3.2**
2000 Gy	2.5	2.3	2.7	**2.4**
Mean	**8.3**	**7.7**	**10.0**	**8.4**
	Gamma dose	**Varieties**		**Interaction**
SEm±	0.109	0.077		0.189
CD (0.05)	0.219	0.155		0.380

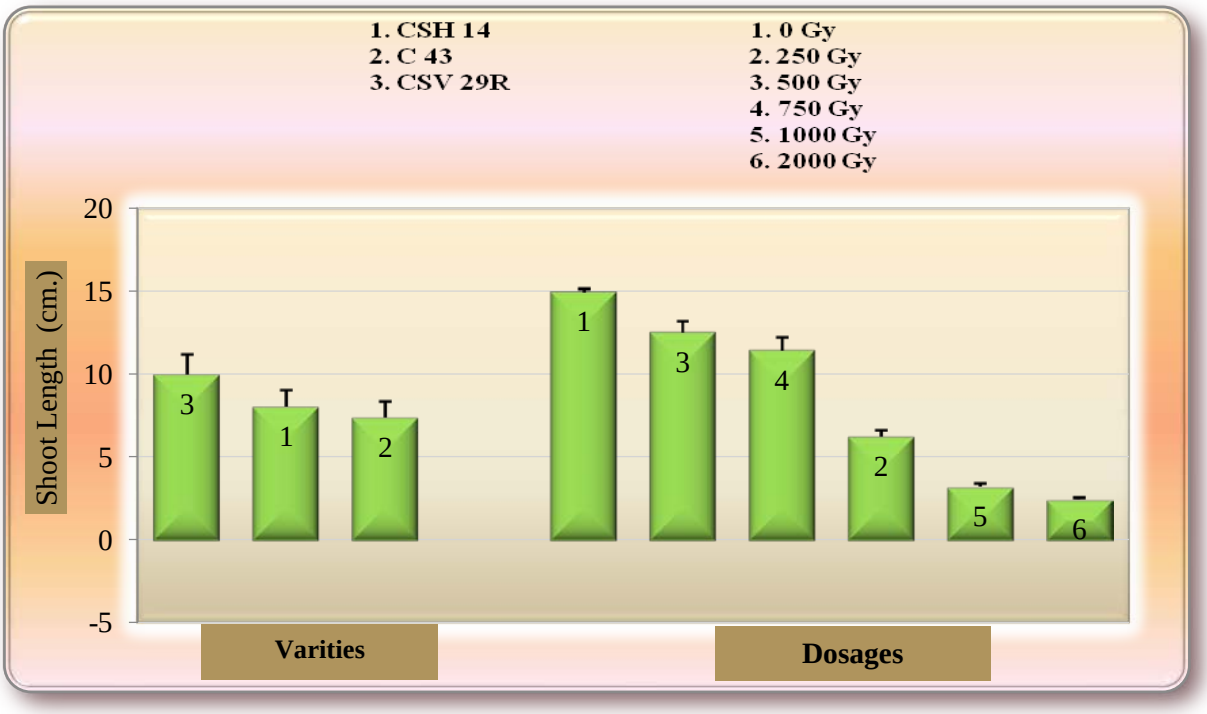

Fig.4.5 a. Shoot length as influenced by gamma doses and varieties

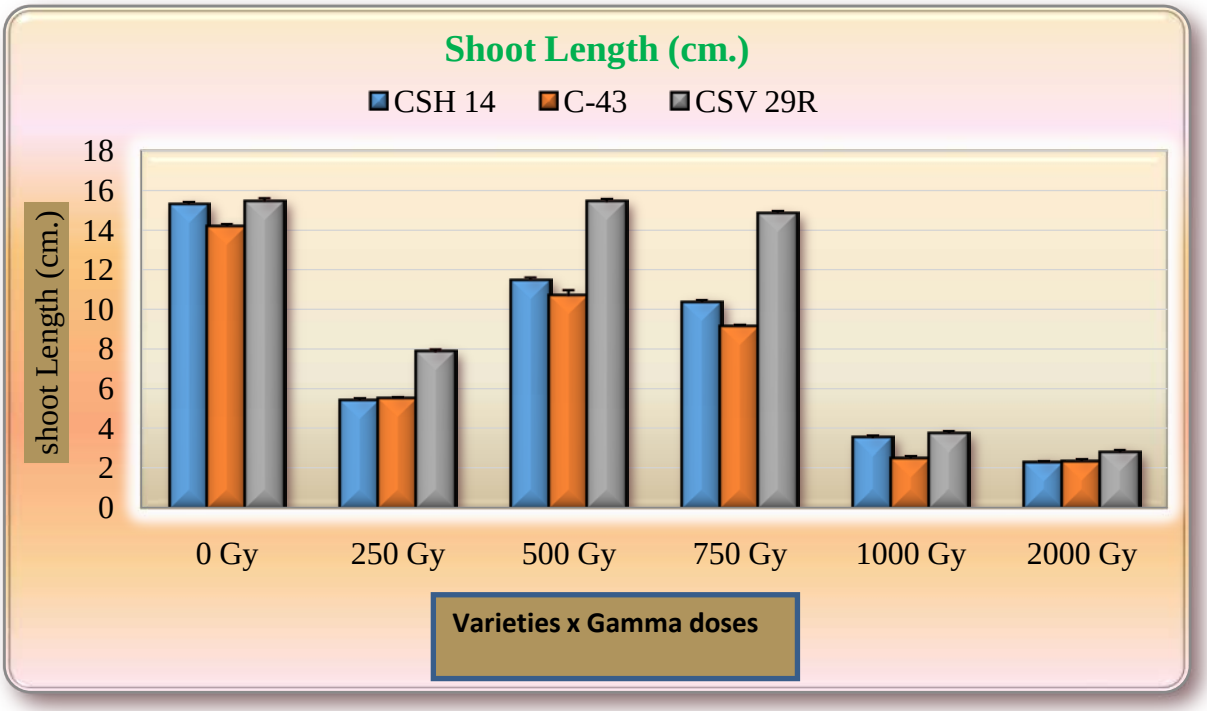

Fig.4.5 b. Shoot length as influenced by the interaction between gamma doses and varieties

General mean of shoot length was 8.4 cm and nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy, 750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy, and C 43/ 0 Gy, 500 Gy, 750 Gy showed significant superiority over others (Table 4.8). Maximum shoot length was recorded in case of CSV 29R / 0 Gy and 500 gy (15.4 cm) and lowest in case of C 43 / 2000 Gy (2.3 cm). Interaction effects presented in Table 4.8were significant for shoot length.

Shoot length for all doses was less than 0 Gy (14.9 cm). However, maximum shoot length of 12.5 cm was observed at 500 Gy and lowest mean of shoot length was recorded at 2000 Gy (2.4 cm) indicating the inhibitory effect of gamma dose on development of shoot growth. Significant influence of varieties (Fig 4.5b) was also noticed for shoot length. Maximum length of 10.0 cm was observed in CSV 29R and lowest shoot length (7.7 cm) in C 43 variety.

Further, in the present study shoot length had decreased with increasing dose of gamma in all three selected sorghum variety. This may be attributed to increase in plant sensitivity to gamma rays leading to reduced amount of endogenous growth regulators, especially cytokinins, due to break down, or lack of synthesis (Kiong *et al*., 2008). This was also earlier confirmed that gamma radiation had inhibitory effect on shoot length due to reduced mitotic activity in meristematic tissues in seeds (Shakoor *et al*., 1978).

The results of present study werealso in agreement with the results of Ashraf *et al*. (2003) who reported that when five varieties of basmati rice (*i.e.* Basmati 370, 385, 2000, Pak and Super Basmati) exposed to different doses of gamma rays (150, 200, 250, 300 and 350 Gy) which revealed, reduced shoot lengths with increasing doses in all the varieties. There was a highly significant effect of variety x dose reaction with shoot length indications that the varieties differed in their response to irradiation. Other research findings of Raj *et al*. (1972), Tabsum *et al*. (2011) and Dehpour *et al*. (2011) were in accordance with present study.

Vigour index quantifies the early efficiency of the seedling to optimum utilisation of available resources and finally gives an indication about probable plant height at later crop phenology. Further, this parameter captures the variability encountered during the process of germination and early seedling growth. In the present investigation highest vigour index (Table 4.9 and Fig 4.6b) was recorded at 0 Gy in species CSV 29R (1396) followed by CSV 29R/ 500 Gy (1386). Nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy,

Table 4.9. Seedling vigour index as influenced by interaction between gamma doses and varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	1343	1272	1396	**1337**
250 Gy	440	469	674	**528**
500 Gy	1001	954	1386	**1114**
750 Gy	894	803	1309	**1002**
1000 Gy	268	198	302	**256**
2000 Gy	161	178	217	**186**
Mean	**685**	**646**	**881**	**737**
	Gamma dose	**Varieties**		**Interaction**
SEm±	10.625	7.513		18.404
CD (0.05)	21.303	15.063		36.898

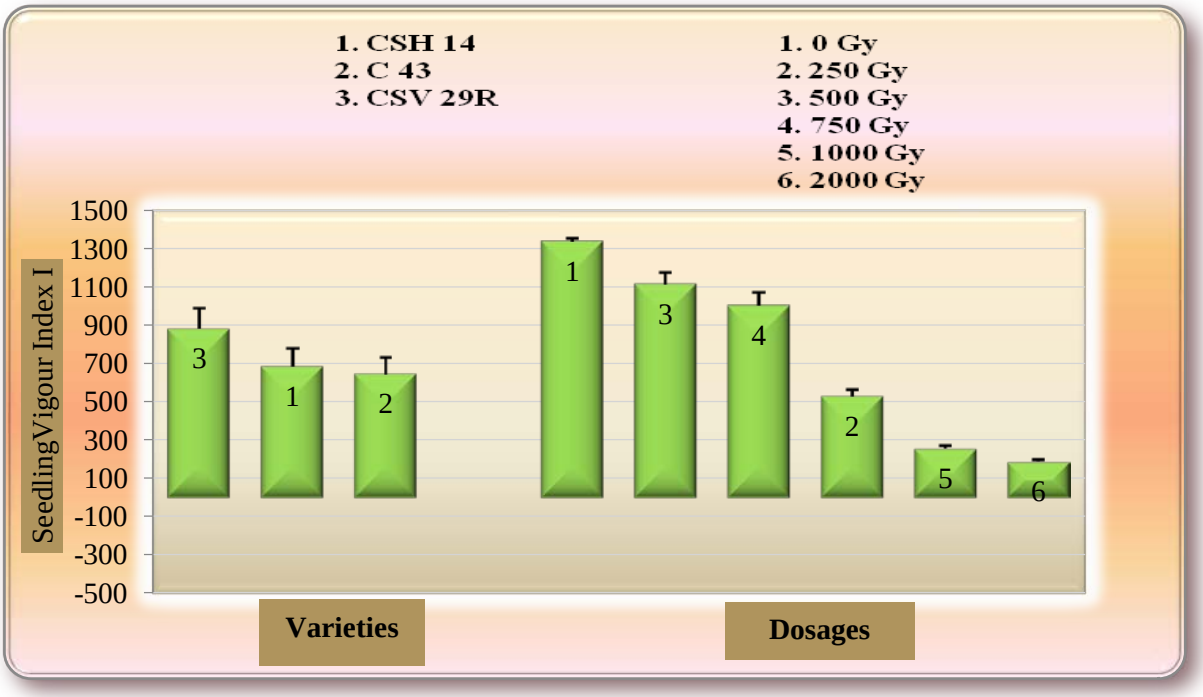

Fig.4.6 a. Seedling vigour index I as influenced by gamma doses and varieties

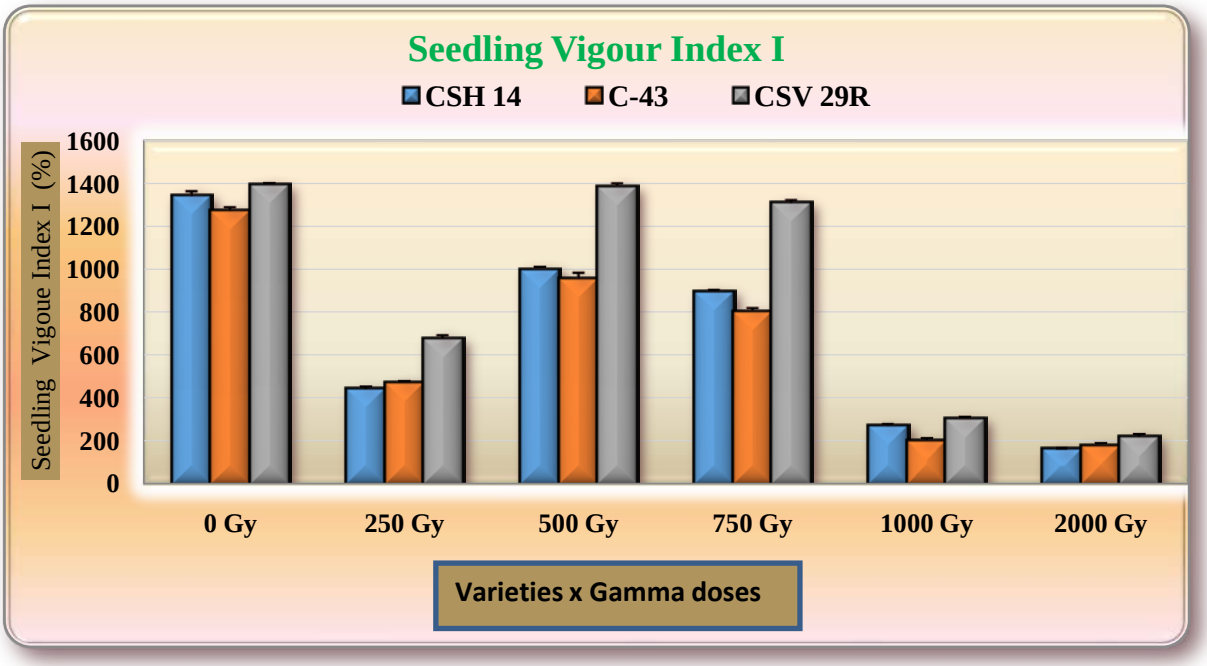

Fig.4.6 b. Seedling vigour index I as influenced by the interaction between gamma doses and varieties

750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy, and C 43/ 0 Gy, 500 Gy, 750 Gy were significantly superior (Table 4.9).

As observed in other seedling parameters, vigour index was significantly influenced by gamma doses. Highest seedling vigour index was noticed at 500 Gy (1114) which was inferior to 0 Gy (1337). However, higher gamma dose of 2000 Gy recorded significantly lower vigour index value of 186 (Table 4.9).

Further, the results also indicated variation among varieties, maximum value was recorded in CSV 29R (881) and lowest value in C 43 variety (646). Significantly superior vigour index valuesindicates their ability to germinate well and project good seedling growth under the stressful conditions created by gamma exposure.

4.2.3 Biochemical parameters

Seed biochemical parameters like electrical conductivity reflect the ability of the seed to endure the deleterious effects of gamma ray stress. Estimation of enzymes involved in the process of germination and early seedling growth gives a measure of genotypic potential to withstand substrate degradation due to ageing and decline in metabolic activities resulted from gamma radiation stress.

Earlier studies which were associated with increased membrane permeability for gamma radiation treatment concluded that enhanced leakage of leachates could be one of its side effects. Predominant effect of ionizing radiation in organisms is formation of reactive oxygen species (ROS) (De-Vita *et al.*, 1993). Accordingly, in the present study, the general mean of electrical conductivity was 45.9 µS cm^{-1}. Nine treatments *viz*., CSV 29R/0 Gy, 250 Gy, 500 Gy, CSH 14/ 0 Gy, 250 Gy, 500 Gy, and C 43/ 0 Gy recorded significantly lower leakage of leachates (Table 4.10). The electrical conductivity ranged from 32.20 µS cm^{-1} (CSV 29R/250 Gy) to 60.30 µS cm^{-1} at 2000 Gy in C 43 variety. Results furnished in Table 4.10 and Fig 4.7b indicated that interaction between gamma doses and varieties was significant for this parameter.

With regard to exclusive effect of gamma dose, significant differences were noticed in the expression of electrical conductivity. It was lower (38.9 µS cm^{-1}) at 0 Gy followed by 250 Gy (40.6 µS cm^{-1}). The highest value of electrical conductivity was recorded at 2000 Gy (52.4 µS cm^{-1}). The results are presented in Table 4.10.Significant differences in electrical conductivity for varieties were observed. CSH 14 recorded a lower leakage of leachates of 43.8 µS cm^{-1}. Whereas, C 43 recorded higher electrical conductivity of 49.1 µS cm^{-1}.

Table 4.10. Electrical conductivity (µs cm^{-1}) as influenced by interaction between gamma doses and varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	33.0	40.7	43.0	**38.9**
250 Gy	43.0	46.5	32.2	**40.6**
500 Gy	52.1	55.5	34.3	**47.3**
750 Gy	45.4	49.1	50.8	**48.4**
1000 Gy	48.3	42.5	53.5	**48.1**
2000 Gy	41.1	60.3	55.8	**52.4**
Mean	**43.8**	**49.1**	**44.9**	**45.9**
	Gamma dose	**Varieties**		**Interaction**
SEm±	0.495	0.350		857
CD (0.05)	0.992	0.701		1.719

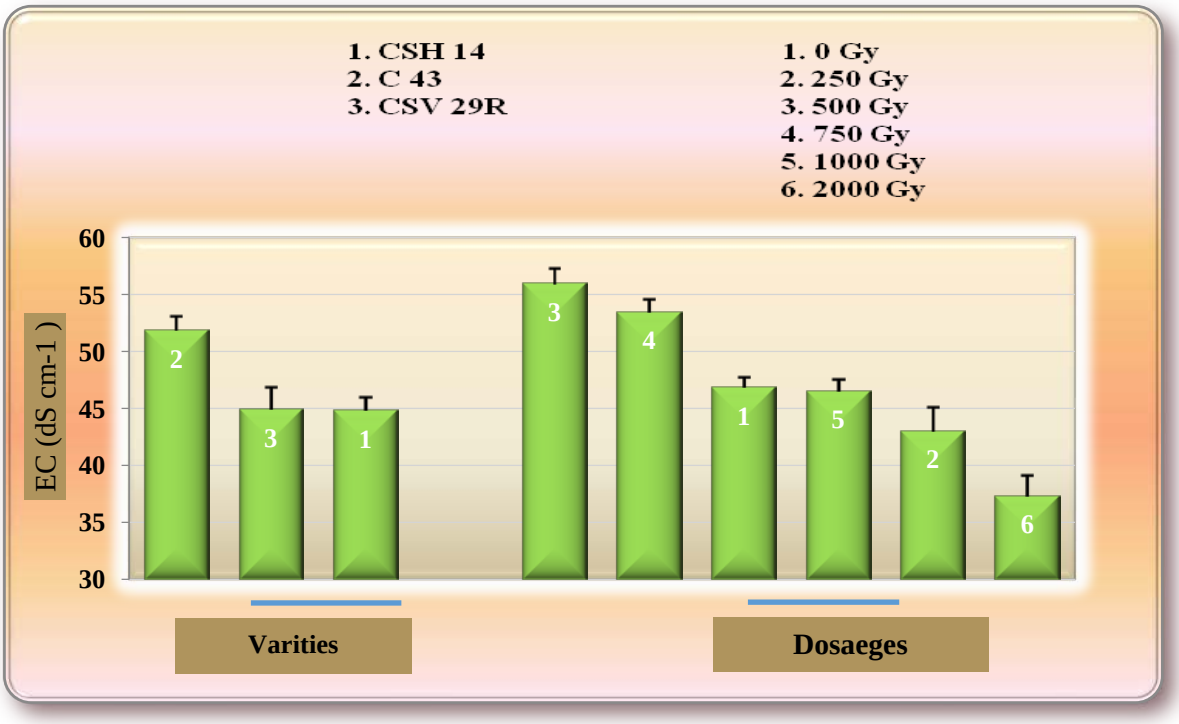

Fig.4.7 a Electrical conductivity as influenced by gamma doses and varieties

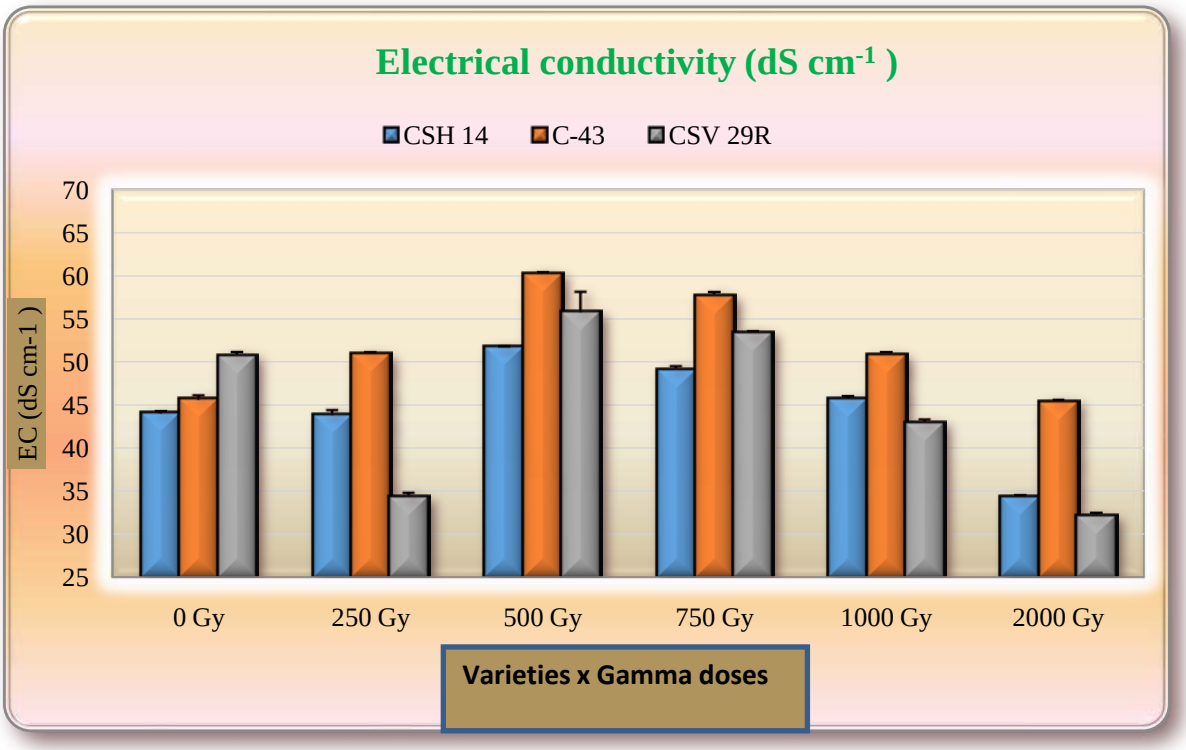

Fig.4.7 b. Electrical conductivity as influenced by the interaction between gamma doses and varieties

Table 4.11. Dehydrogenase activity (µg) as influenced by interaction between gamma doses and varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	0.16	0.17	0.20	**0.18**
250 Gy	0.17	0.16	0.21	**0.18**
500 Gy	0.18	0.19	0.23	**0.19**
750 Gy	0.17	0.18	0.22	**0.17**
1000 Gy	0.16	0.16	0.18	**0.16**
2000 Gy	0.14	0.13	0.14	**0.14**
Mean	**0.17**	**0.17**	**0.20**	**0.18**
	Gamma dose	**Varieties**		**Interaction**
SEm±	0.002	0.001		0.003
CD (0.05)	0.004	0.003		0.007

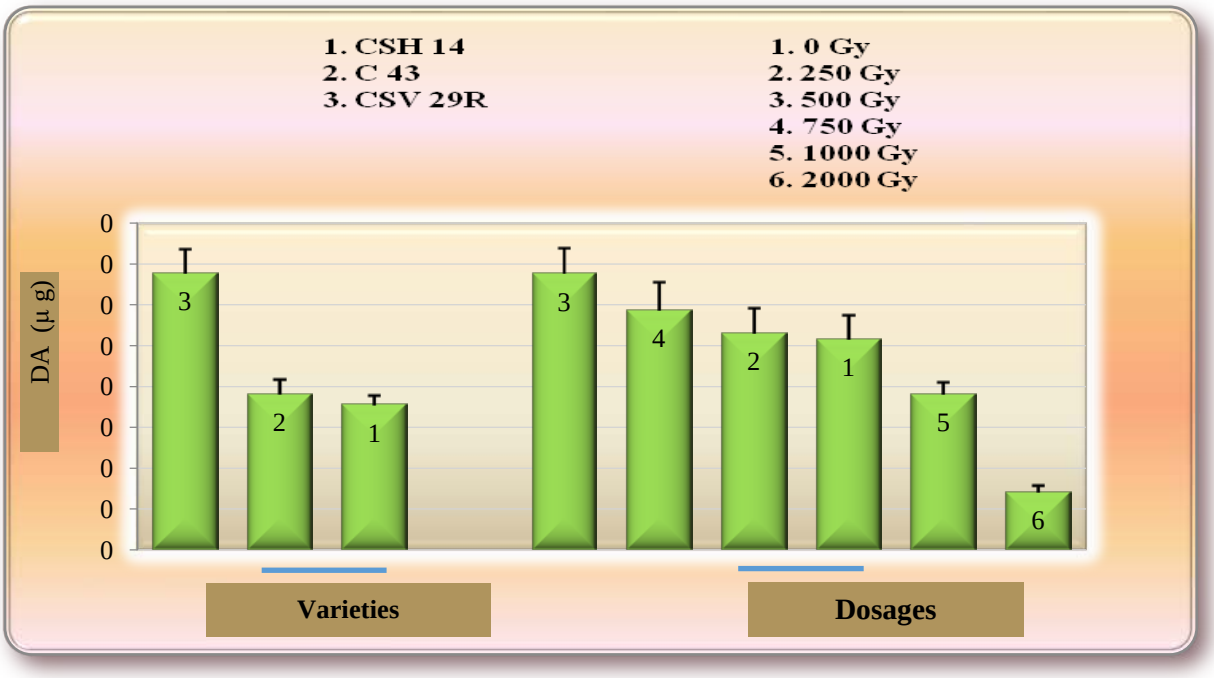

Fig.4.8 a. Dehydrogenase activity as influenced by gamma doses and varieties

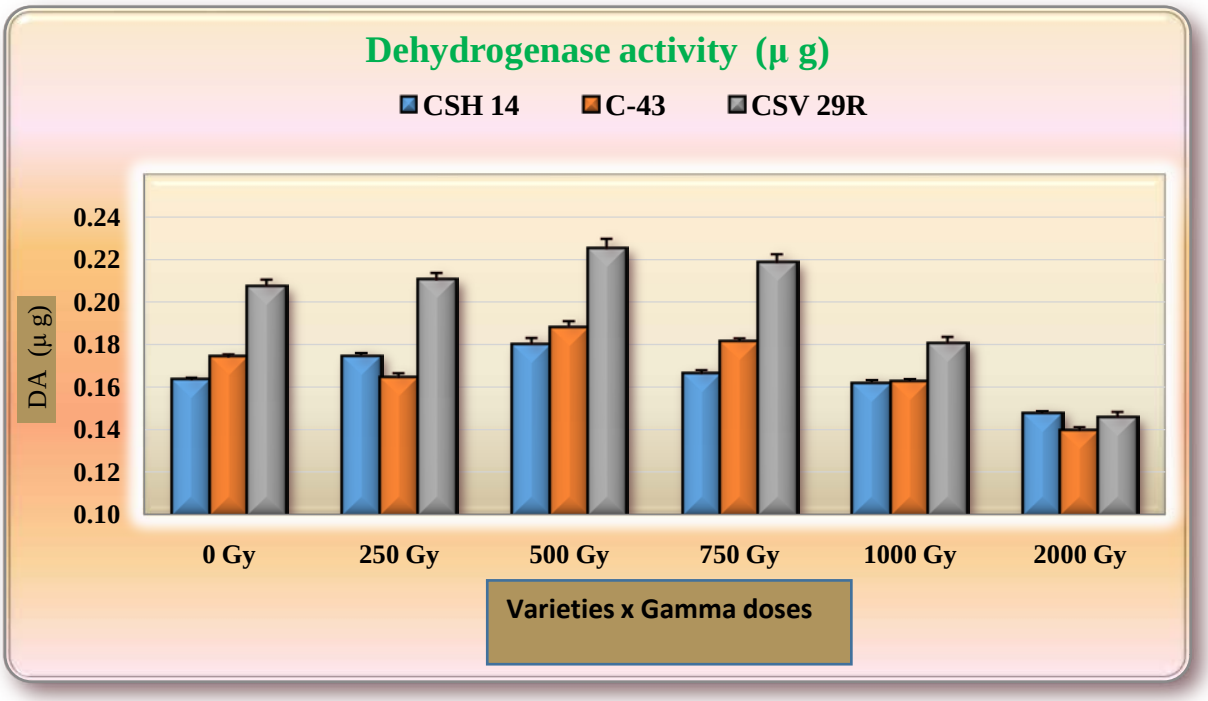

Fig.4.8 b. Dehydrogenase activity as influenced by the interaction between gamma doses and varieties

As per Linko and Milner (1960) who worked on effect of gamma radiation on viability of seeds of hard red winter varieties of wheat, the dehydrogenase activity is relatively resistant to radiation. After irradiation treatment at a dose of 3.0 megarep the formazone color intensity which indicates the activity of the enzyme got decreased only about 60 per cent from the control. In the present experiment also, dehydrogenase activity ranged from 0.13 µg (C 43/2000 Gy) to 0.23 µg (CSV 29R/500 Gy) which was approximately 45 per cent lesser than 500 Gy dose as compared with 2000 Gy. Six treatments *viz.* CSV 29R/ 0 Gy, 250 Gy, 500 Gy, 750 Gy, CSH 14/ 500 Gy, and C 43/ 500 Gy had documented superiority over other treatments. Interaction effects presented in Table 4.11 and Fig 4.8b were significant for dehydrogenase activity.

Significant deferens were observed for dehydrogenase activityin in with respect to the studies varieties and doses of gamma different maximum dehydrogenase activity of 0.19 µg was observed at 500 Gy and lowest mean of dehydrogenase activity was recorded at 2000 Gy (0.14µg). Significant influence of varieties was also noticed for dehydrogenase activity (Fig 4.8a).Maximum dehydrogenase activity of 0.20 µg was observed in CSV 29R and C 43 and CSH 14 had same minimum value (0.17µg).

4.2.4 Seed moisture

Most of the biochemical and physiological processes of seed are dependent upon moisture status. The influence of gamma ray exposure also influenced to a great extend by seed moisture where moisture is the first substrate in the seed to attract the radiation stress. The influence of gamma dose for this parameter was non-significant. The results indicated that seed moisture percentage was high in 6 treatments which have documented less than 9.1 per cent. It ranged from 9.1 per cent (CSV 29R /1000 Gy and CSV 29R, C 43 and CSH 14/2000 Gy) to 9.3 per cent (C 43/ 0 and 250 Gy). Influence of varieties on seed moisture was non-significant (Table 4.12). Same varieties CSV 29R and CSH 14 both cultivars recorded lower moisture content of (9.1 %) and highest moisture was recorded in C 43 (9.3 %).

4.3 ANALYSIS OF VARIANCE FOR SEED QUALITY UNDER STORAGE

Mean data collected on germination percentage, speed of germination, root length, shoot length, seed vigour index, field emergence, electrical conductivity,

Table 4.12. Seed Moisture (%) as influenced by interaction between gamma doses and varieties

Gamma doses	Varieties			
	CSH 14	**C 43**	**CSV 29R**	**Mean**
0 Gy	9.2	9.3	9.2	**9.2**
250 Gy	9.2	9.3	9.2	**9.2**
500 Gy	9.2	9.2	9.2	**9.2**
750 Gy	9.2	9.2	9.2	**9.2**
1000 Gy	9.2	9.2	9.1	**9.1**
2000 Gy	9.1	9.1	9.1	**9.1**
Mean	**9.2**	**9.2**	**9.2**	**9.2**
	Gamma dose	**Varieties**		**Interaction**
SEm±	0.024	0.017		0.041
CD (0.05)	0.048	0.033		0.083

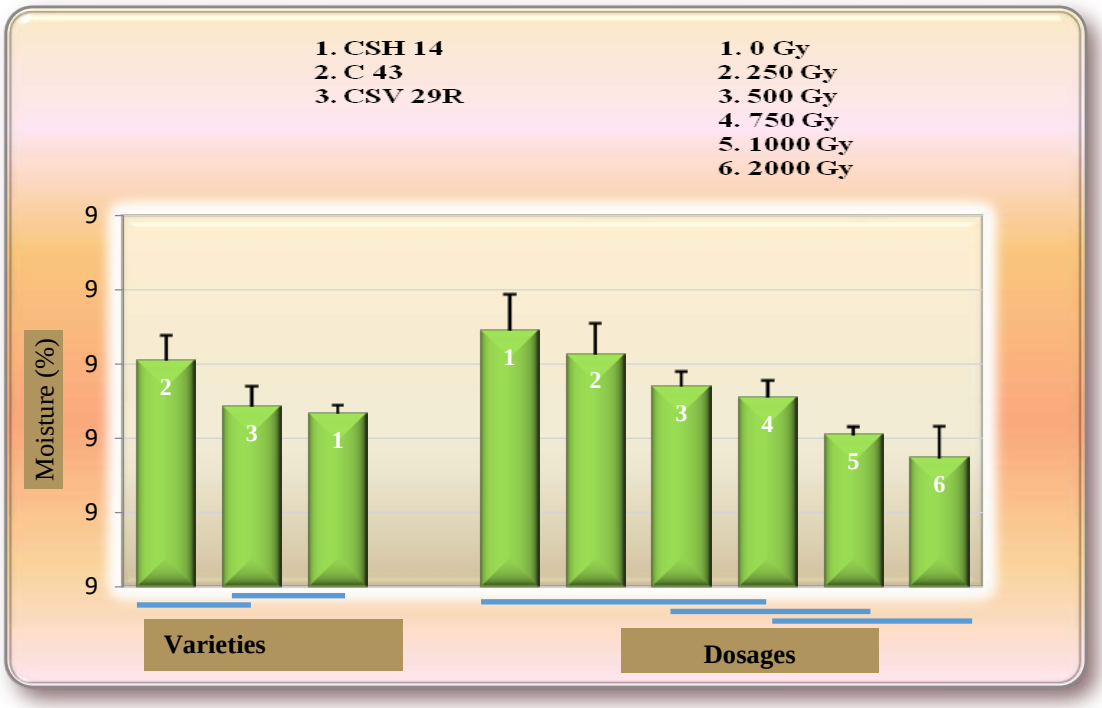

Fig.4.9 a. Seed moisture as influenced by gamma doses and varieties

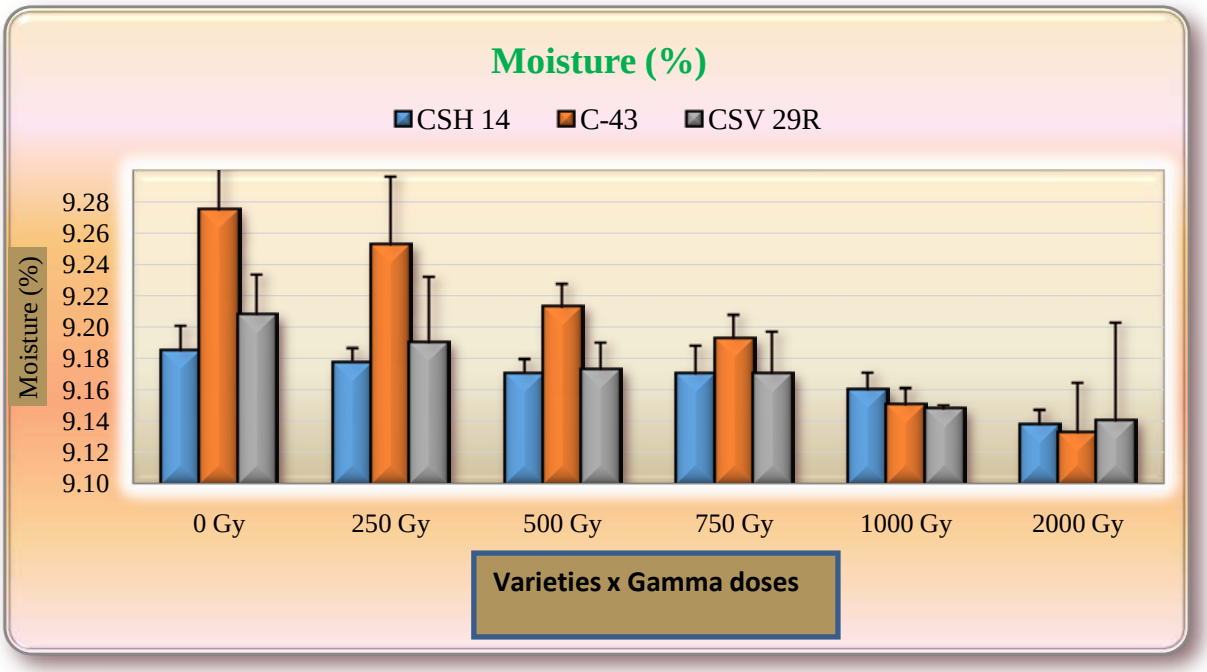

Fig.4.9 b. Seed moisture as influenced by the interaction between gamma doses and varieties

Table 4.13 . Analysis of variance (Mean squares) for seed quality parameters of sorghum varieties during storage

Source of variance	Df	Germination (%)	Speed of Germination	Field emergence (%)	Seedling vigour index	Root Length (cm)	Shoot Length (cm)	Electrical conductivity (μscm^{-1})	Dehydrogenase activity (ug)
Time	3	3662.75**	2936.51**	2150.58**	1296883.25**	97.00**	92.68**	466721.47**	0.12**
Variety	2	185.75**	437.09**	255.38**	968118.56**	73.88**	149.08**	5883.03**	0.02**
TimexVariety	6	2.56	21.21**	63.98**	14479.61**	0.62**	1.04**	1624.16**	0.00**
Radiation	5	1179.38**	575.54**	25077.28**	5238386.50**	893.77**	911.88**	103077.40**	0.01**
TimexRadiation	15	49.03**	15.03**	63.83**	138198.23**	6.56**	10.33**	60198.61**	0.00**
VarietyxRadiation	10	1.83	8.38**	10.34**	88344.66**	10.84**	13.43**	592.51**	0.00**
TimexVarietyxRadiation	30	2.56	12.53**	2.64	8794.72**	0.62**	1.26**	323.07**	0.00**
Error (C)	216	3.35	0.62	3.67	642.51	0.03	0.08	3.12	0.00
Total	287	65.59	47.06	469.22	**123570.52**	**17.92**	**19.11**	**9952.38**	**0.00**

** **Significant at 1% level**

Table 4.13 (cound.). Analysis of variance (Mean squares) for seed quality parameters during storage

Source of variance	Moisture (%)	Weevil infestation (%)	Fungal infection (%)	Alfa amylase (cm)
Varieties	0.26**	289.28**	231.76**	15.96**
Storage	0.12**	201.89**	270.42**	13.51**
Varieties x Storage period	0.00	12.73**	1.06	0.03
Radiation	0.05**	299.37**	938.66**	48.23**
Varieties x Storage period	0.00	14.91**	6.66**	0.04
Varieties x Storage period x Radiation	0.00	16.96**	8.60**	0.22**
Error (C)	0.00	1.43**	0.79	0.03
Total	0.00	0.32	0.56	0.02

** **Significant at 1% level**

Table 4.14. Analysis of variance (Mean squares) for seed quality parameters during storage

Source of variance	df	Protein (%)	Starch (%)	Ash (%)	Fat (%)
Time	1	20.38**	226.03**	3.29**	0.19**
Variety	2	0.55**	39.64**	0.58**	0.07**
TimexVariety	2	1.19**	8.77**	0.06	0.01
Radiation	5	7.04**	184.48**	2.13**	0.53**
TimexRadiation	5	2.29**	10.44**	0.18**	0.00
VarietyxRadiation	10	0.31**	7.06**	0.04	0.03**
TimexVarietyxRadiation	10	0.28**	3.27**	0.04	0.00
Error (C)	108	0.05	0.27	0.02	0.00

starch, protein, fat and ash content of seed, α-amylase activity, dehydrogenase activity, seed moisture percentage, weevil infestation and fungal invasion were analyzed as per factorial CRD and the mean squares are presented in Table 4.13 and 4.14. The mean data indicated that the treatments were highly significant for all the parameters studied at bimonthly intervals up to nine months of storage period.

The influence of varieties, gamma dose and storage time was significant for all the parameters under study. Interaction of gamma doses with varieties was also significant for all the parameters studied during nine months of storage period at bimonthly intervals.

4.4 Influence of storage period, gamma radiation doses, varieties and their interaction on seed quality during storage period.

Mean values for 18 treatments at 3rd, 5th, 7th and 9th month of storage revealed presence of significant differences among treatments for all the seed quality parameters studied (Table 4.2).

4.4.1 Germination parameters

Seed deterioration as a result of ageing and other stresses during storage results in loss of capacity to germinate and failure to put up initial vigour under ambient condition. This could be usually due to alteration in physiology of seeds, fluctuation in seed moisture content, changes in biochemical composition of seed matrix and increased leaching of electrolytes and other low molecular weight substances during imbibitions due to disturbances in membrane dynamics (Kalpana and Rao, 1991).Rajarajan *et al.* (2016) conduct as experiment an effect of physical mutagen gamma rays on rice cultivar ADT (R) 47. Genetically pure seeds were treated with different doses of gamma rays *viz.*, The LD_{50} values were observed based on growth reduction of seedlings after gamma ray treatment. The LD_{50} dose for gamma ray under *in vitro* and *in vivo* condition was fixed at 229Gy and 235Gy based on probity analysis. As the doses of applied gamma ray increased, there was a decrease in germination, survival rate of seedlings, root length, shoot length, seedling height, vigour index under *in vitro* conditions and emergence and survival under field (*in vivo*) conditions in M1 generation as compared to the control. The survival % of seedlings was more at higher doses of gamma ray under *in vivo* conditions compared to *in vitro* conditions.

Table 4.15. Germination (%) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Germination %**
1st Bi-month	78
2nd Bi-month	73
3rd Bi-month	66
4th Bi-month	62
S Em ±	0.305
CD (0.05)	0.600
Influence of Gamma radiation	
Gamma Dose	**Germination %**
0 Gy	70
250 Gy	71
500 Gy	75
750 Gy	73
1000 Gy	69
2000 Gy	61
S Em ±	0.373
CD (0.05)	0.736
Influence of Varieties	
Varieties	**Germination %**
CSH 14	68
C 43	70
CSV 29R	71
S Em ±	0.264
CD (0.05)	0.520

Table 4.16. Germination (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	81	83	83	**82**	69	71	74	**71**	62	63	66	**64**	59	60	62	**60**
250 Gy	78	79	81	**79**	75	76	76	**76**	66	67	68	**67**	62	62	63	**62**
500 Gy	81	84	85	**83**	77	78	79	**78**	70	71	71	**71**	65	67	70	**67**
750 Gy	79	82	82	**81**	76	76	77	**76**	67	69	68	**68**	63	66	68	**66**
1000 Gy	73	75	78	**75**	71	72	73	**72**	65	66	66	**66**	61	62	63	**62**
2000 Gy	66	66	67	**66**	63	64	65	**64**	59	60	63	**61**	48	51	54	**51**
MEAN	**76**	**78**	**79**	**78**	**72**	**73**	**74**	**73**	**65**	**66**	**67**	**66**	**60**	**61**	**63**	**61**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.747**	**0.528**	**0.646**	**0.903**
CD (0.05)	**1.471**	**1.040**	**1.274**	**2.559**

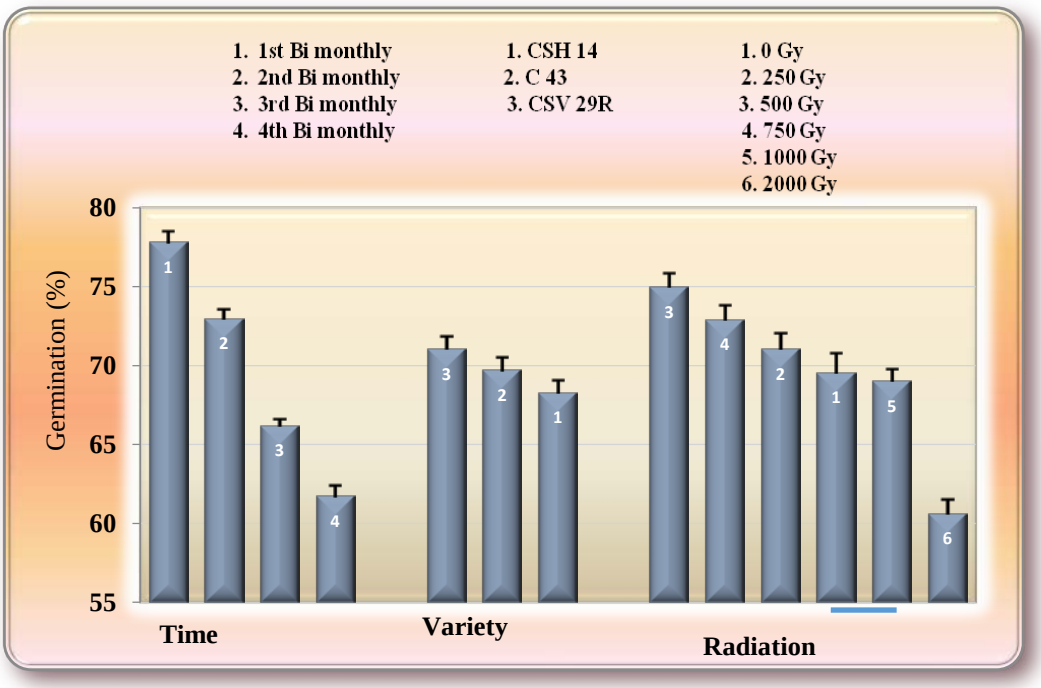

Fig. 4.10a: Germination as influenced by storage period, gamma doses and varieties

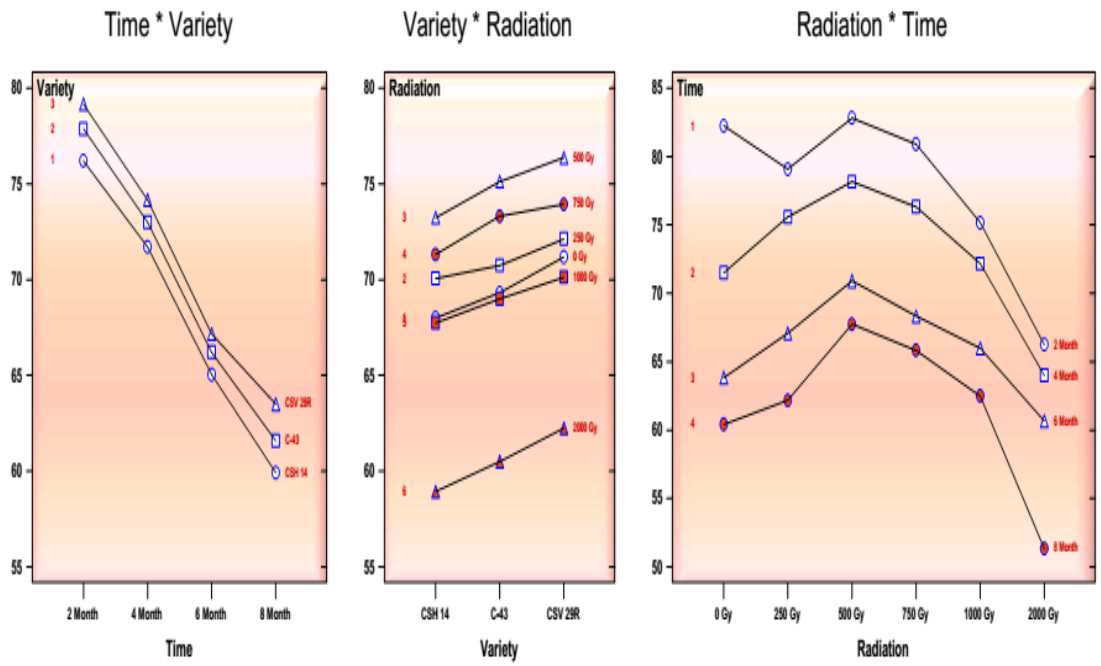

Fig.4.10b: Germination as influenced by the interactions among storage period, gamma doses and varieties

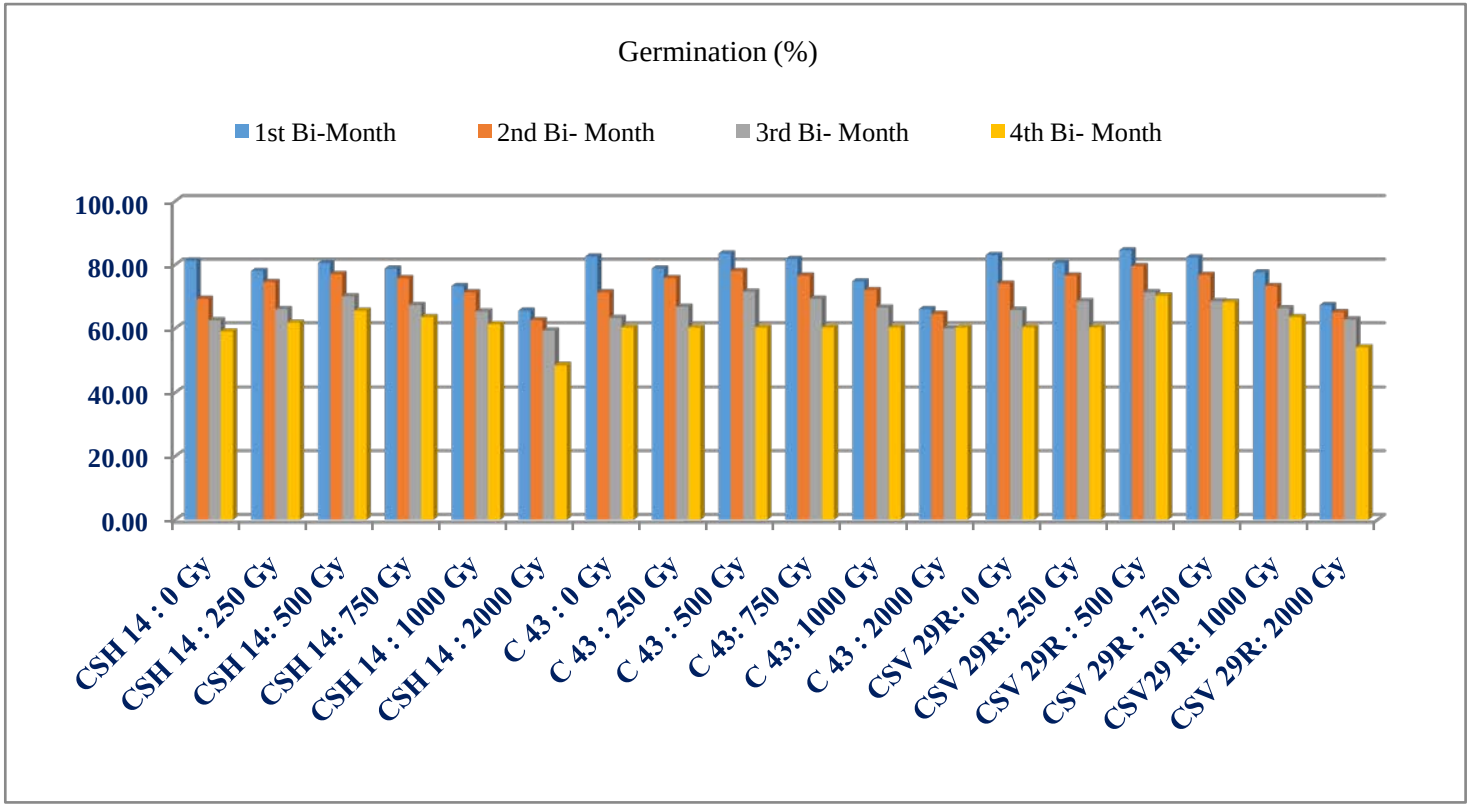

Fig.4.10 c: Germination as influenced by the interaction among storage period x gamma doses x varieties

Harrington (1972) in his studies on seed storage and longevity opined that crop seeds differ considerably for viability and longevity depending on plant species and varieties as well as the conditions of storage. Further, it has been amply demonstrated that early deteriorative change in seeds under storage was due to various biochemical processes *viz*., denaturation of biomolecules and accumulation of toxic substances in addition to loss of membrane integrity (Abdul Baki and Anderson, 1973).

Further, it was also opined that, seed deterioration is mainly due to lipid peroxidation and membrane degradation. Biochemical changes associated with seed deterioration increased with acidity and leaching of sugars and electrolytes (Halder *et al.,* 1983). The leachate of seed as measured by electrical conductivity (Bradnock and Mathews, 1970 and Powell and Mathews, 1986) was shown to be associated with the loss of vigour and viability. Crowe *et al*. (1992) reported that decrease in membrane stability is due to non-enzymatic reaction between the carboryl group of CH_2O and amino group of amino acid and protein. Dighe *et al*. (1995) opined that membrane degradation during deterioration as judged by increased seed leachate and electrical conductivity.

Earlier researchers also suggested that the enzymes play an important role in the progress of seed deterioration and changes in their activity can be an indication of quality loss (Copeland and McDonald, 1995). The relationship between seed deterioration and the enzymes involved in lipid peroxidation, free radical removal and seed respiratory metabolism also has been studied. All enzyme activity is positively correlated with germination of seed. As ageing progressed germination also decreased and enzyme activity also decreased which showed significant deterioration in both accelerated as well as in natural aged seed lot. All seeds undergo ageing process during long-term storage which leads to deterioration in seed quality, especially in the humid tropical regions.

Many hypothesis have been proposed regarding causes of seed ageing such as lipid peroxidation mediated by free radicals, inactivation of enzymes or decrease in proteins, disintegration of cell membranes and genetic damage (McDonald, 1999 and Murthy *et al.,* 2003). Degradation and inactivation of enzymes due to changes in their macromolecular structures is one of the most important hypothesis proposed regarding causes of ageing in seeds (Bailly, 2004, Basavarajappa *et al.,* 1991, Goel *et al.,*2002 Lehner*et al.,* 2008 and McDonald, 2004). Most of these studies suggested that decrease occur in the activity of enzymes such as superoxide dismutase, catalase, peroxidase and

glutathione reductase in aged seeds. The general decrease in enzyme activity in the seed lowers the respiratory capacity, which in turn lowers both the energy (ATP) and assimilates supply of the germinating seed. Therefore, several changes in the enzyme macromolecular structure may contribute to their lowered germination efficiency.

The leading attribute causing seed deterioration increasingly appears to be free radical production. It is primarily initiated by oxygen and has been related to the peroxidation of lipids and other essential compounds found in cells. This causes a host of undesirable events to include decreased lipid content. Lipid peroxidation begins with the generation of a free radical either by auto oxidation or enzymatically by oxidative enzymes such as lipoxygenase present in many seeds. Seed moisture content due to the absence of free water in dry seeds, non-enzymatic mechanisms such as lipid peroxidation are likely to be involved in ROS accumulation during dry storage, but as soon as seeds imbibe, enzymatic mechanisms participate in ROS production. One of the major sources of ROS in metabolically active seeds is the mitochondrial respiratory chain (Bailly, 2004). Lipid peroxidation occurs in all cells, but in fully imbibed cells, water acts as a buffer between the autoxidatively-generated free radicals and the target macromolecules, thereby reducing damage. Thus, as seed moisture content is lowered, autoxidation is more common and is accelerated by high temperatures and increased oxygen concentrations. Lipid autoxidation may be the primary cause of seed deterioration at moisture contents below 6 %. Above 14 % moisture content, lipid peroxidation may again be stimulated by the activity of hydrolytic oxidative enzymes such as lipoxygenase, becoming more active with increasing water content.

Festus *et. al.*(2016) reported that seeds of eight cowpea ac-cessions were irradiated with ^{60}Co gamma radiation doses of 100, 200, 300, 400 and 500 Gy. The seeds were sown in pots to evaluate the treatment effects on seed germination (SG), seedling sur-vival (SS) and growth habits of M_1 generation. Data were analyzed using descriptive statistics. Low rates of SG (10% - 45%) were recorded at higher doses (500 - 400 Gy) in Ife Brown (IB) and its de-rivatives, whereas high SGrates (74% - 94%) were observed in IT90K-284-2 across all treatments. Percentage of SS was inversely related to gamma dosage. A wide range of LD_{50} for SG (329 - 1054 Gy) and SS (149 - 620 Gy) were observed across the cowpea accessions. Low LD_{50} scores for SG (329 - 516 Gy) and SS (149 - 357 Gy) were observed among cowpea with rough seed coat, whereas cow-pea with smooth seed coat recorded higher $LD_{50}$for SG (521 and 1054 Gy) and SS (449 and 620 Gy). Seed germination LD_{50} and SS LD_{50} were highly correlated

with mean coat thickness (0.899 and 0.937) than mean seed weight (0.621 and 0.678). Gamma irradiation of cowpea seed at low dosage (100 Gy) increased the vigor of M_1 seedlings with respect to primary leaf area, terminal leaflet area, seedling height and plant height at six weeks. Doses of 200 Gy and above resulted in a progressive reduction in vigor of plant and seed setting of cowpea.

In view of this, in the present investigation the alterations in seed quality of popular sorghum varieties during storage under the influence of gamma doses were studied. Periodical observations at bimonthly intervals were recorded up to nine months of storage on three germination parameters *viz*., germination, speed of germination, field emergence; three seedling parameters *viz*., root length, shoot length, and vigour index; seven biochemical parameters *viz*., electrical conductivity, starch, protein, fat and ash content of seed, α-amylase activity, dehydrogenase activity and in addition seed moisture and seed health in terms of percentage weevil infestation and fungal invasion were also ascertained.

In the present investigation 7 treatments *viz*., CSH 14 / 0 Gy, C 43/ 0 Gy, 500 Gy, 750 Gy and CSV 29R/ 0 Gy, 500 Gy, 750 Gy recorded significantly higher germination values after firstbi-month of storage (Table 4.2). Minimum percentage of 66.0 was recorded at CSH 14 and C 43/ 2000 Gy. Mean germination values after second bi-month of storage ranged from 63.00 (CSH 14 / 2000 Gy) to 78.0 per cent (C 43/ 500 Gy). At the end of 3rd and 4th bi-months of storage, eight treatments recorded significantly higher mean germination. Highest mean germination percentage was recorded at 500 Gy in C 43 (72.0 %) after 3rd bi-month and lowest (49.0 %) was recorded in CSH 14/ 2000 Gy at the end of 4th bi-months of storage.

Further, the data revealed that, germination per cent was significantly influenced by period of storage. Data is furnished in Table 4.15 and Figure 4.10a. Among treatments CSV 29R/500 Gy, C 43/ 500 Gy and CSH 14/ 500 Gy maintained the higher germination percentage up to 4th bi-months of storage (70, 67 and 65 per cent respectively) and were significantly superior than corresponding value at 0 Gy gamma dose *i.e.* 62, 60 and 59 respectively and other treatments like CSV 29R/ 250, 750 Gy, C 43/ 250, 750 Gy and CSH 14/ 250, 750 Gy recorded moderately high germination percentage after 4th bi-month storage (Fig 4.10c).

Further, the data revealed that, germination per cent was significantly influenced by period of storage. Data is furnished in Table 4.15. After 1st bi-month of storage

Table 4.17. Field emergence (%) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Field emergence %**
1st Bi-month	57
2nd Bi-month	53
3rd Bi-month	48
4th Bi-month	45
S Em ±	0.319
CD (0.05)	0.630
Influence of Gamma radiation	
Gamma Dose	**Field emergence %**
0 Gy	67
250 Gy	57
500 Gy	69
750 Gy	67
1000 Gy	28
2000 Gy	16
S Em ±	0.391
CD (0.05)	0.771
Influence of Varieties	
Varieties	**Field emergence %**
CSH 14	49
C 43	52
CSV 29R	52
S Em ±	0.277
CD (0.05)	0.545

Table 4.18. Field emergence as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	73	77	78	**76**	69	72	72	**71**	62	64	60	**62**	58	59	57	**58**
250 Gy	63	64	65	**64**	59	60	62	**61**	53	55	53	**54**	51	52	51	**51**
500 Gy	71	75	78	**75**	68	71	73	**71**	66	68	66	**67**	62	66	64	**65**
750 Gy	69	73	76	**73**	66	69	70	**68**	64	67	64	**65**	60	64	62	**62**
1000 Gy	31	36	42	**36**	28	31	36	**32**	23	27	23	**24**	18	22	19	**20**
2000 Gy	17	19	20	**19**	16	17	19	**17**	14	16	15	**15**	14	14	13	**14**
MEAN	**54**	**57**	**60**	**57**	**51**	**53**	**56**	**53**	**47**	**50**	**47**	**48**	**44**	**46**	**45**	**45**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.782**	**0.553**	**0.677**	**0.840**
CD (0.05)	**1.542**	**1.090**	**1.335**	**2.775**

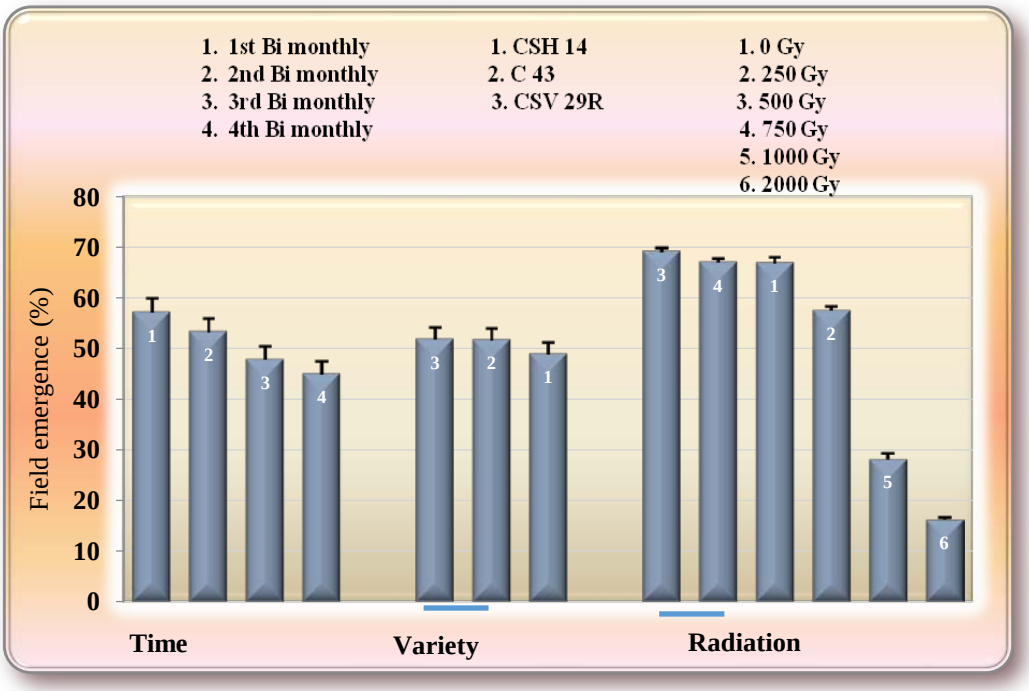

Fig. 4.11a: Field emergence as influenced by storage period, gamma doses and varieties

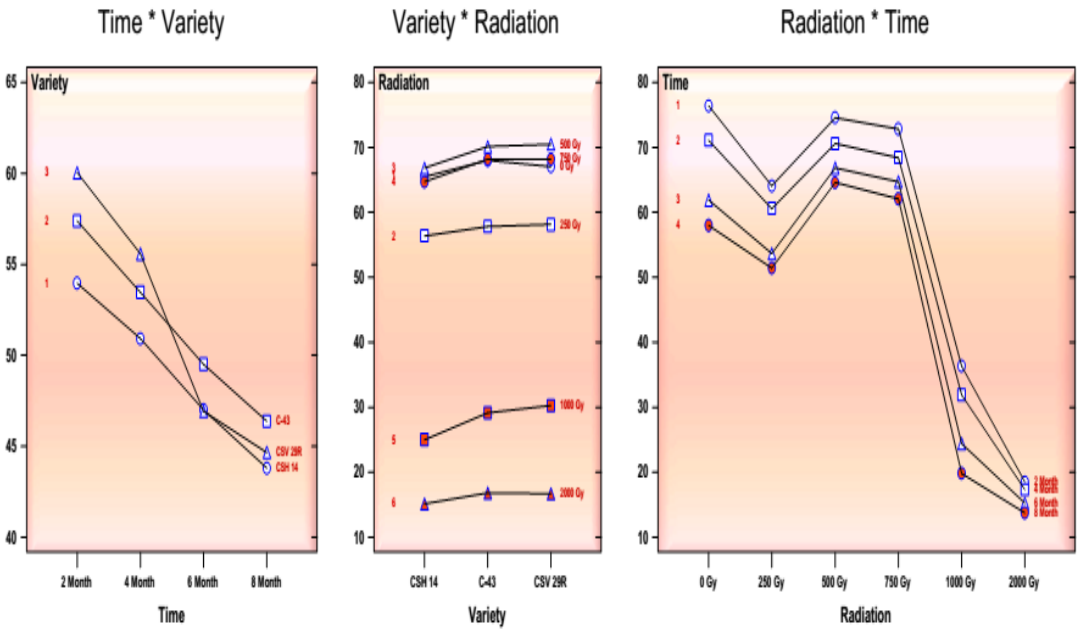

Fig. 4.11b. Field emergence as influenced by the interactions among storage period, gamma doses and varieties.

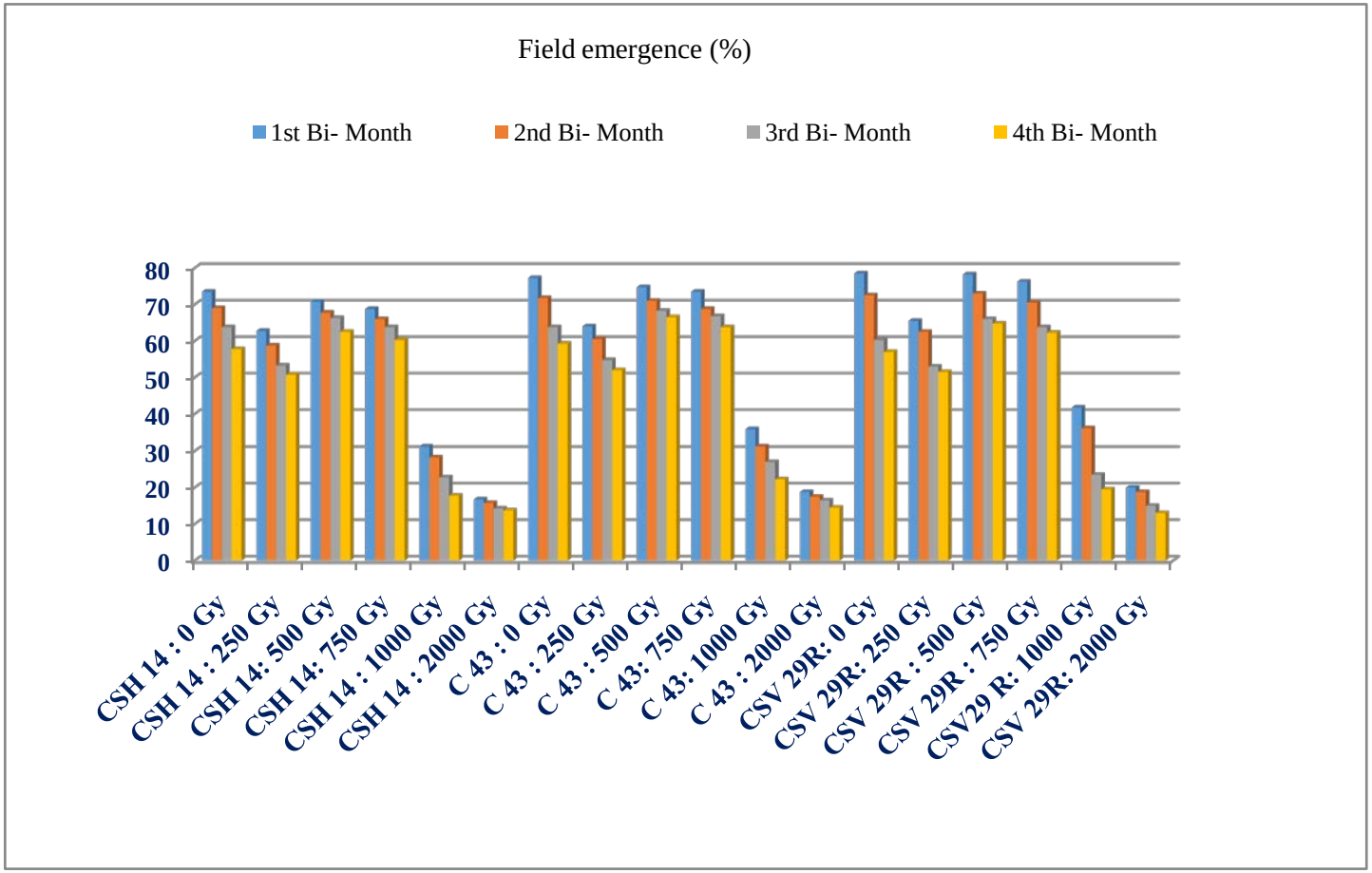

Fig.4.11 c: Field emergence as influenced by the interaction among storage period x gamma doses x varieties

highest mean germination per cent of 78.0 was recorded which got reduced to 62.0 per cent at the end of 4th bi-month period where reduction of 21.0 per cent was observed.

Similarly gamma doses also exhibited profound influence on germination percentage. 500 and 750 Gy doses exhibited maximum germination percentage of 75 and 73 percent which were significantly higher compared to other doses (Table 4.15). Doses of 2000 Gy recorded lower germination of 61 per cent.Significant influence of varieties on germination percentage was observed. Highest germination was noticed in CSV 29R (71%), followed by C 43 (70 %) and the lowest germination percentage was observed in CSH 14 (68%) (Figure 4.10a).

As per the results, significant differences were observed among the treatment combinations of varieties and gamma dose in response to storage under ambient conditions. Information on seed germination behaviour, viability and longevity of seeds under ambient conditions is needed to ascertain the storability and to prevent stand failure in the field on sowing (Dhakal and Pandey, 2001). The weather data provided in Annexure (I) indicated considerable fluctuations during the period of storage in terms of temperature and relative humidity.

Singh and Singh (1992) suggested that seed moisture and temperature are the two main factors determining the seed performance during storage. However, in the present study apart from these abiotic factors, storage time, gamma radiation dose and varieties were also found to be significantly influencing germination percentage under ambient storage conditions. The influence of gamma dose on sorghum seed germination during storage was evident from the results. Gamma dose of 500 Gy and 750 Gy recorded highest percentage of germination (83% and 81%) after first bimonthly evaluation and maintained highest germination values even after fourth bimonthly period by recording 67 and 66 per cent respectively. These results were in conformity with the findings of Chaoudhary(2002) who reported that when the local cultivar of the Lentil seeds was irradiated with gamma doses of 0.1, 0.2, 0.5, and 1.0 2.0 kGy exhibited inhibited germination at higher doses after 12 months.

Further, the results were in accordance with findings of Wang and Yu (2011) who reported that after 22 months of long-term storage, germination rates of irradiated rice variety Zhenong at 2 and 5 k Gy were 86 % and 84 % respectively which were higher than that of non-irradiated sample (73%). These enhanced germination rates of

irradiated samples were attributed to self-repair mechanism of irradiated organism. This was further described as mitochondrial reaction to irradiation which temporarily promoted activity of biological processes, followed by a remarkable increase in resistance to irradiation and /or capacity for radiation repair and/or stimulatory effect due to activation of RNA synthesis (Kuzin *et al*., 1975) or protein synthesis (Kuzin *et al*., 1976).

Field emergence gives accurate and reproducible result in predicting the planting value in field condition. As per the result of present study, field emergence was linearly associated with germination and seedling vigour index under lab condition. Significant decrease in field condition during storage period was observed as indicated in Table 4.17. The mean field emergence deceased from 57.0 percent at the end of 1st bi- month to 45.0 percent at the end of 4th bi-month of storage.Similarly, gamma doses had significant influenced on field emergence during storage. 500 Gy dose recorded 69 per cent mean field emergence which was significantly higher over other treatments (Fig. 4.11a). Lowest field emergence of 16 per cent was observed at 2000 Gy. Results were presented in Table 4.17.Varieties also exhibited significant difference in expression of field emergence (Fig 4.11 a). CSV 29R and C43 recorded highest field emergence (52). Lowest field emergence of 49 per cent was noticed in CSH 14 during storage period.

Interaction effect of gamma doses and varieties were significant during all bi- monthly interval of storage. The field emergence ranged from 17 percent (CSH 14/ 2000 Gy) to 78 per cent (CSV 29R/0 Gy and 500 Gy) after 1st bi-month of storage while it ranged from 13 per cent (at 2000 Gy in CSV 29R) to 66 percent (C 43/ 500 Gy) at the end of 4th bi- month. Results were given in Table 4.18.

Speed of germination is an indirect indicator of seed viability and seed vigour. Estimates of speed of germination could be applied with reasonable accuracy to the seeds under the influence of natural ageing to predict the storability.

Mean speed of germination values in seven treatments *viz.*, CSH 14/250, 500, 750 Gy, C 43/ 500, 750 Gy and CSV 29R/ 500, 750 Gy were statistically significant at the end of 1st bi-month of storage (Table 4.2). However, the treatments which recorded higher speed of germination after 1st bi-month had maintained and documented nearvalues at the end of 2nd bi-month and the same treatments recorded higher speed of germination even up to 4th bi-month. Speed of germination ranged from 20.9 (CSV 29R/ 2000 Gy) to 38.3 (CSH 14/ 500 Gy) in 2nd bi-month, from 21.1 (CSV 29R/ 2000

Table 4.19. Speed of Germination as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Speed of Germination**
1st Bi-month	37.4
2nd Bi-month	30.9
3rd Bi-month	25.8
4th Bi-month	22.8
S Em ±	0.130
CD (0.05)	0.257
Influence of Gamma radiation	
Gamma Dose	**Speed of Germination**
0 Gy	29.6
250 Gy	28.2
500 Gy	33.7
750 Gy	32.6
1000 Gy	26.8
2000 Gy	24.6
S Em ±	0.160
CD (0.05)	0.315
Influence of Varieties	
Varieties	**Speed of Germination**
CSH 14	31.6
C 43	28.6
CSV 29R	27.5
S Em ±	0.113
CD (0.05)	0.223

Table 4.20. Speed of Germination as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	40.9	37.4	37.0	**38.5**	32.6	30.3	27.9	**30.3**	29.8	26.3	25.6	**27.3**	25.6	20.8	20.5	**22.3**
250 Gy	41.1	33.5	35.2	**36.6**	33.7	28.7	26.3	**29.6**	26.7	24.8	22.8	**24.8**	24.1	21.3	19.9	**21.8**
500 Gy	44.5	40.4	41.4	**42.2**	38.3	34.3	37.5	**36.7**	32.5	29.3	25.6	**29.2**	30.6	26.4	23.4	**26.9**
750 Gy	43.3	39.5	40.5	**41.1**	37.4	33.3	36.2	**35.7**	31.5	28.3	24.6	**28.2**	29.4	24.7	22.2	**25.5**
1000 Gy	36.3	32.6	36.6	**35.2**	31.1	28.9	23.1	**27.8**	24.4	24.4	21.2	**23.4**	21.7	22.0	18.9	**20.9**
2000 Gy	29.2	30.7	32.5	**30.8**	28.2	27.8	20.9	**25.7**	24.2	21.7	21.1	**22.4**	21.6	18.2	18.7	**19.6**
MEAN	**39.3**	**35.7**	**37.2**	**37.4**	**33.6**	**30.6**	**28.7**	**31.0**	**28.2**	**25.9**	**23.5**	**25.9**	**25.5**	**22.3**	**20.6**	**22.8**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.320**	**0.226**	**0.277**	**0.325**
CD (0.05)	**0.631**	**0.446**	**0.546**	**0.920**

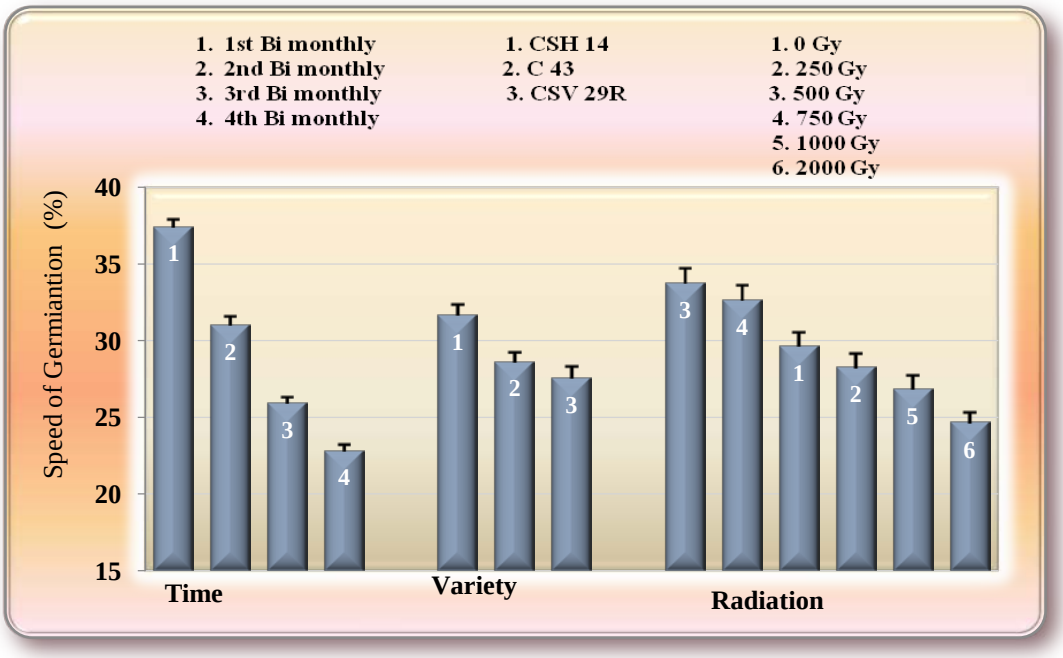

Fig. 4.12a:Speed of germination as influenced by storage period, gamma doses and varieties

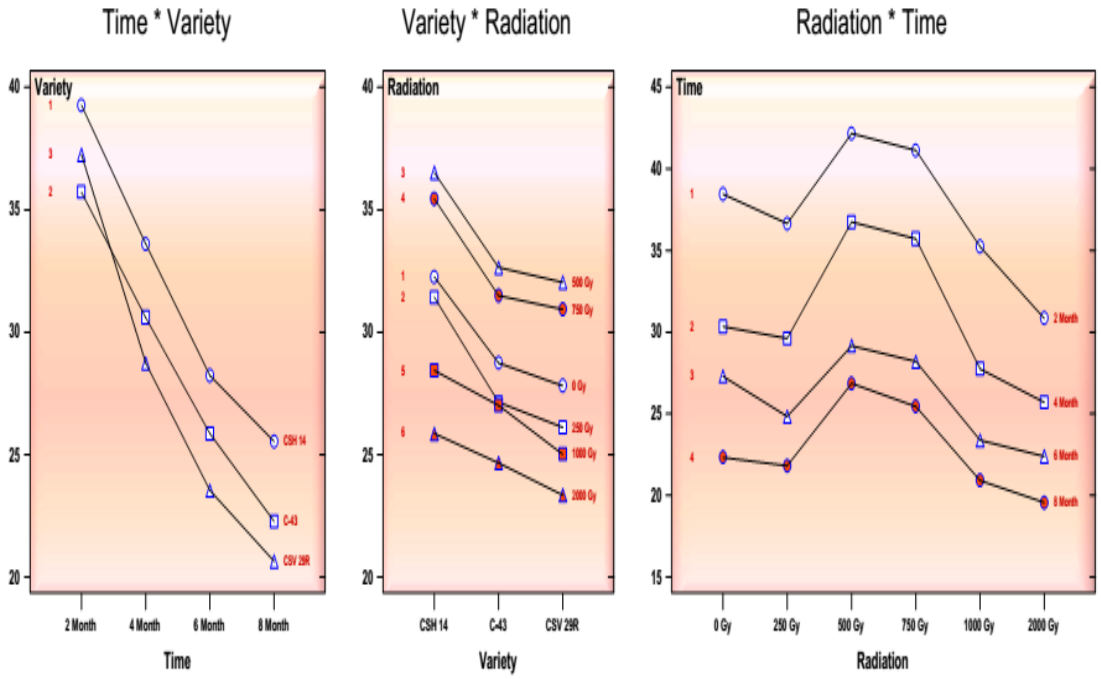

Fig. 4.12b: Speed of Germination as influenced by the interactions among storage period, gamma doses and varieties

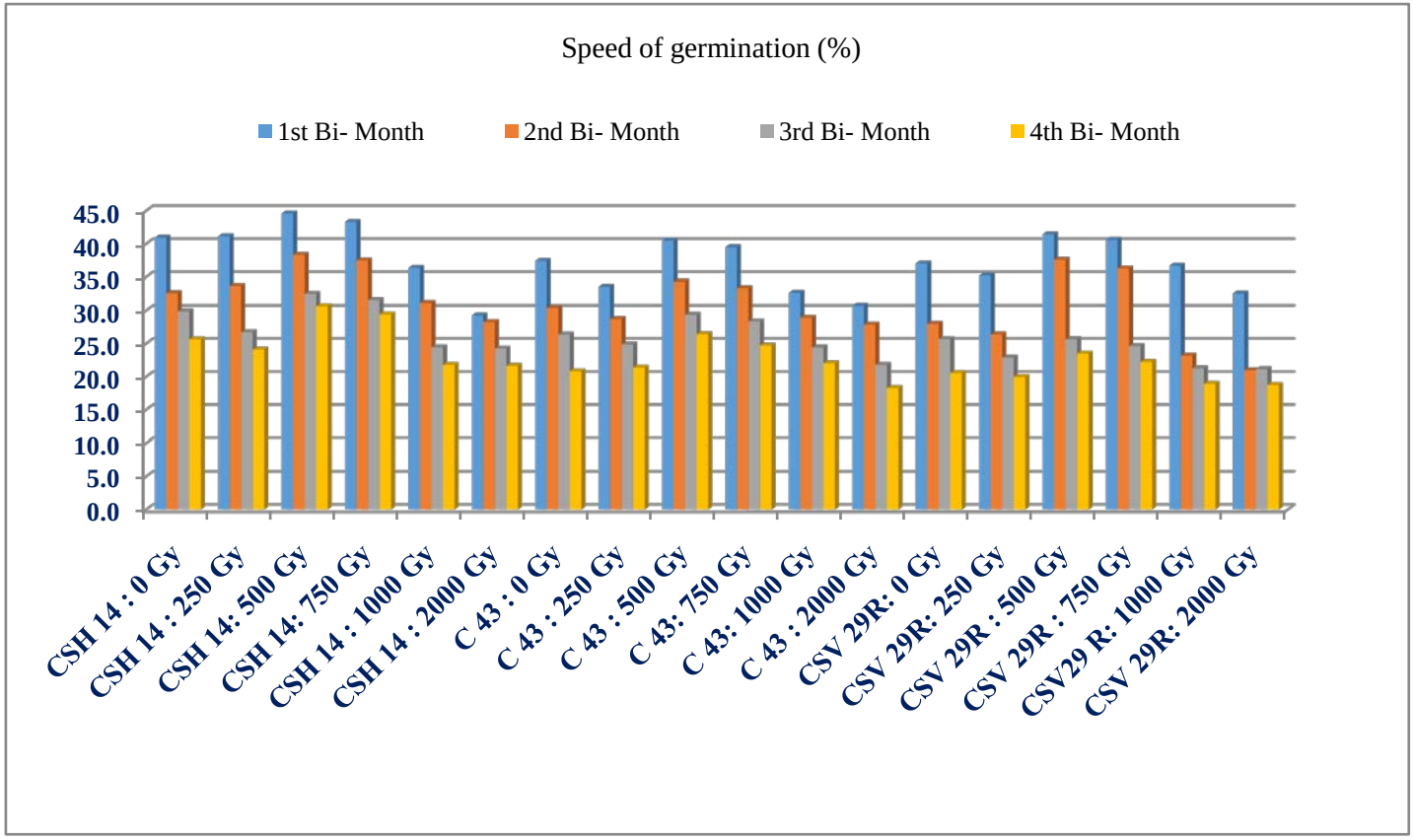

Fig.4.12 c: Speed of germination as influenced by the interaction among storage period x gamma doses x varieties

Gy) to 32.5 (CSH 14/ 500 Gy) in 3rd bi-month and from 18.2 (C 43/ 2000 Gy) to 30.6 (CSH 14/ 500 Gy) in 4th bi-month. Among significant interaction effects (Table 4.20, Fig. 4.12c) maximum speed of germination were recorded at CSH 14/500 Gy after 1st bi-month and decreased to 30.6 at the end of 4th bi-month. But CSV 29R/500 Gy showed 41.4 at 1st bi-month and recorded 23.4 at the end of the 4th bi-month.

Considering the storage period, lowest speed of germination (22.8) was recorded after 4th bi-month and highest speed of germination was registered after first bi-months of storage (37.4). The results were presented in Table 4.19.

Gamma doses also exercised significant influence on speed of germination. Highest speed of germination was recorded at 500 Gy and 750 Gy gamma dose (33.7 and 32.6). Lowest speed of germination was recorded at 2000 Gy (24.6) over all periods of storage(Table 4.19, Fig. 4.12a).Further, effect of varieties were significant for speed of germination during storage. The results were graphically represented in Figure 4.12a. Maximum speed of germination was recorded in CSH 14 (31.6) followed by C 43 (28.6). Lowest speed of germination was recorded in CSV 29R (27.5).

In this study, storage had a profound influence on reducing the speed of germination from 37.4 to 22.8 during nine month of storage. Further, highest mean value of 33.7 for the speed of germination was recorded at 500 Gy gamma dose.

Perusal of results also indicated that speed of germination was positively associated with germination. At 1000 Gy and 2000 Gy speed of germination was low due to lower germination levels which could be attributed to diminished metabolic activity and increased susceptibility to stress induced by gamma irradiation and natural ageing (Rao, 1990) Higher speed of germination up to 500 Gy was presumably due to higher germination caused by stimulatory effect at lower gamma doses (Grabe, 1964).

4.4.2 Seedling parameters

In addition to germination attributes for evaluating the storability of irradiated sorghum seed of test variety, seedling parameters were also studied in detail at four bimonthly intervals up to a period of nine months under specified storage conditions. Dimensions of root, shoot and vigour index in terms of length formed a major part of this work in objectively ascertaining the influence of gamma doses on sorghum variety during storage.

The mean root length ranged from 1.3 cm (CSH 14 / 2000 Gy) to 14.8 cm (C 43/0 Gy) after first bimonthly interval and from 0.4 cm (CSH 14 / 2000 Gy) to 9.9 cm (C 43 / 0 Gy) at 4th bi-month completion respectively (Table 4.2). The mean reduction in root length at the end of nine months of storage was 36.0 per cent (Table 4.22). Similarly, mean values for shoot length ranged from 1.8 cm (CSH 14 /2000Gy) to 15.6 cm (CSV 29R / 500 Gy) after first bimonthly interval and from 1.2 cm in C 43 / 2000 Gy to 10.6 cm CSV 29R /500 Gy after 4th bi-month (Table 4.24) recording a percentage reduction of 33.3 in mean shoot length at the end of the nine month storage period (Table 4.24).

Significant influence of gamma doses on root and shoot during storage was recorded.A 500 Gy dose 9.3 cm mean root length and shoot length of 10.6cm were registered, which were significantly higher than 250, 750, 1000 and 2000 Gy but were less than 0 Gy. Results were presented in Table 4.21. Table 4.23, Fig. 4.13a and Figure 4.14a.

Analysis of results revealed that varieties had significant influence on root and shoot length (Fig 4.13a and 4.14a). Highest root length of 7.0 cm was recorded by CSV 29R followed by CSH 14 (5.6 cm). Maximum shoot lengths of 8.1 cm were recorded in CSV 29R followed by CSH 14 and C 43(6.0 cm). The data indicated that root length and shoot length were more sensitive in the varieties CSV 29R to storage under the influence of gamma radiation.

Variation in root and shoot length due to interaction effects were significant (Table 4.22 and Table 4.24). Interaction effect on CSV 29R / 0 Gy recorded highest root length of 14.5 cm after 1st bi-month of storage and continued up to 4th bi-month interval by recording root length of 9.9 cm. Where as, the mean root length of 7.5 cm after 1st bi-month was reduced to 4.8 cm after 4th bi-month. Root length had decreased with increase in storage period and gamma dose. Increase in peroxidase activity was determined to be one of biochemical changes involved with low doses of gamma irradiation (Croci *et al*., 1991). Moreover, peroxidase was known to be involved in growth and cellular differentiation. Further, Choudhary (2002) reported that gamma radiation had little effect on reduction of root length in long term storage (12 months) when irradiated with doses between 0.1 to 0.5 kGy. He mentioned that, the recovered cells easily tolerated minimum dose and put forth normal development of root and shoot. In present study also the results were in close conformity with this finding as the root length was less effected at gamma doses 500 and 750 Gy in all varieties, except

Table 4.21. Root length (cm) as storage influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Root length (cm)**
1st Bi-month	7.5
2nd Bi-month	6.3
3rd Bi-month	5.4
4th Bi-month	4.8
S Em ±	0.030
CD (0.05)	0.059
Influence of Gamma radiation	
Gamma Dose	**Root length (cm)**
0 Gy	11.4
250 Gy	4.2
500 Gy	9.3
750 Gy	8.4
1000 Gy	1.5
2000 Gy	1.1
S Em ±	0.037
CD (0.05)	0.072
Influence of Varieties	
Varieties	**Root length (cm)**
CSH 14	5.6
C 43	5.4
CSV 29R	7.0
S Em ±	0.026
CD (0.05)	0.051

Table 4.22. Root length (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	13.5	14.2	14.5	**14.1**	12.4	12.6	12.3	**12.5**	9.6	9.6	10.6	**10.0**	8.4	9.9	9.9	**9.3**
250 Gy	4.6	5.2	6.5	**5.5**	3.4	4.0	5.7	**4.4**	2.5	3.8	5.4	**3.9**	2.2	2.7	4.2	**3.1**
500 Gy	10.5	9.7	13.7	**11.4**	9.6	7.9	11.3	**9.7**	7.9	7.7	10.2	**8.6**	7.4	6.2	9.3	**7.7**
750 Gy	9.5	8.3	13.2	**10.4**	8.1	6.7	10.	**8.4**	7.6	6.3	9.5	**7.9**	7.3	5.3	8.2	**7.0**
1000 Gy	2.4	1.8	2.1	**2.2**	1.7	1.0	2.0	**1.6**	1.2	1.0	1.5	**1.3**	0.9	0.8	1.5	**1.1**
2000 Gy	1.2	1.7	1.7	**1.6**	1.2	1.2	1.6	**1.4**	0.4	0.8	1.4	**0.9**	0.4	0.8	1.3	**0.9**
MEAN	**7.0**	**6.9**	**8.7**	**7.5**	**6.1**	**5.6**	**7.3**	**6.3**	**4.9**	**4.9**	**6.5**	**5.4**	**4.5**	**4.3**	**5.7**	**4.8**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.074**	**0.052**	**0.064**	**0.075**
CD (0.05)	**0.146**	**0.103**	**0.146**	**0.214**

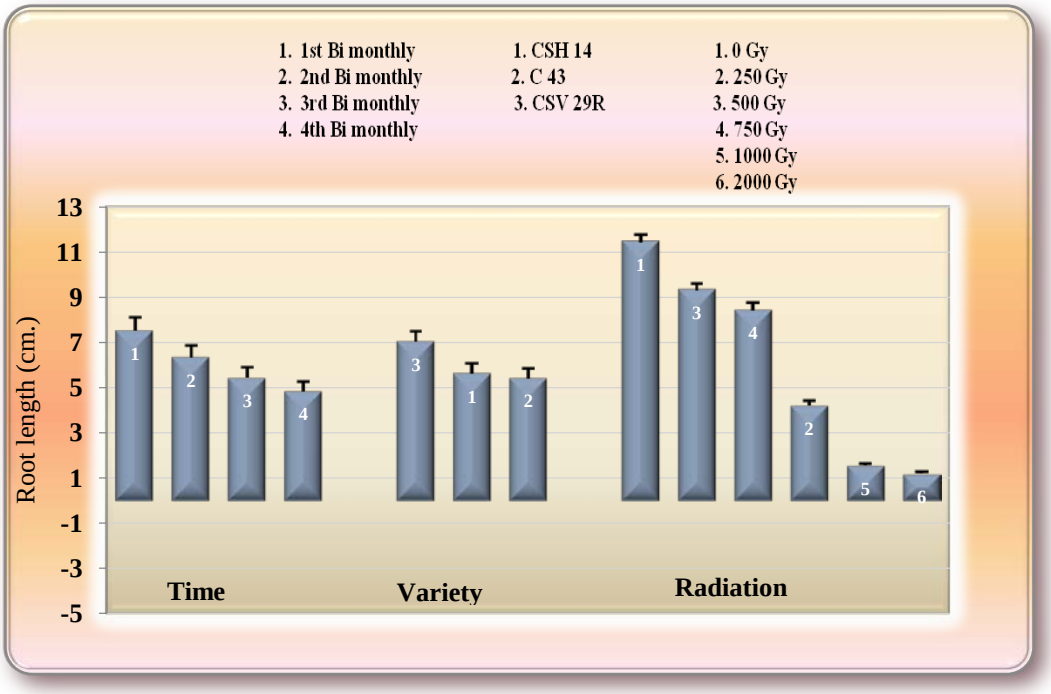

Fig. 4.13a: Root length as influenced by storage period, gamma doses and varieties

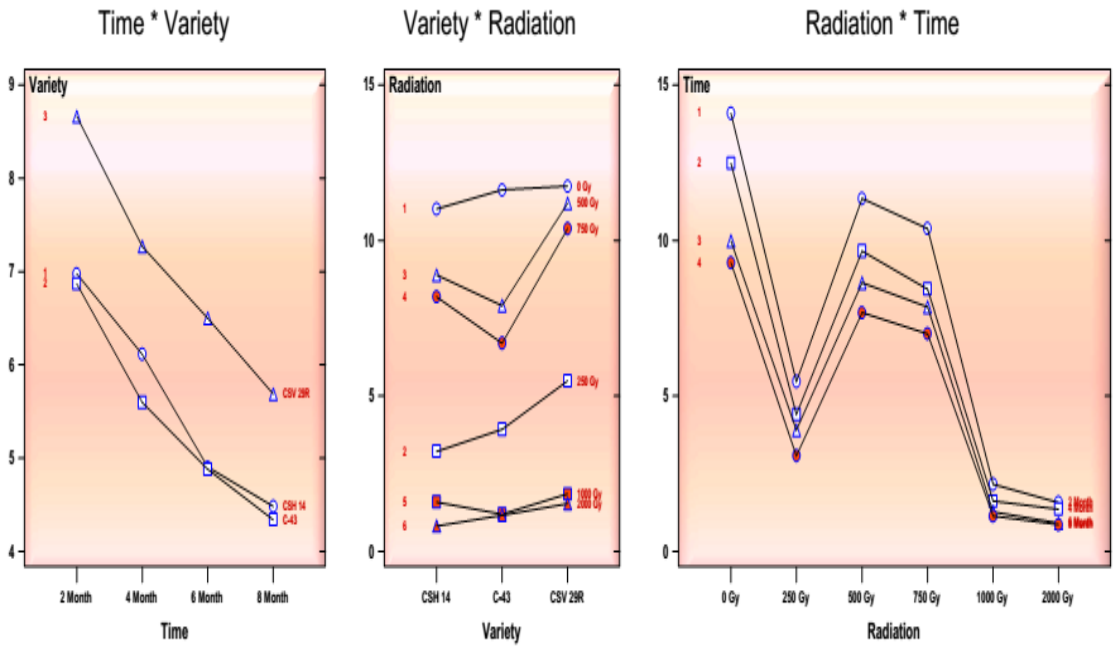

Fig.4.13b: Root length as influenced by the interactions among storage period, gamma doses and varieties

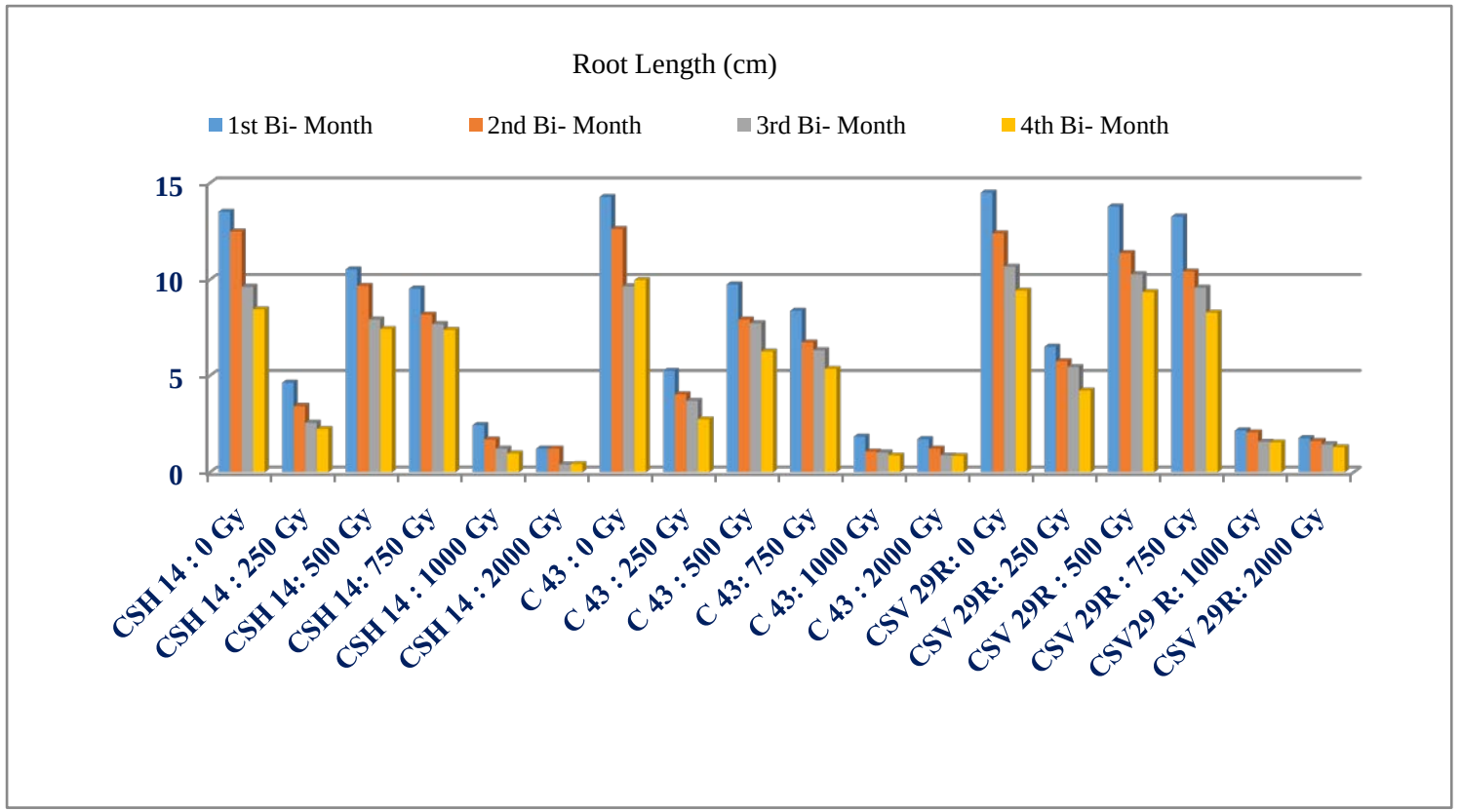

Fig.4.13 c: Root length as influenced by the interaction among storage period x gamma doses x varieties

Table 4.23. Shoot length (cm) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Shoot length (cm)**
1st Bi-month	8.0
2nd Bi-month	7.1
3rd Bi-month	6.3
4th Bi-month	5.3
S Em ±	0.046
CD (0.05)	0.091
Influence of Gamma radiation	
Gamma Dose	**Shoot length (cm)**
0 Gy	11.9
250 Gy	4.9
500 Gy	10.6
750 Gy	9.0
1000 Gy	2.1
2000 Gy	1.8
S Em ±	0.056
CD (0.05)	0.111
Influence of Varieties	
Varieties	**Shoot length (cm)**
CSH 14	6.0
C 43	6.0
CSV 29R	8.1
S Em ±	0.040
CD (0.05)	0.079

Table 4.24. Shoot length (cm) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	15.4	13.9	15.6	**15.0**	12.6	12.9	13.7	**13.1**	10.4	10.5	11.7	**10.9**	8.4	8.4	9.6	**8.8**
250 Gy	4.4	5.3	7.6	**5.8**	4.2	4.8	7.3	**5.4**	3.8	4.0	6.6	**4.8**	2.8	3.3	5.6	**3.9**
500 Gy	10.7	10.3	15.6	**12.2**	9.9	10.1	13.6	**11.2**	9.2	8.4	12.7	**10.1**	8.6	7.9	10.7	**9.1**
750 Gy	8.4	9.3	14.8	**10.8**	7.4	7.8	12.5	**9.2**	7.5	7.8	11.0	**8.8**	6.4	6.7	8.5	**7.2**
1000 Gy	2.5	2.5	2.6	**2.5**	2.4	1.9	2.6	**2.3**	1.8	1.6	2.7	**2.0**	1.5	1.5	2.5	**1.8**
2000 Gy	1.9	2.2	2.3	**2.1**	1.7	1.7	2.3	**1.9**	1.6	1.4	2.5	**1.8**	1.3	1.2	2.3	**1.6**
MEAN	**7.2**	**7.2**	**9.7**	**8.1**	**6.4**	**6.5**	**8.7**	**7.2**	**5.7**	**5.6**	**7.8**	**6.4**	**4.8**	**4.8**	**6.5**	**5.4**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.113**	**0.080**	**0.098**	**0.124**
CD (0.05)	**0.223**	**0.158**	**0.193**	**0.350**

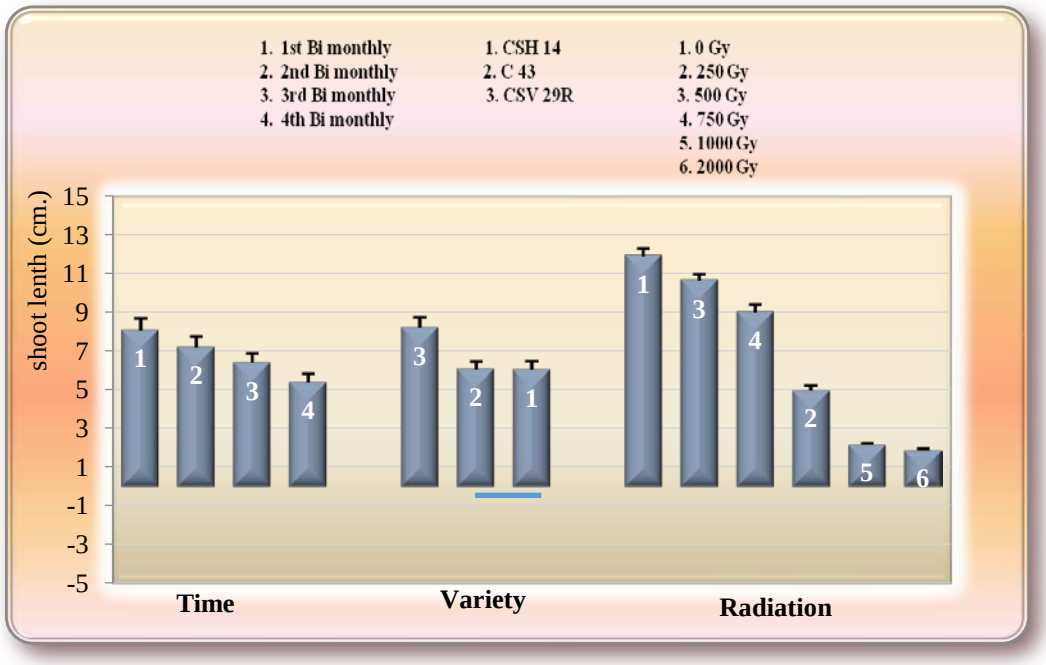

Fig. 4.14a: Shoot length as influenced by storage period, gamma doses and varieties

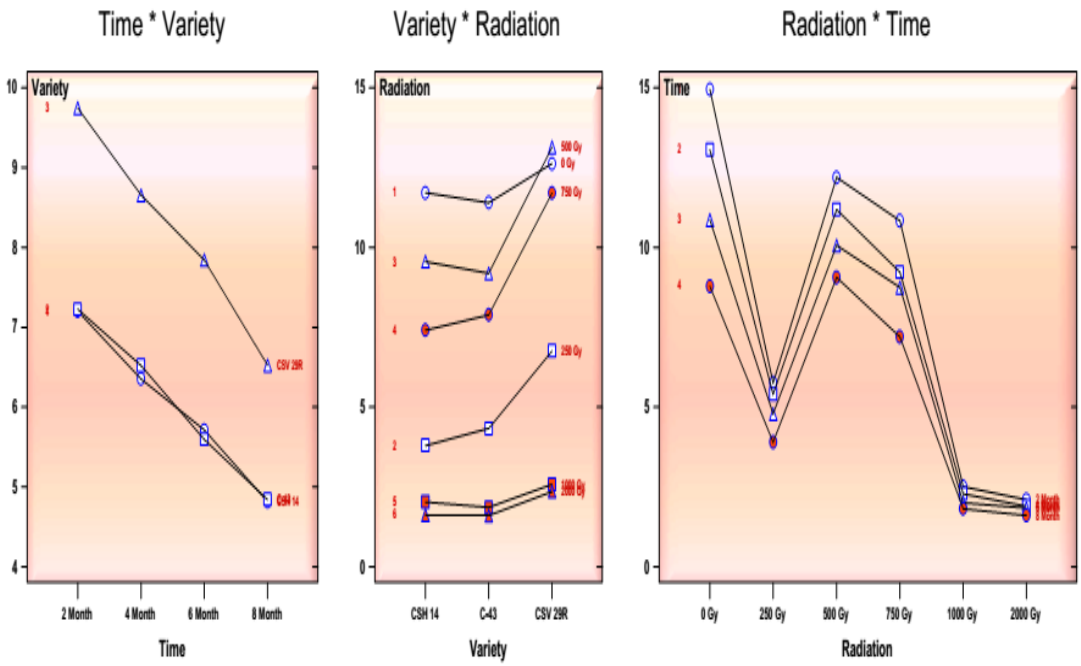

Fig. 4.14b: Shoot length as influenced by the interactions among storage period, gamma doses and varieties

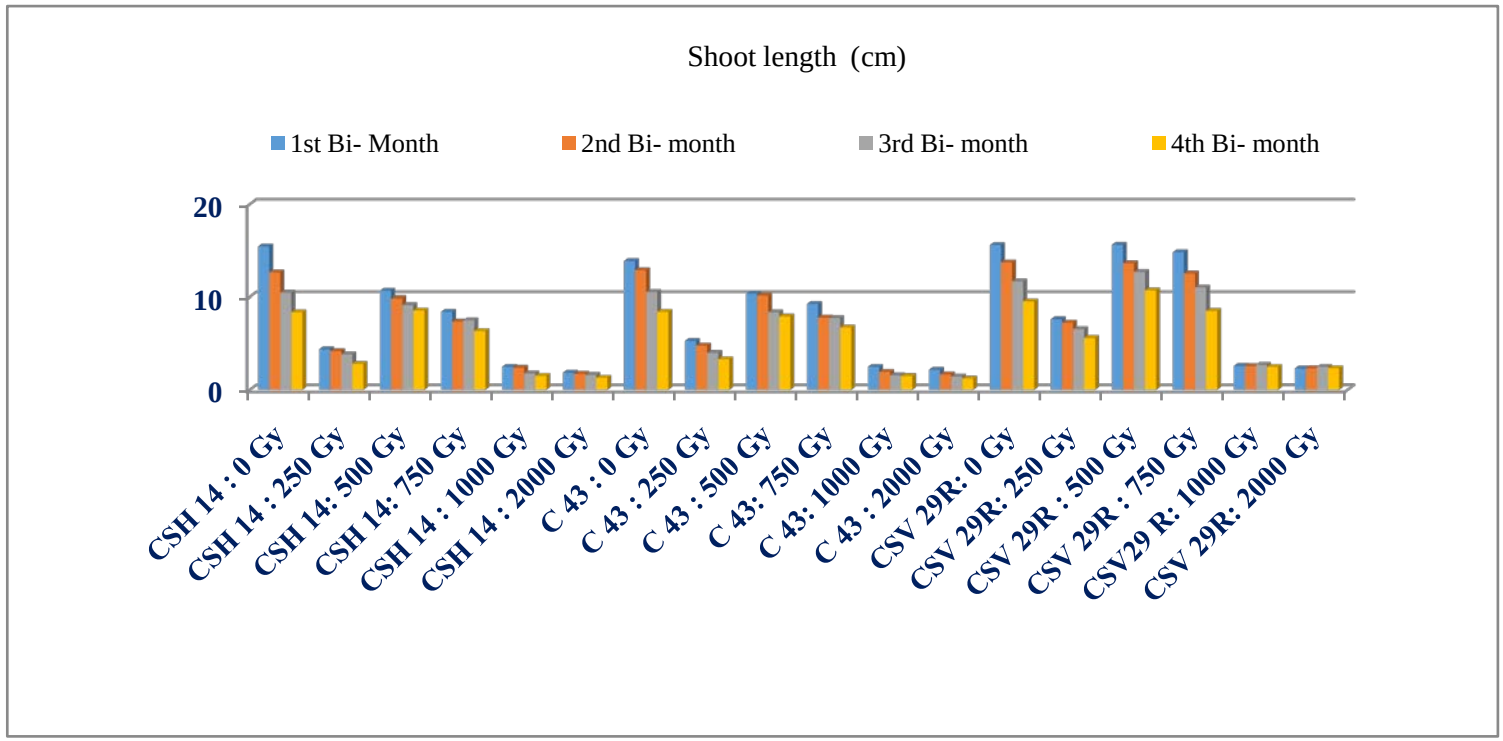

Fig.4.14 c: Shoot length as influenced by the interaction among storage period x gamma doses x varieties

CSV 29R when compared with root length reduction at 0 Gy after 4th bi-month interval.

Marcu *et al*. (2013) studying plant germination,growth and development, and biochemical characteristics of maize. Maize dry seeds are ex-posed to a gamma source at doses ranging from 0.1 to 1 KGy. Our results show that the germination potential, expressed through the final germination percentage and the germination index, as well as the physiological parameters of maize seedlings (root and shoot lengths) decreased by increasing the irradiation dose. Moreover, plants derived from seeds exposed at higher doses (≤0.5 K Gy) did not survive more than 10 days. Biochemical differences based on photosynthetic pigment (chlorophyll *a*, chlorophyll *b*, carotenoids) content revealed an inversely proportional relationship to doses of exposure. Furthermore, the concentration of chlorophyll *a* was higher than chlorophyll *b* in both irradiated and non-irradiated seedlings. Electron spin resonance spectroscopy used to evaluate the amount of free radicals induced by gamma ray treatment demonstrates that the relative concentration of radiation-induced free radicals depends linearly on the absorbed dose.

Seedling vigour estimates are commonly evaluated for their ability to predict crop performance particularly field emergence, plant uniformity and storability (Dhakal and Pandey, 2001). Vigour indices arrived at in the present study indicated significant alterations among all interaction effects under the influence of nano scale particles and gamma doses during storage. Further, vigour index estimates are inclusive of variability for germination percentage and seedling dimensions. Since, germination and seedling dimensions were significantly influenced by gamma dose, the realized vigour index values were due to differences in performance with regard to germination and seedling dimensions.

The data from 1st bi-month of storage revealed that, mean vigour index ranged from 123 (CSH 14 / 2000 Gy) to 1332 (CSV 29R / 500 Gy). Among the treatments which exhibited significantly superior vigour index after 1st bi-monthly interval and maintained till the end of ninth month storage period are CSH 14/ 500 Gy, C 43/ 500 Gy and CSV 29R/ 500, 750 Gy which were important (Table 4.26). Similarly, values of vigour index ranged from 63 (C 43 / 2000 Gy) to 759 (CSV 29R/ 500 Gy) at the end of 4th bi-month of storage. It was interesting to note that during first and second bi-month intervals seedling vigour index at 0 Gy was more than all other gamma doses in all

Table 4.25. Seedling vigour index l as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Seedling vigour index l**
1st Bi-month	659
2nd Bi-month	542
3rd Bi-month	434
4th Bi-month	349
S Em ±	4.424
CD (0.05)	8.327
Influence of Gamma radiation	
Gamma Dose	**Seedling vigour index l**
0 Gy	859
250 Gy	362
500 Gy	814
750 Gy	673
1000 Gy	152
2000 Gy	115
S Em ±	5.174
CD (0.05)	10.198
Influence of Varieties	
Varieties	**Seedling vigour index l**
CSH 14	432
C 43	443
CSV 29R	612
S Em ±	3.359
CD (0.05)	7.211

Table 4.26. Seedling vigour index l as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	1267	1157	1307	**1244**	886	927	1026	**947**	661	674	777	**704**	503	518	601	**541**
250 Gy	346	421	620	**462**	314	366	560	**413**	255	269	454	**326**	175	207	357	**246**
500 Gy	868	872	1332	**1024**	768	798	1093	**886**	649	607	913	**723**	569	541	759	**623**
750 Gy	673	766	1231	**890**	567	603	970	**713**	512	543	763	**606**	411	447	590	**483**
1000 Gy	184	187	202	**191**	171	140	189	**167**	117	104	180	**134**	93	93	158	**115**
2000 Gy	123	144	156	**141**	108	108	153	**123**	95	87	157	**113**	63	63	127	**84**
MEAN	**577**	**591**	**808**	**659**	**469**	**490**	**665**	**542**	**382**	**381**	**541**	**434**	**302**	**312**	**432**	**349**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**10.348**	**7.317**	**8.961**	**10.546**
CD (0.05)	**20.396**	**14.422**	**17.663**	**29.897**

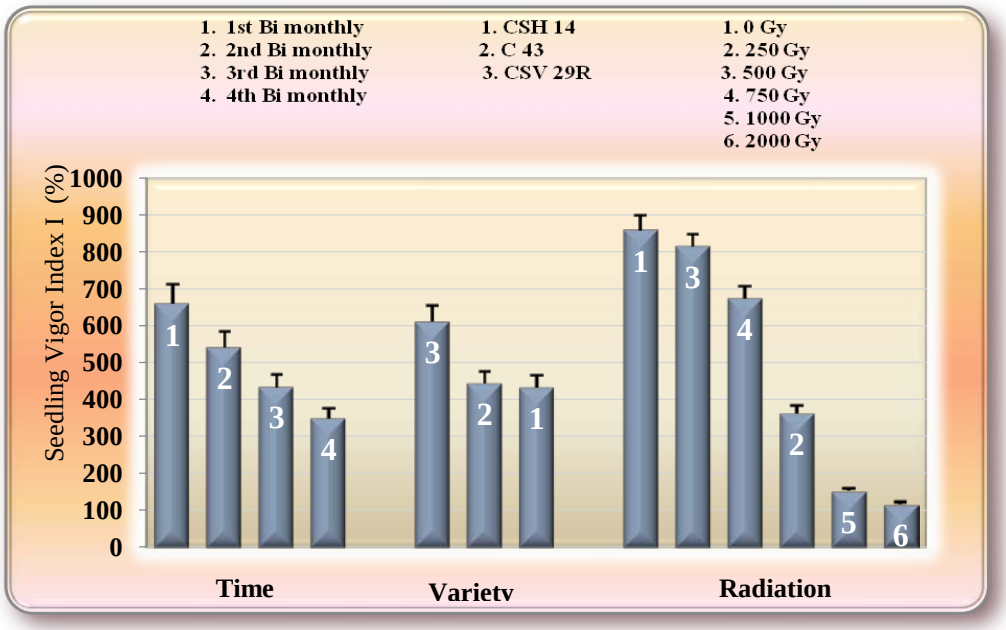

Fig. 4.15a: Seedling vigour Index I as influenced by storage period, gamma doses and varieties

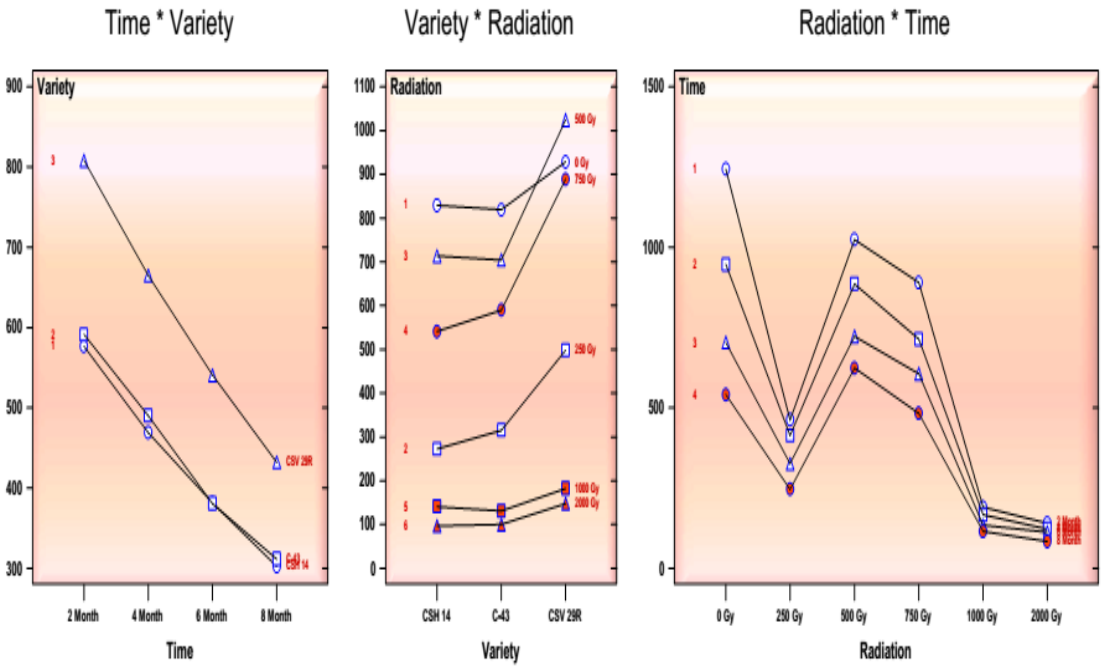

Fig. 4.15b: Seedling vigour Index I as influenced by the interactions among storage period, gamma doses and varieties

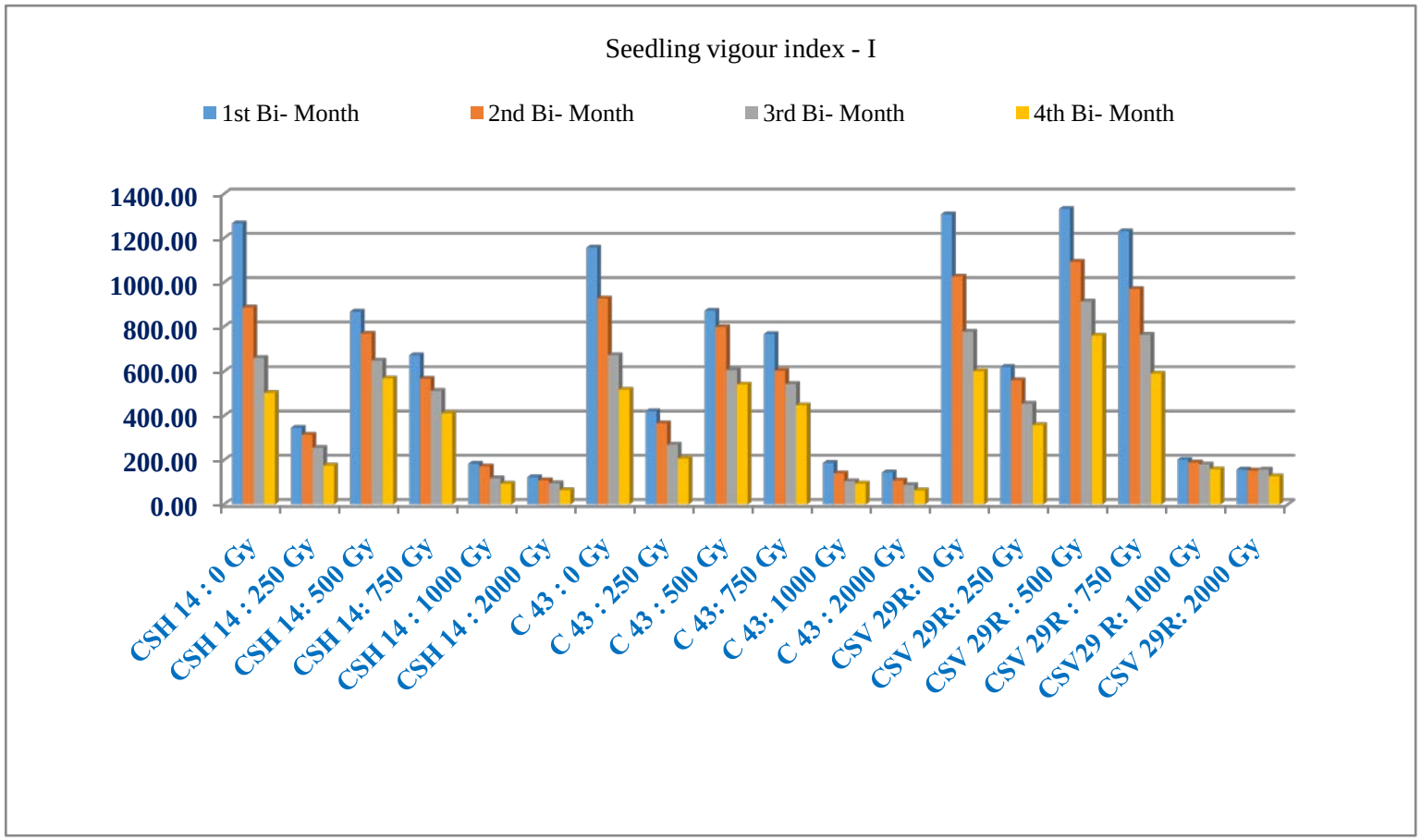

Fig.4.15 c: Seedling vigour index I as influenced by the interaction among storage period x gamma doses x varieties

selected varieties. However, in respect of observations made during third and fourth bi-monthly interval, seedling vigour index at 0 Gy were less than 500 Gy gamma dose in all genotypes. Differences in vigour index due to interaction effects were significant. The results are given in Table 4.26 and depicted in Fig 4.15c.

Significant influence of storage period in the reduction of vigour index was evident from the data during four bi-monthly intervals of storage (Table 4.25). As the storage period progressed from 3rd month to 9th month, the vigour index has also declined from 659 to 349 recording a reduction of 47.0 per cent. Further, 500 Gy recorded marginally higher vigour index of 814 which was significantly higher over other doses. Lowest vigour index (115) was noticed at 2000 Gy indicating its detrimental effect on germination percentage and seedling dimensions (Table 4.25).

The influence of varieties on vigour index was assessed and it was found to be significant. Highest vigour index recorded in CSV 29R (612) and the lowest was noticed in CSH 14 (432). The results are presented in Table 4.26. The influence of storage, gamma doses and varieties are graphically represented in Fig 4.15a.

Gamma irradiation was reported to induce oxidative stress with over production of Reactive Oxygen Species (ROS) such as superoxide radicals, hydroxyl radicals and hydrogen peroxides, which react rapidly with almost all structural and functional organic molecules including proteins, lipids and nucleic acids causing disturbances of cellular metabolism (Salter and Hewitt, 1992). To avoid oxidative damage, plants have evolved various protective mechanisms to counteract the effects of ROS in cellular metabolism. One of the protective mechanisms was the enzymatic system, which operate with the sequential and simultaneous actions of a number of enzymes including peroxidase (Kovacs and Keresztes, 2002) which removes peroxides especially lipid hydro peroxides.

Kara *et al.* (2015) In this research study, the dose of gamma radiation on seed germination of two*Hordeum vulgare*Tokak-157/37 barley kind and Karahan-99 wheat *Triticum aestivum*, and the mechanisms of the dose required to maximizing the rate and percentage of germination and seedling, growth of root TAEK was conducted in Ankara. The barley and wheat seeds whose germination per cent is 98 % has been irradiated with 9 different doses between 0-600Gy in the centre of ^{60}Co which has 1.92 kGy/h powers. At the laboratory experiment it has been seen that the percentage of germination of rising radiation doses has no effect on M_1 generation, but after

diminishing of root length and seedling height with rising radiation doses it has been determined that the growth of the first leaf has stopped on the 14th day and this event has been given importance statistically for Tokak-157/37 barley kind, 50 % efficient dose has been determined as ED50 485 Gy, for Karahan-99 wheat kind , 50 % efficient dose has been determined as ED50 370 Gy.

In this context, maximum decline in vigour index at 0 Gy during storage may be attributed to decreased mobilisation of reserve substances during germination of seed subjected to ageing. However, considering the better performance of gamma interactions in terms of retaining vigour index till the end storage period at lower doses (at 500 and 750 Gy). It could be stated that higher scavenging activity of free radicals by defence mechanism could have resulted in mobilisation of higher amount of seed reserves which could have supported better seedling dimensions upon enhanced germination rates even after 4th bi-month of storage.

4.4.3 Biochemical parameters

Assessment of membrane integrity through estimation of electrical conductivity of seed leachates, dehydrogenase activity by tetrazolium test, alpha amylase activity, starch, protein, fat and ash content of seed, gives a reflection about changes in seed vigour associated with storage under the influence of seed treatments like gamma ray exposure. Studies on biochemical mechanisms in long term stored seed can provide an important link to the understanding of storage effects on seed quality. Electrical conductivity (EC) is a direct measure of membrane integrity and is suggested as an indicator of seed vigour (Vieira *et al*., 2001). The present study provided an apparent evidence for deteriorative changes during ageing of sorghum seeds obtained from combination of various gammadosesand varieties with selected grain type under the influence of storage.

At the end of 1st bi-month of storage, the EC values ranged from 36.3 µS cm^{-1} (CSV 29R / 250 Gy) to 68.4 µS cm^{-1} (CSV 29R / 2000 Gy). The mean values ranged from 81.5 µS cm^{-1} (CSH 14 / 250 Gy.) to 114.7 µS cm^{-1} (C 43 / 2000 Gy) at the end of 2nd bi- month of storage while, after 3rd bi-month highest EC of 201.8 µS cm^{-1} was recorded in respect of C 43 / 2000 Gy and lowest value of 105 µS cm^{-1} at CSV 29R /25 0 Gy. After nine months of storage the leakage of leachiest was low (124.5 µS cm^{-1}) in case of C 43/ 250 Gy and highest value of 446.2 µS cm^{-1} in case of C 43/2000 Gy (Table 4.28, Fig. 4.16c).

Significant increase in electrical conductivity from first bimonthly storage to final bimonthly storage period was evident as per the results presented in Table 4.27. The mean EC values increased from 54 µS cm^{-1} to 241.7 µS cm^{-1} during the storage period. When the performance of gamma doses was examined, it was revealed that, significantly higher EC of 197.3 µS cm^{-1} was observed at 2000 Gy. However, 500 Gy and 250 Gy doses recorded lowest EC of 101.2 µS cm^{-1} and 98.9 µS cm^{-1} respectively. Study of significance of varieties on EC indicated low values (126.6 µS cm^{-1}) in CSV 29R. Highest electrical conductivity of 142.2 µS cm^{-1} recorded in C 43. Graphical representation of the mean data is furnished in Fig. 4.16a.

The decrease in the content due to degradation of food reserves like starch, protein and lipids which occurred during ageing could be one of the ill effects of loss of membrane integrity. Further, leaching of seed substrates during storage is believed to be related to metabolic activity of seeds. Deteriorating seeds would operate at low level of metabolic activity leading to higher degree of leakage, while seed with optimum metabolism utilize the seed reserves for various vital seed processes like germination and seedling growth. The probable reason could be the release of free fatty acids as a result of lipid peroxidation due to ageing which reacted with membrane lipids and ultimately destroyed the structure of cellular membranes and denatured the food reserves (Basavarajappa *et al*., 1991). Copeland and McDonald (1995) reported that continuous accumulation of free fatty acids culminated in a reduction of cellular pH and was detrimental to normal cellular metabolism. Furthermore, it denatured enzymes resulting in their loss of activity. Earlier, Ching and Craft (1968) stated that deterioration of seeds with ageing results in loss of viability and vigour during storage which is usually due to the changes in biochemical composition and results in leaching of electrolytes and other low molecular weight substances during imbibition. Earlier workers Zan and Brewbaker (1999) suggested that higher leachate conductivity was associated with inferior field germination and viability retention in storage.

At fourth bi-monthly interval in the present study the leakage of leachates was higher than earlier periods which may be attributed to reasons mentioned above which formed a part of ageing effects. This may be attributed to defence mechanism generated (against loss of membrane integrity) due to stress created after irradiation in which, polar lipids were degraded to generate free fatty acids and diacylglycerols, resulting in an eventual accumulation of TAG (Triacylglycerols) as a defence mechanism (Olsson, 1995 and Navari-Izzo *et al*., 1990).

Table 4.27. Electrical conductivity (µscm^{-1}) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Electrical conductivity (µscm^{-1})**
1st Bi-month	54.0
2nd Bi-month	97.7
3rd Bi-month	145.6
4th Bi-month	241.7
S Em ±	0.294
CD (0.05)	0.580
Influence of Gamma radiation	
Gamma Dose	**Electrical conductivity (µscm^{-1})**
0 Gy	106.9
250 Gy	98.9
500 Gy	101.2
750 Gy	113.3
1000 Gy	191.1
2000 Gy	197.3
S Em ±	0.360
CD (0.05)	0.710
Influence of Varieties	
Varieties	**Electrical conductivity (µscm^{-1})**
CSH 14	135.3
C 43	142.2
CSV 29R	126.6
S Em ±	0.255
CD (0.05)	0.502

Table 4.28. Electrical conductivity (µscm^{-1})as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	51.9	56.2	48.5	**52.3**	95.6	106.7	91.9	**98.1**	146.2	151.0	116.3	**138.3**	156.0	145.5	135.5	**146.0**
250 Gy	41.5	51.3	36.3	**43.1**	81.5	103.1	87.3	**90.6**	118.8	124.0	105.0	**116.1**	127.0	124.5	132.0	**127.9**
500 Gy	48.3	53.3	36.9	**46.2**	93.8	105.6	89.1	**96.1**	133.8	142.0	106.6	**127.5**	140.0	134.	135.5	**136.9**
750 Gy	53.7	57.7	54.5	**55.4**	96.9	105.6	92.2	**98.3**	154.3	165.0	124.3	**148.2**	159.5	169.	176.0	**168.5**
1000 Gy	57.8	63.6	66.4	**62.7**	100.5	112.8	96.1	**103.0**	170.8	183.8	138.9	**164.5**	430.0	443.5	428.5	**434.3**
2000 Gy	59.5	65.5	68.4	**64.5**	102.8	114.7	98.3	**105.2**	184.5	201.8	151.3	**179.2**	442.0	446.5	432.5	**440.3**
MEAN	**52.2**	**58.0**	**51.9**	**54.0**	**95.0**	**108.1**	**92.5**	**98.6**	**151.6**	**161.4**	**123.9**	**145.6**	**242.6**	**244.1**	**240.3**	**242.3**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.721**	**0.510**	**0.624**	**1.152**
CD (0.05)	**1.421**	**1.005**	**1.231**	**3.266**

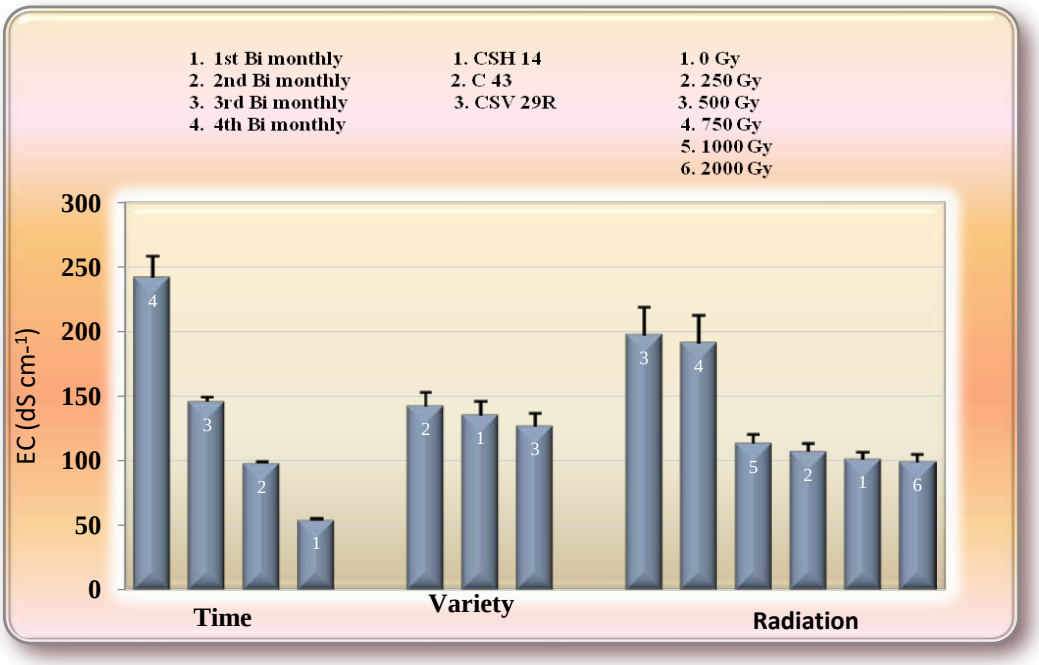

Fig. 4.16a: Electrical conductivity as influenced by storage period, gamma doses and varieties

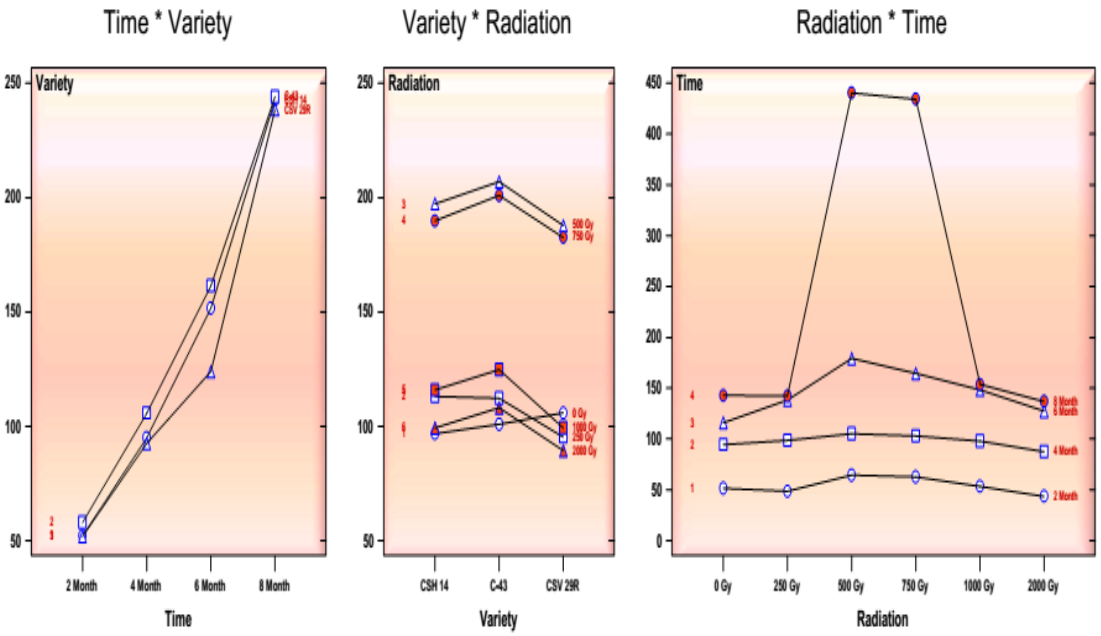

Fig. 4.16b: Electrical conductivity as influenced by the interactions among storage period, gamma doses and varieties

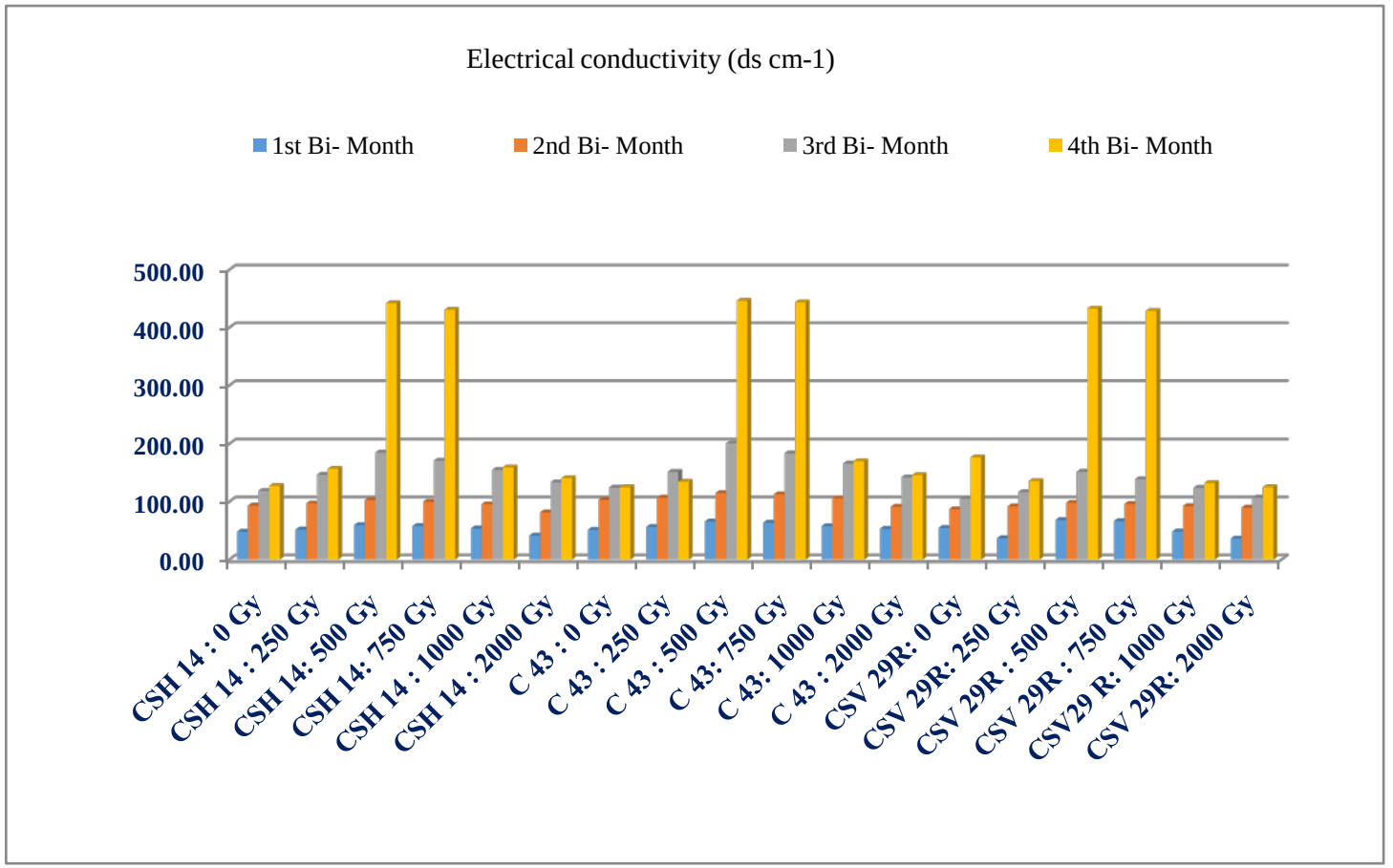

Fig.4.16 c: Electrical conductivity as influenced by the interaction among storage period x gamma doses x varieties

Another important enzyme, Dehyrogenase activity is also known as terazolium reduction ability. The activity of this enzyme is directly correlated with seed vigour (Chauhan *et al.*, 2011).

At the end of 1st bi-month of storage the dehydrogenase activity values ranged from 0.12 µg (C 43/ 2000 Gy) to 0.22 µg (CSV 29 R / 500 Gy). The mean values ranged from 0.10 µg (CSH 14 / 2000 Gy.) to 0.20 µg (CSV 29R / 500 Gy) at the end of 2nd bi-month of storage while, after 3rd bi-month highest dehydrogenase activity values of 0.15 µg was recorded in respect of CSV 29R / 500,750 Gy and lowest value of 0.07 µg at CSH 14/ 1000, 2000 Gy. After nine months of storage dehydrogenase activity values was low (0.05µg) in case of CSV 29R/ 2000 Gy and CSH 14/ 2000 Gy and highest value of 0.9 µg in case of CSV 29R/ 500 Gy and C 43/ 500 Gy (Table 4.30, Fig. 4.17c).

In general the levels of enzyme activity are correlated with germination and vigour of seed under the influence of storage. Decrease in enzyme activity lowers the respiratory potential which in turn lowers both energy and food supply to the germinating seed. Several changes in enzyme macromolecular structure may contribute to their lower effectiveness. They may undergo compositional changes by losing or gaining certain functional groups by oxidation of sulfhydryl groups or by conversion of amino acids within the protein structure. The enzyme may undergo configurational changes such as partial folding or unfolding of the ultra structure (Chauhan *et al*., 2011).

Significant decrease in dehydrogenase activity from first bimonthly storage to final bimonthly storage period was evident as per the results presented in Table 4.29. The mean dehydrogenase activity values declined from 0.16 µg to 0.07 µg during the storage period. When the performances of gamma treatment were examined, it was revealed that, significantly higher dehydrogenase activity of 0.14 µg was observed at 500 Gy. However, 2000 Gy doses recorded lowest dehydrogenase activity of 0.10 µg. Study of significance of varieties on dehydrogenase activity indicated low values (0.10 µg) in CSH 14. Highest dehydrogenase activity of 0.13 µg recorded in CSV 29R. Graphical representation of the mean data is furnished in Fig.4.17a.

The enzyme alpha amylase is involved in the hydrolysis of reserve carbohydrates and is synthesized *de novo* within the sorghum endosperm. Synthesis of this enzyme in

Table 4.29. Dehydrogenase activity (µg)as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Dehydrogenase activity (µg)**
1st Bi-month	0.16
2nd Bi-month	0.14
3rd Bi-month	0.10
4th Bi-month	0.07
S Em ±	0.001
CD (0.05)	0.001
Influence of Gamma radiation	
Gamma Dose	**Dehydrogenase activity (µg)**
0 Gy	0.11
250 Gy	0.12
500 Gy	0.14
750 Gy	0.13
1000 Gy	0.11
2000 Gy	0.10
Mean	0.001
CD (0.05)	0.002
Influence of Varieties	
Varieties	**Dehydrogenase activity (µg)**
CSH 14	0.10
C 43	0.11
CSV 29R	0.13
S Em ±	0.001
CD (0.05)	0.001

Table 4.30.Dehydrogenase (µg) activities as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	0.14	0.15	0.19	**0.16**	0.11	0.12	0.12	**0.12**	0.09	0.07	0.08	**0.08**	0.09	0.09	0.09	**0.09**
250 Gy	0.15	0.16	0.18	**0.16**	0.11	0.14	0.14	**0.13**	0.08	0.09	0.11	**0.09**	0.07	0.08	0.06	**0.07**
500 Gy	0.16	0.18	0.22	**0.19**	0.15	0.16	0.20	**0.17**	0.11	0.11	0.15	**0.12**	0.06	0.06	0.05	**0.06**
750 Gy	0.16	0.17	0.21	**0.18**	0.14	0.15	0.19	**0.16**	0.10	0.11	0.15	**0.12**	0.05	0.06	0.05	**0.05**
1000 Gy	0.15	0.15	0.17	**0.16**	0.11	0.13	0.14	**0.13**	0.07	0.09	0.12	**0.09**	0.06	0.09	0.09	**0.08**
2000 Gy	0.13	0.12	0.14	**0.13**	0.10	0.12	0.14	**0.12**	0.07	0.08	0.11	**0.09**	0.07	0.09	0.07	**0.08**
MEAN	**0.15**	**0.16**	**0.19**	**0.16**	**0.12**	**0.14**	**0.16**	**0.14**	**0.09**	**0.09**	**0.12**	**0.10**	**0.07**	**0.08**	**0.07**	**0.07**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.002**	**0.001**	**0.001**	**0.001**
CD (0.05)	**0.003**	**0.002**	**0.003**	**0.004**

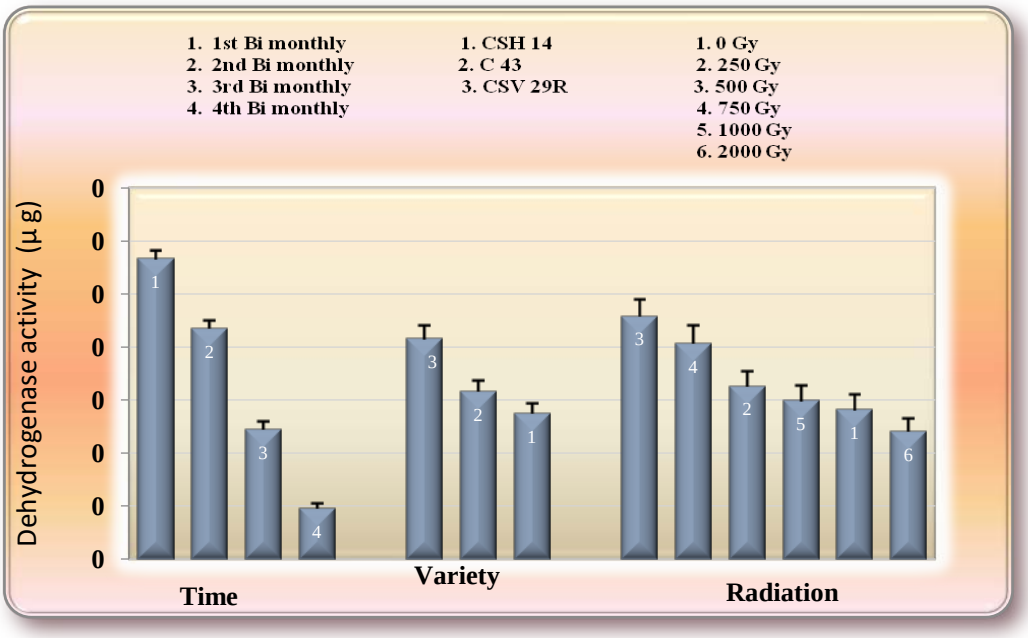

Fig. 4.17a: Dehydrogenase activity as influenced by storage period, gamma doses and varieties

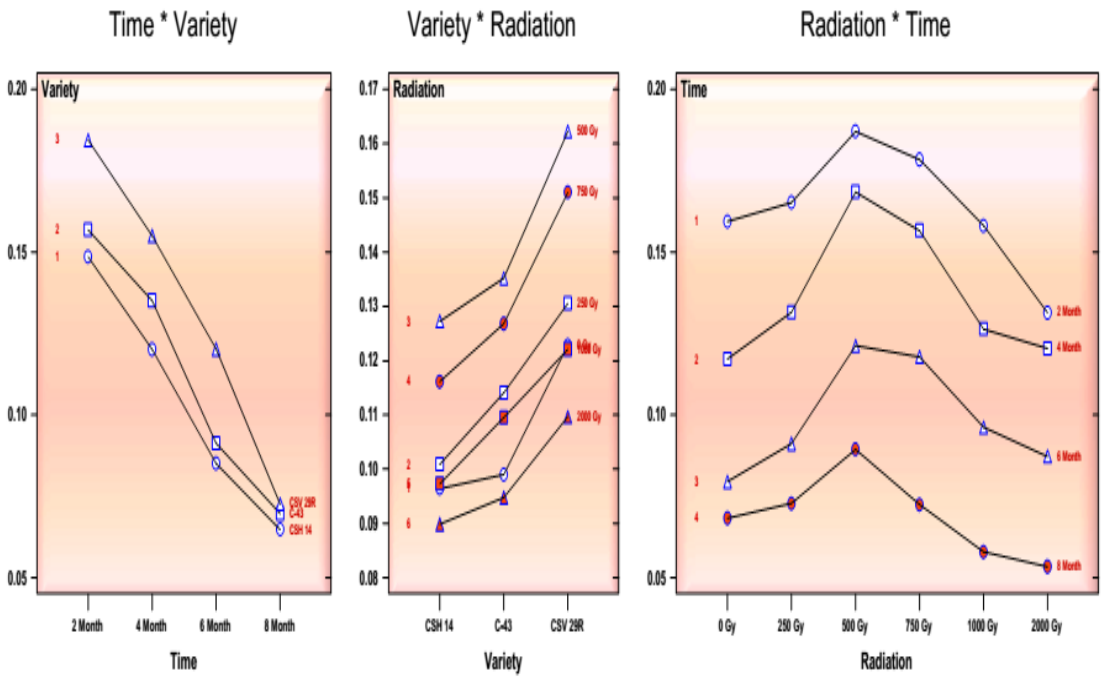

Fig. 4.17b: Dehydrogenase activity as influenced by the interactions among storageperiod, gamma doses and varieties

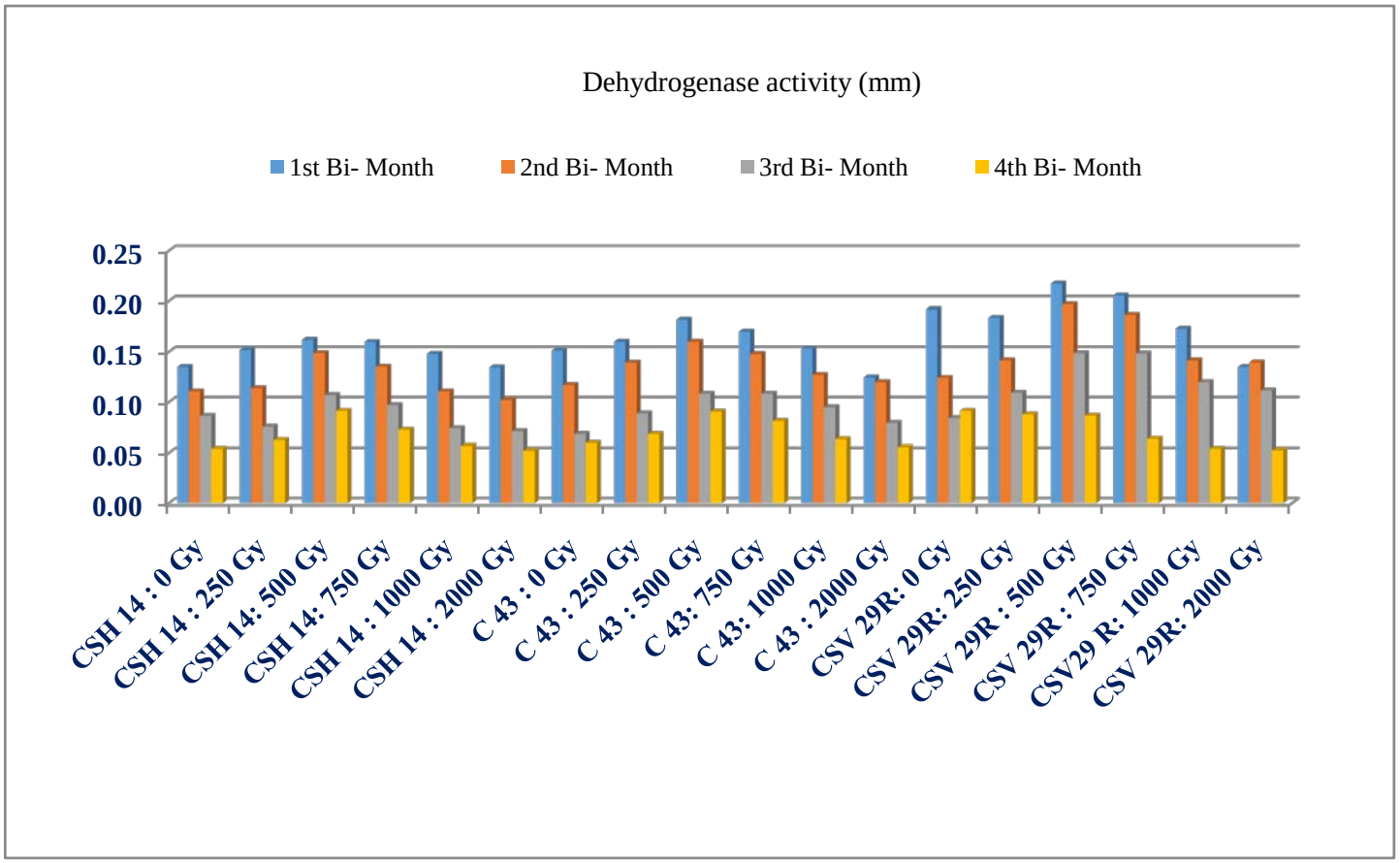

Fig.4.17 c: Dehydrogenase activity as influenced by the interaction among storage period x gamma doses x varieties

germinating sorghum seeds parallels the disappearance of endospermic starch and appearance of reducing sugars. These products of catabolism would finally be mobilized to the growing axis and utilized in the growth of seedlings. With respect to alpha amylase activity it was observed that, highest mean alpha amylase activity was recorded in treatments *viz.* CSH 14/250, 500, 750 Gy, C43/ 0,250, 500, 750 Gy and CSV 29R/ 0, 250, 500 and 750 Gy and were maintained up to 2nd bi-month of storage (Table 4.32). Progressively, CSV 29R/500 Gy had higher alpha amylase activity at the end of 3rd bi-month. Data on final bi-monthly storage studies revealed that eight treatments which recorded higher alpha amylase activity in 3rd bi-month maintained the same up to 4th bi-month storage. The amylase activity ranged from 4.08mm (CSH 14/ 2000 Gy) to 7.68 mm (CSV 29R/500 Gy) after 1st bi-month. While it ranged from 3.18 mm (CSH 14/ 2000 Gy) to 6.45 mm (CSV 29R/500 Gy) at the end of 4th bi-month. Results are given in Table 4.31 and Fig. 4.18c.

Significant reduction in alpha amylase from first bimonthly storage to final bimonthly storage period was evident as per the results presented in Table 4.31. The mean alpha amylase activity of 6.0 mm after 1st bi-month of storage was reduced to 4.9 bi-months after 4th bi-month. Data is presented in Table 4.31. Influence of gamma doses on alpha amylase activity during storage was found to be significant. When the performance of gamma treatment were examined, it was revealed that, significantly higher alpha amylase activity of 6.5 mm was observed at 500 Gy followed by 750 Gy (6.2 mm) which were higher than 0, 250, 1000 and 2000 Gy doses. Varieties also had significant influence in the expression of alpha amylase activity (Fig. 4.18a). CSV 29R recorded the highest alpha amylase activity of 5.9 mmand the lowest in CSH 14 (5.1 mm). Graphical representation of the mean data is furnished in Fig. 4.18a.

Gradual reduction of alpha amylase activity was noticed in the present investigation which could be attributed to its levels in the seed during germination as this enzyme was responsible for hydrolysis of reserve carbohydrates *de novo* within the sorghum endosperm. The reduction in alpha amylase activity could be due to loss in seed membrane integrity, since both mitochondria (sites of energy production) and endoplasmic reticulum (necessary for secretion of synthesized enzymes) are depend on ageing and is likely to be reflected in reduced alpha amylase activity.

Hamideldin and Eliwa (2015) study the effect of gamma irradiation on Seeds of*Eruca sativa*were irradiated with different doses of gamma irradiation (0, 20, 40 and 60 Gy) on growth, seed oil composition and protein electrophoresis of the yield.

Table 4.31. Alpha amylase (mm) activity as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Alpha amylase activity (mm)**
1st Bi-month	6.0
2nd Bi-month	5.7
3rd Bi-month	5.3
4th Bi-month	4.9
S Em ±	0.020
CD (0.05)	0.040
Influence of Gamma radiation	
Gamma Dose	**Alpha amylase activity (mm)**
0 Gy	5.6
250 Gy	5.9
500 Gy	6.5
750 Gy	6.2
1000 Gy	4.7
2000 Gy	3.8
S Em ±	0.025
CD (0.05)	0.050
Influence of Varieties	
Varieties	**Alpha amylase activity (mm)**
CSH 14	5.1
C 43	5.4
CSV 29R	5.9
S Em ±	0.018
CD (0.05)	0.035

Table 4.32.Alpha amylase activity (mm) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	6.1	6.1	6.7	**6.3**	5.7	5.9	6.4	**6.0**	5.2	5.6	6.0	**5.6**	4.6	5.1	5.4	**5.0**
250 Gy	6.2	6.2	7.0	**6.5**	5.9	5.9	6.7	**6.1**	5.3	5.6	6.2	**5.7**	5.0	5.3	5.9	**5.4**
500 Gy	6.7	7.0	7.7	**7.1**	6.4	6.6	7.3	**6.7**	6.0	6.2	6.8	**6.3**	5.8	5.9	6.5	**6.1**
750 Gy	6.4	6.7	7.4	**6.8**	6.0	6.4	7.1	**6.5**	5.7	5.9	6.5	**6.0**	5.3	5.7	6.1	**5.7**
1000 Gy	5.0	5.3	5.6	**5.3**	4.7	5.1	5.2	**5.0**	4.3	4.7	5.0	**4.6**	4.0	4.3	4.5	**4.3**
2000 Gy	4.1	4.4	4.7	**4.4**	3.9	4.1	4.3	**4.1**	3.5	3.7	4.0	**3.7**	3.2	3.3	3.7	**3.4**
MEAN	**5.7**	**5.9**	**6.5**	**6.1**	**5.4**	**5.6**	**6.1**	**5.7**	**5.0**	**5.3**	**5.7**	**5.3**	**4.6**	**4.9**	**5.3**	**5.0**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.050**	**0.035**	**0.044**	**0.072**
CD (0.05)	**0.099**	**0.070**	**0.086**	**0.205**

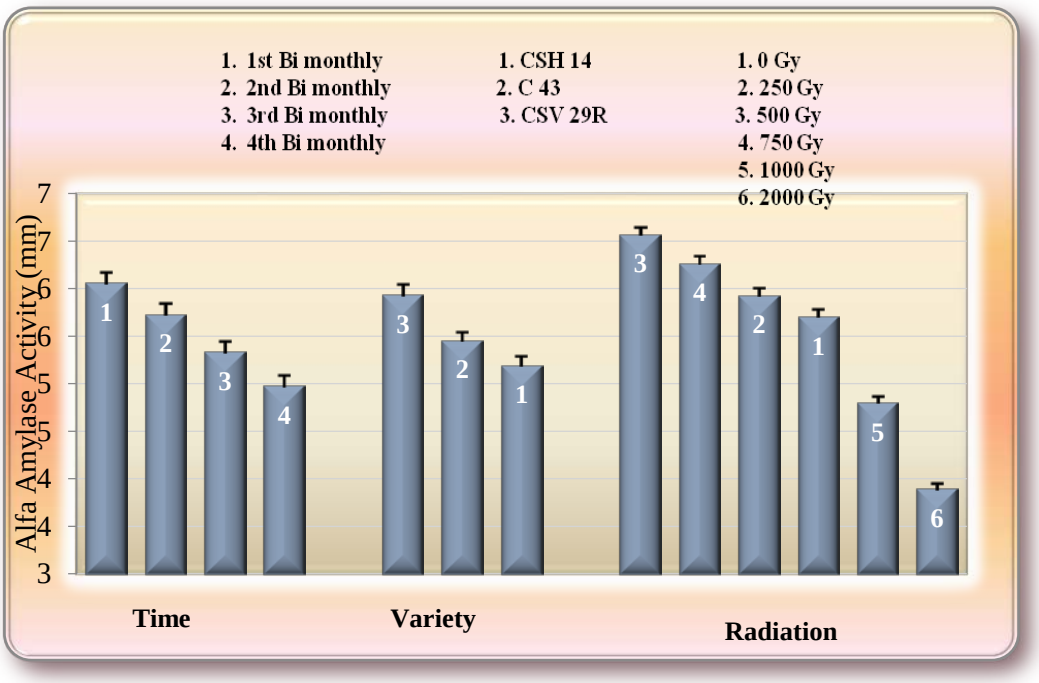

Fig. 4.18a: Alfa amylase activity as influenced by storage period, gamma doses and varieties

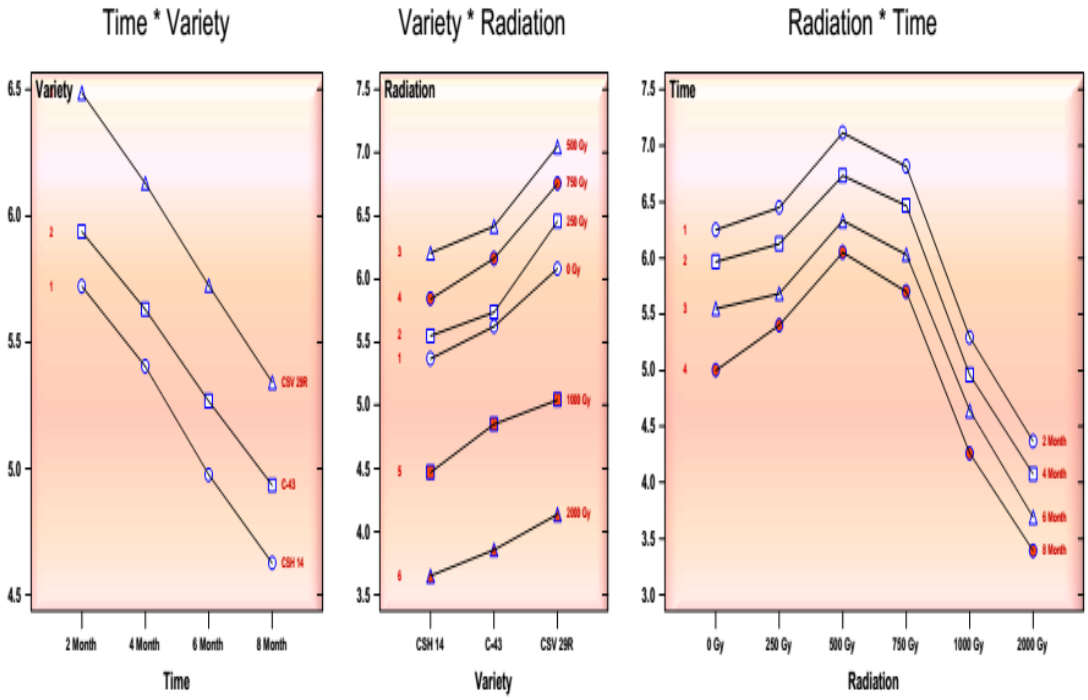

Fig. 4.18b: Alfa amylase activity as influenced by the interactions among storage period, gamma doses and varieties

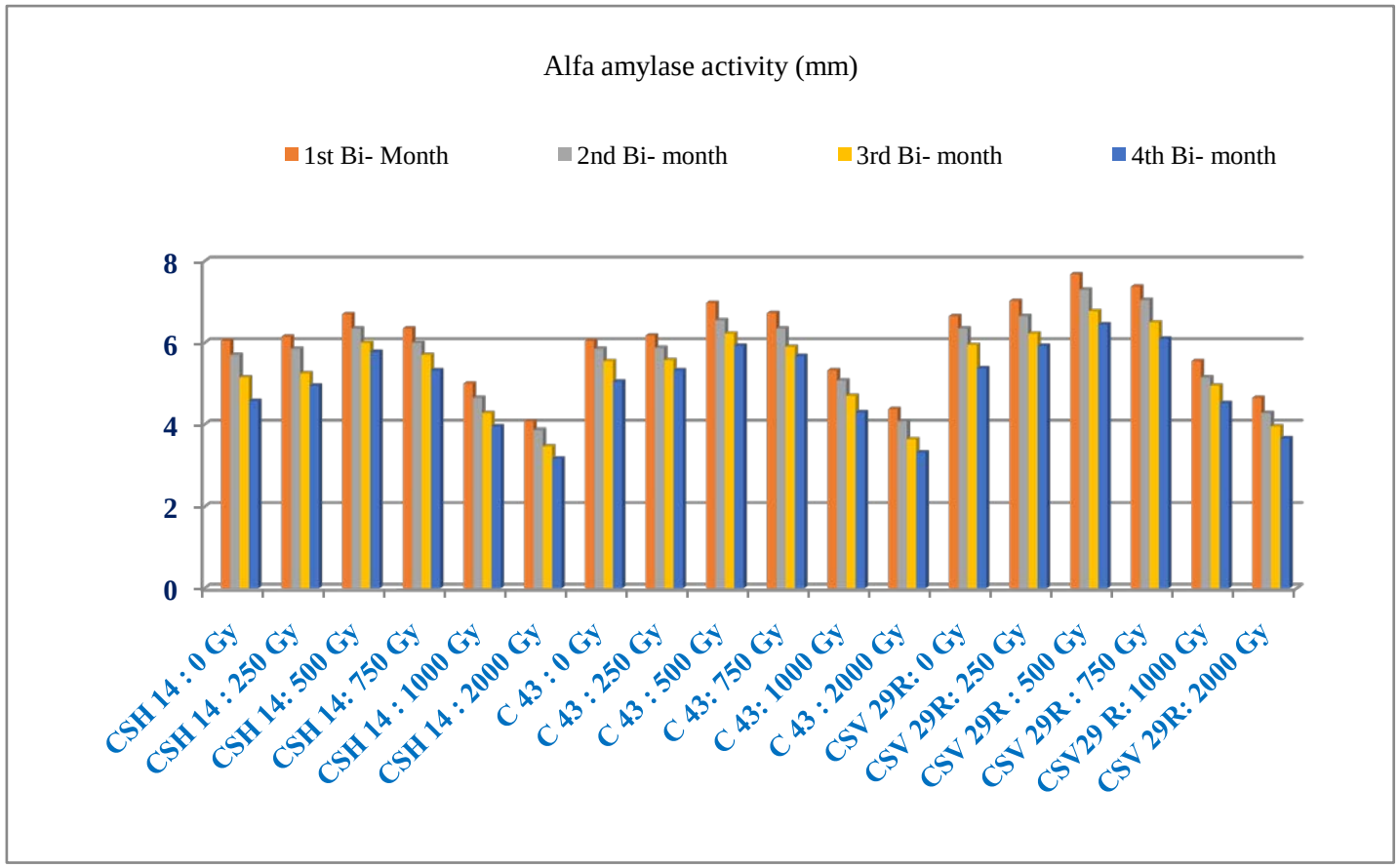

Fig.4.18 c: Alfa amylase activity as influenced by the interaction among storage period x gamma doses x varieties

The treatments induced significant enhancements of growth. The maximum increment observed with gamma radiation dose (60Gy). This enhancement was accompanied with an increase in photosynthetic pigments. Analysis of seed oil by gas chromatography – mass revealed that there was variation in concentration of fatty acids, aliphatic alcohol, carbonyl, phenol, sterol compounds, Sulphur and nitrogen compounds, alkaloids as well as alkane compounds.

Ahsan *et al*.(2013) studied the Effectiveness of γ-irradiation in rice samples contaminated with high concentrations of aflatoxin (AFB_1) and total aflatoxins produced by *Aspergillus flavus* and *Aspergillus parasiticus* was significantly ($p<0.05$) dependant on radiation dose. Initial fungal population of rice samples was evaluated at 2.4×10^6 CFU g^{-1} while maximum reduction percentage was observed at radiation dose 6 kGy (6.4 CFU g^{-1}) when compared to the control sample. Amino acid profiles remained predominantly unchanged except for an increase ($p<0.05$) in leucine at 4 kGy. Rice fat, after irradiation, showed minor changes in the composition of fatty acid methyl esters. Effect of dose on palmitic (16:0), stearic (18:0), linoleic (18:2), linolenic (18:3) and arachidic (20:0) acids was statistically non significant whereas, olenic acid showed a significant change in concentration. The results indicate that γ-irradiation is a good technique for removing contaminants such as aflatoxins from cereal commodities.

With respect to starch it was observed that, starch content in seed ranged from 57.30 per cent (C 43/ 2000 Gy) to 64.92 (C43/0 Gy) after 2nd bi-month of storage while it ranged from 56.28 per cent (CSH 14/ 2000 Gy) to 62.93 percent (CSV 29R/500 Gy) at the end of 4th bi-month. Results were given in Table 4.34 and Fig. 4.19c. The mean starch content of 62.0 percent after 2nd bi-month of storage was reduced to 59.5 percent after 4th bi-month of storage.

Influence of gamma doses on starch content during storage was found to be significant. When the performance of gamma doses was examined, it was observed that, significantly higher starch content of 63.7 per cent was observed at 500 Gy followed by 750 Gy (63.2 per cent) which were higher than 0, 250, 1000 and 2000 Gy doses. Varieties alsohad brought significant influence in the expression of starch content (Fig. 4.19a). CSV 29R recorded the highest starch content of 61.9 percent and the lowest in CSH 14 and C 43 (60.3%). Graphical representations of the mean data were furnished in Fig. 4.19a.

Table 4.33. Starch content of seed (%) of seed as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Starch content (%)**
2nd Bi-month	62.0
4th Bi-month	59.5
S Em ±	0.021
CD (0.05)	0.42
Influence of Gamma radiation	
Gamma Dose	**Starch content (%)**
0 Gy	62.6
250 Gy	59.6
500 Gy	63.7
750 Gy	63.2
1000 Gy	58.1
2000 Gy	57.4
S Em ±	0.036
CD (0.05)	0.072
Influence of Varieties	
Varieties	**Starch content (%)**
CSH 14	60.3
C 43	60.3
CSV 29R	61.9
S Em ±	0.025
CD (0.05)	0.051

Table 4.34. Starch content of seed (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	2nd Bi-month (3 Month)				4th Bi-month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	64.72	65.92	64.19	**64.9**	58.94	60.00	62.01	**60.3**
250 Gy	63.02	57.96	62.33	**61.1**	56.95	56.43	61.09	**58.2**
500 Gy	64.40	65.42	65.46	**65.1**	61.69	62.69	62.93	**62.4**
750 Gy	64.43	64.16	65.17	**64.6**	60.99	62.26	62.69	**62.0**
1000 Gy	57.93	57.80	60.35	**58.7**	56.69	56.56	59.36	**57.5**
2000 Gy	57.61	57.30	58.86	**57.9**	56.28	56.58	57.80	**56.9**
MEAN	**62.0**	**61.4**	**62.7**	**62.1**	**58.59**	**59.09**	**60.98**	**59.55**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.051**	**0.036**	**0.063**	**0.279**
CD (0.05)	**0.102**	**0.072**	**0.125**	**0.791**

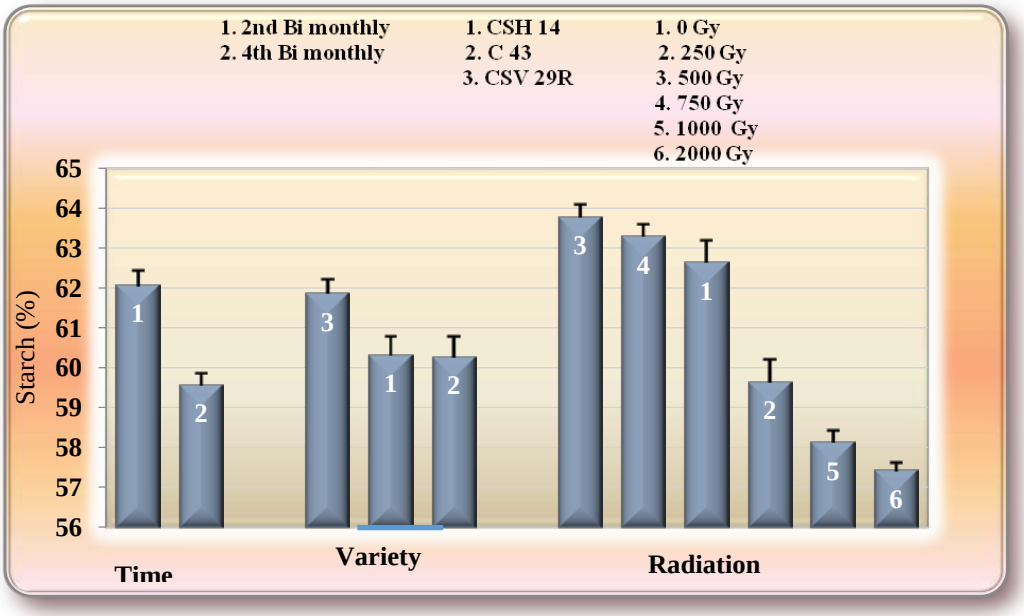

Fig. 4.19a: Starchcontent as influenced by storage period, gamma doses and varieties

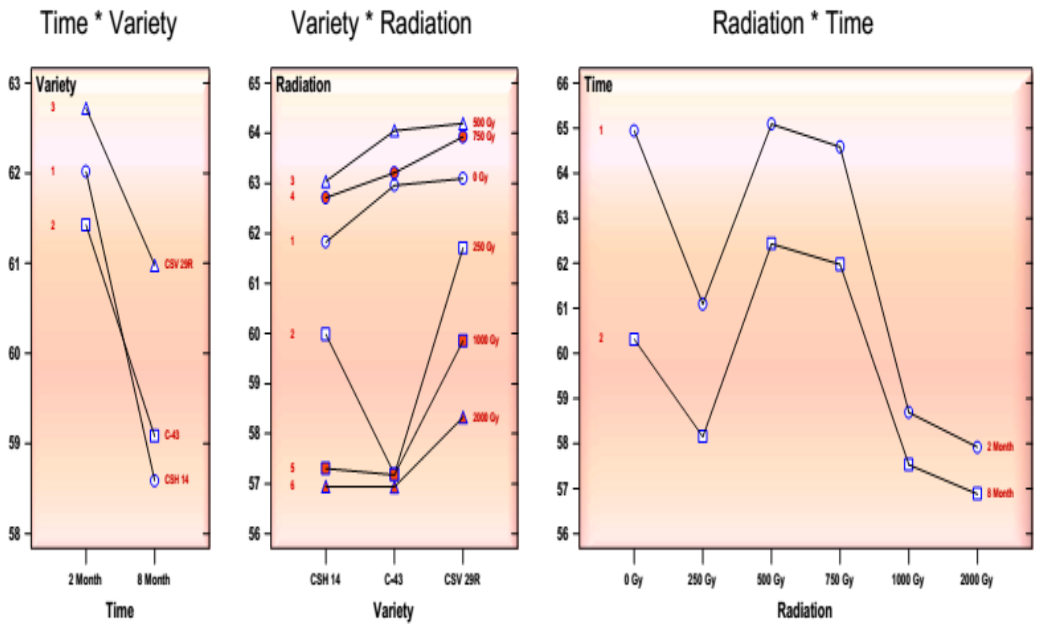

Fig. 4.19b: Starch contentas influenced by the interactions among storage period, gamma doses and varieties

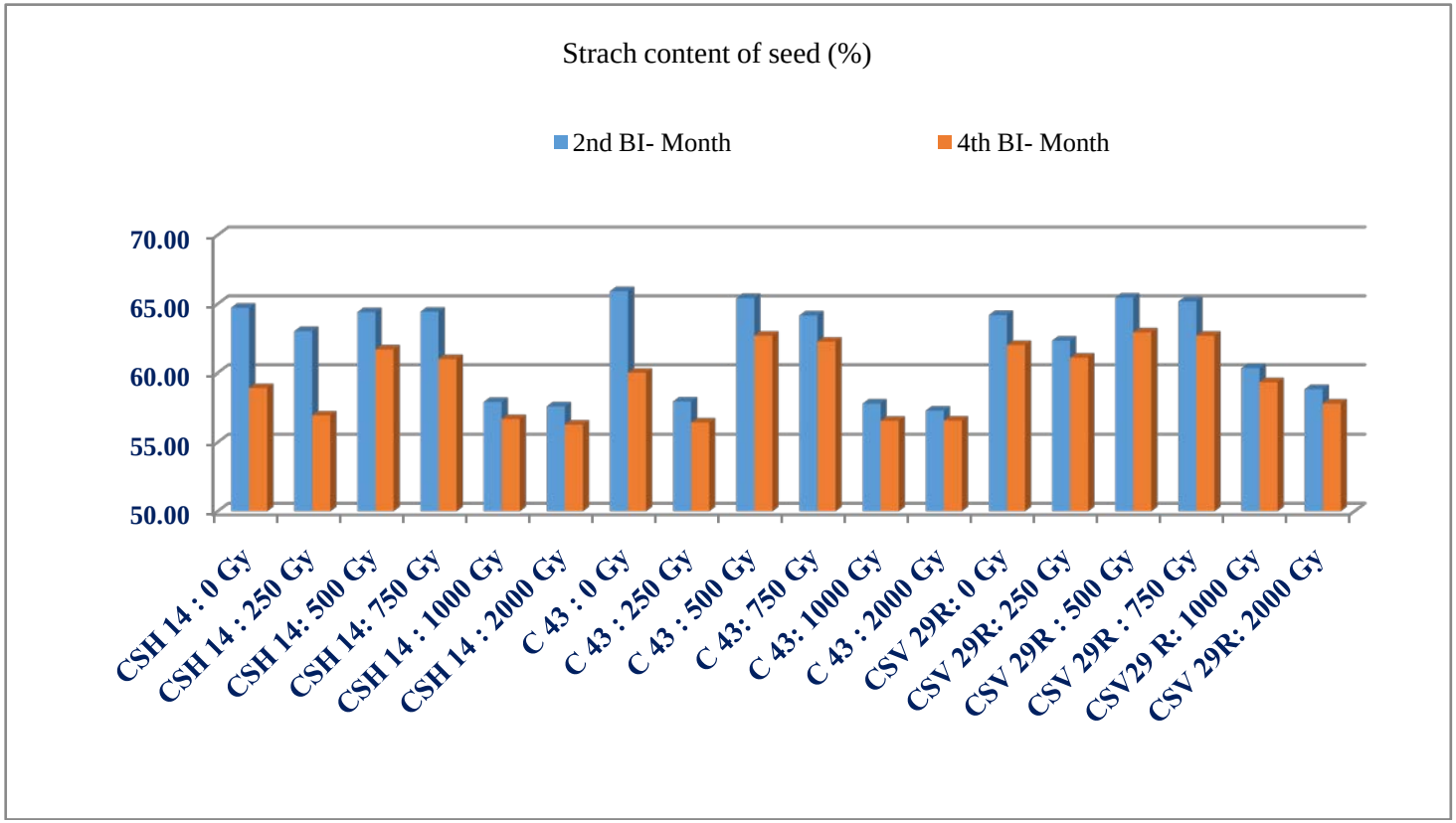

Fig.4.19 c: Starch content influenced by the interaction among storage period x gamma doses x varieties

Table 4.35. Protein content of seed (%) of seed as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Protein content (%)**
2nd Bi-month	11.0
4th Bi-month	10.2
S Em ±	0.036
CD (0.05)	0.071
Influence of Gamma radiation	
Gamma Dose	**Protein content (%)**
0 Gy	9.9
250 Gy	10.6
500 Gy	11.4
750 Gy	11.1
1000 Gy	10.6
2000 Gy	10.2
S Em ±	0.062
CD (0.05)	0.123
Influence of Varieties	
Varieties	**Protein content (%)**
CSH 14	10.8
C 43	10.6
CSV 29R	10.6
S Em ±	0.044
CD (0.05)	0.087

Table 4.36. Protein content of seed (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	2nd Bi-month (3 Month)				4th Bi-month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	11.34	10.67	10.78	**10.9**	8.35	8.87	9.77	**9.0**
250 Gy	11.18	10.97	10.54	**10.9**	10.59	10.26	10.21	**10.4**
500 Gy	11.61	11.54	11.23	**11.5**	11.42	11.17	11.20	**11.3**
750 Gy	11.56	11.38	11.09	**11.3**	11.10	10.91	10.88	**11.0**
1000 Gy	11.01	11.13	10.52	**10.9**	10.43	10.22	10.15	**10.3**
2000 Gy	10.83	10.50	10.45	**10.6**	9.77	9.44	10.04	**9.8**
MEAN	**11.3**	**11.0**	**10.8**	**11.0**	**10.3**	**10.1**	**10.4**	**10.3**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.088**	**0.062**	**0.107**	**0.104**
CD (0.05)	**0.174**	**0.123**	**0.213**	**0.296**

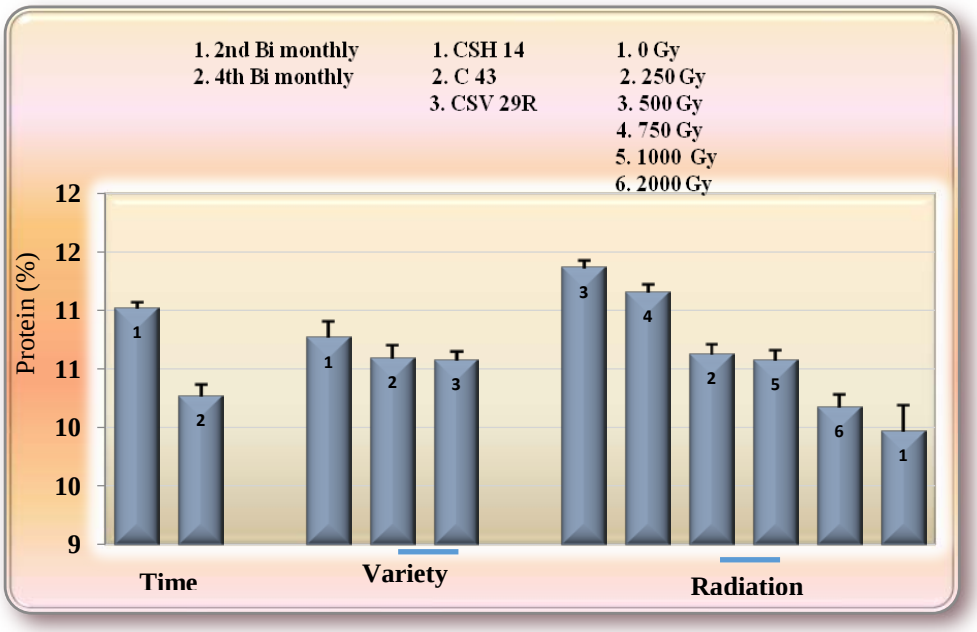

Fig. 4.20a: Proteincontent as influenced by storage period, gamma doses and varieties

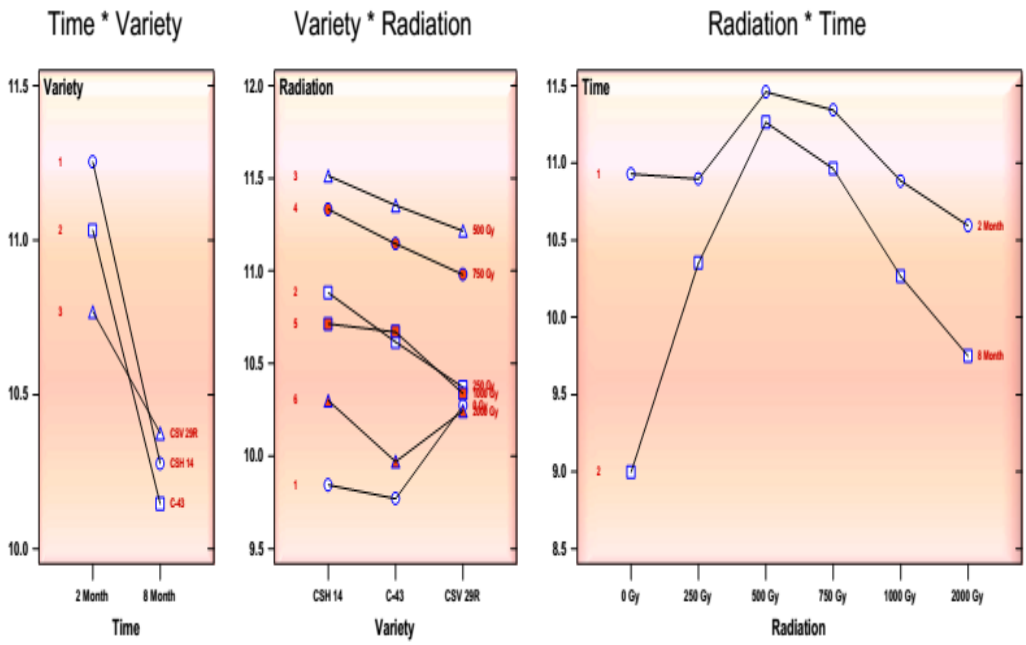

Fig. 4.20b: Protein contentas influenced by the interactions among storage period, gamma doses and varieties

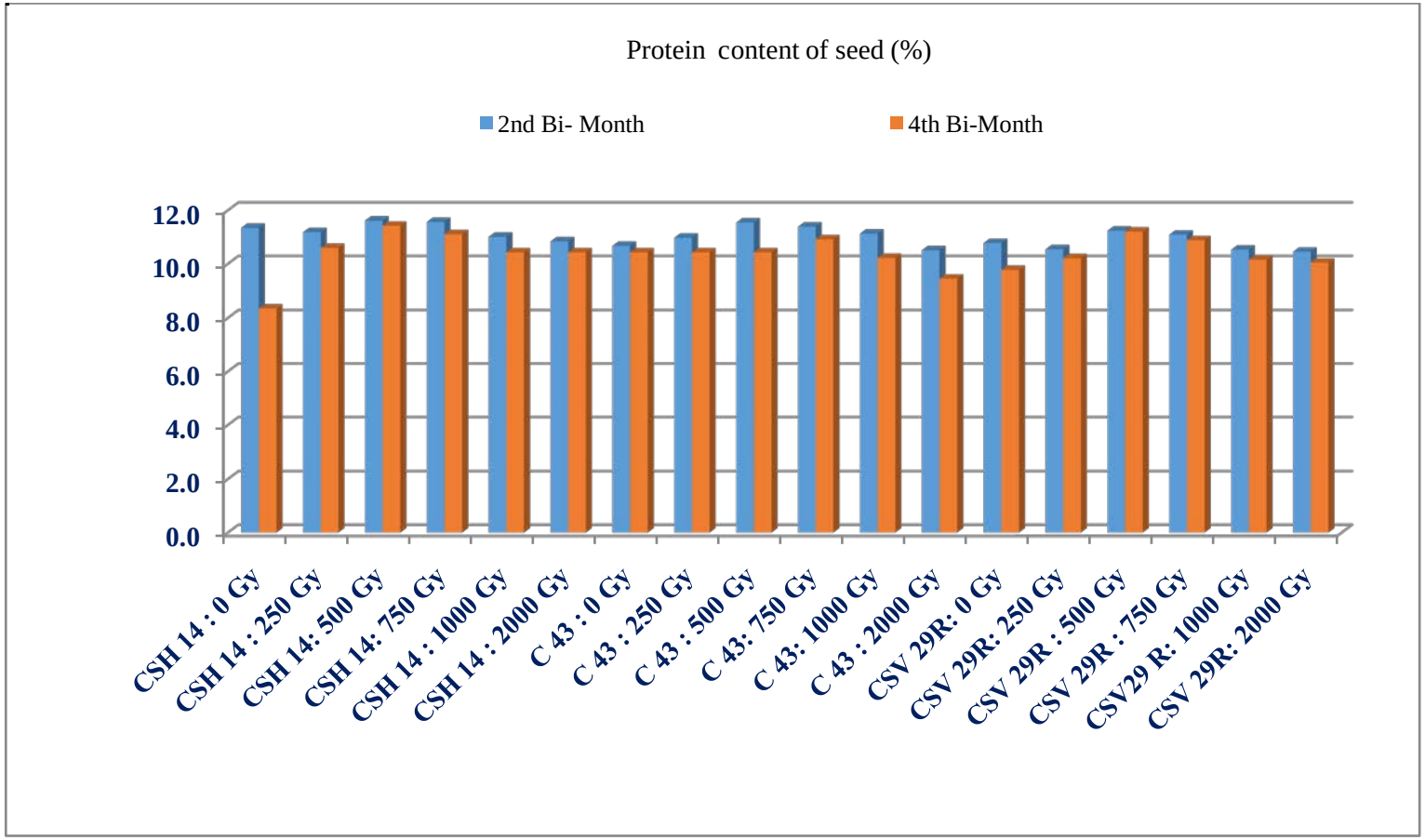

Fig.4.20 c: Protein content influenced by the interaction among storage period x gamma doses x varieties

There is strong evidence that proteins are the most important targets for oxidants (Davies, 2005). Protein metabolisms are altered by carbonylation in deteriorated seeds. Protein metabolism regroups several biological functions, such as protein folding, protein translocation, thermo-tolerance, oligomeric assembly, and switching between active and inactive protein conformations. Impairment of these functions is closely linked with the loss of seed vigour. (Narayana*et al.*, 2002).

The interaction effect of gamma radiation and varieties on protein content was found to be significant. After 2nd bi-month of storage, protein content in seed ranged from 10.45 % (CSV 29R/ 2000 Gy) to 11.61 % (CSH 14 /500 Gy). While it ranged from 8.35 % (CSH 14/ 0 Gy) to 11.42 % (CSH 14/500 Gy) at the end of 4th bi-month. Results were given in Table 4.36 and Fig. 4.20c. The mean protein content of 11.0 per cent after 2nd bi-month of storage was reduced to 10.2 percent after 4th bi-month. Gamma doses affected protein content significantly during storage. When the performance of gamma doses was examined, it was revealed that, significantly higher protein content of 11.4% was observed at 500 Gy followed by 750 Gy (11.1 %) which were higher than 0, 250, 1000 and 2000 Gy doses. Varieties alsohad significant influence in the expression of protein content (Fig. 4.20a). CSV 29R and C 43 recorded the same protein content of 10.6%and the highest was in CSH 14 (10.8 %).

Effects of gamma irradiation on pigeon pea flour at various doses (0, 5, 10, 15 and 20 k Gy) on the proximate composition and functional properties were investigated by (Bamidele and Akanbi, 2013).Gamma irradiation resulted in a slight increase of crude protein at all doses and the crude lipid. Crude fibre and ash content showed no apparent effects of irradiation between the non-irradiated sample and the irradiated sample.

Results revealed that fat content in seed ranged from 2.56% (CSH 14/ 2000 Gy) to 3.71 % (CSV 29R/500 Gy) after 2ndbi-month of storage. While fat content value ranged from 2.47 % (C 43/ 2000 Gy) to 3.47 % (CSV 29R/500 Gy) at the end of 4th bi-month of storage. Results are given in Table 4.38 and Fig 4.21c. The mean fat content of 3.2 percent after 2nd bi-month of storage was reduced to 2.9 percent after 4th bi-month. The influence of gamma doses on fat content during storage was found to be significant. When the performance of gamma treatment was observed, it was found that, significantly higher fat content of 3.4 % at 500 Gy followed by 750 Gy (3.3 %) which were higher than 0, 250, 1000 and 2000 Gy dose. The effect of varieties on expression

Table 4.37. Fat content of seed (%) of seed as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Fat content (%)**
2nd Bi-month	3.2
4th Bi-month	2.9
S Em ±	0.021
CD (0.05)	0.041
Influence of Gamma radiation	
Gamma Dose	**Fat content (%)**
0 Gy	3.1
250 Gy	3.1
500 Gy	3.4
750 Gy	3.3
1000 Gy	2.9
2000 Gy	2.5
S Em ±	0.036
CD (0.05)	0.072
Influence of Varieties	
Varieties	**Fat content (%)**
CSH 14	2.9
C 43	3.0
CSV 29R	3.2
S Em ±	0.025
CD (0.05)	0.051

Table 4.38. Fat content of seed (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	2nd Bi-month (3 Month)				4th Bi-month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	3.29	3.41	3.54	**3.4**	2.67	3.05	2.69	**2.8**
250 Gy	3.16	3.21	3.37	**3.2**	2.85	2.93	3.21	**3.0**
500 Gy	3.35	3.55	3.71	**3.5**	3.31	3.21	3.47	**3.3**
750 Gy	3.27	3.38	3.61	**3.4**	3.21	3.11	3.34	**3.2**
1000 Gy	2.98	3.12	3.29	**3.1**	2.73	2.56	2.91	**2.7**
2000 Gy	2.56	2.70	2.76	**2.7**	2.50	2.47	2.59	**2.5**
MEAN	**3.1**	**3.2**	**3.4**	**3.2**	**2.9**	**2.9**	**3.0**	**2.9**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.051**	**0.036**	**0.063**	**0.061**
CD (0.05)	**0.102**	**0.072**	**0.125**	**0.173**

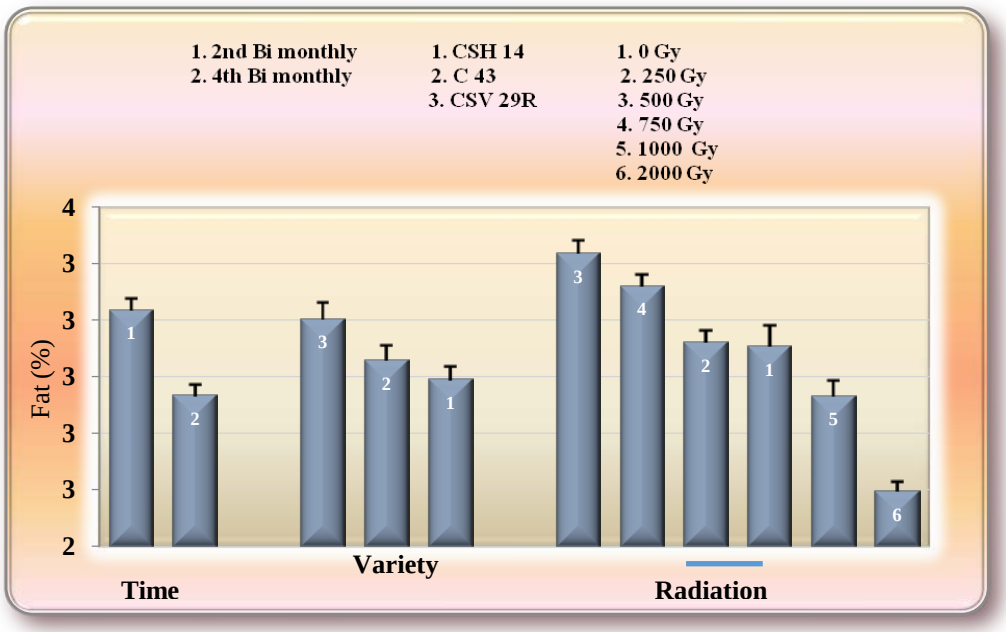

Fig. 4.21a: Fatcontent as influenced by storage period, gamma doses and varieties

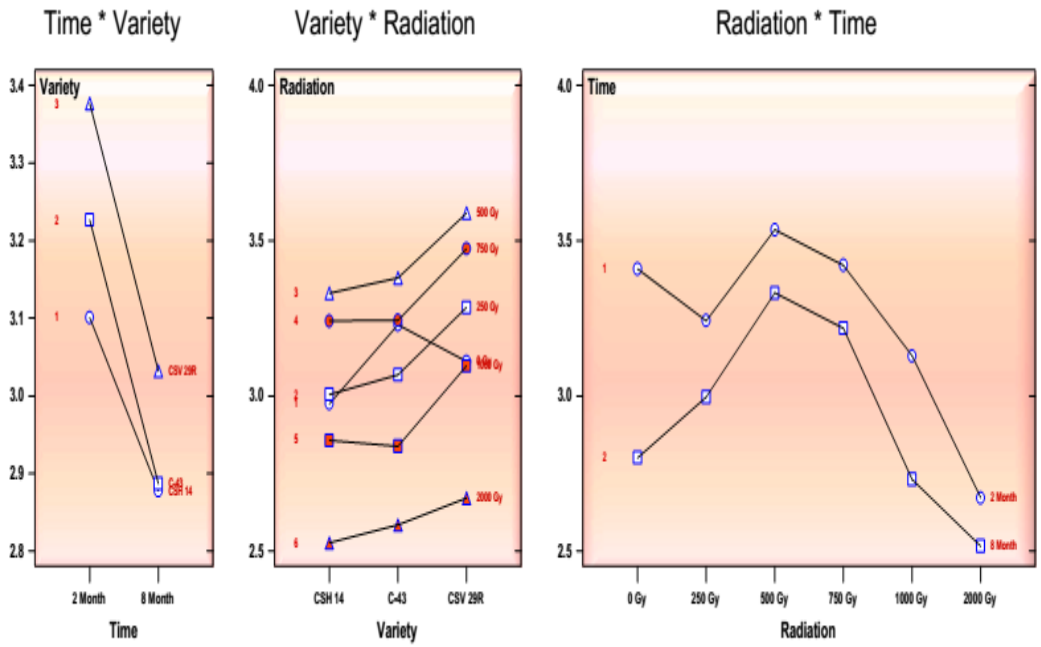

Fig. 4.21b: Fatcontent as influenced by the interactions among storage period, gamma doses and varieties

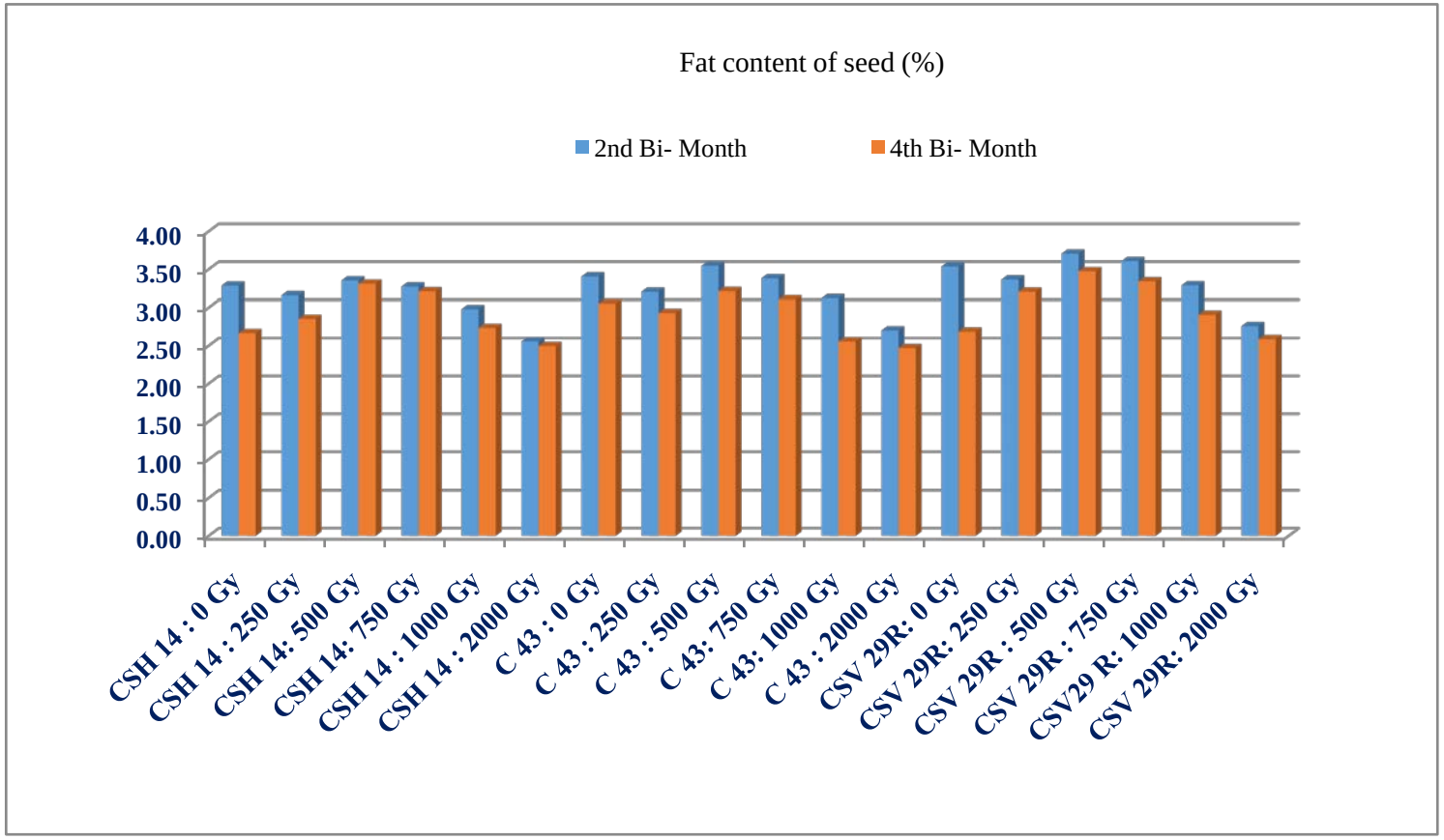

Fig.4.21 c: Fat content as influenced by the interaction among storage period x gamma doses x varieties

Table 4.39. Ash content of seed (%) of seed as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Ash content (%)**
2nd Bi-month	1.5
4th Bi-month	1.4
S Em ±	0.008
CD (0.05)	0.017
Influence of Gamma radiation	
Gamma Dose	**Ash content (%)**
0 Gy	1.4
250 Gy	1.4
500 Gy	1.7
750 Gy	1.6
1000 Gy	1.3
2000 Gy	1.3
S Em ±	0.020
CD (0.05)	0.041
Influence of Varieties	
Varieties	**Ash content (%)**
CSH 14	1.4
C 43	1.5
CSV 29R	1.5
S Em ±	0.010
CD (0.05)	0.020

Table 4.40. Ash content of seed (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	2nd Bi-month (3 Month)				4th Bi-month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	1.39	1.54	1.61	**1.5**	1.34	1.53	1.46	**1.4**
250 Gy	1.47	1.40	1.58	**1.5**	1.43	1.33	1.40	**1.4**
500 Gy	1.72	1.75	1.70	**1.7**	1.62	1.67	1.61	**1.6**
750 Gy	1.61	1.68	1.61	**1.6**	1.51	1.67	1.56	**1.6**
1000 Gy	1.37	1.29	1.46	**1.4**	1.26	1.25	1.41	**1.3**
2000 Gy	1.30	1.26	1.40	**1.3**	1.20	1.24	1.37	**1.3**
MEAN	**1.5**	**1.5**	**1.6**	**1.5**	**1.4**	**1.4**	**1.5**	**1.4**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.020**	**0.015**	**0.025**	**0.023**
CD (0.05)	**0.041**	**0.029**	**0.050**	**0.065**

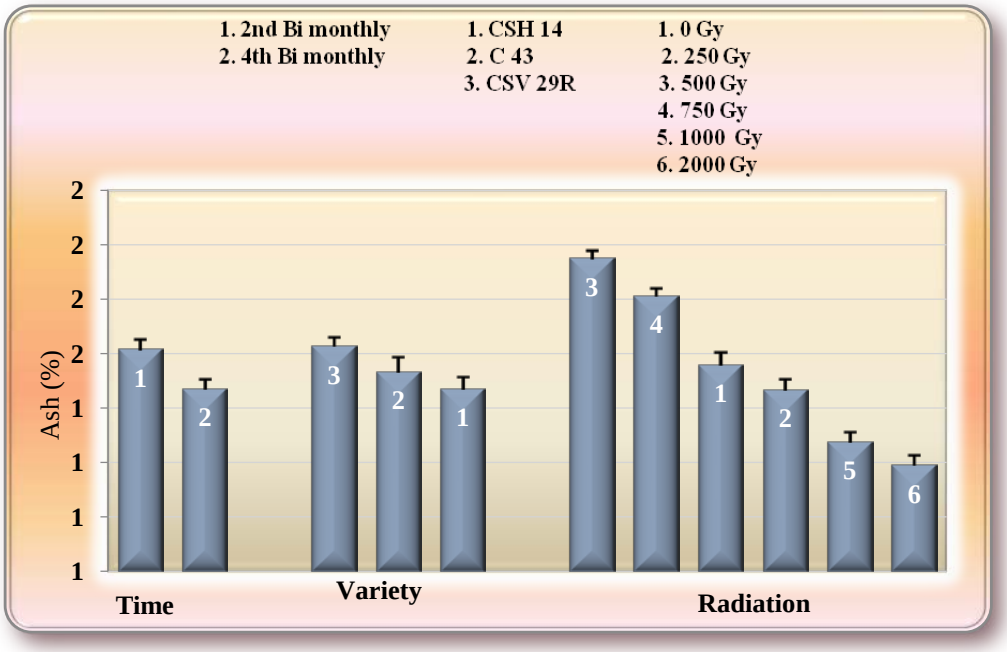

Fig. 4.22a: Ash content as influenced by storage period, gamma doses and varieties

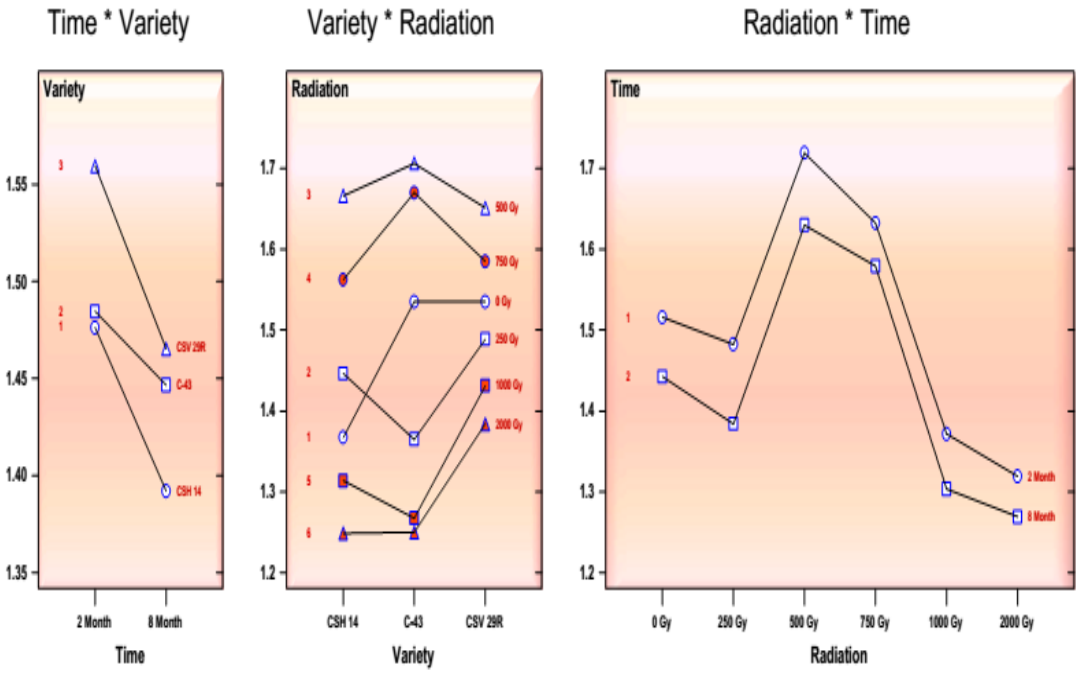

Fig. 4.22b: Ash content as influenced by the interactions among storage period, gamma doses and varieties

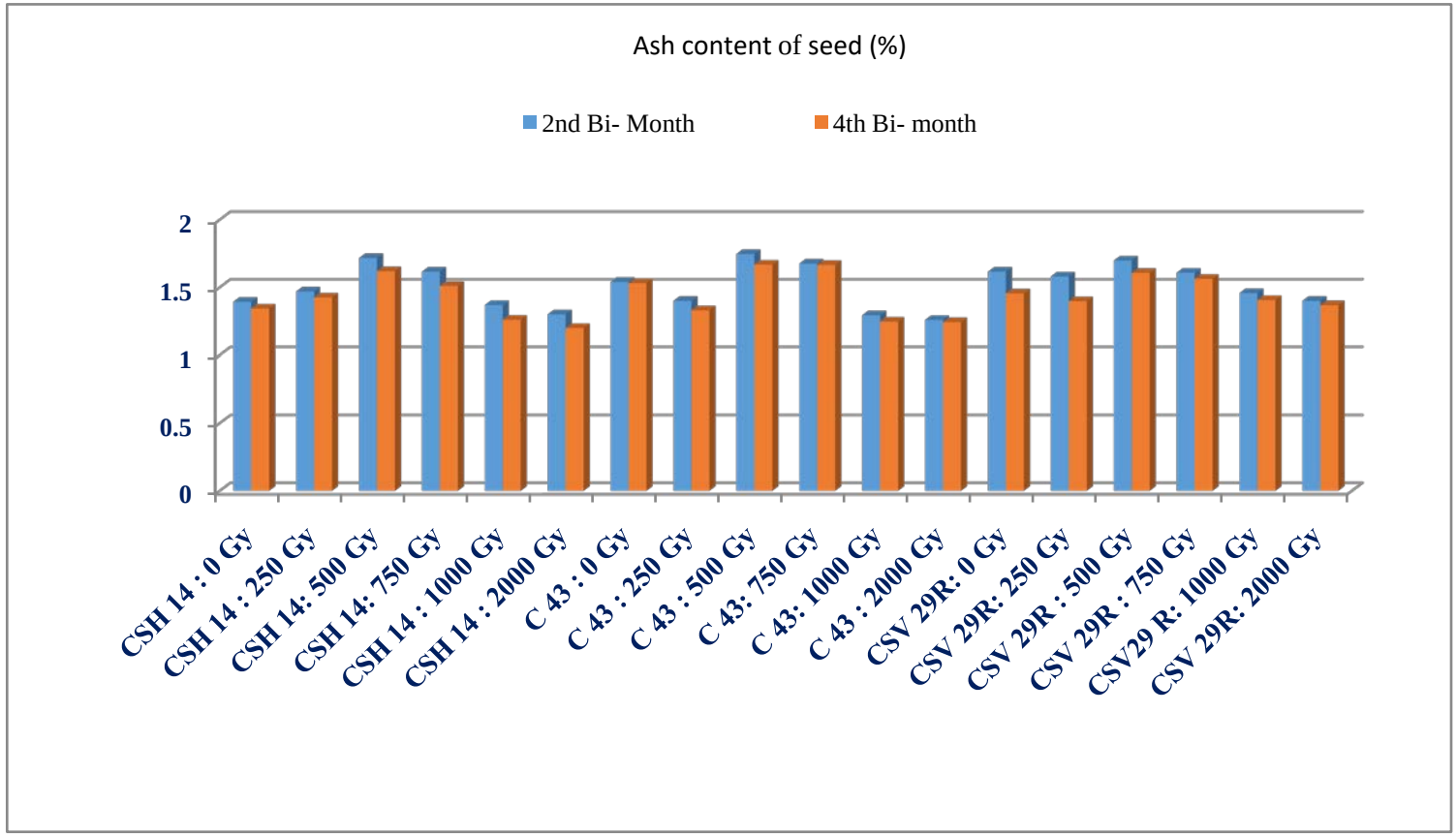

Fig.4.22 c: Ash content influenced by the interaction among storage period x gamma doses x varieties

fat content was found to be significant (Fig. 4.21a). CSV 29R recorded the highest fat content of 3.2 % and the lowest was in CSH 14 (2.9%).

Amro *et al*. (2009) investigated the effect of gamma irradiation on the nutritional quality of maize and sorghum grains, packs were exposed to doses of 0 and 2 k Gy. The results indicated that in maize cultivars no significant differences were observed in all protein fractions except in prolamins and glutelins of maize. While for sorghum significant increase in globulins, prolamins and glutelins was observed.

With respect to ash content it was observed that, ash content in seed ranged from 1.26 % (C 43/ 2000 Gy) to 1.75 % (C 43/500 Gy) after 2^{nd} bi-month of storage while it ranged from 1.20 % (CSH 14/ 2000 Gy) to 1.67 % (C 43/500, 750 Gy) at the end of 4^{th} bi-month. Results were given in Table 4.40 and Fig. 4.22c. The mean fat content of 1.5 percent after 2^{nd} bi-month of storage was reduced to 1.4 percent after 4^{th} bi-month. Influence of gamma doses on ash content during storage was found to be significant. When the performance of gamma doses were examined, it was found that, significantly higher ash content of 1.7 % at 500 Gy followed by 750 Gy (1.6 %) which were higher than 0, 250, 1000 and 2000 Gy dose. Varieties alsohad significant influence in the expression of ash content (Fig. 4.22a). CSV 29R and C 43 recorded the sample amount of ash content of 1.5 %and the lowest was in CSH 14 (1.4 %).

4.4.4 Seed moisture and seed health parameters

The storage studies made by Singh and Tripathi (1968) in maize seeds revealed that, seeds with lower moisture content (10-12%) stored in sealed moisture vapour proof containers maintained viability for longer period than the seeds stored in moisture pervious containers.

In the present investigation, treated seedsof different varieties were irradiated and stored at 8.0 per cent moisture at ambient temperature. During the initial five months of storage period the relative humidity ranged from 69.8to 83.0 per cent. In the present study the weevil infestationimmediately after radiation were nil in all treatments with different gamma dosages.

Significant increase in seed moisture content during storage period was observed as indicated in Table 4.41.The seed moisture content increased from 9.2 per cent at1^{st}

Table 4.41. Moisture content (%) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Moisture (%)**
1st Bi-month	9.2
2nd Bi-month	9.3
3rd Bi-month	9.3
4th Bi-month	9.3
S Em ±	0.008
CD (0.05)	0.016
Influence of Gamma radiation	
Gamma Dose	**Moisture (%)**
0 Gy	9.3
250 Gy	9.3
500 Gy	9.3
750 Gy	9.2
1000 Gy	9.2
2000 Gy	9.2
S Em ±	0.010
CD (0.05)	0.019
Influence of Varieties	
Varieties	**Moisture (%)**
CSH 14	9.2
C 43	9.3
CSV 29R	9.2
S Em ±	0.007
CD (0.05)	0.014

Table 4.42.Moisture content (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	9.2	9.3	9.2	**9.3**	9.3	9.4	9.3	**9.3**	9.3	9.4	9.4	**9.4**	9.4	9.4	9.4	**9.4**
250 Gy	9.2	9.3	9.2	**9.2**	9.3	9.3	9.3	**9.3**	9.3	9.4	9.3	**9.3**	9.4	9.4	9.4	**9.4**
500 Gy	9.2	9.3	9.2	**9.2**	9.2	9.3	9.3	**9.3**	9.3	9.4	9.3	**9.3**	9.4	9.4	9.4	**9.4**
750 Gy	9.2	9.3	9.2	**9.2**	9.2	9.3	9.3	**9.3**	9.3	9.3	9.3	**9.3**	9.4	9.4	9.4	**9.4**
1000 Gy	9.2	9.3	9.2	**9.2**	9.2	9.3	9.2	**9.3**	9.2	9.3	9.3	**9.3**	9.3	9.4	9.3	**9.3**
2000 Gy	9.2	9.2	9.2	**9.2**	9.2	9.2	9.2	**9.2**	9.2	9.3	9.2	**9.2**	9.3	9.4	9.3	**9.3**
MEAN	**9.2**	**9.3**	**9.2**	**9.2**	**9.2**	**9.3**	**9.3**	**9.3**	**9.3**	**9.3**	**9.3**	**9.3**	**9.4**	**9.4**	**9.3**	**9.4**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.020**	**0.014**	**0.017**	**0.015**
CD (0.05)	**0.040**	**0.028**	**0.034**	**0.042**

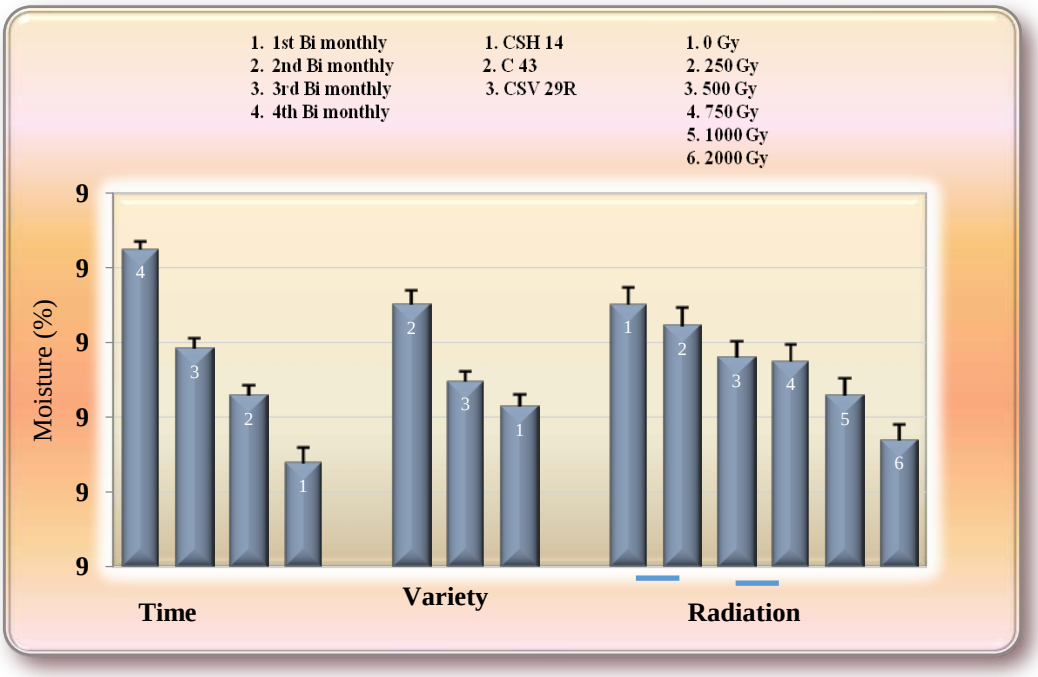

Fig. 4.23a: Seed moisture as influenced by storage period, gamma doses and Varieties

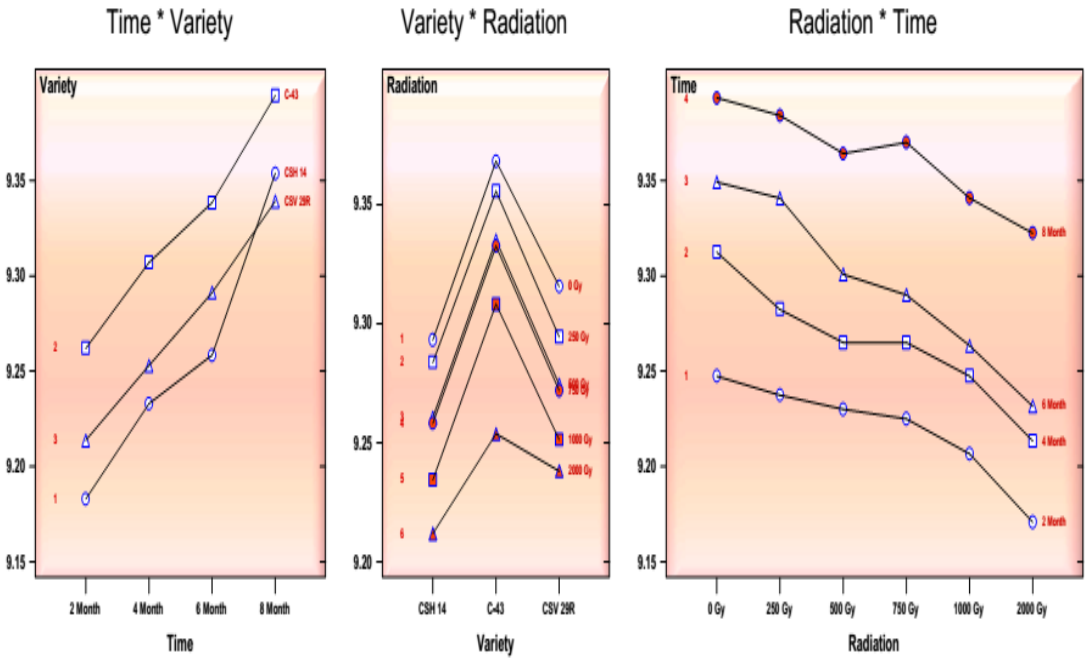

Fig. 4.23b: Seed moisture as influenced by the interactions among storage period, gamma doses and varieties

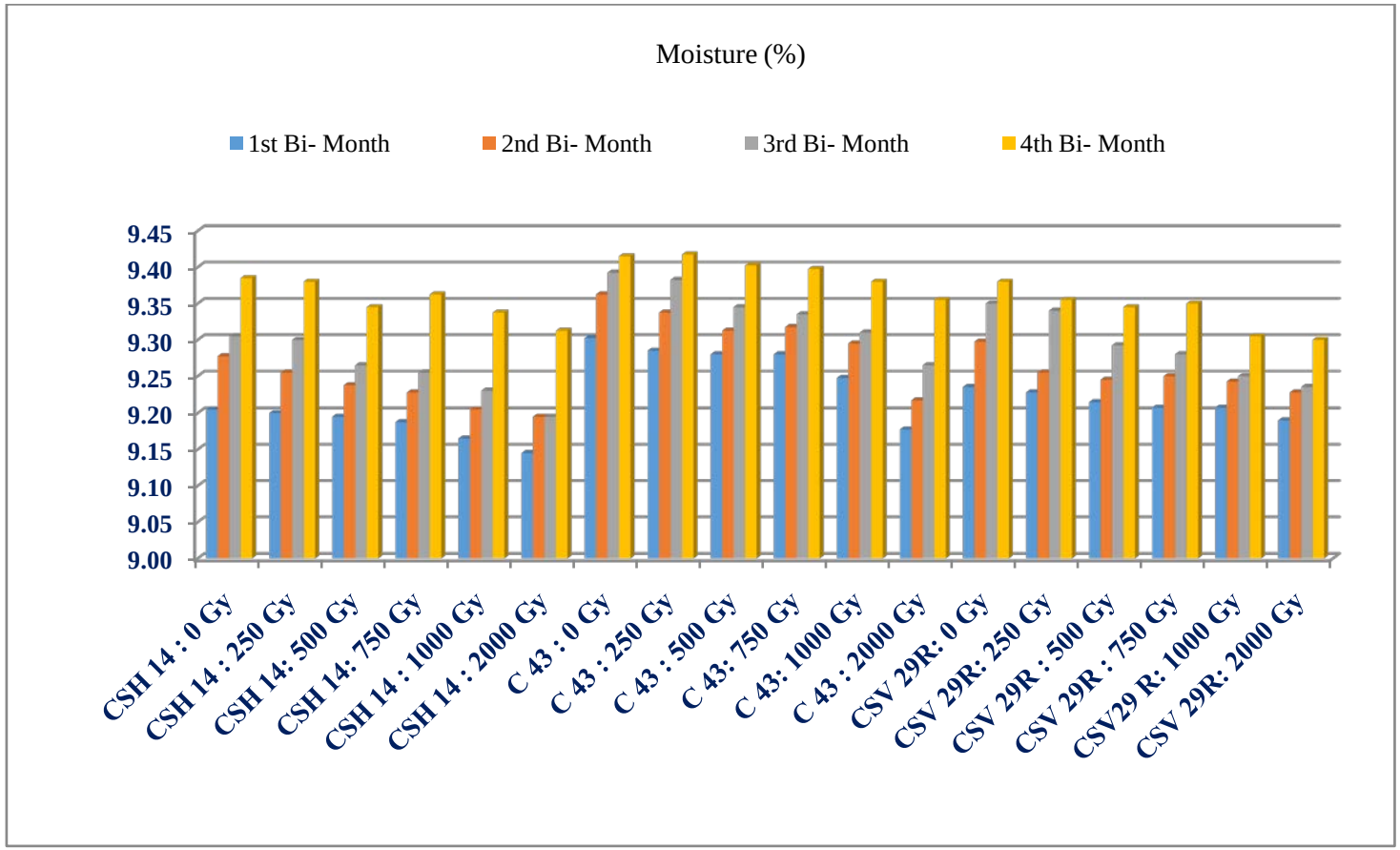

Fig.4.23 c: Seed Moisture as influenced by the interaction amongstorage period x gamma doses x varieties

bi-month to 9.3 per cent after 4th bi-month of storage. Gamma dose of 750, 1000 and 2000 Gy recorded lower seed moisture content of 9.2 per cent which was significantly more than other doses. Higher seed moisture content (9.3 %) was observed at 0, 250 and 500 Gy.

In the present study, moisture content increased with increase in storage period but it was within safe moisture limit *i.e.* less than 10 per cent (which is within the minimum seed certification standards) at the end of storage period. Further, in case of irradiated seed the moisture content was less when compared to non-irradiated seeds.

The interaction effect of gamma radiation and varieties was found to be significant. After 2nd bi-month of storage, moisture content in seed ranged from 9.20 % (CSH14/ 2000 Gy) to 9.36 % (C 43 /0 Gy). But at the end of 4th bi-month, seed moisture content ranged from 9.31% (CSH 14/2000 Gy) to 9.42 % (C 43/0, 250 Gy). Results were given in Table 4.42 and Fig. 4.23c. The mean moisture content of 9.3 per cent after 2nd bi-month of storage was increased to 9.4 percent after 4th bi-month.

Seed health studies were carried out to ascertain the intensity of pest and disease incidence in general in terms of percentage infected seed. Throughout the storage period damage caused by storage insects was recorded in the treatments evaluated including the untreated variety samples while researching on the magnitude of weevil infestation Byun *et al.* (1988) evaluated the effect of gamma irradiation on controlling infestation of insects on irradiated rice grain. The egg and larval stages of rice weevil (*Sitophilus oryzae*) were radiosensitive. The complete mortal dose of the egg and larva stages was 0.05 kGy. In a study on influence of gamma irradiation on pest incidence in rice, it was observed that reduction in percent pupation, adult emergence, fecundity and fertility of the resulting adults depended upon the dose and larval age at the time of treatment. The severe reduction in fecundity and fertility was observed in 25days old larvae treated with a gamma dose of 80 Gy (Kareem and Baki, 2013).

Accordingly, some researchers worked on the mode of host resistance towards weevil infestation in stored sorghum seed. Subbarayudu *et al.* (2013) reported on sorghum resistance to rice weevil, (*Sitophilus oryzae)* through antibiosis and antixenosis. Twenty sorghum cultivars along with a maintainer line, 296B were screened for susceptibility to *Sitophilus oryzae*at Directorate of Sorghum Research (DSR), Hyderabad, India. The grain traits such as hardness, fat and protein content

imparting resistance to rice weevil were studied and correlated with weevil damage. Considering the adult weevil population, colonization, oviposition and seed damage, the genotypes *viz*., CSV 15,SPV 1330, SPV 462, SPV 1231, CSV 13, 296 B and Local Yellow were found to be least susceptible to *S. oryzae*. The higher quantities of protein imparting resistance to rice weevil oviposition and its adult colonies with SPV 1330, SPV 462, SPV 1231, SPV 1328, CSV 13, CSV 11, CSH 5, CSH 16 and SPH 821 indicating antibiosis for dominant component of resistance among the sorghum genotypes.

Similarly, Shyam Prasad *et al.* (2015) stated that sorghum is the fifth most important cereal and suffers heavy damage from rice weevil *Sitophilus oryzae*, reducing their quality and quantity. Studies were conducted to identify the association of grain characteristics and their relationship with resistance to the rice weevil. The paper discussed the associations between sorghum seed parameters, insect oviposition, development data and grain weight loss. The important grain characteristics, *viz*., 100 seed weight was significantly, positively correlated with grain hardness (0.55**) and median development period (0.47**) and significantly negatively correlated with grain weight loss (- 0.43*).

Research on influence of storage period on pest incidence levels assumes significance in order to devise appropriate storage protocols. Kudachi and Balikai (2014) reported on evaluation of *rabi* sorghum genotypes against rice weevil, *Sitophilus oryzae* in storage, they conducted a laboratory experiment on *rabi*sorghum genotypes against rice weevil, *Sitophilus oryzae* L. during 2007-08. Twenty five *rabi* sorghum genotypes were evaluated based on parameters like % of damaged seeds, % germination, % loss in weight of seed and population build up recorded at 30, 90 and 180 days after storage. Results revealed that, cumulative seed damage at 180 days after storage was minimum in DJ 6514 (17.0%) followed by RS 585, CSV 216R, SPV570, BRJ 356 with minimum % damage ranging from 21.00 to 24.00 % indicating their high degree of resistance and maximum viability was noticed in RS 585 (78.00%) followed by BRJ 356 (76.50%). The genotype, CSV 8R showed high degree of resistance with minimum population buildup of 55.00 followed by RS 585 (56.0) and CSV 216R (56.00) and more number of adult weevils emerged in the RSE 03 (180.00), 5-4-1 (152.50) and Y 75(154.50) followed by Dagadi Solapur (133.00).

Table 4.43. Insect infestation (%) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Insect infestation (%)**
1st Bi-month	1.8
2nd Bi-month	2.4
3rd Bi-month	3.8
4th Bi-month	6.3
S Em ±	0.095
CD (0.05)	0.187
Influence of Gamma radiation	
Gamma Dose	**Insect infestation (%)**
0 Gy	7.8
250 Gy	4.7
500 Gy	3.8
750 Gy	2.8
1000 Gy	1.6
2000 Gy	0.8
S Em ±	0.116
CD (0.05)	0.229
Influence of Varieties	
Varieties	**Insect infestation (%)**
CSH 14	3.0
C 43	2.5
CSV 29R	5.2
S Em ±	0.082
CD (0.05)	0.162

Table 4.44.Insect infestation (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	4.00	2.50	6.00	**4.2**	5.00	3.25	7.00	**5.1**	7.25	5.50	13.50	**8.8**	11.25	9.50	19.25	**13.3**
250 Gy	2.25	2.25	4.00	**2.8**	3.25	2.75	5.00	**3.7**	4.00	3.50	7.50	**5.0**	6.50	5.50	10.50	**7.5**
500 Gy	2.75	1.50	3.50	**2.6**	3.00	2.00	4.00	**3.0**	3.50	2.25	5.75	**3.8**	5.50	4.50	8.00	**6.0**
750 Gy	1.00	1.00	2.75	**1.6**	1.50	1.50	3.25	**2.1**	2.25	2.00	4.25	**2.8**	4.25	3.75	7.00	**5.0**
1000 Gy	0.00	0.00	0.00	**0.0**	0.00	0.75	1.75	**0.8**	1.00	2.50	3.25	**2.3**	2.50	3.25	4.75	**3.5**
2000 Gy	0.00	0.00	0.00	**0.0**	0.00	0.00	0.00	**0.0**	0.00	0.00	1.75	**0.6**	1.75	2.50	4.25	**2.8**
MEAN	**1.7**	**1.2**	**2.7**	**1.9**	**2.1**	**1.7**	**3.5**	**2.4**	**3.0**	**2.6**	**6.0**	**3.9**	**5.3**	**4.8**	**9.0**	**6.4**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.232**	**0.164**	**0.200**	**0.360**
CD (0.05)	**0.457**	**0.323**	**0.396**	**1.021**

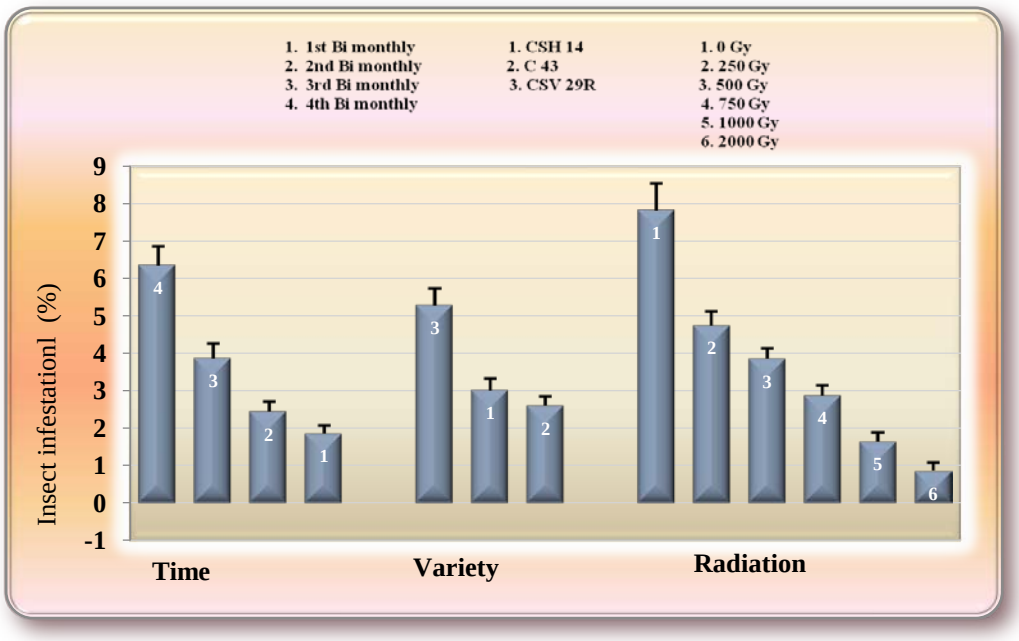

Fig. 4.24a: Insect infestation as influenced by storage period, gamma doses and varieties

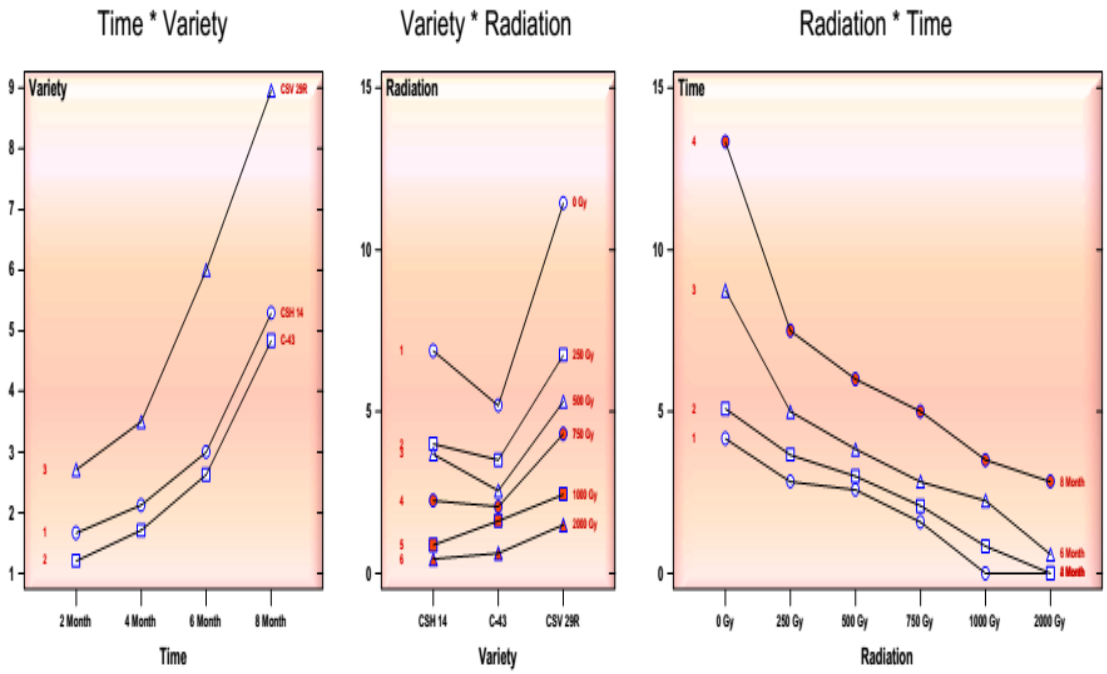

Fig. 4.24b: Insect infestation as influenced by the interactions among storage period, gamma doses and varieties

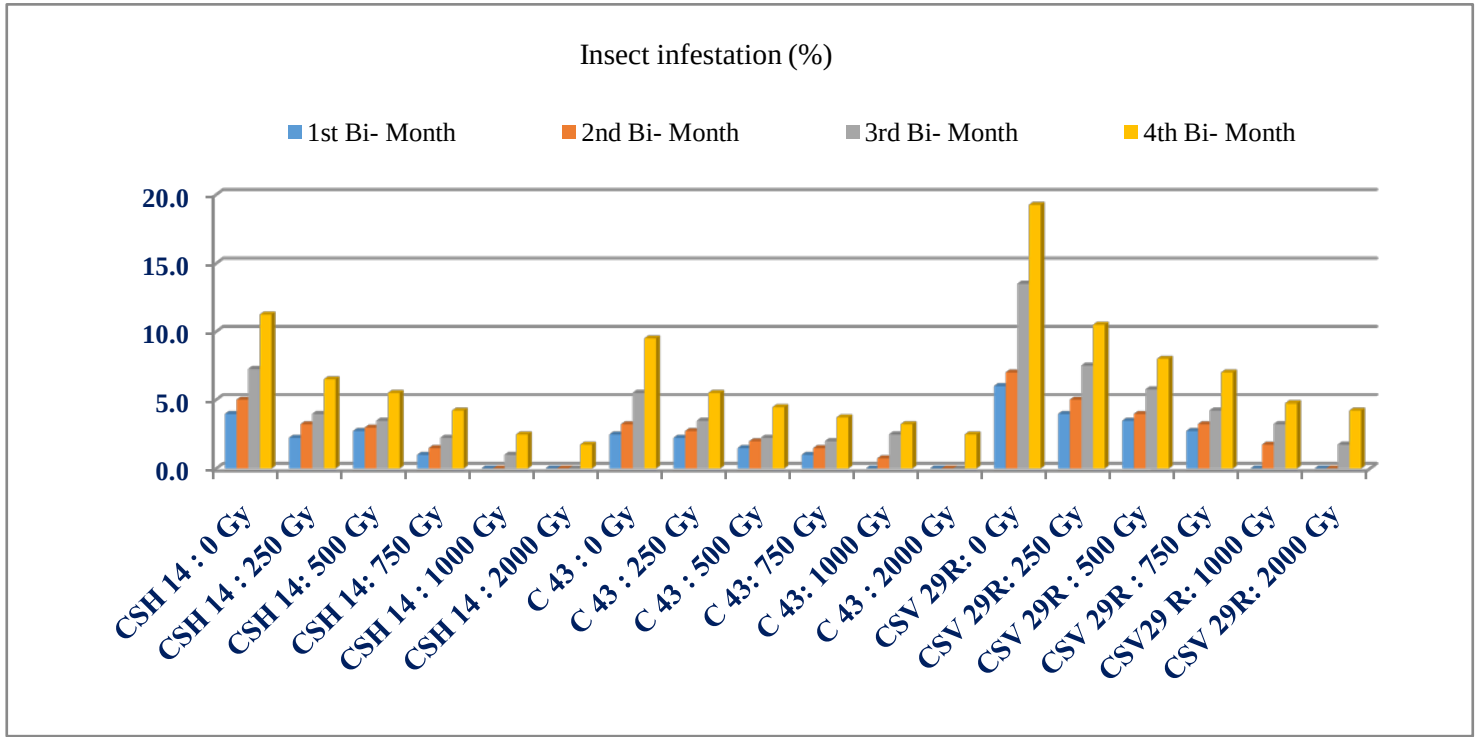

Fig.4.24 c: Insect infection influenced by the interaction among storage period x gamma doses x varieties

In the present experiment also, the results indicated that the insect infestation ranged from 0 (CSV 29R, C 43 and CSH 14 /2000 Gy) to 7.0 per cent (CSV 29R / 0 Gy) during second bi-month of storage.Mean insect infestation values after 4th bi-month of storage ranged from 1.75 (CSH 14/2000 Gy) to 19.25 per cent (CSV 29R/0 Gy). Interaction effects were significant for all the treatments (Table 4.44, Fig.4.24c).After nine months of storage period, elite interactions in the study *viz*., CSV 29R/ 1000, 2000 Gy, C 43/ 500, 750, 1000, 2000 Gy, and CSH 14/ 500, 750, 1000, 2000 Gy, recorded relatively lower weevil incidence percentages than the overall mean insectinfestation values and indicated the superiority of these combinations in responding well to ambient storage. After 1st bi-monthly interval over all mean insect infestation was 1.9 per cent and got increased to 6.4 per cent after fourth bi-month of storage. Significant influence of storage period was observed with regard to insect infestation for all the treatment evaluated. Results werepresented in Table 4.43 and depicted in Fig.4.24a. Significant influence of varieties wasalso observed for insect infestation for all the treatments evaluated.

In the present experiment, the results indicated that minimum insect infestation was observed at 750, 1000 and 2000 Gy (2.8, 1.6 and 0.8 per cent respectively) and all gamma doses percentage of insect infestation was lower than at control. The results were also revealed that the varieties C 43 had minimum insect infestation (2.5 percent) followed by CSH 14 (3 per cent) and CSV 29R (5.2 per cent).

Pathogen infectivity was estimated using standard blotter method and the results indicated that during first bi-monthly storage the fungal invasion ranged from 1.50% (CSH 14/ 2000 Gy) to 14.75% (CSV 29R/ 0 Gy). Mean fungal invasion values after 4thbi-month of storage ranged from 4.75 to 22.50 per cent. Interaction effects (Table 4.45) were Significant for all treatments.

Significant influence of storage period was observed with regard to fungal invasion for all the treatment evaluated. Results were given in Table 4.44 and depicted in Fig.4.25a. After1st bi-monthly interval over all mean fungal invasions was 8.1 per cent and got increased to 12.2 per cent after fourth bi-month of storage. In the present experiment also, the results indicated that minimum fungal invasion was observed at 2000, 250 and 1000 Gy (4, 7.6 and 8.4 per cent respectively) and at all gamma doses percentage of pathogen infestation was lower than at control. The lowest fungal

invasionwas noticed in CSH 14 (8.6 %) followed by C 43 (10%). Highest fungal invasion was recorded in CSV 29R (11.9 %).

Considering all the germination, seedling, biochemical and seed health parameters it could be obviously concluded that CSV 29R variety with gamma irradiation at lower dose of 500 Gy was found superior in respect of germination, seedling dimension and bio-chemical parameters followed by C 43 at 500 Gy. As far as seed health parameters were concerned, both CSH 14 and C 43 varieties at 1000 and 2000 Gy gamma irradiation performed well.

Table 4.45. Fungal invasion (%) as influenced by storage period, gamma dose and varieties

Influence of Storage period	
Storage period	**Fungal invasion (%)**
1st Bi-month	8.1
2nd Bi-month	9.4
3rd Bi-month	10.9
4th Bi-month	12.2
S Em ±	0.125
CD (0.05)	0.246
Influence of Gamma radiation	
Gamma Dose	**Fungal invasion (%)**
0 Gy	15.7
250 Gy	7.6
500 Gy	14.5
750 Gy	10.7
1000 Gy	8.4
2000 Gy	4.0
S Em ±	0.153
CD (0.05)	0.301
Influence of Varieties	
Varieties	**Fungal invasion (%)**
CSH 14	8.6
C 43	10.0
CSV 29R	11.9
S Em ±	0.108
CD (0.05)	0.213

Table 4.46.Fungal invasion (%) as influenced by the interaction among gamma dose, storage period and varieties

Gamma Dose	1st Bi-month (3 Month)				2nd Bi-month (5 Month)				3rd Bi-month (7 Month)				4th Bi- month (9 Month)			
	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN	CSH 14	C 43	CSV 29R	MEAN
0 Gy	11.00	12.25	14.75	**12.7**	12.00	14.50	**14.50**	13.7	15.00	17.00	19.50	**17.2**	16.50	19.00	22.50	**19.3**
250 Gy	4.50	6.50	7.50	**6.2**	5.50	7.25	**7.25**	6.7	7.50	8.75	9.00	**8.4**	8.00	9.50	9.50	**9.0**
500 Gy	9.50	11.75	14.00	**11.8**	11.75	14.00	**14.00**	13.3	13.00	14.75	18.00	**15.3**	14.50	16.50	19.50	**16.8**
750 Gy	7.00	9.25	10.50	**8.9**	8.50	10.50	**10.50**	9.8	9.25	10.75	14.00	**11.3**	10.25	11.50	14.75	**12.2**
1000 Gy	5.50	6.25	8.50	**6.8**	7.50	7.50	**7.50**	7.5	8.75	8.00	10.50	**9.1**	9.25	9.00	11.50	**9.9**
2000 Gy	1.50	2.75	3.00	**2.4**	2.00	3.00	**3.00**	2.7	3.75	4.50	5.75	**4.7**	4.75	6.00	7.75	**6.2**
MEAN	**6.5**	**8.1**	**9.7**	**8.1**	**7.9**	**9.5**	**9.5**	**8.9**	**9.5**	**10.6**	**12.8**	**11.0**	**10.5**	**11.9**	**14.3**	**12.2**

	Storage x Gamma dose	Storage x Variety	Gamma dose x Variety	Storage x Gamma dose x variety
S Em ±	**0.306**	**0.216**	**0.265**	**0.434**
CD (0.05)	**0.602**	**0.426**	**0.521**	**1.231**

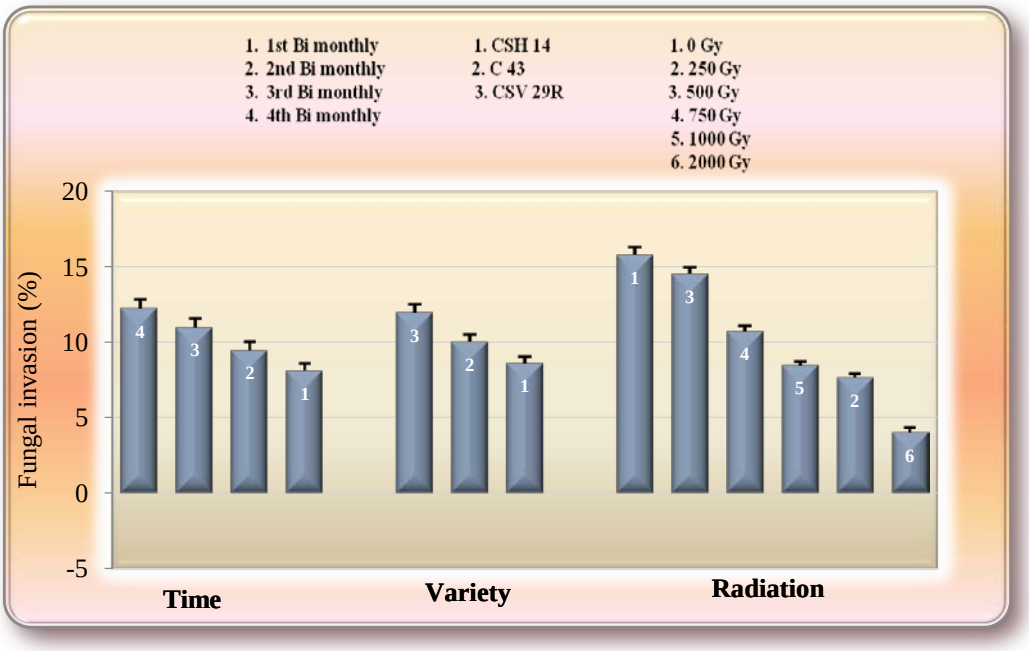

Fig. 4.25a: Fungal invasion as influenced by storage period, gamma doses and varieties

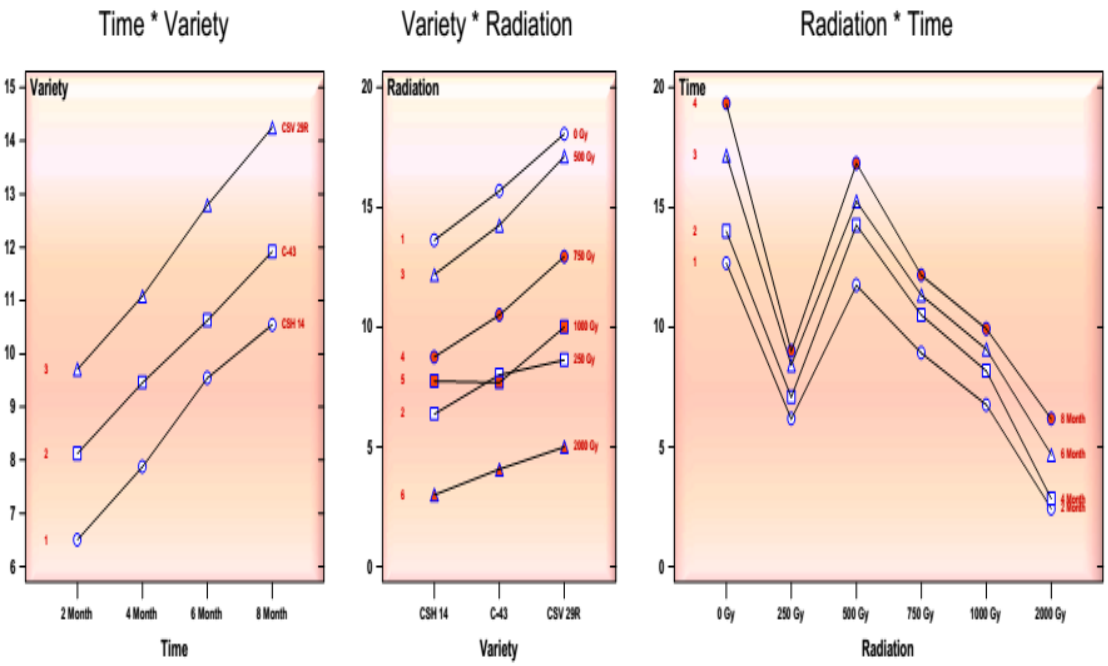

Fig. 4.25b: Fungal invasion as influenced by the interactions among storage period, gamma doses and varieties

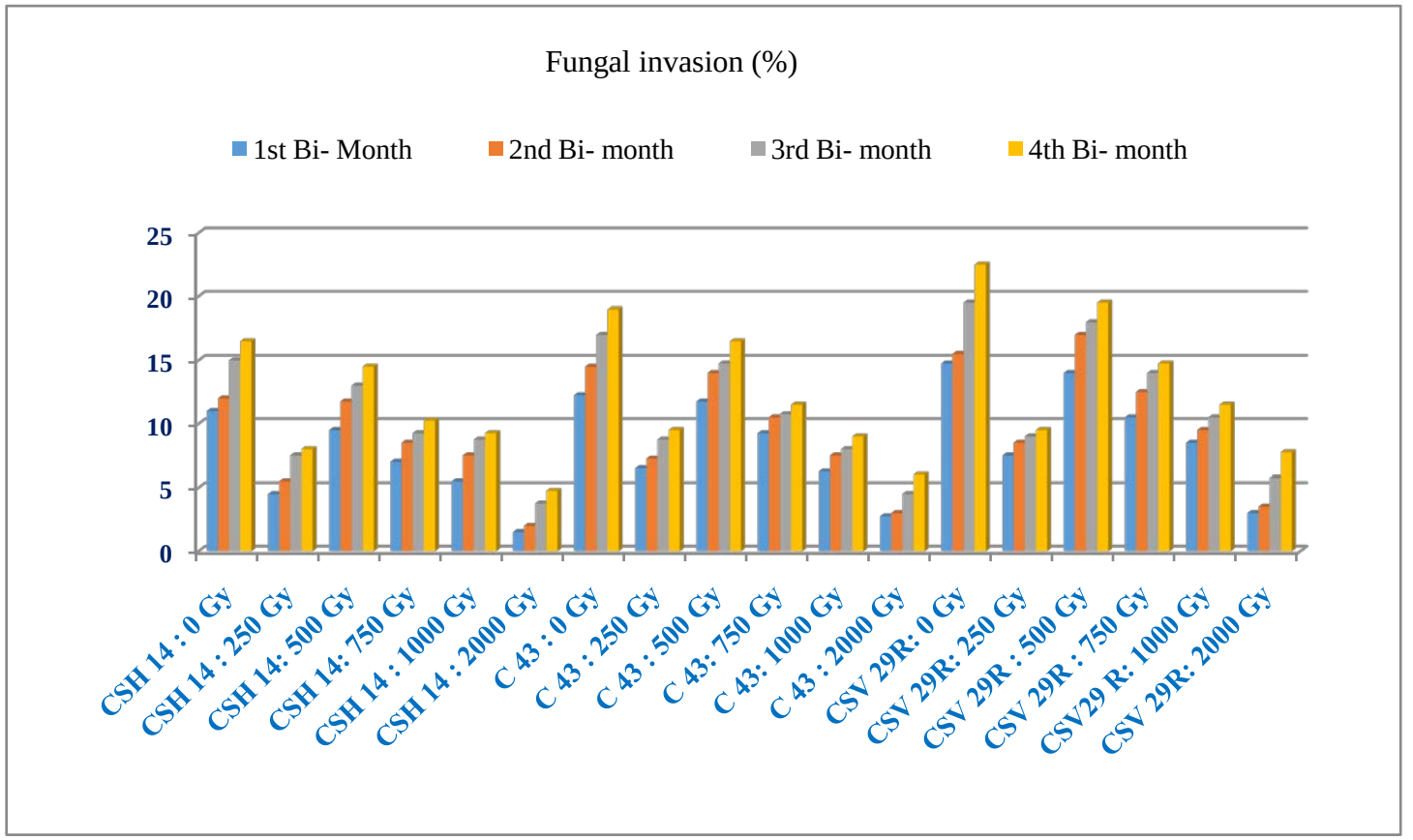

Fig.4.25 c: Fungal invasion as influenced by the interaction among storage period x gamma doses x varieties

Chapter V

SUMMARY AND CONCLUSIONS

Chapter V

SUMMARY AND CONCLUSIONS

The present investigation entitled “Effect of gamma irradiation on seed quality and storage of sorghum (*Sorghum bicolour* L.Moench)” was aimed at studying the influence of five gamma doses along with control on three different sorghum varieties during storage leading to identification of superior interaction effects for seed quality and seed storability. The experiment was carried out at ICAR-Indian institute of Millets Research and College of Agriculture, PJTSAU, Rajendranagar, Hyderabad during 2015-16 Rabi season through Completely Random Design in factorial concept with four replications. The gamma rays (0, 250, 500, 750, 1000 and 2000 Gy) were irradiated to varieties CSV 29R, C43 and CSH 14 along with untreated control was evaluated for seed quality parameters like germination, seedling, biochemical and seed health parameters following irradiation. Further, alterations during seed storage over a period of nine months at bimonthly intervals under ambient conditions were investigated. Studies were carried out to determine the interrelationship between seed quality components and storability for 18 combinations ofgamma doses and sorghum varieties.

Immediately after exposure, gamma radiation dose and interaction componentswere found to be significant for germination percentage, field emergence, speed of germination, root length, shoot length, seedling vigour index, electrical conductivity, dehydrogenase activity and moisture percentage.

In the present investigation, mean germination percentage ranged from 71.0 to 90.0% among different treatments. Maximum values were noticed in CSV 29R irradiated with 0 Gy (90.0 %) followed by CSV 29R: 500 Gy, C 43: 0 Gy and C 43: 500 Gy. Lowest germination percent of 71.0 % were recorded in CSH 14 with 2000 Gy irradiation.Highest speed of germination (45.3) was recorded in the treatment CSH 14/ 500 Gy and lowest (31.8) was noticed at 2000 Gy in C 43 variety.

Immediately after exposure of gamma radiation to nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy, 750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy and C 43/ 0 Gy, 500 Gy, 750 Gy, recorded significantly higher root length than general mean of 7.7 cm. The values ranged from 1.8 cm (CSH 14/ 2000 Gy) to 15.2 cm (CSV 29R / 0

Gy).Significant influences of gamma doses were observed in the expression of root length. But all doses exhibited inhibitory effect on root length, which was less than that of 0 Gy. Maximum shoot length was recorded in case of CSV 29R / 0 Gy and 500 gy (15.4 cm) and lowest in case of CSH 14 / 2000 Gy (2.3 cm).

As observed in other seedling parameters, vigour index was significantly influenced by gamma doses. Highest seedling vigour index was noticed at 500 Gy (1114) which was inferior to 0 Gy (1337). However, higher gamma dose of 2000 Gy recorded significantly lower vigour index value of 186.

Mean data collected on germination percentage, speed of germination, root length, shoot length, seed vigour index, field emergence, electrical conductivity, starch, protein, fat and ash content of seed, α-amylase activity, dehydrogenase activity, seed moisture percentage, weevil infestation and fungal invasion during nine month of storage were analyzed.The mean data indicated that the treatments were highly significant for all the parameters studied at bimonthly intervals up to nine months of storage period.

In the present investigation 7 treatments *viz*., CSH 14 / 0 Gy, C 43/ 0 Gy, 500 Gy, 750 Gy and CSV 29R/ 0 Gy, 500 Gy, 750 Gy recorded significantly higher germination values after firstbi-month of storage. Minimum germination percentage of 67.0 was recorded at CSV 29R/ 2000 Gy. Further, the data revealed that, germination per cent was significantly influenced by period of storage.Among treatments CSV 29R/500 Gy, C 43/ 500 Gy and CSH 14/ 500 Gy maintained the higher germination percentage up to 4^{th} bi-months of storage (70, 67 and 65 per cent respectively) and were significantly superior than corresponding value at 0 Gy gamma dose *i.e.* 62, 60 and 59 % respectively and other treatments like CSV 29R/ 250, 750 Gy, C 43/ 250, 750 Gy and CSH 14/ 250, 750 Gy recorded moderately high germination percentage after 4^{th} bi-month storage.

Further, the data revealed that, germination per cent was significantly influenced by period of storage.After 1^{st} bi-month of storage highest mean germination per cent of 78.0 were recorded which got reduced to 62.0 per cent at the end of 4^{th} bi-month period a reduction of 20.5 per cent was observed.

The influence of gamma dose on sorghum seed germination during storage was evident from the results. Gamma dose of 500 Gy and 750 Gy recorded highest

percentage of germination (83% and 81%) after first bimonthly evaluation and maintained highest germination values even after fourth bimonthly period by recording 67 and 66 per cent germination respectively. Significant decrease in field condition during storage period was observed. The mean field emergence deceased from 57.0 percent at the end of 1st bi- month to 45.0 percent at the end of 4th bi-month of storage. Similarly, gamma doses had significant influence on field emergence during storage. 500 Gy dose recorded 69 per cent mean field emergence which is significantly higher over other treatments.

Considering the storage period, lowest speed of germination (22.8) was recorded after 4th bi-month and highest speed of germination was registered after first bi-month of storage (37.4). Gamma doses also exercised significant influence on speed of germination. Highest speed of germination was recorded at 500 Gy and 750 Gy gamma doses (33.7 and 32.6). Lowest speeds of germination were recorded at 2000 Gy (24.6) over all periods of storage. Further, effects of varieties were significant for speed of germination during storage. Maximum speed of germination was recorded in CSH 14 (31.6) followed by C 43 (28.6). Lowest speed of germination was recorded in CSV 29R (27.5).

Significant influence of gamma doses on root and shoot length during storage was recorded at 500 Gy dose 9.3 cm mean root length and shoot length ofcm 10.6 were registered, which were significantly higher than 250, 750,1000 and 2000 Gy but were less than 0 Gy. Examination of results revealed that varieties had significant influence on root and shoot length. Highest root length of 7.0 cm was recorded by CSV 29R followed by CSH 14 (5.6 cm). Maximum shoot lengths of 8.1 cm were recorded in CSV 29R followed by CSH 14 and C 43(6.0 cm).

The data from 1st bi-month of storage revealed that, mean vigour index ranged from 122.9 (CSH 14 / 2000 Gy) to 1332.3 (CSV 29R / 500 Gy). Among the treatments which exhibited significantly superior vigour index after 1st bi-monthly interval and maintained till the end of ninth month storage period, CSH 14/ 500 Gy, C 43/ 500 Gy and CSV 29R/ 500, 750 Gy were found to be important. Similarly, values of vigour index ranged from 62.6 (C 43 / 2000 Gy) to 759.3 (CSV 29R/ 500 Gy) at the end of 4th bi-month of storage. It was interesting to note that during first and second bi-month intervals seedling vigour index at 0 Gy was more than all other gamma doses in all selected varieties. However, in respect of

observations made during third and fourth bi-monthly interval seedling vigour index at 0 Gy were less than 500 Gy gamma dose in all genotype.

Significant influence of storage period in the reduction of vigour index was evident from the data during four bi-monthly intervals of storage. As the storage period progressed from 3rd month to 9th month, the vigour index was also declined from 659 to 349 recording a reduction of 47.0 per cent. Further, 500 Gy doses treatment recorded marginally higher vigour index of 814 which was significantly higher over other doses. Lowest vigour index (115) was noticed at 2000 Gy indicating its detrimental effect on germination percentage and seedling dimensions.

Significant increase in electrical conductivity from firstbimonthly storage to final bimonthly storage period was evident as per the results obtained. The mean EC values increased from 52.1 µS cm^{-1} to 241.7 µS cm^{-1} during the storage period. When the performance of gamma doses was examined, it was revealed that, significantly higher EC of 197.3 µS cm^{-1} was observed at 2000 Gy. However, 500 Gy and 250 Gy doses recorded lowest EC of 101.2 µS cm^{-1} and 98.9 µS cm^{-1} respectively. Study of significance of varieties on EC indicated low values (126.6 µS cm^{-1}) in CSV 29R. Highest electrical conductivity of 142.2 µS cm^{-1} recorded in C 43 variety.

After nine months of storage dehydrogenase activity values were low (0.05µg) in case of CSV 29R/ 2000 Gy and CSH 14/ 2000 Gy and highest value of 0.9 µg in case of CSV 29R/ 500 Gy and C 43/ 500 Gy.Were observed. Significant decrease in dehydrogenase activity from first bimonthly storage to final bimonthly storage period was evident as per the results analyzed. The mean dehydrogenase activity values declined from 0.16 µg to 0.07 µg during the nine month of storage period. When the performance of gamma doses was examined, it was revealed that, significantly higher dehydrogenase activity of 0.14 µg was observed at 500 Gy. However, 2000 Gy doses recorded lowest dehydrogenase activity of 0.10 µg. Study of significance of varieties on dehydrogenase activity indicated low values (0.10 µg) in CSH 14. Highest dehydrogenase activity of 0.13 µg recorded in CSV 29R variety.

The mean alpha amylase activity of 6.0 mm after 1st bi-month of storage was reduced to 4.9 after 4th bi-month. When the performance of gamma doses was examined, it was revealed that, significantly higher alpha amylase activity of 6.5 mm was observed at 500 Gy followed by 750 Gy (6.2 mm) which were higher than 0, 250, 1000 and 2000 Gy dose. Varieties also had significant influence in the expression of alpha amylase activity. CSV 29R recorded the highest alpha amylase activity of 5.9 mmand the lowest in CSH 14 (5.1 mm).

The mean starch content of 62.0 percent after 2nd bi-month of storage was reduced to 59.5 percent after 4th bi-month of storage. Influence of gamma doses on starch content during storage were found to be significant. When the performance of gamma doses was examined, it was observed that, significantly higher starch contain of 63.7 per cent was observed at 500 Gy followed by 750 Gy (63.2 per cent) which were higher than 0, 250, 1000 and 2000 Gy doses.

The interaction effect of gamma radiation and varieties on protein content were found to be significant. After 2nd bi-month of storage, protein content in seed ranged from 10.45 % (CSV 29R/ 2000 Gy) to 11.61 % (CSH 14 /500 Gy). When the performance of gamma doses was examined, it was revealed that, significantly higher protein content of 11.4% were observed at 500 Gy followed by 750 Gy (11.1 %) which were higher than 0, 250, 1000 and 2000 Gy doses. Varieties also had significant influence in the expression of protein content. CSV 29R and C 43 recorded the same protein content of 10.6%and the highest was in CSH 14 (10.8 %).

When the performance of gamma doses were observed, it was found that, significantly higher fat content of 3.4 % was observed at 500 Gy followed by 750 Gy (3.3 %) which were higher than 0, 250, 1000 and 2000 Gy dose.CSV 29R recorded the highest fat content of 3.2 % and the lowest was in CSH 14 (2.9%).

With respect to ash content it was observed that, ash content in seed ranged from 1.26 % (C 43/ 2000 Gy) to 1.75 % (C 43/500 Gy) after 2nd bi-month of storage while it ranged from 1.20 % (CSH 14/ 2000 Gy) to 1.67 % (C 43/500, 750 Gy) at the end of 4th bi-month. CSV 29R and C 43 recorded the same ash content of 1.5 %and the lowest in CSH 14 (1.4 %).

A significant increase in seed moisture content during storage period were observed.The seed moisture content increased from 9.2 per cent at1st bi-month to 9.3 per cent after 4th bi-month of storage. Gamma dose of 1000 and 2000 Gy recorded lower seed moisture content of 9.2 per cent which was significantly more than other doses. Higher seed moisture content (9.3 %) were observed at 0 Gy.

The interaction effect of gamma radiation and varieties were found to be significant. After 2nd bi-month of storage, moisture content in seed ranged from 9.20 % (CSH14/ 2000 Gy) to 9.36 % (C 43 /0 Gy). But at the end of 4th bi-month, seed moisture content ranged from 9.31% (CSH 14/2000 Gy) to 9.42 % (C 43/0, 250 Gy). The mean moisture content of 9.3 per cent after 2nd bi-month of storage was increased to 9.4 percent after 4th bi-month.

In the present experiment, the results indicated that the insect infestation ranged from 0 (CSV 29R, C 43 and CSH 14 /2000 Gy) to 7.0 per cent (CSV 29R / 0 Gy) during second bi-month of storage. After 1st bi-monthly interval over all mean insect infestation was 1.9 per cent and got increased to 6.4 per cent after fourth bi-month of storage. Significant influence of storage period was observed with regard to insect infestation for all the treatment evaluatedinsect infestation had increased with storage period.

Experiment on fungal invasion study indicated that during first bi-monthly storage the fungal invasion ranged from 1.50% (CSH 14/ 2000 Gy) to 14.75% (CSV 29R/ 0 Gy). Mean fungal invasion values after 4thbi- month of storage ranged from 4.75 to 22.50 per cent. Significant influences of storage period were observed with regard to fungal invasion for all the treatment evaluated. After1st bi-monthly interval over all means fungal invasionswere 8.1 per cent and got increased to 12.2 per cent after fourth bi-month of storage. In the present experiment also, the results indicated that minimum fungal invasionwere observed at 2000, 250 and 1000 Gy (4, 7.6 and 8.4 per cent respectively) and at all gamma doses percentage of pathogen infection were lower than at control. The lowest fungal invasionwere noticed in CSH 14 (8.6 %) followed by C 43 (10%). Highest fungal invasionwere recorded in CSV 29R (11.9 %).

The following conclusions were drawn from present investigation.

1. As per the results from the experimentation in sorghum seed treatment immediately after radiation treatment exposure, it could be concluded that gamma doses up to 750 Gy were found to exercise positive influence in enhancing all the germination, seedling and biochemical parameters. The doses beyond 750 Gy had detrimental effects by interfering with various seed quality attributes.
2. Among the interactions CSV 29R and C 43 varieties at 500 Gy and 750 Gy performed better than other gamma irradiation of 0, 250, 1000, 2000 Gy in all seed quality parameters during nine months of storage.
3. Gamma doses of 500 and 750 Gy showed superiority in positivelyinfluencing all the seed quality parameters during storage period.
4. CSV 29R found better in maintaining the seed biochemical constituents during nine month of storage.
5. As far as seed health parameters were concerned, both CSH 14 and C 43 varieties at 1000 and 2000 Gy gamma irradiation performed well.

It can be inferred from the present investigation that at lower doses irradiation of sorghum genotypes showed superiority in seed quality parameters over higher gamma doses. Each variety exhibited better performance at different level of gamma doses based on their radio sensitivity.

Hence breeder/ seed producer who want to save the 2 or 3 season by irradiation need to be aware of radio sensitivity of varieties in respect of seed quality issues to be sure that irradiated seed do not show unexpected and detrimental seed quality problems during and after storage.

Considering the economy of gamma treatment to seed material it could be stated that it very is cost effective and affordable for farming community. Establishment of semi commercial gamma radiation plant in collaboration with Bhaba Atomic Research Centre (BARC) on a business incubation mode would lead to enhancement in general use by the farmers.

In view of merits of this approach for seed treatment, such plant could be established at certain important points in seed production map to facilitate large scale treatment.

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