STUDY OF MUTATION BREEDING FOR IMPROVEMENT OF FOXTAIL MILLET (*Setaria italica* B.)

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STUDY OF MUTATION BREEDING FOR IMPROVEMENT OF FOXTAIL MILLET (*Setaria italica* B.)

BY
MANNUJAN

A THESIS
SUBMITTED TO THE UNIVERSITY OF DHAKA
IN FULFILMENT OF THE REQUIREMENTS OF
THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
PLANT BREEDING

382423

NOVEMBER, 1998

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CERTIFICATE

This is to certify that the research work embodying the results reported in this thesis has been carried out under our joint supervision in the Breeding Laboratory, Cereal Section and in the experimental field both located at BARI (Bangladesh Agriculture Research Institute), Joydebpur, Gazipur, Bangladesh.

It is further certified that the research work presented here is original and suitable for submission for the award of Ph.D. degree.

382423

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Mannujan
The Author

November, 1998

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LIST OF CONTENTS

		Page No.
1. Introduction	...	1
2. Review of Literature	...	4
2.1. Use of gamma radiation as mutagenisis	...	6
2.2. Mutagenic effects in M_1 generation	...	7
2.3. Chlorophyll and viable mutations in M_2 and advanced generation	...	17
2.4. Differential genotypic response to various mutagenic treatments	...	25
2.5. Induced micromutations	...	25
2.6. Induced macromutations	...	32
3. Materials and Methods	...	34
3.1. Materials	...	34
3.2. Methods	...	35
3.2.1. Studies in M_1 generation	...	36
3.2.2. Studies in M_2 generation	...	37
3.2.2.1. Estimation of mutation frequencies	...	37
3.2.2.2. Estimation of mutagenic effectiveness and efficiency	...	38
3.2.3. Studies in M_3 generation	...	38
3.2.3.1. Polygenic variability	...	38
3.2.3.2. Breeding behaviour	...	39
3.2.3.3. Study of variants isolated in M_1 generation	...	39
3.2.3.4. Study of useful macromutants in isolated M_2 generation	...	39
4. Experimental Results	...	41
4.1. M_1 generation	...	41
(a) Germination	...	41
(b) Shoot length	...	43
(c) Root length	...	43
(d) Dry weight of seedlings	...	50
(e) Pollen sterility	...	50
(f) Grain fertility	...	56

Dhaka University Institutional Repository

Page No.

4.1.1. Quantitative characters ... 56

4.2. M_2 generation ... 78
4.2.1. Chlorophyll mutations ... 78
4.2.2. Frequency of chlorophyll mutations ... 82
4.2.3. Spectrum of chlorophyll mutants ... 82
4.2.4. Frequency of viable mutants ... 96
4.2.5. Spectrum of viable mutants ... 96
4.2.6. Mutagenic effectiveness and efficiency ... 116
4.2.1. Potency of gamma rays ... 117
4.2.1. Response of the three varieties ... 118

4.3. M_3 generation ... 121
4.3.1. Micromutation ... 121
4.3.2. Breeding behaviour of viable mutants ... 178
4.3.3. Variants in M_1 generation ... 178
4.3.4. Evaluation of useful macromutants ... 181
4.3.4.1. Early type ... 181
4.3.4.2. Induced dwarf type ... 195
4.3.4.3. High yielding mutants ... 203

5. Discussion ... 204

5.1. Studies in M_1 generation ... 204
5.1.1. Germination ... 204
5.1.2. Seedling growth, seedlings dry weight, pollen sterility and grain fertility ... 205
5.1.3. Quantitative characters ... 205
5.1.4. Variants in M_1 ... 206

5.2. Studies in M_2 generation ... 208
5.2.1. Frequency and spectrum of chlorophyll mutations ... 208
5.2.2. Efficiency and effectiveness of mutagen ... 209
5.2.3. Frequency and spectrum of viable mutations ... 209

5.3. Studies in M_3 generation ... 210
5.3.1. Polygenic mutations in M_3 ... 210
5.3.2. Breeding behaviour and breeding value of viable mutants (macromutations) ... 213

6. Summary ... 216

7. References ... 219

Dhaka University Institutional Repository

LIST OF TABLES

		Page No.
Table 1.	ANOVA for seed germination of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.	42
Table 2.	Effect on seed germination (%) of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma rays treatments in M_1 generation.	42
Table 3.	ANOVA among shoot lengths in gamma ray treated materials of three varieties, BSi1, BSi427and BSi467 of Foxtail millet in M1 generation.	44
Table 4.	Effect on shoot length of three varieties of foxtail millet following Gamma irradiation in M_1 generation.	44
Table 5.	ANOVA among root lengths in gamma ray treated material of three varieties, BSi1, BSi427and BSi467 of foxtail millet in M_1 generation.	45
Table 6.	Effect on root length of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.	45
Table 7.	ANOVA among seedling dry weights in gamma irradiated material of three varieties, BSi1, BSi427and BSi467 of foxtail millet in M_1 generation.	51
Table 8.	Effect on seedling dry weight of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.	51
Table 9.	ANOVA for pollen sterility in gamma irradiated material of three varieties, BSi1, BSi427and BSi467 of Foxtail millet in M_1 generation.	52
Table 10.	Effect on pollen sterility of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.	52
Table 11.	ANOVA for grain fertility in gamma irradiated material of three varieties, BSi1, BSi427and BSi467 of foxtail millet in M_1 generation.	57

Dhaka University Institutional Repository

		Page No
Table 12.	Effect on grain fertility of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.	57
Table 13.	Range, mean, standard deviation and coefficient of variation for days to panicle emergence following gamma irradiation in BSi1 in M_1 generation.	61
Table 14.	Range, mean, standard deviation and coefficient of variation for days to panicle emergence following gamma irradiation in BSi427 in M_1generation.	61
Table 15.	Range, mean, standard deviation and coefficient of variation for days to panicle emergence following gamma irradiation in BSi467 in M_1generation	63
Table 16.	Range, mean, standard deviation and coefficient of variation for plant height following gamma irradiation in BSi1 in M_1generation	63
Table 17.	Range, mean, standard deviation and coefficient of variation for plant height following gamma irradiation in BSi427 in M_1generation	65
Table 18.	Range, mean, standard deviation and coefficient of variation for plant height following gamma irradiation in BSi467 in M_1generation	65
Table 19.	Range, mean, standard deviation and coefficient of variation for panicle length following gamma irradiation in BSi1 in M_1generation	67
Table 20.	Range, mean, standard deviation and coefficient of variation for panicle length following gamma irradiation in BSi427 in M1generation in the variety BSi427	67
Table 21.	Range, mean, standard deviation and coefficient of variation for panicle length following gamma irradiation in BSi467 in M_1generation.	69
Table 22.	Range, mean, standard deviation and coefficient of variation for tiller number following gamma irradiation in BSi1 in M1 generation.	69

Dhaka University Institutional Repository

		Page No
Table 23.	Range, mean, standard deviation and coefficient of variation for tiller number following gamma irradiation in BSi427 in M_1generation.	71
Table 24.	Range, mean, standard deviation and coefficient of variation for tiller number following gamma irradiation in BSi467 in M_1generation.	71
Table 25.	Range, mean, standard deviation and coefficient of variation for days to maturity following gamma irradiation in BSi1 in M_1generation	73
Table 26.	Range, mean, standard deviation and coefficient of variation for days to maturity following gamma irradiation in BSi427 in M_1generation.	73
Table 27.	Range, mean, standard deviation and coefficient of variation for days to maturity following gamma irradiation in BSi467 in M_1generation.	75
Table 28.	Range, mean, standard deviation and coefficient of variation for grain yield following irradiation in BSi1 in M1 generation.	75
Table 29.	Range, mean, standard deviation and coefficient of variation for grain yield following gamma irradiation in BSi427 in M_1generation.	77
Table 30.	Range, mean, standard deviation and coefficient of variation for grain yield following gamma irradiation in BSi467 in M_1generation.	77
Table 31.	Frequency of chlorophyll mutants following gamma irradiation in BSi1 in M_2 generation.	79
Table 32.	Frequency of chlorophyll mutants following gamma irradiation in BSi427 in M_2 generation.	80
Table 33.	Frequency of chlorophyll mutants following gamma irradiation in BSi467 in M_2 generation.	83
Table 34.	Spectrum of chlorophyll mutants following gamma irradiation in BSi1 in M_2 generation.	84
Table 35.	Spectrum of chlorophyll mutants following gamma irradiation in BSi427 in M_2 generation.	91

Dhaka University Institutional Repository

		Page No
Table 36.	Spectrum of chlorophyll mutants following gamma irradiation in Bsi 467 in M_2 generation.	93
Table 37.	Frequency of viable mutants following gamma irradiation in BSi1 in M_2 generation.	94
		Page No
Table 38.	Frequency of viable mutants following gamma irradiation in BSi427 in M_2 generation.	97
Table 39.	Frequency of viable mutants following gamma irradiation in BSi467 in M_2 generation.	98
Table 40.	Spectrum of viable mutants following gamma irradiation in BSi1 in M_2 generation.	107
Table 41.	Spectrum of viable mutants following gamma irradiation in BSi427 in M_2 generation.	114
Table 42.	Spectrum of viable mutants following gamma irradiation in BSi467 in M_2 generation.	115
Table 43.	ANOVA for different quantitative characters of gamma irradiated materials of three varieties, BSi1, BSi427, and BSi467 of foxtail millet in M_3 generation	122
Table 44.	Effect on days to maturity and flowering of three varieties, BSi1, BSi427 and BSi467 of foxtail millet following gamma rays treatments in M_3 generation.	123
Table 45.	Effect on plant height, panicle length and tiller number of three varieties, BSi1, BSi427 and BSi467 of foxtail millet following gamma rays treatments in M_3 generation.	124
Table 46.	Effect on grain yield and 500 grain weight of three varieties, BSi1, BSi427 and BSi467 of foxtail millet following gamma rays treatments in M_3 generation.	125
Table 47.	Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for days to panicle emergence in BSi1 following gamma rays treatments in M_3 generation.	128
Table 48.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to panicle emergence in BSi427 following gamma rays treatments in M_3 generation.	129

Dhaka University Institutional Repository

		Page No.
Table 49.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to panicle emergence in BSi467 following gamma rays treatments in M_3 generation.	130
Table 50.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for plant height in BSi1 following gamma rays treatments in M_3 generation.	136
Table 51.	Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for plant height (cm) in BSi427 following gamma rays treatments in M_3 generation.	Page No 137
Table 52.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for plant height (cm) in BSi467 following gamma rays treatments in M_3 generation.	138
Table 53.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for panicle length in BSi1 following gamma rays treatments in M_3 generation.	144
Table 54.	Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for panicle length (cm) in BSi427 following gamma rays treatments in M_3 generation.	145
Table 55.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for panicle length (cm) in BSi467 following gamma rays treatments in M_3 generation.	146
Table 56.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for tiller number in BSi1 following gamma rays treatments in M_3 generation.	152
Table 57.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for tiller number in BSi427 following gamma rays treatments in M_3 generation.	153
Table 58.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for tiller number in BSi467 following gamma rays treatments in M_3 generation.	154
Table 59.	Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for days to maturity in BSi1 following gamma rays treatments in M_3 generation.	156

Dhaka University Institutional Repository

		Page No.
Table 60.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to maturity in BSi427 following gamma rays treatments in M_3 generation.	157
Table 61.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to maturity in BSi467 following gamma rays treatments in M_3 generation.	158
Table 62.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain yield per plant in BSi1 following gamma rays treatments in M_3 generation.	164
		Page No
Table 63.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for yield per plant (gm) in BSi427 following gamma rays treatments in M_3 generation.	165
Table 64.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain yield per plant in BSi467 following gamma rays treatments in M_3 generation.	166
Table 65.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain weight in BSi1 following gamma rays treatments in M_3 generation.	172
Table 66.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain weight in BSi427 following gamma rays treatments in M_3 generation.	173
Table 67.	Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain weight in BSi467 following gamma rays treatments in M_3 generation.	174
Table 68.	Breeding behaviour of viable mutants in M_3.	179
Table 69.	Variants in M_1 generation.	179
Table 70.	ANOVA for different characters in two early mutants and their parent, BSi427 in M_3 and M_4 generations.	182
Table 71.	Mean values of different quantitative characters in two early mutants and their parent, BSi427 in M_3 and M_4 generations	183
Table 72.	ANOVA of combined analysis for days to maturity and yield per plant in two early mutants and their parent, BSi427	183

Dhaka University Institutional Repository

		Page No.
Table 73.	Mean values for days to maturity and yield per plant (over two years) in two early mutants and their parent, BSi427	184
Table 74.	Correlation coefficients among different characters in two early mutants and parent, BSi427 in M_3 and M_4 generations	184
Table 75.	ANOVA for different quantitative characters in twenty early mutants and their parent, BSi1 in M_3 and M_4 generations.	185
Table 76.	Mean values for different characters in twenty early mutants and their parent, BSi1 in M_3 generation.	186
Table 77.	Mean values of different quantitative characters in twenty early mutants and their parent, BSi1in M_4 generation.	187
		Page No
Table 78.	ANOVA of combined analysis for days to maturity and yield in twenty early mutants and parent BSi1	189
Table 79.	Mean values (over two years) for days to maturity and yield per plant in twenty early mutants and their parent BSi1.	189
Table 80.	Correlation coefficient among different characters in twenty early mutants and their parent, BSi1 in M_3 and M_4 generations	190
Table 81.	ANOVA for different quantitative characters in sixteen early mutants and their parent, BSi467 in M_3 and M_4 generation.	190
Table 82.	Mean values for different quantitative characters in sixteen early mutants and parent, BSi467 in M_3 generation	191
Table 83.	Mean values for different quantitative characters in sixteen early mutants and parent, BSi467 in M_4 generation	192
Table 84.	ANOVA of combined analysis for days to maturity and yield in sixteen early mutants and their parent, BSi467.	193
Table 85.	Mean values (combined over two years) for days to maturity and yield per plant in sixteen early mutants and their parent, BSi467	193
Table 86.	Correlation coefficients among different quantitative characters in sixteen early mutants and their parent, BSi467 in M_3 and M_4 generations.	194

Dhaka University Institutional Repository

		Page No.
Table 87.	Different quantitative characters in five selected dwarf mutants and their parent BSi427 in M_2 generation in BSi427 (observed data).	196
Table 88.	Different quantitative characters in five selected dwarf mutants in M_3 generation (mean data).	196
Table 89.	ANOVA for different quantitative characters in five dwarf mutants and their parents, BSi427 in M_4 generation.	197
Table 90.	Mean values of different quantitative characters in five dwarf mutants and their parent, BSi427 in M_4 generation	197
Table 91.	Mean values of different quantitative characters in five dwarf mutants and their parent, BSi427 in M_3 and M_4 generation.	198
Table 92.	Genetic parameters for different characters in M_4 generation in five dwarf mutants and their parent BSi427	200

		Page No
Table 93.	Correlation coefficients among different characters in five dwarf mutants and their parent, BSi427	200
Table 94.	ANOVA for different quantitative characters in M_3 generation in seven high yielding mutants and parent, BSi427	201
Table 95.	Mean values of different quantitative characters in seven high yielding mutants and their parent, BSi427 in M_3 generation.	202
Table 96.	Comparative increase (percent) in yield of seven high yielding mutants over their parents, BSi427 in M_2 and M_3 generation.	202

Dhaka University Institutional Repository

LIST OF FIGURES

		Page No.
1	Effect of gamma rays on seed germination in BS1, BSi427 and BSi467 in M1 generation.	46
2	Effect of gamma rays on shoot length in BSi1, BSi427 and BSi467 in M1 generation.	46
3	Effect of gamma rays on root length in BSi1, BSi427 and BSi467 in M1 generation.	53
4	Effect of gamma rays on seedling dry weight in BSi1, BSi427 and BSi467 in M1 generation.	53
5	Effect of gamma rays on pollen stainability in BSi1, BSi427 and BSi467 in M1 generation.	58
6	Effect of gamma rays on grain fertility in BSi1, BSi427 and BSi467 in M1 generation.	58
7	Frequency of chlorophyll mutants based on M2 population (%) in three varieties.	81
8	Spectrum of chlorophyll mutants in BSi1.	85
9	Spectrum of chlorophyll mutants in BSi427.	86
10	Spectrum of chlorophyll mutants in BSi467.	87
11	Frequency of viable mutants based on M2 population (%) in three varieties.	95
12	Spectrum of viable mutants in BSi1.	108
13	Spectrum of viable mutants in BSi427.	109
14	Spectrum of viable mutants in BSi467.	110
15	Frequency curves of induced variability for days to flowering in BSi1.	131
16	Frequency curves of induced variability for days to flowering in BSi427.	132
17	Frequency curves of induced variability for days to flowering in BSi467.	133
18	Frequency curves of induced variability for plant height in BSi1.	139

Dhaka University Institutional Repository

		Page No.
19	Frequency curves of induced variability for plant height in BSi427.	140
20	Frequency curves of induced variability for plant height in BSi467.	142
21	Frequency curves of induced variability for panicle length in BSi1.	147
22	Frequency curves of induced variability for panicle length in BSi427.	148
23	Frequency curves of induced variability for panicle length in BSi467.	150
24	Frequency curves of induced variability for days to maturity in BSi1.	160
25	Frequency curves of induced variability for days to maturity in BSi427.	161
26	Frequency curves of induced variability for days to maturity in BSi467.	162
27	Frequency curves of induced variability for yield per plant in BSi1.	167
28	Frequency curves of induced variability for yield per plant in BSi427.	168
29	Frequency curves of induced variability for yield per plant in BSi467.	170
30	Frequency curves of induced variability for grain weight in BSi1.	175
31	Frequency curves of induced variability for grain weight in BSi427.	176
32	Frequency curves of induced variability for grain weight in BSi467.	177

Dhaka University Institutional Repository

LIST OF PLATES

Page No.

Plate 1. a. Effect of gamma irradiation on height at seedling stage in BSi1 [Control (L) — higher dosages (R)] 47
b. Effect of gamma irradiation on height (harvested plants) in BSi1 [Control (L) — higher dosages (R)] 47

Plate 2. a. Effect of gamma irradiation on height at seedling stage in BSi427 [Control (L) — higher dosages (R)] 48
b. Effect of gamma irradiation on height (harvested plants) in BSi427 [Control (L) — higher dosages (R)] 48

Plate 3. a. Effect of gamma irradiation on height at seedling stage in BSi467 [Control (L) — higher dosages (R)] 49
b. Effect of gamma irradiation on height (harvested plants) in BSi467 [Control (L) — higher dosages (R)] 49

Plate 4. a. Pollen stainability of control in BSi1 54
b. Pollen stainability at 40 Kr in BSi1 54

Plate 5. a. Pollen stainability of control in BSi427 55
b. Pollen stainability at 80 Kr in BSi427 55

Plate 6. a. Pollen stainability of control in BSi467. 59
b. Pollen stainability at 80 Kr in BSi467. 59

Plate 7. a. Chlorophyll mutants in BSi1as a result of gamma irradiation. 88
b. Chlorophyll mutants in BSi467as a result of gamma irradiation. 88

Plate 8. a. Chlorophyll mutants in BSi427as a result of gamma irradiation. 89
b. Chlorophyll variant (striata) at 30 Kr in BSi427 in M_1 generation. 89

Plate 9. a. Effect of gamma irradiation on stem colour: BSi467 control showing purple stem (L); mutants showing green stem (R) at seedling stage. 99
b. Effect of gamma irradiation on stem colour: BSi427 control showing green stem (lower); mutants showing purple stem (upper). 99

Plate 10. a. Beautifully shaped five ash coloured seeded panicles in purple coloured stem background in BSi1 (experimental field view). 100
b. Black seeded panicle in purple coloured stem background in BSi1 (experimental field view). 100

Dhaka University Institutional Repository

Page No.

Plate 11. a. Black seeded panicle in green coloured stem background in BSi427 (experimental field view). 101
b. Beautifully shaped four orange coloured seeded panicles in BSi427 (experimental field view) 101

Plate 12. a. Green stem colour and cream seeded panicle in BSi467 as a result of gamma irradiation (experimental field view). 102
b. Variation in seed colour in BSi1, BSi427 and BSi467 as a result of gamma irradiation (upper line, BSi1; middle line BSi467 and the lower line, BSi427). In all the three rows seeds of the control are shown on the extreme right. 102

Plate 13 a. Flowering dwarf mutants of BSi427 grown in experimental field. Control (left); dwarf mutant (right). 103
b. Dwarf mutants of BSi427 at half maturity stage. Control (left and right); dwarf mutants (middle) × 12 103

Plate 14. a. A few harvested plants of dwarf mutant of BSi427. Control (lower); dwarf mutants (upper). 104
b. A magnified view of dwarf mutant of BSi427 (single harvested plant. Control (lower); dwarf mutant (upper) × 7.5 104

Plate 15. a. Extreme tall and short mutants in BSi467 (experimental field view). 105
b. Early mutant in BSi427 (experimental field view). 105

Plate 16. a. Variation in panicle characters observed in BSi1. Characters include: shape, size, length, lobe arrangement and tip. Control (extreme right); mutants (all others to the left). 111
b. Variation in panicle characters observed in BSi427. Characters include: shape, size, length, lobe arrangement and tip. Control (lower right); all others to the left and material on the upper row are mutants. 111

Plate 17. a. Variation in panicle characters observed in BSi467. Characters include: shape, size, length, lobe arrangement and tip. Control (lower right); all others to the left and material on the upper row are mutants. 112
b. Large sized panicle in BSi427. Mutant (left); control (right) × 4.6 112

Plate 18. a. Seed colour variant at 20 Kr in BSi467. Control (lower); variant (upper) in M_1. 180
b. Seed colour variant at 20 Kr in BSi467 in M_1 × 1.75 180

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LIST OF ABBREVIATIONS

Abbreviations	Full meaning
cm	Centimeter
et al.	Et alia = and others
Fig	Figure
GA_3	Gibberellic Acid
gm	gram
i.e.	Id est, that is (to say)
viz	Videlieet (L), namely
No.	Number
e.g.	For example
TN	Thermal neutron
EMS	Ethyl Methane Sulphonate
DS	*Diethyl sulphate*
MMS	Methyl methane sulphonate
DES	Diethyl sulphonate
EI	Ethylene imine
NEU	N-nitroso N-ethyl Urea
NMU	N-nitroso N-methyl Urea
GA	Genetic Advance
NNNG	N-methyl-N-nitroso-N-nitroguanidin
H_b	Heritability in broad sense
BARI	Bangladesh Agricultural Research Institute

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Chapter 1
INTRODUCTION

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1. INTRODUCTION

The term small millets refer to a group of small seeded cereals which comprise as many as eight species, namely, finger millet (*Eleusine coracana*), foxtail millet (*Seteria italica*), proso millet (*Panicum miliaceum*), kodo millet (*Paspalum scrobiculatum*), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa spp.*), fonio (*Digitaria excilis*) and teff (*Eragrostic tef*). Millets play an important role in global agriculture and have been grown from ancient times in traditional agricultural systems with low or without inputs with consequent low productivity. Millets are major cereal crops grown in fairly large areas of South Asia, China, Russia, Africa and also on a limited scale in certain areas of the United States of America and Europe. It is estimated that in the world the above crops may occupy between 18 and 20 million hectors producing 15 and 18 million tonnes of grain.

Among the countries of South Asia, India has the largest acreage under small millets. The area is around 6.0 M ha producing 4.45 million tonnes of food grain. Nepal is the second largest having an area of 151,000 ha producing 137,900 tonnes of food grain. There has been a trend in several countries in the last two decades to replace these crops by major cereals like maize and wheat. This has been a significant factor in the reduction of areas under these crops. Unlike major cereals such as rice, wheat and maize millets have not received sufficient research backing and extension support. In the context of present day food shortage millets should receive more attention for its varietal improvement so that it can be grown in areas where irrigation water is limited and other cereals cannot be grown successfully.

The unique traits possessed by millets are :

(i) Millets are generally early maturing which enables them to fit into intensive cropping system and could be used as a catch or relay crop in association with other crops like rice, oilseeds etc.

(ii) Millets can tolerate both drought and saline soil conditions and possess wider adaptation to environmental fluctuations and as such they can escape drought or flood and give more or less yield.

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(iii) Most millets are tolerant to major pests and diseases and can be stored for longer periods ensuring a continued food supply during dry season or when there is a crop failure.

(iv) The grains are nutritionally rich and comparable to major cereal grains in protein content and mineral composition. It contains a high level of essential minerals such as iron and calcium.

(v) The grains are consumed in a variety of ways and may form a major component in the daily diet of rural people and particularly in semiarid regions.

Foxtail millet (*Setaria italica* Beauv.) and prosomillet (*Panicum miliaceum* Linn.) are important among millets cultivated in Bangladesh. Millets altogether occupy an area of 40,000 ha producing 35,000 tonnes of grain with an average grain yield of 865 kg/ha.

In Bangladesh millets are grown in both rabi and kharif seasons in all types of soil as a sole crop or mixed crop with chilli, aus rice, sesame and mustard etc but the main cultivated area is mostly concentrated to flood prone river beds and marginal lands. The low yields of millets can be attributed to poor soil, non-use of fertilizers, irrigation water, pesticides, lack of improved cultural practices and finally use of indigenous low yielding varieties.

A clear understanding of the nature and magnitude of gene effects controlling complex characters such as yield and also of quantitatively inherited characters is very important before applying appropriate breeding methods for improving a character. Induced polygenic variability has been preferred recently for increasing genetic variability thereby increasing the chances of improvement through selection.

In many countries both physical and chemical mutagens have been successfully used to create genetic variability for increasing the scope of selection of quantitative characters as have been demonstrated in many crop plants such as reported by Swaminathan et al. (1962) in wheat; by Sharma (1965) in sorghum; by Gaul (1965) in barley; by Gregory (1968) in peanuts; by Bhatia and Swaminathan (1962) and Goud (1967) in wheat; by Miah and Yamaguchi (1965) in paddy; by Brock (1965) in subterranean clover and Arabidopsis; by Aastveit (1966) in Drosophila; by Burton et al. (1974) and Singh et al. (1978) in pearl millet.

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Varietal improvement work on millets has been so far limited all over the world. Small floret size of the crop is one of the major limitations for lack of any breeding program for its improvement. The varietal improvement programme in most countries is confined to the use of land races and their selection. Similarly in foxtail millet conventional breeding is a problem because of the small size of the florets compactly arranged making it extremely difficult to do effective hybridization. The other alternative is to take recourse to mutation breeding for creation of genetic variability to look for superior genotypes and breed them through selection.

Although extensive studies on induced mutation in barley and in many other cereals have been undertaken in the past, systematic studies and reports on induced mutations for foxtail millet are very limited. However, in many countries (India, Russia, Japan, Germany and Sweden etc) physical and chemical mutagens such as gamma rays and EMS have been found to be effective and efficient in creating desirable variability in millets. The above mutagens have also been found to be effective for the improvement of the quantitative traits of millets such as reported in *Setaria* by Bhat et al. (1961), Srirangasayi et al. (1971) and Madova and Goud (1973); in *Panicum* by Steucadart (1960), Konstantinov et al. (1975) and Islam (1987); in ragi by Goud, Nayer and Rao (1969, 1971) and Seetharam et al. (1975). The present study was, therefore, undertaken with the following objectives :

(i) To study the effect of physical mutagen, namely, gamma radiation in various biological end points in M_1;

(ii) To assess the frequency and spectrum of different types of chlorophyll and viable mutations and to know the effectiveness and efficiency of gamma rays to bring about any useful genotypes; and

(iii) To study the role and value of induced quantitative variability for yield and protein in M_3 generation with special reference to genetic improvement of foxtail millet.

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Chapter 2
REVIEW OF LITERATURE

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2. REVIEW OF LITERATURE

A breeder's aim is to improve crop plants. Earlier efforts in crop improvement were through introduction, selection and hybridization (Allard, 1960). All the three methods were used to improve the existing genetic material either to create variability or to select improved plant types.

It is obvious that a breeder cannot create new traits, rather a breeder works on existing traits. Creation of new traits involves changes in the genetic material. These changes of genetic material are possible through mutation. Hugo De Vries (1901) for the first time used the term "mutation" which has been considered as the sudden and heritable changes that take place in animals and plants in addition to Mendelian recombination.

Mutation brings about changes in the hereditary material mainly in DNA. Changes in DNA can be done by ionizing radiation and by chemical agents. X-ray was used to induce genetic changes in Drosophila (Muller, 1927). X-ray was also used to bring about high mutation rate in maize and barley (Stadler, 1929). The notable discovery of Muller and Stadler opened a new horizon in plant breeding. Many plant breeders took advantage immediately of this new discovery and tried to utilize it in applied plant breeding. Later on, many workers have studied the different effects of radiation on plants of economic importance. Important contributions to this field have been made by Ehrenburg et al. (1952), Yamashita and Willweber (1958), Grunckel (1957), Matsumura and Fuji (1958), Bora et al. (1961), Shaikh and Godward (1972).

Subsequently, a number of chemicals with mutagenic action were described. Auerbach and Robson (1942) using the chemical mustard gas in Drosophila and Oehlkers (1943) using urethen in *Oenothera* demonstrated first the mutagenic activity of chemicals. Rapoport (1946) discovered the creation of mutation by chemicals through alkylation in *Drosophila*. Genetic changes mainly occur due to mechanical disruption of genetic material or chemical changes in the genetic material or both (Lea, 1946). Any change in DNA can be termed mutation; however, the small changes such as point mutations are useful. A big change in hereditary material usually disrupts the natural balance is obviously not useful. Most of the earlier works were discouraging as many of the induced heritable changes were deleterious; some workers on various crops were able to demonstrate the practical utility

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of induced mutation in crop improvement. Useful genetic mutants were reported by Tollenmar (1938) on tobacco, Gustafsson (1947) on barley, Andersson and Olsson (1954) on white mustard and Gregory (1955) on peanuts.

Borojevic and Borojevic (1972) indicated mutation breeding as a useful tool in cases where a variety needs to be changed for only one character keeping other characters unchanged.

Physical and chemical mutagens bring about not only genetic changes but also changes in the chromosomal structure; however, the more sparsely ionizing radiation (X-rays, gamma rays) have a tendency to induce more point mutations. Dubinin and Soyfer (1969) considered mutation as a result of both chromosome breakage and gene mutation. Many physical and chemical mutagens are able to induce various types of mutations leading to mutation frequencies ten times higher than natural ones as well as a broader mutation spectrum (Van Harten, 1991). Different mutagens appeared to have varying efficiencies for producing mutation (Heslot et al. 1959 and 1961). X-rays and neutrons have been the most widely used ionizing radiation for increasing mutation rates (Caldecott et al. 1954; Ehrenberg and Nybom, 1953). Scarascia et al. (1961) observed that ethyl methane sulphonate (EMS) was three to ten times more mutagenic than gamma radiation when used on barley and durum wheat. In the past a large number of works on induced mutagenesis showed that in plants, several mutagens of both physical and chemical nature were effective in creating genetic variability. Among ionizing radiations gamma rays and EMS among chemical mutagens have been extensively employed in induced mutation studies and proved to be effective in creating genetic variability aimed at selection of new genotypes or mutants with desirable characters of economic importance.

A search of literature for information on the use of mutagens on foxtail millet disclosed a very limited number of papers. So, in the present study the pertinent literature available on foxtail millet and mainly in other millets and on few other cereal crops have been reviewed under the following heads :

2.1. Use of gamma radiation as means of mutagenesis

2.2. Mutagenic effects in M_1 generation

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2.3. Chlorophyll and viable mutations in M_2 and advanced generation

2.4. Differential genotypic response to various mutagenic treatments

2.5. Induced micro mutations and

2.6. Induced macro mutations.

2.1. Use of gamma radiation as means of mutagenesis

Gamma rays : This physical mutagenic agent belongs to the class of electromagnetic radiation with a short wavelength of 0.005 Å to 1.4 Å discovered by Bequerel in 1896. It is a high energy radiation and consists of photons that is small packets of energy. It is produced by radioactive decay of certain elements e.g. Radium, ^{14}C, ^{60}Co, etc. ^{60}Co is the common source of gamma rays used for biological studies. Gamma rays are highly penetrating and sparsely ionizing radiation. Exposure of the cells to gamma rays brings in ionization and production of free radicals from water present in the cell which react with DNA bases causing change in base, e.g. loss of base, breaking of hydrogen bonds in DNA, single and double breaks in DNA and cross-linking of protein.

The absorption of ionizing radiation in a bacterial, plant or animal cell produces a variety of structural aberrations in chromosomes which are visible in microscope. These chromosomal aberrations are deletions, inversions, bridges and other forms. These structural aberrations in chromosomes is due to the action of ionizing radiation on DNA. Radiation may cause the following alterations in DNA, (a) rupture of hydrogen bonds which link the base pairs adenine-thymine, cytosine-guanine, (b) induction of breaks in either or both of the DNA chains, between a sugar and a phosphate group, (c) formation of dimers between adjacent thymine residues on a chain to form a dimer, (d) cross linking between the single strands of the helix, or between a strand and another DNA molecule, or between a strand and the protein (histone) associated in the chromosome.

According to Pollard (1969), ionizing radiation introduces transcription errors into the precise information storage and retrieval system of the cell and that such errors result into mutations. Ionizing radiation leads to non-directional damages in all molecules of the treated material. Damage to the DNA can be caused either by a direct heat or indirect

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production of free OH-radicals from the aqueous solution. It appears that indirect effects account for about two-thirds total damage to watery system (Ahnstrom, 1988). Radiation damages predominantly consist of single and double strength breaks and different types of base damage, with no damage occurring in nearby base groups of DNA (Ahnstrom, 1988). Stadler (1954) observed that the so called point mutations induced by physical mutagens were actually small deletions. Demerec (1960) also supported the view of Stadler (1954) by reporting that most of the ionizing radiation induced mutations in *Salmonella* were deficiencies.

Gilles (1955) reported reverse mutation in *Neurospora* by ionizing radiation at certain loci, but such reports for higher plants are few.

Sparrow (1961) identified various kinds of aberrations such as deletions, duplication, translocation, inversion, isochromosome, breakage-fusion-bridge cycle with their phenotypic changes produced by ionizing radiation. At present electromagnetic radiation are known to produce genetic effects by damaging chromosomes rather than inducing point mutations (Shukla et al. 1979).

2.2. Mutagenic effects in M_1 generation

Mansurova et al. (1958) in a mutation study in diploid and autotetraploid of prosomillet following gamma irradiation reported that diploids were more sensitive to gamma radiation compared to tetraploids as far as germination and seedling growth were concerned in M_1 generation.

For a given mutagenic treatment their is a correlation between seedling height and survival (Gaul, 1959).

Steucadart (1960) studied the effect of X-rays on germination, seedling growth, plant height, fertility in prosomillet in M_1 generation. He indicated the optimum dose for prosomillet as between 18 and 20 Kr.

Fevret (1960) reported selective mutagenicity of EMS. He studied forward mutation frequencies of four genes for albinism in barley following treatments with X-rays and EMS. In this study the number of chlorophyll deficient streaks on leaves of the M_1 plants were scored comparing heterozygous and homozygous strains. The genes analysed were alb_t,alb_{20}, alb_{14} and alb_{15}. All of them were mutated in X-rays treated material with similar frequency. The EMS, on the other hand, showed mutation in alb_t and none in the other three genes. He described EMS as more efficient and effective mutagen than X-rays as it was evident from the relationship of lethality and mutation rate in treatments with X-rays and EMS.

Bhat et al. (1961) studied the radio-sensitivity of finger millet by exposing seeds to various ionizing radiation. They reported 20 Kr for X-rays as LD_{50}, 30 Kr for gamma rays and less than $5x10^{12}$ pn/cm^2 for pile neutrons.

Bhat et al. (1961) reported radio-sensitivity of foxtail millet to varying dosages of neutron radiation. They reported that lower radiation dosages increased the germination percentage; higher dosages reduced it but such effects were not seen in pile neutron treatments. The M_1 plants in thermal neutron treatments were vigorous and flowered earlier compared to pile neutron treatments. Cytological observations showed differences in chromosome damage between thermal neutron and pile neutron treated plants. The pile neutron treated plants showed aberrant meiotic cells ranging from 15-17% but thermal neutron treated plants showed no detectable meiotic alterations.

Bhaskaran and Swaminathan (1961) studied sensitivity of polyploidy to radiation and observed that germination percentage was in decreasing trend with an increase in dosages of X-rays in wheat; 4x and 6x wheat species showed identical radio sensitivity as measured by survival, while in barley the 4x plants showed better survival than the diploid at 50,000 r. The height of seedlings was measured at 7-day-old and the data showed that beyound at dosage of 25,000 r there was a depression in growth in all the species. The extent of depression was more in 2x wheat and 2x barley in comparison with 4x and 6x wheat and 4x barley. Germination percentage was severely affected by Fast neutrons in 2x ,4x and 6x wheat and 2x and 4x barley. In barley, the 2x had a slightly better survival. Height measurement of 7-day-old seedlings showed that 2x and 4x wheat

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were drastically affected while 6x wheat and 2x and 4x barley did not show any significant reduction in growth. Some morphological changes such as grass clump and chimeras in M_1 generation in the irradiated wheat and barley were obtained . In *T. aestivum* treated with fast neutrons for 6 hours, 2 grass clump plants presenting a xerophytic appearance with thick ,deep green leaves and few tillers in late season bearing ear heads were obtained. In diploid barley treated with fast neutrons for 3 hours a chimera plant with one of the tillers showing alternate white and green stripes on the leaves was observed. In *T. aestivum* treated with ultraviolet +11,000r of X-rays a few chimeras related to ear head characters were obtained in M_1 generation. Pollen fertility was reduced in fast neutrons treated 4x and 6x wheat and 2x and 4x barley materials particularly at higher dosages. Regarding fertility all the wheat materials were not equally sensitive to X-radiation. 2x and 6x wheat showed a rise of 2.7 and 19.4% over its control respectively while 5% fertility was reduced in 4x wheat. However, 2x wheat showed a reduction of 10.96% in the 16,000r X-ray treatment. In 2x and 6x wheat some progenies showed a higher seed set compared to their respective controls. In 4x wheat no such highly fertile plants were recorded. The maximum seed fertility in X-ray treated plant progenies of 6x wheat was 4.88 seeds per spikelet whereas in corresponding control the figure was 3.55. In 4x wheat some plants were very much affected in their fertility. It was appeared that in case of X-ray treatment 6x wheat was most resistant to radiation damage followed by 2x and 4x wheat. In the thermal neutron treatment, 4x wheat showed a reduction in fertility of 11.25% and 6x wheat of 1.3%. Diploid wheat did not germinate or grow to maturity after germination. In hexaploid some plants showed a slight rise in seed set per spikelet in the thermal neutron treatment. In tetraploid, however, no plant showed such rise in fertility. The maximum in the range in control was 3.55 while in the treated material the corresponding value was 3.96. Thus with thermal neutrons hexaploid was also the least affected regarding seed fertility. In the barley series, the tetraploid was found to be more affected than diploid. The average seed fertility of 2x and 4x controls were 2.73 and 2.33 respectively while the percentage reductions in fertility in the thermal neutron treatment were 11.8 and 17.5%. It was observed that all wheat (2x,4x,6x) and diploid barley segregated for chlorophyll mutations. Tetraploid barley did not give rise to any type of chlorophyll mutations. The percentage of M_1 plant progenies segregating for chlorophyll mutations was 22.2%, 2.7% and 1.4% in 2x, 4x

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and 6x wheat treated with X-rays (11,000r) respectively; the percentage was 4% in 6x wheat and 28.1% in 2x barley irradiated with thermal neutrons. It was obvious from the study that polyploidy confers a phenotypic stability against induced chlorophyll mutations. The higher the ploidy status the lower the incidence of chlorophyll mutations. Gustafsson (1940) found that the occurrence of Xantha and Viridis types in M_2 generation was positively correlated with a decreased fertility of the M_1 plant. He reported that Xantha and Viridis type of chlorophyll mutations may be associated with or eventually produced by intergenic alterations that is those plants which show meiotic disturbances and structural changes. On the other hand, albina mutations may arise as intragenic changes, since their incidence shows no particular connection with any M_1 fertility range.

Boda (1964) studied the effects of acute dosages of 5-150 Kr X-rays on dry seeds of prosomillet and observed delayed germination, morphological effects, chlorophyll deficiencies and sterility in X_1 generation.

Froese -Gertzen et al. (1964) studied the effects of EMS and X-rays on the growth response, chromosome structure and mutation rate in barley. They noted certain obvious differences between the effects of X-rays and EMS on barley. Similar decreases in seedling growth, spike fertility and survival were caused due to X-rays treatments; whereas EMS treatment affected fertility and consequently survival more than seedling growth. They reported direct relation of the reduction of fertility to the frequency of chromosome aberrations and mutations after X-ray treatment, whereas the frequency of chromosome aberrations observed in EMS treatments was negligible and inspite of that a high rate of chlorophyll deficient mutations was induced in both M_1 and M_2 progenies.

Burton and Powell (1966) reported that the emergent percentage of seedling was reduced by progressively higher concentration of EMS in the laboratory but thermal neutron treatments did not affect seedling emergence. EMS treatments also reduced seven day-old seedling height with the increase of dosages when only the ninty-minute TN exposure significantly reduced the height of seven day old seedlings, whereas both thermal neutron and EMS treatments delayed seedling emergence in the field and increased with the increasing dosages of each mutagent. Both EMS and TN delayed maturity. All EMS

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dosages reduced the number of matured plants and the heaviest EMS dosages reduced the average number of matured plants by more than 55%, but thermal neutrons had very little effect on this character. Only the two heaviest treatments of TN and EMS significantly reduced plant height. Although the heaviest dosages of TN and EMS significantly decresaed leaves per culm, both the mutagents did not affect head length. Plant yield was reduced only by the heaviest TN treatment. Fertility was reduced by the increasing dosages of both the mutagens. Regarding sectorial mutants they reported TN as more effective than EMS. They reported chromosome interchanges identified as a ring of four chromosome in EMS treated materials. In addition to plants with rings of four chromosome, plants with rings of six and eight chromosomes, plants with two and three separate rings of four chromosomes and plants with a ring of four plus a ring of six chromosomes were found in plants from TN treated seeds. The ninty minute TN treatment produced four times as many plants (28%) with chromosome interchanges as the heaviest EMS treatment.

Owen (1967) exposed seeds of paspalum to thermal neutrons and observed that the optimum duration of treatment was three hours. He observed albina seedlings in 7% of the progenies in M_1 generation. Differential sensitivity of the Puspalum strans in respect of mutation rate, plant vigour and fertility was also observed in M_1 generation.

Goud et al. (1969) studied the mutagenic effects in three varieties of finger millet following two dosages of gamma radiation treatments (20 and 30 Kr) in M_1 generation. Radiation effects on seedling growth, polen and seed fertility were directly correlated with dosage. They reported 30 Kr as LD_{50} for seedling growth. Various chromosomal aberrations were observed during meiosis in M_1 generation.

Budarov (1969) studied the effects of varying dosages of gamma rays on yield of prosomillet. Exposure of seeds to low dosages of gamma rays resulted in increased grain yield, spikeletes per ear, grains per ear and 1000 grain weight. High dosages of gamma irradiation resulted in poor germination under field condition and reduction in number of productive tillers and yield.

Goud and Nayer (1969) reported twin seedlings in gamma irradiated finger millet seeds.

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Kumar et al. (1969) reported the genotypic control of response to irradiation in finger millet. Seeds of six varieties, viz, Purna, Annapurna, Cauveri, Hamsa, Aruna and 921-1 were irradiated with five dosages of gamma rays, 20, 40, 60, 80 and 120 Kr. The germination and seedling height varied with the variety and the treatment. The LD_{50} showed the variety Purna as the most radio resistant tolerating as high a dosage as 80 Kr and Cuvery as the least resistant with LD_{50} only at 4o Kr.

Ekberg (1969) carried out investigation with the purpose of analysing the genetical background of the induced partial sterelity in X_1 and later generations following treatments of barley seeds with various mutagenic agents. In the study (1) neutrons and X-rays as ionizing radiation, (2) alkane sulfonic esters, Epoxides and ethylene imines and diethyll sulfate as chemical mutagens, and oxygen and combined treatments with X-rays and 8-ethoxy-caffeine were used. Regarding induced X_1 sterelity in barley the mutagenic effect of ionizing radiation was compared with the effect of chemical mutagens. The following five types of sterelity occuring in X_1 and later generations were described.

Sterility typeI	Translocations
Sterility type 2	Inversions
Sterility type 3	Lethals causing abortion in 25% of the seeds in heterozygous plants
Sterility type 4	Lethals causing abortion in 50% of the seeds or gamets in heterozygous plants.
Sterility type 5	Viable recessive mutations causing a more or less pronounced sterility in homozygous plants.

Sterility types 1-4 were observed in the X_1 generation, whereas sterility type 5 did not appear until the X_2 generation. The ionizing radiation (neutrons and X-rays) were reported to cause predominantly chromosome aberrations of sterility type I and 2 (82%). The chemicals mostly of alkylating type induced mainly seed lethality (sterility type 3 and 4).

Budarov (1970) observed a close relationship between the frequency of chromosomal aberrations and dosage of gamma radiation in anaphase and telophase in prosomillet.

Goud et al. (1970) studied mutations in two varieties of sorgham (M35-1, GM2-3-1) following irradiation of different dosages of gamma rays, 20, 30 & 40 Kr. They observed

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that germination, seedling growth and survival and polen sterelity were affected to a considerable extent with the increase in the dosages but no detectable chromosomal changes were noticed in meiotic metaphase in M_1 generation. None of the M_1 plants showed either chimera or whole plant changes for chlorophyll characteristics. However, a number of plants showed abnormalities for other morphological characters. The percentage of abnormal plants ranged from 0.00% in control, about 1.4% to 2.0% in 20 Kr irradiated population to 12-14% in 30 Kr irradiated plants. The plant abnormalities were less at 40 Kr dosage in both the varieties in M_1. The M_1 abnormalities types included small grains, sterile ears, lax ears, dwarf, tall and early types, etc.

Ananthaswamy et al. (1971) reported a metabolic disturbance in gamma irradiated wheat during germination. Irradiation of wheat seeds with ^{60}CO gamma rays at 20-200krad dosage levels inhibited seedling growth. Seedling growth was inhibited by 50-60% at low dosages from 20-40krad and almost completely at higher dosages. Metabolic disturbance evident from impaired seedling growth on garmination was observed. Pre-soaking of control and irradiated grains in 2×10^{-5} M gibberelic acid (GA) for 16 hour resulted in stimulation of seedling growth and synthesis of alpha-amylase and ribonuclease in control seeds; GA also caused its normal effects despite radiation treatment with low dosages.

Sreekantaradhya (1971) studied in detail the sensitivity of finger millet to gamma rays and EMS. Seeds of variety Co-1 were exposed to 10, 20, 30, 40 and 50 Kr of gamma rays and treated with 0.5, 1.0, 1.5 and 2.0 percent concentrations of EMS. He reported the LD_{50} for seedling height and seed fertility to be 50 Kr and 30 Kr respectively. The mutagenic efficiency as estimated on the basis of seed fertility also proved EMS as more efficient than gamma rays. Gamma rays treatment was most efficient at 20 Kr while EMS at 1.5% concentration.

Goud et al. (1971) studied the effects of EMS on polygenic characters in two varieties of Ragi viz, Purna and Hamsa. They observed increased variability in most of the treatments in M_1 generation.

Srirangasayi et al. (1971) reported reduced germination and occurance of chlorophyll chimera in M_1 generation when the seeds of the variety K-221-1 were treated with 0.6 and 0.9 percent EMS for four hours.

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Burton et al. (1974) reported that pearl millet has many specific yield genes, none of which exerts a very great effect on yield. They studied the effects on mutation frequency and combining ability in pearl millet following recurrent seed treatment with thermal neutrons (TN), EMS and DS for 11 years. They observed that TN seed treatments alone had no effects on seedling emergence, but both chemicals reduced emergence of seedlings. When TN was combined with EMS or DS emergence was reduced further. All mutagenic treatments significantly reduced M_1 seedlings height and the deleterious effects of combined mutagens were additive. They observed that TN seed treatments gave the highest percentage of M_1 striped plants, the lowest percentage of M_1 selfed seed set, and the highest M_2 frequency of chlorophyll deficient seedlings. They noted that combining a low dose of EMS or DS with high and low TN treatments generally increased these effects. They observed that treated seeds of pearl millet inbred lines with mutagens TN, EMS and DS for three cycles failed to alter the average yield or the highest forage yield of 1,637 single crosses between normal lines selected after three cycles of treatment when compared with 825 control single crosses. From the study they suggested that attemps to improve the combining ability of inbred lines of pearl millet by mutagen treatment without several cycles of recurrent selection are not likely to succeed.

Sing and Godward (1974) studied the effects of high energy Beta-rays, hard X-rays and gamma rays on finger millets. Dry dormant seed and the dosages of 2-500kr of three types of radiation were used in the study. They reported the following effects: There was cent percent germination at all dosages. Survival percentage of seedlings decreased with the increase of dosages. There was 7-8% survival at 100 Kr and there was no survival beyond one week above 150 Kr. At 500 Kr, there was germination but no further growth. At high dosages an ultimate increase of height was found. The time before flowering increased with dosage. The longevity of the plant increased with dosage provided. In case of ß-rays increased branching giving increased spike production with the increase of dosages was noticed. No marked effect on branching was observed with gamma rays. There was not much difference in seed yield up to 50kr and then there was a slight reduction. The seed weight at all dosages was nearly constant. A percentage of sterile spike and of sterile plants occurred among survivors of 70 Kr and 100 Kr but not at lower dosages. Yellowish flacks were seen on the leaves of 50 Kr to 100 Kr plants. Regarding cytological effects they observed that the percentage of anaphase bridges and of fragments increased with the

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increasing dosage. No more anaphase bridge in root tips in plants surviving for 50 days below 50 Kr were reported. Plants surviving at 70 and at 100 Kr showed translocations and other abnormalities at meiosis.

Viraktamath (1975) investigated to find out the genotypic response of 5 sorghum genotypes to gamma rays and EMS in relation to the effect of mutagens on some quantitative characters, induced chlorophyll, viable and desirable mutants. The variety RCR-408 was found highly sensitive to both gamma irradiation and EMS treatments. The variety 302 was fairly resistant. There was a reduction in mean values of all the quantitative characters in treated population of M_1 generation except for days to 50% flowering.

Seetharam et al. (1975) reported asynaptic mutants in a ragi variety, Co-1 following 1.5% aqueous EMS treatment of ragi seeds in M_1 generation. Asynapsis was reported to be medium strong with a high frequency of univalent at diakinesis and metaphase-I, along with a few bivalent like associations. The association in the bivalent was very week with end to end attachment of homologous chromosomes in a rod like fashion without the formation of any visible chiasmata. The asynaptic mutants were highly sterile, few progeny showed varying number of chromosomes suggesting the feasibility of developing aneuploid lines in finger millet.

Tyagi and Singh (1975) reported translocation heterozygotes in partial sterile plants obtained in M_1 generation in pearl millet following irradiation of pearl millet seeds with different doses of gamma rays. The pollen and ovule sterility of translocation heterozygotes involving the two pairs of chromosomes ranged from 24.5% to 58.4% and 11.2% to 37.4% respectively in various dosages of gamma rays.

Mahishi (1977) studied the effect of gamma rays, EMS, MMS, NMU and NNMG in the finger millet variety, EC4840. In M_1 generation gamma rays and chemical mutagens reduced germination, seedling growth, pollen fertility, seed set and flowering.

Gowda (1977) studied the mutagenic response of foxtail millet variety, Co3 following irradiation of gamma rays, EMS treatments and combined treatments of foxtail millet seeds. He observed decrease in the values in the biological criteria such as germination, seedling growth, survival, plant height, pollen and seed fertility with an increase in the

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dosage or concentration of the mutagen in M_1 generation, while drastic effect on different criteria were noticed only in higher combinations.

Sreekantaradhya (1979) studied the sensitivity of ragi seeds of the variety, Co-1 to gamma rays and EMS in relation to germination, survival, growth rate, fertility and morphological deviants in M_1 generation. EMS affected very much the germination while gamma rays had no significant effect. The growth rate and survival were affected comparatively to a greater extent in gamma rays. The seed fertility was affected much by gamma rays and EMS had no significant effect. The LD_{50} estimated for all the parameters were around 40 Kr gamma rays and 1.5% for EMS.

Sandhu (1981) reported reduction in all the characters in two pearl millet inbreds, K560-230 and M-46 following gamma rays and EMS treatments in M_1. The reduction in characters was increased with the increase in dosage and duration of the treatments. More reduction was observed in EMS treated material than gamma rays.

Islam (1987) studied mutagenic response of three varieties of *Panicum meliaceum* to different dosages of gamma rays and EMS in M_1, M_2 and M_3 generations. Well dried seeds were exposed to 20, 30, 40, 60 and 70 Kr gamma rays while presoaked seeds were treated with 0.45, 0.60, 0.75 and 0.90 percent of EMS for eight hours. In M_1 generation he observed delayed panicle emergence, reduction in plant height, increased tillering and significant reduction in mean yield per plant compared to control.

Tikka and Desai (1989) reported a significant reduction in germination in six varieties of *Eleusine coracana* following treatment of grains with different mutagens. They observed highest reduction in methyl methane sulphonate (MMS) treatment followed by ethyl methane sulphonate (EMS), gamma rays and diethyl sulphonate (DES).

Khanna (1990) studied the response of two varieties of aestivum wheat and two varieties of durum wheat to different dosages of gamma rays. The seeds were irradiated with 1, 3, 5, 15 and 30 Kr gamma rays. He observed stimulation in seedling growth at lower dosages compared to control in all the varieties, whereas seedling height decreased as the dose increased from 5 to 30 Kr.

Shashidhara et al. (1990) studied induced variability for different traits in sorghum following gamma irradiation in M_1, M_2 and M_3 generations. They observed linear decrease

Swaminathan et al. (1962) observed a high frequency and wide spectrum of chlorophyll mutations following treatments of EMS in diploid (2x) barley and tetraploid (4x) and hexaploid (6x) wheat. The spectrum and frequency of mutants found in 4x and 6x wheat was different. Frequency was more in case of 4x wheat compared to 6x wheat. Varietal differences were also observed by them regarding the frequency of chlorophyll mutants.

Boda (1964) isolated 100 different types of mutants after exposure of dry seeds of proso millet to acute dosages of 5-150kr X-rays. The mutants included changes in plant size, leaf form, panicle form, seed form and seed colour.

Induction of mutations were very effective to rectify one or two undesirable character(s) in an established variety (Joshi, 1968). Joshi (1968) carried out an experiment following irradiation of dry seeds of bajra with 25 Kr gamma rays in an attempt to bring about certain changes in plant height and ear characters. He reported that in M_2 generation out of 215 lines 8 segregated for chlorophyll mutations; 5 lines segregated for albina and striata. Albina mutants proved lethal whereas striata ones developed into stunted plants. Three lines segregated for dwarfness having height ranging from 105 cm to 130 cm at maturity compared to 200 cm of the parent. One line segregated for bristled ear mutants. Dwarf and bristled ear mutants were followed in M_3 and M_4 generations. Bristled ear mutant lines were reported to be uniform lines after 4th generation but dwarf plants were reported to be still segregating.

Goud et al. (1969) reported less frequency of chlorophyll mutants at 30 Kr than 20 Kr in three varieties of finger millet Annapurna, Purna and H-22 when they studied the mutagenic effects of gamma rays on finger millet. A wide spectrum and a high frequency of viable mutations were produced in Purna. They reported many viable mutations isolated during the study as potential from breeding point of view.

Pilnikova et al. (1971) reported mutations for various characters such as shape and size of the panicle, colour and shape of the grain and early maturing types in prosomillet following treatment of prosomillet seeds with N-nitroso N-ethyl Urea (NEU).

Sreekantaradhya (1971) studied the sensitivity of finger millet to gamma rays and EMS. Following irradiation of seeds with 10, 20, 30, 40 and 50 Kr of gamma rays and treatments with 0.5, 1.0, 1.5 and 2.0 percent concentrations of EMS he observed

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increased and higher frequency of chlorophyll and viable mutations at higher dosages in M_2 generation. He also reported that though gamma rays induced higher chlorophyll mutation frequency after estimation on M_1 plant basis, EMS was found to give higher frequency of chlorophyll mutations on M_2 plants basis. In general, gamma rays induced a wide spectrum of viable mutations than EMS.

Goud et al. (1971) reported an opposite trend of induced mutation for characters such as plant height and number of fingers per plant which were subjected to previous selection in two ragi varieties (Purna and Hamsa) following EMS treatments of ragi seeds. He also reported a random effect in the variability for the character such as number of tillers per plant; tiller number was not subjected to previous selection.

Srirangasayi et al. (1971) following treatment of seeds of *Setaria italica* cultivar K-21-1 with EMS recovered some useful mutants in M_2 generation. The mutants were dwarf, stiff-strawed types with profuse tillering. A tall uniculm mutant was also obtained.

Panchenko and Yashovskii (1971) reported occurrence of dominant mutations affecting grain colour, type of panicle in chemical mutagen treated prosomillet. The highest incidence of dominant mutations up to 5.2% was for grain colour.

Seetharam et al. (1973) reported anuploid plants with chromosome numbers ranging from 2n=37 to 2n=43 in the progeny of an induced asynaptic mutant. These plants showed reduced vigour and fertility compared to normal ones. The extra chromosome in them remained either as an univalent or paired with their homologous partners forming multivalents. The breeding behaviour of the plants with extra chromosome was studied and observed as disomics, trisomics, tetrasomics in their progenies and they also reported that the extra chromosomes in finger millet are transmitted to their progeny both through male and female gametes.

Konstantinov et al. (1974) reported various types of chlorophyll mutations such as albina, striata and xantha in treated seeds of three varieties of prosomillet with N-nitroso-N-methyl Urea (NMU) and N-nitroso-N-ethyl Urea(NNU). In M_3 generation some mutants (72-5814, 72-5916 and 72-5976) exceeded the control in yield, thousand grain weight (72-5800) and protein content (72-5292, 72-5306 and 72-5310).

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Seetharam et al. (1974) reported interchange heterozygotes with ring and chain quadrivalents in meiotic cells in the variety Co-1 in M_2 generation following 20, 30 and 40 Kr gamma rays treatments.

Nayar et al. (1974) reported viable mutations for earliness, height, grassy types and various ear characters such as gappy ears, ears with apical sterility, compact, open and lax ears following treatments of dry seeds of five ragi varieties with gamma rays (20 and 30 Kr), Fast neutrons (0.8 Kr and 1.2 Kr) and EMS (0.2 and 0.3 percent aqueous solution for 16 hours). Generally mutation frequency was higher in EMS treated progenies than in gamma rays. A total of 60 dwarfs were isolated in four varieties in M_2 generation.

Gupta and Yashvir (1975) studied chlorophyll mutations induced by gamma rays, EMS and DES in foxtail millet using two cultures, namely MU-1 (bristiled) and MU-2 (non-bristiled). The frequencies of chlorophyll mutations were recorded by three different methods viz, (a) mutations percent M_1 plants, (b) mutations percent M_1 spikes and (c) mutations percent M_2 plants. They observed that there were no significant differences in the mutagenic response of the two cultures and no significant differences in the results obtained by the three methods were observed. Among the chlorophyll mutations in M_2 generation, chlorina type was reported as most frequent and viridoalbina least frequent, *striata and virescens were reported as quite common. They further reported that albina* which was reported frequently in other crops was found to be less frequent in foxtail millet. The efficiency of gamma rays decreased with increasing dosages in culture MU-1 but increased in culture MU-2 up to the dosage of 30 Kr. The efficiency of EMS increased with increase in duration in both the cultures up to 18 hours. Under DES treatments, the survival improved in culture MU-1, while efficiency decreased with increasing duration in culture MU-2.

Viraktamath (1975) studied the genotypic response of five sorghum genotypes to gamma rays and EMS and reported that among the two mutagens, EMS treatment induced maximum number of chlorophyll mutations compared to gamma irradiation. He also reported EMS as most effective and efficient in inducing chlorophyll as well as viable mutations. Among the dosages, the moderate dosage of 30 Kr and 0.075 percent EMS were effective, whereas lower dosages of 20 Kr gamma rays and 0.05 percent EMS treatments were highly efficient. He isolated a wide range of viable mutations. Among

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them the tall mutations in the variety 148, dwarf and early mutations in the variety RCR-408 were interesting. Mutants with high grain weight were isolated in gamma irradiated population of RCR-408. He further reported that mutagenic treatments delayed flowering date. Means of all quantitative characters such as number of leaves, plant height, peduncle length, grain yield and 1000 grain weight flowing mutagenic treatments were reduced .

Gupta and Yashvir (1976) studied viable mutations for ear characters in two cultures of foxtail millet (MU-1and MU-2) treated with individual and combined treatments of gamma rays, EMS and DES . They reported differential response of the two cultures to the mutagenic treatments . The mutation frequencies were recorded as mutants per $100M_2$ plants and these were found to be higher in MU-1 than in MU-2 in all the treatments except DES. The frequencies also increased with the increase in dosage or duration of treatments and were found to be much higher in the combined treatments than in the individual treatment. The mutation spectrum was also found to be wider in culture MU-1 where 11 different kinds of mutants were recorded compared to only eight kinds of mutants occurred in MU-2 .

Sreekantaradhya and Menon (1976) reported induction of a mutant with rosette habit in finger millet and its response to GA_3. The mutant was a deviant from the seedling stage and was crowded with short, thick and dark green leaves. This mutant showed significantly increased plant height in response to GA_3 when stem elongation was measured after one week but attained normal height and appearance with continuous application of GA_3. The mutant without GA_3 treatment flowered as late as three months and the inflorescence was extremely compact and almost hidden in the leaf whorl. The treated mutants had some seed set but the untreated ones had none.

Singh and Sharma (1976) studied the gene action in relation to yield per plant, 1000 grain weight and number of grains per spike in 9x9 diallel F_1 and F_2 populations derived separately from normal and EMS treated spring wheat cultivars. They reported increased additive component for 1000 grain weight and grain yield in EMS treated F_2 populations and increased non additive components for number of grains per spike.

Dhonukshe and Bhowal (1976) reported that it is possible to induce more variability in polygenic charecters such as culm length, titter number and yield for enlarging the scope

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of selection in developed wheat varieties. In an induced mutation studies carried out with dry seeds of three dwarf wheat varieties and 20 and 25 Kr gamma rays they observed much variation in culm length, tiller number and yield in M_2 generation. Mean culm length decreased significantly with increased variance in the M_2 population of all the three varieties (Sonalica, Chhoti Lerma and Hira). In case of Sonalica and Chhoti Lerma, the variance and mean for tiller number and yield increased considerably.

Rao and Siddiq (1976) studied induced variability for amylose content with reference to yield components and protein characteristics in two rice varieties, namely TKM-6 and Norin-27 following gamma rays and EMS treatments. They reported that the range of amylose content in treated materials in M_2 altered significantly compared to that of the control. Gamma rays treated materials exhibited a relatively wider range of variation than that of EMS treatments. In case of frequency distribution curves, the phenotypic variability increased in gamma irradiated populations and the mode tended to shift towards the positive and negative direction. Differences in mean due to treatment effects indicated that in gamma rays treated populations the mean was either significantly decreased or increased depends upon the materials. However, the mean values remained unaltered after EMS treatment. The genetic variability between the line variance and within line variance increased significantly in all the treatments compared to their respective control, the maximum difference was observed after EMS treatment. In M_3 generation, the treated population exhibited a wider range of variability than the control. The mean values showed significant changes in gamma rays as well as in EMS treated population compared to that of the control.

Konstantinov et al. (1977) studied the role of hybridization and mutagenesis in breeding early ripening prosomillet. They isolated early, high yielding types that could be used in further breeding programme.

Mahishi (1977) studied the response of a pearl millet variety, EC-4840 to gamma rays, EMS, MMS, NMU and NNMG. He reported heigher frequency of chlorophyll mutations induced by gamma rays followed by EMS and lower dosages proved to be more effective than heigher dosages. Heigher frequency of viable mutations were also induced by gamma rays and EMS.

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Gowda (1977) following gamma irradiation, EMS and combine treatments of foxtail millet cultivar CO- 3 reported that gamma rays induced heigher frequency of viable mutations compared to EMS in M_2 generation. Additivity in inducing viable mutations was noticed only in a few lower combination treatments. The different types of viable mutations observed were plants with spikeletless ears, complete sterility, proliferated ears, nodal tillering, sparse ears and those affecting rachis and bristle characters of ears. He also reported increase in mean of all the quantitative characters studied viz., plant height, tiller number and grain yield in M_3 generation. Besides, there was an increase in the variability released and it was in positive direction for plant height and tiller number and in both positive and negative directions for grain yield.

Singh et al. (1978) observed albina, chlorina, xantha and viridis in M_2 Progenies of different inbreds of peal millet. Gamma rays produced heigher frequency of chlorophyll mutations than EMS.

Nayar et al. (1979) studied mutagenic response of finger millet variety, Hamsa to 20 Kr gamma rays and 0.8 -1.2 Kr fast neutrons. The frequency of early and open ear mutants was higher in fast neutrons (5.24 to 6.87 percent) than in gamma rays (2.09 percent). The open ear mutants were taller than the original Hamsa and they reported three distinct types of mutants, mutant I (semi-compact), mutant II (open) and mutant III (lax). The grain bearing area per plant was 51.95, 46.12 and 56.75 cm^2 for semi - compact, open and lax types respectively compared to 34.78 cm^2 in the parent variety.

Sreekantaradhya and Madhava menon (1979) studied induced mutagenesis in finger millet. The grains of finger millet variety CO-1 were treated with 10-50 Kr gamma rays and 0.5-2.5 percent EMS. The spectrum of chlorophyll mutations in M_2 consisted of albina, chlororina, xantha, alboviridis ,tigrina and striata. The frequency of tigrina was higher. EMS gave higher frequency of chlorophyll mutations than gamma rays and 2.0 percent EMS produced the widest spectrum of mutations. A linear increase in mutation frequency was observed with the increase from low to medium dosages and concentrations, whereas the higher dosages and concentrations produced erratic effects.

Yel'Sovskaya and Yakovlav (1980) reported two setaria like mutants in M_2 population of prosomillet after treatment of grains with 0.03% ethyleneimine(EI) for 12 hours. A mutant with compact, erect inflorescence with connate branches was observed. Their grain weight

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was low and light red in colour. These setaria like forms were less taller than parent and had a shorter internodes and inflorescence.

Sandhu (1981) reported differential response of pearl millet genotypes for chlorophyll mutations in M_2 generation. K560-230, an inbred of pearl millet gave higher frequency of chlorophyll mutations than that of M-46. However, spectrum of chlorophyll mutations was wider in M-46. Albina, xamtha, viridis, striata, albo-virdis and viridis-albo were observed in M_2. A number of viable mutations affecting the growth habit, charecters of leaf, flower and ear were isolated.

Tiwari et al. (1983) reported in millet that variance in yield and its components increased significantly in M_2 and M_3 generations and also reported that the use of 1.5% EMS and 30 Kr gamma rays were more effective.

Islam (1987) studied the mutagenic response of three prosomillet varieties to gamma rays and EMS treatments. Well dried seeds were exposed to 20, 30, 40, 60 and 70 Kr gamma rays while presoaked seeds were treated with a 0.45, 0.60, 0.75 and 0.90 percent EMS for eight hours. In M_1 generation he found delayed panicle emergence, reduction in plant height increased tillering and significant reduction in mean yield per plant compared to control. In M_2 generation a wide spectrum of chlorophyll mutations at 50-70 Kr gamma rays and 0.75-0.90 percent EMS were observed but viable mutation spectrum was narrow and restricted to only changes in panicle form and grain colour. He reported albina type chlorophyll mutation as the most abundant and striata as the least.

Konstantitov et al. (1987) used six chemical mutagens at various concentrations in prosomillet with a view to induce useful mutations such as high yield, large grains, good quality milled product, resistance to Spacelotheca destruens and melanosis, and high grain protein content. The high yielding variety Khar'kovskoe 57 was produced using mutagens.

Pillai and Subramanian(1990) isolated 78 lodging resistant semi dwarf and 5 dwarf mutants from some 60,000 M_2 plants following exposure of grains of tall, lodging susceptible early rice cultivars PMK1 and poongar to 20-30 Kr gamma rays and 40-60 mh EMS.

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2.4 Differential genotypic response to various mutagenic treatments

Genetic differences, though as small as single gene differences, showed significant changes in radio sensitivity and in frequency and spectrum of recoverable mutation (Gustafson, 1944; Nilam, 1956; Sparrow, 1961 and many other workers).

Owen 1967 observed differential sensitivity of paspalum strains to thermal neutrons in respect of mutation rate, plant vigour and fertility in M_1 generation.

Radio sensitivity following different mutagenic treatments were studied in different varieties of finger millet by a number of authors (Goud et al. 1969; Kumar et al. 1969; Raveendran et al. 1984 and Tikka and Desai, 1989). They observed differences in the reactions of different varieties for various treatments in M_1 and M_2 generations.

Goud et al. (1970), reported varietal differences of two sorghum varieties (GM-2-3-1 and M35-1) in mutation yielding ability with regard to both frequency as well as spectrum of chlorophyll and viable mutations following gamma irradiation of sorghum seeds.

Pilnikova et al. (1971) observed differential response of prosomillet varieties to mutagens and reported 16.0% morphological mutants in K208 and 13.8% in K929.

Viraktamath (1975) reported differential response of sorghum genotypes to gamma rays. Variety RCR-408 was found highly sensitive and variety 302 was fairly resistant. He isolated tall mutants in 148, and dwarf and early mutants in RCR408.

Gupta and Yashvir (1976) observed differential response of foxtail millet varieties in the frequency and spectrum of viable mutations following treatments with different mutagens.

Singh et al. (1978) and Sandhu (1981) observed differential response of pearl millet genotypes to gamma rays, EMS and combined treatments in respect of mutation frequency and spectrum of chlorophyll mutations.

Islam, (1987) observed differential response regarding chlorophyll and viable mutation frequencies in M_2 generation in *Panicum miliaceum*. EMS was more effective than gamma rays and both effectiveness and efficiency varied with genotypes and mutagenic dosages.

2.5 Induced Micromutations

It is generally believed that induced mutants may not be beneficial as these are considered to be deleterious or less effective. However, a number of reports indicate that such types

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of assumptions are not always true and it is possible to obtain mutants with higher productivity. It is known that almost all characters of economic importance such as yield, earliness and tillering are governed by polygenes and inherited quantitatively. There are reports that considerable amount of variability may be induced for polygenic characters including yield and its components. The concept of polygenic mutations which is also referred to as micromutations was first developed by East (1935, 1936) and later by Fisher (1958). Allard (1960) assumed induced mutations as poly-directional and postulated that (i) in a population treated with mutagenic agent, it should be possible to make genetic advance under selection; (ii) such quantitative characters should be fixed at random under inbreeding; (iii) normal appearing but mutant inbred lines should show heterosis when hybridized; (iv) and quantitative characters should be represented in a series of intensities in independent mutant families. Based on these postulations Gregory (1956) who is considered as a pioneer in the area of induced micromutations developed a peanut mutant with significantly heigher yield than the control variety following treatment of seeds with X-rays. Gregory also found other postulates stated by Allard to be fulfilled in his work with irradiated populations of peanut.

The detection of useful mutants with small effects per locus is difficult as such effects are often masked by environmental effects and can be observed only after detail quantitative analysis. Differences in characters such as earliness and height are much easier to recognize than is the case for yield or protein content. However, it is known that relatively small mutagenic changes occur more often than large ones and at the same time show less negative side effects.

In micro mutation studies abnormal plants showing recognizable and physiological deviations are avoided and only normal looking plants are carried forward through the generations and the micro mutations are detected at population level applying statistical parameters like mean, range and variance .

In recent years , the number of papers published on induced polygenic variability are so numerous that they have included almost every quantitative character of economic importance of both self and cross pollinated crops .

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Gregory(1955) in his mutation study in peanuts demonstrated that for quantitative characters genetic variance gets increased following the treatment of seeds with X-rays. Further, the means of the characters significantly reduced.

Oka et al. (1958) reported significantly increased genetic variability in X -ray treated progeny of rice, while there was no significant change in mean values for plant height and heading date. They concluded that mutations for polygenes could occur in 'plus' as well as in 'minus' direction with the same frequency.

Kondo (1963) pointed out three major characteristics of micro mutations. They are (i) increase in quantitative variance of polygenic characters, (ii) more or less symmetrical distribution of the frequency of mutants and (iii) a high mutation rate per locus per unit dosage .

Yonezawa (1979) discussed the various methods that are followed in the assessment of induced quantitative variation and has opined M_3 generation as the best generation for assessment of variability and to initiate selection.

Definite and clean evidences for increased quantitative variance following mutagenic treatments were reported in many self and cross pollinated crops (by Sakai and Suzuki,1964 in rice; Rawlings et al., 1958 in soybean; Papa et al., 1961 in soybean; Gaul, 1963, Swaminathan, 1963, Dhonukshe and Bhowal, 1976 and Larik, 1975 in wheat; Gupta and Swaminathan, 1967 in brassica; Gardner, 1969, Morgan et al., 1972 in maize; Seetharam, 1976 in linseed; Ramakantha et al., 1977 in field been; Virk et al., 1985 in pearl millet and Giriraj et al., 1986 in sunflower). However, there are a few reports where reduction or no increase in variance has been observed in mutagen treated population (Brock, 1965; Gonzalez and Frey, 1965; Borojevic and Borojevic, 1968 ; Virk et al., 1978 and Ilyas Ahmed, 1977). They attributed the reduction to lethality following high dosage of mutagens and due to balancing of segregation in heterozygous genotypes and mutation.

There is no doubt that polygenic mutations result in the release of considerable variability in irradiated populations but the only opinion seems to differ regarding the direction of meximum mutations.

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Gregory (1955,1956) first mentioned experimental evidence on the decrease of mean of charecters following mutagenic treatment. He observed a decrease in population, mean for pod yield of the normal looking progenies following X-irradiation.

Regarding the reaction of quantitatively inheriting charecters to mutagenic treatment Bateman (1959), Brock (1965) and Goud (1967) hold the view that the incidence of polygenic mutations follow a trend opposite to that of previous selection. Based on his studies in subterranean clover, Brock(1965) proposed a hypothesis. According to the hypothesis the effect of micro-mutations depends on :

(i) the total number of genes involved,

(ii) the relative proportion of genes with positive and negative effects,

(iii) the extent to which the genes of the parental genome operate as a balanced set, and

(iv) *correlations due to linkage and pleiotrophic* effects.

But on the basis of experimental results in wheat and barley Gaul (1965,1966) and Aastveit (1966) hold the opposite view. Gaul and Aastveit hypothesized that the occurrence of micro-mutations is random and the effect of micro-mutations in any character is associated with their effect on vitality besides operating in the direction opposite to previous adaptation.

The effect of previous selection history as hypothesized by Brock(1965) has been confirmed by Goud (1967a, 1968) in wheat; by Goud et al. (1971) in ragi; by Rao and Siddiq (1976) in rice; by Seetharam (1976) in linseed; by Virk et al. (1978,1985) in wheat, rice and pearl millet; and by many other workers of late.

There are also evidences to demonstrate that the direction of micro-mutation is not only dependent on previous selection history but also on previous factors like genotype, charecters and mutagen dosage (Aastveit, 1967; Sharma and Saini, 1969; Gupta, 1969; Singh and Sharma, 1976).

Rao and Siddiq (1977) who observed the direction of shift in mean productive tiller number in Norin 27 which has unidirectional selection history suggested that other factors as suggested by Gaul and Aastveit(1966) and Gregory might influence the effect of micro-mutations besides past selection history.

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Gaul (1961) suggested that micro mutations i.e, mutation which causes a small magnitude of change in expression in attributes is more effective than macro mutations i.e, mutations which cause a large degree of change in expression in attributes, when trying to inprove quantitative charecters through mutation breeding. Micro mutation approach in various crops including rice was effective in improving complex quantitative traits like yield, maturity and height (Brock, 1965, 1971; Gaul, 1965 and Gregory, 1968). Similar approach to charecters relating to nutritive quality was found equally effective (Dumanovic et al. 1973; Ismail, 1972).

Swaminathan et al. (1962) evaluated the use of induced micro and macro mutants in wheat and barley following the treatment of seeds with X-rays and EMS and suggested that enhanced variation may be created for quantitative traits by EMS through increased recombination in the chromosome segments proximal to the centromere.

Hykoyuki Yamaguchi(1962) studied the mutations which affected quantitatively inherited charecters such as length and width of grain in a rice variety, Norin no.29 following irradiation of dry seeds of the rice variety with 10,000r and 30,000r dosages of gamma rays. He suggested that to obtain maximum amount of genetic variance in quantitative charecters, the materials must be irradiated with lower dosages in inducing mutations in major genetic systems.

Gaul (1964) studied irradiated progeny of four barley varieties, Haisad, Wise, Volla, and Amsel. He studied M_1—M_5 generations with reference to both macro and micro-mutations. He concluded that the genetic variance for quantitative charecters can be increased providing scope of selection of micro-mutations for higher yield and other quantitative charecters.

Abrams and Frey (1964) reported that there was no significant differences among mutagen and check populations for mean weight per 100 seed weight in oat. The mean heading date of check population was significantly earlier than that of any of the mutagen derieved populations. The mean plant height for the mutagen derieved populations were all less than the mean of the check populations. Whereas Krull and Frey (1961) reported that populations derieved from thermal neutron irradiation of oats had significantly higher mean seed weight than did the check populations. They also reported a significantly delay in mean heading date for neutron derived populations.

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Abrams and Frey (1964) also reported that mutagens increased the genetic variances in heading date, plant height and 100 seed weight. They also suggested that selection for seed weight, plant height or heading date in mutagen treated populations should be delayed until at least the M_3 generation.

There was neither a consistent positive nor negative change in Skewness of the frequency distribution for weight per 100 seeds due to mutagen treatment indicating that the variability for this character occurred in both directions from the mean. Except for EMS flower treatment, Skewness values for heading date shifted positively in mutagen treatment whereas for plant height (except for EMS seed treatment) the shifts were negative. Kurtosis values were consistently changed in a positive direction in mutagen treated material except for weight per 100 seeds in EMS seed and flower treatments (Abrams and Frey (1964).

Goud (1967) in his study on polygenic variability in hexaploid wheat found that the variance was increased by most of the treatments for yield and number of tillers in M_2. He suggested that the polygenic mutations seem to follow a trend opposite in direction to that of the previous selection history.

Madhava Rao and Goud (1973) reported increased polygenic variability for various quantitative charecters following gamma irradiation of setaria seeds. Promising lines with shorter plants, increased tiller number and grain yield per plant were isolated in M_3 and M_4 generations. They reported higher genotypic variances with consequent high heritability values for all the charecters in M_4 generation. They reported ninety one percent heritability for grain yield in M_4 generation. They noted it as interesting one and advised to wait till M_3 or later generation for effective selection of character controlled by polygenes.

Gustafsson (1947) reported that mutation for qualitatively inherited attributes have appeared to be predominately deleterious whereas mutations expressed in quantitatively inherited attributes have tended to be somewhat equally distributed between deleterious and beneficial (Krull and Frey, 1961; and Oka et al. 1958).

Dhonekshe and Bhowal (1976) reported that it is possible to induce more variability in polygenic characters such as culm length, tiller number and yield for enlarging the scope of

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selection in developed wheat varieties. They found considerable genetic variability of quantitative characters in wheat varieties (Sonalica, Chhoti Lerma and Hira) following irradiation with gamma rays, the dosages were 20 and 25 Kr. Much variation was observed for culm length. Both taller and dwarf plants were obtained. The mean culm length significantly decreased in the irradiated population but the variance increased enormously in both the treatments. Range of tiller number was much wider in irradiated populations compared to respective control. The range for tiller number shifted towards positive direction only. Mean tiller number per plant and variance increased in irradiated population also. Mean yield and variance increased significantly in 25 Kr but decreased in 20 Kr.

Gowda (1977) reported increased mean of quantitative characters such as plant height, tiller number and grain yield in gamma irradiated population of foxtail millet in M_3 generation. Besides, there was increase in the variability.

In a mutation study Raveendran et al. (1982) treated two finger millet genotypes, MS2698 and Sarada with N-Methyl-N-nitroso-N-nitroguanidin. The mean, genetic variance, heritablity and genetic advance were estimated in M_2 and M_3 generations of these treated genotypes for seven metrical traits. The mean values of most of the treatments in M_2 and M_3 did not deviate substantially from the control. There was an increase in the genetic variance both in M_2 and M_3. The M_3 variance of plant height was higher than that of M_2. For all other characters the M_3 variance was less than the M_2 variance. The heritability and genetic advance values were higher in the treatments than in the control. Short duration mutants in Sarada and bold seeded mutants in MS2698 were obtained as a result of these investigations.

Islam (1987) studied induced polygenic variability in M_3 generation for six quantitative characters in prosomillet varieties. He observed that mean plant height shifted towards positive direction but mean tiller number shifted towards positive only in the shy tillering variety and remained almost unchanged in the medium and high tillering varieties. Mean number of days to panicle emergence remained almost unaffected. Similarly there was little change in mean and range values for test weight compared to control, offering little scope of selection. Yield however, was amenable for further improvement as evidenced by enlarged mean and variance in all the varieties studied.

Shashidhara et al. (1990) studied induced variability for different traits in sorghum in M_2 and M_3 generations. The mutagenes were MMS and gamma rays. They observed that variance for a character increased with the increase of mutagen dosages. Varieties differed in their response to mutagens.

In mutation breeding programme for quantitative characters, it is advisable to work with number of plants and to wait till the M_3 generation or later before selection is started (Van Harten, 1991).

2.6 Induced macro -mutations

Though there are numerous reports reported by many workers both in self and cross pollinated crops and also suggestion (Gaul,1961) for micro-mutation as technique for the improvement of quantitatively inherited characters, reports for macro-mutation approach for improvement of character(s) are not negligible and scanty. There are reports that macro-mutation approach is effective when one or few characters in a established variety need to be changed or improved since suitable macro-mutant can be used as breeding material or back ground material in breeding programme. There are also reports that macro-mutant has also been proved to be economic or useful mutant directly regarding height, yield, earliness and diseases resistance.

Vijayaraghavan and Seshadri Sarma (1938) reported a single spontaneous mutant with "In curved" ears isolated from the plants of E.C.593 ragi strain with "Top-curved" ears. This odd plant was labeled as R-42 and it bred true to all its characters. The plant resembled E.C.593 very closely in all morphological characters except in the shape of ear-head. They concluded that the change seems to have taken place in a single gene only as the "In curved " head is a simple recessive to the "Top -curved ". They reported it as the heaviest yielder giving 9 to 10 percent heigher yield of grain over E.C 593.

Bilquiz et al. (1964) obtained bristled, dense, awned mutants of *Pennisetum typhoides* by subjecting the seeds to X-radiation. Bristled ear character helps in increasing the grain yield of the plant mainly through cutting down the damage by birds, there by signifying the character.

Emery et al. (1964) pointed out breeding value of the X-ray induced macro -mutant in peanuts. They noted that because of striking appearance and usually accompanying low vitality, the X-ray induced macro-mutant has been the source of much speculation

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concerning the deleterious character of induced mutations . They reported that morphological mutant expression in peanuts was commonly associated with one to a few gene mutations .They also reported that genetic variances around the means and selection responses among the hybrid families within background blocks were in general greater than those associated with control families. Selection for increased yield among F_2 families in the F_5 generation was usually effective in those back grounds where significant genetic variances were noted in the F_4 generation.

Joshi (1968) obtained bristled ears and dwarf progressive macro-mutants in Pusa Moti, an improved variety of bajra following irradiation of dry seeds of the bajra variety with 25 Kr gamma rays. He noted the changes as desired in the established variety which increases the potentiality and thus the utility of the improved strain evolved thereby.

Goud et al. (1970) recorded drought resistant types of sorghum in addition to many agronomic types of viable mutations in M_2 generation following gamma irradiation of sorghum seeds.

Rahman et al. (1973) isolated and developed two high yielding rice mutants, namely IRATOM24 and IRATOM38 through macro-mutation approach following exposure of dry seeds of rice variety IR8 to 30Kr gamma rays.

Nayar et al. (1974) isolated eight dwarf mutants in bajra following mutagenic treatments. Out of eight dwarfs two of Cauvery and three of Annapurna were reported to be promising with yield significantly higher or on par with their parents. They reported another dwarf mutant, H_{1-2} in other variety H_{22}, the dwarf mutant matured 15 days earlier but its yield potentiality was lower than its parent. They suggested that it can form an excellent breeding material for earliness and dwarfness.

Viraktamath (1975) recorded early and dwarf mutations in the sorghum variety RCR-408 following mutagenic treatments. He also isolated mutants with high grain weight in gamma irradiated population of RCR-408.

Konstantinov et al. (1975) isolated mutants with high content of protein following treatment of dry seeds of millet with 0.012% solution of N-nitrosoethyl urea(NEU). These mutants were used in reciprocal crosses with regional cultivars.

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Chapter 3
MATERIALS AND METHODS

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3. MATERIALS AND METHODS

3.1. Materials : Dry seeds of foxtail millet (*Setaria italica* Beauv.) and physical mutagen (Gamma rays) were used in the present investigation.

A. Seeds : Dry seeds of uniform size of three advanced lines of foxtail millet with distinct morphological features and moisture around 10-11 per cent were used in the study.

The salient features of the advanced lines are as follows :

(I) **BSi1** : It is of tall stature (av. height 130.0 cm), green with medium tillering ability (av. tiller no. 1.7) and medium panicle length (av. length 19.50 cm), possessing semi-loose and distinct lobes; medium maturing (av.122.5 days), medium yield (av. 9.5 gm per plant) and an orange-seeded line.

(II) **BSi427**: It is green, medium sized plant (av. height 120 cm), with less tillering ability (av. no. 1.4) and large panicle length (av. length 23.5 cm) possessing semi compact and distinct lobes, medium maturing (av. 123.5 days), high yield (av. 12.5 gm per plant) and a cream-seeded line.

(III) **BSi467**: It is tall, purple (av. height 140.0 cm), with medium tillering (av. tiller no. 1.6) and big panicle (av. length 20.5 cm) possessing loose and distinct lobes; late maturing (av. 130.5 days), medium yield (av. 8.5 gm per plant) and a black-seeded line.

B. Gamma rays (Kr) : The following eight dosages of gamma rays (Kr) were given to different samples of seeds.

Dosages : 10, 20, 30, 40, 50, 60, 70 and 80.

3.2. Methods : Dry seeds of uniform size and a moisture content of about 10-11 per cent were irradiated with eight dosages of gamma rays from a Co^{60} (Cobalt^{60}) source at the Atomic Energy Centre, Savar, Dhaka. Soon after the treatment, seeds were sown in

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December 1989 in experimental field of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur to raise the M_1 generation. In addition to mutagenic treatments one control for each variety was included in the study. In M_1 generation irradiated seeds were sown in a replicated trial following RCBD with three replications. Seeds per dosage were 450 in three replications of 150 each. In all, there were 27 treatments with three controls.

To study germination and other biological parameters 100 seeds were set apart from each treatment prior to sowing in the field. Seeds were placed for germination in Petri dishes lined with wet filter paper in four replications. Each replication consists of 25 seeds spread uniformly on the filter paper wet with 5 ml of distilled water.

3.2.1. Studies in M_1 generation

(i) Germination and seedling growth : Germination counts and growth measurements were taken on seven-day-old seedlings along with controls. Root and shoot lengths were measured separately for seedling growth studies.

(ii) Dry weight of seedlings : The seedlings after root and shoot length measurement were dried in hot air oven at 50°C for three days till constant weight was reached. Then they were weighed and mean seedling weight was calculated.

(iii) Pollen sterility : Pollens in M_1 plants were stained in acetocarmine and their percentage of stainability was measured. Ten panicles from the main culm were selected at random. Pollen grains were collected at anthesis and stained with one per cent acetocarmine + glycerol (1:1). Fully formed and well stained pollen grains were treated as fertile. Pollen counts per slide were taken from observations of three microscopic fields. The sterility percentage was calculated as shown below :

$$\text{Pollen sterility (\%)} = \frac{\text{Number of sterile pollen grains} \times 100}{\text{Total number of pollen grains scored}}$$

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(iv) Grain fertility : Grain or seed fertility was scored at maturity and observation was taken uniformly on the main panicle and only from the middle portion of the panicle. Length of about 4cm was considered for assessment of seed fertility. Seed fertility was recorded from 10 randomly selected plants in each treatment and the method of calculation was as follows:

$$\text{Grain fertility (\%)} = \frac{\text{Number of grains observed} \times 100}{\text{Total number of florets}}$$

For the following characters 25 plants were selected randomly and data were collected at maturity.

(i) Days to panicle emergence : Number of days taken from the date of sowing to ear emergence in each plant.

(ii) **Plant height (cm)** : Plant height was measured at harvesting time in centimeters from the base to the tip of the panicle on the longest culm.

(iii) Length of panicle (cm) : Panicle of the main culm was measured in centimeters at harvest.

(iv) Number of panicle-bearing tillers : Number of panicle-bearing tillers were counted in each randomly selected plant at the time of harvest.

(v) Yield per plant : The seed harvested from each individual plant was weighed and expressed in gram.

For any morphological changes involving either the entire plant or chimeras M_1 plants were carefully observed until maturity. The M_1 plants were harvested individually and the seeds were kept separately to raise the M_2 generation.

3.2.2. Studies in M_2 generation

M_2 generation was raised by sowing the seeds of each M_1 plant in two rows each 2.0 m long with 25 cm distance between the rows. In the M_2 generation studies included scoring of both chlorophyll and viable mutations. Chlorophyll mutations were scored during the

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seedling stage and viable mutations during the entire life cycle prior to harvest. The chlorophyll mutations were scored in a separate nursery raised for this purpose. Seeds from each M_1 plant were sown in a non-replicated 2.0 m long row on nursery beds. To record chlorophyll mutations properly continuous sowing was done on different dates. The control and treated populations were carefully observed and scored for chlorophyll and viable mutations. For two weeks data were recorded for chlorophyll mutations from the time of emergence. In the present investigation M_2 chlorophyll mutants were scored as follows and classified as suggested by Gaul (1964) for barley :

1. **Albina**: Seedlings with no chlorophyll or carotenoid pigments, albino, non-viable seedlings.
2. **Viridis**: Weakening of individual pigments, light green to yellow green, partly viable seedlings.
3. **Xantha**: Carotenoid pigments predominate, absence of chlorophyll deficiency, yellow, non-viable seedlings.
4. **Striata**: Longitudinal stripping with bright green, yellow or white colour tones.
5. **Tigrina**: Brown to yellow transverse stripping of leaf blades due to zonal pigment deficiency or necrosis of leaf tissues.
6. **Albo-viridis** : White tip of the first leaf, enhancement of green pigment towards the leaf base.
7. ***Virido-albina***: *Leaf base white, enhancement of green pigment content towards* the leaf tip.

3.2.2.1. Estimation of mutation frequencies : The frequency of all chlorophyll and viable mutants were estimated in the following two ways:

(i) Based on M_1 plants : It has been estimated on the number of segregating progenies. This method gives an idea on the number of affected seeds carrying mutations, but does not give any idea of how many mutational events have occurred in a treated *population as it gives only percentage of M_2 progenies segregating for mutation* without considering the size of the progeny and the proportion of mutants within it.

$$\text{Mutation frequency (\%)} = \frac{\text{Number of segregating progenies} \times 100}{\text{Total progenies scored for mutation}}$$

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(ii) Based on M_2 plants : This method takes into account the same type of mutations occurring more than once in an ear head.

$$\text{Mutation frequency (\%)} = \frac{\text{Number of mutant plants} \times 100}{\text{Total plants scored for mutation}}$$

3.2.2.2. Estimation of mutagenic effectiveness and efficiency : Mutagenic effectiveness is defined as a measure of frequency of mutation induced by a unit of mutagen while mutagenic efficiency gives an idea of the proportion of mutants in relation to deleterious effects like lethality, sublethality and sterility. In the present study mutagenic efficiency was calculated based on M_1 sterility only. Both these measures were calculated using the formula suggested by Konzak et al. (1965).

$$\text{Mutagenic effectiveness} = \frac{M}{Kr}$$

$$\text{Mutagenic efficiency} = M/S$$

where, M = Chlorophyll mutation frequency on M_2 plants

Krad (kilorad) = Unit of gamma radiation

S = Percentage of fertility reduction in M_2 seeds

3.2.3. Studies in M_3 generation

3.2.3.1. Polygenic variability : For the assessment of polygenic variability in all the three varieties a separate field trail was laid out. The experiment was conducted in the experimental plot in Bangladesh Agricultural Research Institute (BARI). Seeds were collected from M_2 individuals with normal phenotype. Split plot design with three replications was followed. The main and sub-treatments were as follows :

Main treatments : Varieties (3), namely BSi1, BSi427 and BSi467.

Sub-treatments: Mutagenic dosages (Kr) and control.

Dosages of gamma rays in Kr : 10, 20, 30, 40, 50, 60, 70 and 80.

Due to poor survival of 80 Kr irradiated seeds in M_1 generation, this lot was excluded from the present study.

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In all, there were 24 treatments (7 dosages × 3 var. + 3 control). Each treatment consists of ten rows of 25 plants in a plot of 2 m × 2 m. From each treatment and each replication a random sample of 50 plants was selected for observations on six selected quantitative characters, namely plant height, days to panicle emergence, days to maturity, number of fertile tillers, panicle length, 1000 grain weight and yield per plant.

3.2.3.2. Breeding behaviour of mutants isolated in M_2 generation : The breeding behaviour of different types of viable and chlorophyll mutants observed in M_2 generation were studied in M_3 generation. The seeds collected from mutant plants in M_2 generation were grown in plant progeny rows and were studied.

3.2.3.3. Study of variants isolated in M_1 generation : The seeds collected from one chlorophyll (striata) variant and from one colour variant (seed colour) in M_1 generation were sown in plant to progeny rows and were studied in M_2 and M_3 generations to identify the two variants.

3.2.3.4. Study of useful macro mutants isolated in M_2 generation : Seeds of five dwarfs, 38 early maturing type and seven large sized head mutants isolated in M_2 generation were grown in replicated trials in M_3 and M_4 generations to study their breeding behaviour and other quantitative characters.

In case of dwarfs, the mutants were placed in 2.5 m long row observation trial. In M_3 generation early type and high yielding mutants were placed in two rows of 2.5 m observation trial with three replications. In M_4 generation all the useful mutants were tested in randomized complete block design with three replications. Except for dwarfs, unit plot size was 2.5 m × 1.0 m. with a spacing of 25 cm between rows and 10 cm between plants within a row. The unit plot size for dwarf mutants was 2.5 m × 2.0 m.

Data on days to flowering, days to maturity, plant height, panicle length, tiller number, yield per plant, grain per panicle and 1000 grain weight were recorded from ten randomly selected plants from each replication. In dwarf mutants such data from 50 randomly selected plants were recorded in each replication; data for leaf number, number of nodes, inter nodal length between the 4^{th} and 5^{th} nodes of the main tiller were also recorded at maturity. Harvest index was calculated from 50 randomly selected plants. Data collected were statistically analysed for variance, t test, correlation following the methods of

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Gomez and Gomez (1984) and Heritability (H_b) was calculated following the methods of Singh and Chaudhury (1979). In case of dwarf mutants "t" test was done to test the significance of the response of the above quantitative characters in diverse environments. In case of early types, response of the mutants to environmental variation was tested by simple combined analysis of variance over generations.

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Chapter 4
EXPERIMENTAL RESULTS

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4. EXPERIMENTAL RESULTS

Mutagenic effects in M_1 generation were assessed by the study of different biological parameters as follows :

(a) germination,
(b) shoot length of seedlings,
(c) root length of seedlings,
(d) dry weight of seedlings,
(e) pollen sterility, and
(f) grain fertility.

Quantitative parameters in M_1 generation were also assessed. Mutagenic effects such as frequency of chlorophyll and viable mutants in M_2 generation were recorded and micro-mutations or polygenic variabilities in M_3 generation were studied. Macro-mutants isolated in M_2 generation were also evaluated up to M_4 generation for useful mutants. The results are presented below.

4.1. M_1 generation

(a) Germination: The analysis of variance (Table 1) shows that the varieties differed significantly in their germination capacity as a result of gamma irradiation; germination percentage also differed significantly by different dosages. The interaction effect was found insignificant. Table 2 shows that the variety BSi467 was found the most sensitive to gamma radiation and 60 Kr affected germination more than all other dosages. Table 2 also shows that germination was affected at 10 Kr; and different dosages reduced germination in different degrees in all the three varieties, but not drastically and did not show dosage dependent relationship (Fig. 1). Among the gamma dosages 60 Kr reduced maximum germination in BSi1 and BSi467, whereas in BSi427 maximum reduction in germination was at 50 and 70 Kr.

As far as germination is concerned BSi467 was found more sensitive to gamma radiation compared to other two varieties and dosage of 60 Kr was the most effective in reducing germination.

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Table 1. ANOVA for seed germination of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.

Sources of variation	df	SS	MS	F Value
1. Replication	2	0.519	0.259	0.2964
2. Treatments: i) Factor A(Varieties)	2	20.933	10.481	11.9837**
ii) Factor B (Gamma radiation)	8	28.444	3.556	4.0651**
iii) Interaction (AB)	16	10.593	0.662	0.7569
3. Error	52	45.481	0.875	

(** Significant at 1% level of probability.)

Table 2. Effect on seed germination (%) of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma rays treatments in M_1 generation.

Gamma rays (Kr)	BSi1		BSi427		BSi467	
	Mean Germination	Percent of Control	Mean Germination	Percent of Control	Mean Germination	Percent of Control
0	19.33	100.00	20.00	100.00	19.67	100.00
10	19.33	100.00	19.33	96.65	18.33	93.19
20	18.33	94.83	19.67	98.35	18.00	91.51
30	18.67	96.58	19.00	95.00	18.67	94.92
40	19.33	100.00	19.33	96.65	18.00	91.51
50	17.33	89.65	18.67	93.35	17.33	88.10
60	17.00	87.95	19.00	95.00	17.00	86.43
70	18.00	93.12	18.67	93.35	18.00	91.51
80	17.67	91.41	19.67	98.35	17.67	89.83

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(b) Shoot length: The analysis of variance for shoot length (Table 3) shows that the varieties, dosages of gamma radiation and their interactions differed significantly. Table 4 shows that BSi1 was found more sensitive compared to the other two varieties and 80 Kr was more effective in reducing shoot growth. It is also evident from Table 4 that reduction in shoot growth started at 10 Kr in the two varieties (BSi427 and BSi467). In BSi467 shoot growth reduced gradually and showed dosage dependent relationship (Fig.2). In BSi1 shoot growth did not show dosage dependent relationship. In BSi427, excepting at the dosage of 60 Kr, the shoot growth gradually reduced up to the highest dosage of 80 Kr. At the highest dosage of 80 Kr shoot length was drastically affected in all the three varieties and the extent of growth was less than 50 percent of the control in BSi1 and in BSi467 and less than 60 percent of the control in BSi427 (Plates 1, 2 and 3).

On comparison it is observed that drastic shoot growth reduction was at the highest dosage of 80 Kr and the two varieties BSi467 and BSi1 were found sensitive to gamma irradiation as far as shoot growth is concerned compared to the other varieties.

(c) Root length: Highly significant difference was observed among the varieties and the effect of the dosages of gamma radiation. Their interaction was also significant (Table 5).

Table 6 shows that BSi1 was found sensitive and the highest dosage of 80 Kr was found to reduce the root length more than any other dosages. Table 6 also indicates that the root length was affected at 10 Kr in all the three varieties. Root length gradually decreased with the increase of dosages and showed dosage dependent relationship in BSi1 and BSi427 except in BSi467 (Fig. 3). The extent of reduction in root growth was different in the three varieties. The maximum reduction was at 80 Kr in all the three varieties showing reduction of less than 30 percent of the growth of the control in BSi1, and less than 40 percent of the growth of the control in BSi427 and BSi467 (Plate 1a, 2a and 3a).

Comparison of dosages of gamma rays and varieties indicates that the variety BSi1 was found more sensitive to gamma radiation compared to the other two varieties and the highest dosage of 80 Kr was more effective in reducing root length.

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Table 3. ANOVA among shoot lengths in gamma ray treated materials of three varieties, BSi1, BSi427and BSi467 of Foxtail millet in M1 generation.

Sources of variation	df	SS	MS	F Value
1. Replication	2	0.067	0.034	0.2891
2. Treatments: i) Factor A(Varieties)	2	3.877	1.938	16.6712**
ii) Factor B (Gamma radiation)	8	46.264	5.783	49.7354**
iii) Interaction (AB)	16	4.325	0.270	2.3247*
3. Error	52	6.046	0.116	

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)

Table 4: Effect on shoot length of three varieties of foxtail millet following Gamma irradiation in M_1 generation.

Gamma Rays (Kr)	Bsi 1		Bsi 427		Bsi 467	
	Mean Shoot length(cm)	Percent of Control	Mean Shoot length(cm)	Percent of Control	Mean Shoot length(cm)	Percent of Control
0	3.88	100.00	4.3	100.00	4.58	100.00
10	3.90	97.94	3.90	94.43	4.41	96.29
20	3.34	86.08	3.89	94.19	4.33	94.54
30	3.82	98.45	3.82	92.49	3.92	85.59
40	3.09	79.64	3.61	87.41	3.76	82.10
50	2.94	75.77	3.11	75.30	3.35	73.14
60	2.47	63.66	3.14	76.03	2.84	62.00
70	1.92	49.48	3.08	74.58	2.10	45.85
80	1.58	40.72	2.41	58.35	1.65	36.03

LSD (0.050) = 0.56

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Table 5. ANOVA among root lengths in gamma ray treated material of three varieties, BSi1, BSi427and BSi467 of foxtail millet in M_1 generation.

Sources of variation	df	SS	MS	F Value
1. Replication	2	0.272	0.136	0.8730
2. Treatments:				
i) Factor A(Varieties)	2	110.300	55.150	353.5373**
ii) Factor B (Gamma radiation)	8	106.272	13.284	85.1564**
iii) Interaction (AB)	16	12.213	0.736	4.8933**
3. Error	52	8.112	0.156	

(** Significant at 1% level of probability.)

Table 6. Effect on root length of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.

Gamma Rays (Kr)	Bsi 1		Bsi 427		Bsi 467	
	Mean Root length (cm)	Percent of Control	Mean Root length (cm)	Percent of Control	Mean Root length (cm)	Percent of Control
0	3.66	100.00	7.24	100.00	5.42	100
10	2.79	76.23	6.72	92.82	5.31	97.97
20	2.61	71.31	6.23	86.05	4.57	84.32
30	2.58	70.49	6.18	85.36	4.80	88.56
40	2.25	61.47	5.10	70.44	4.11	75.83
50	1.65	45.08	3.67	50.69	4.02	74.17
60	1.58	43.17	3.53	48.76	3.09	57.01
70	1.32	36.06	3.60	49.72	2.67	49.26
80	1.04	28.41	2.55	35.22	2.05	37.82

LSD (0.010) = 0.8623

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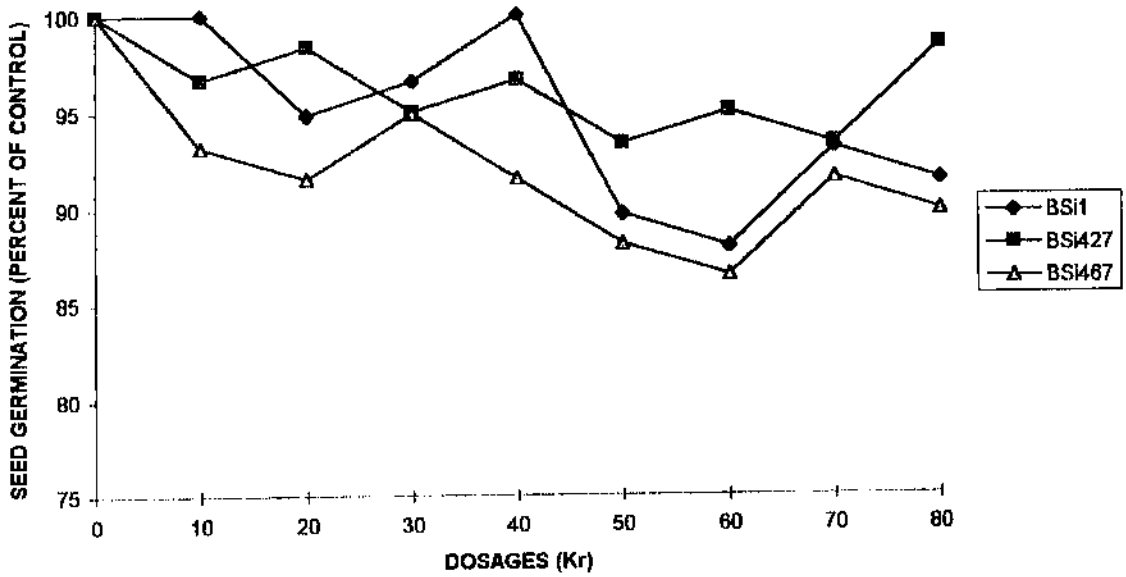

Fig.1. Effect of Gamma rays on seed germination in BSi1,BSi427 and BSi467 in M_1 generation.

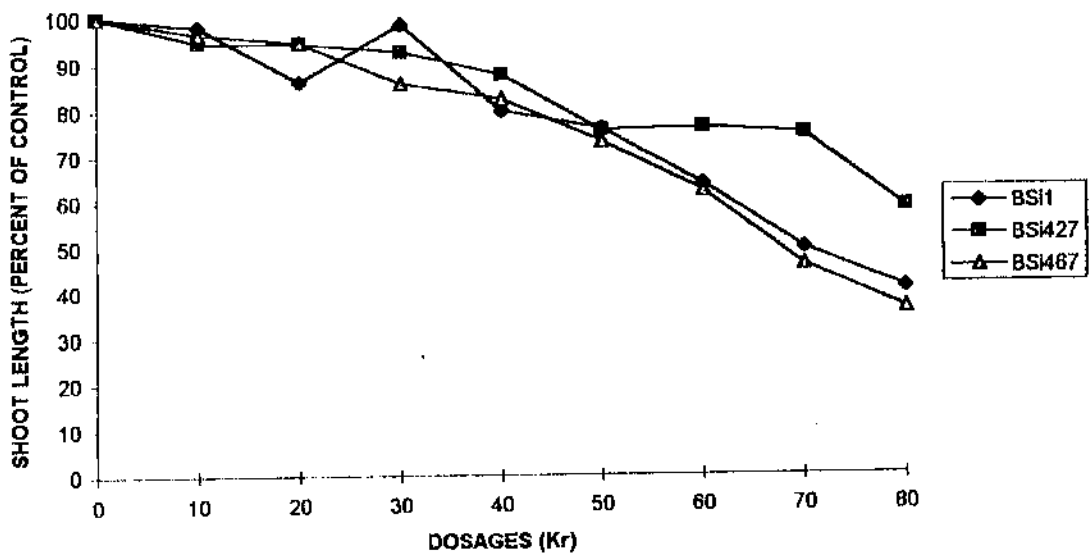

Fig.2. Effect of Gamma rays on shoot length in BSi1,BSi427 and BSi467 in M_1 generation.

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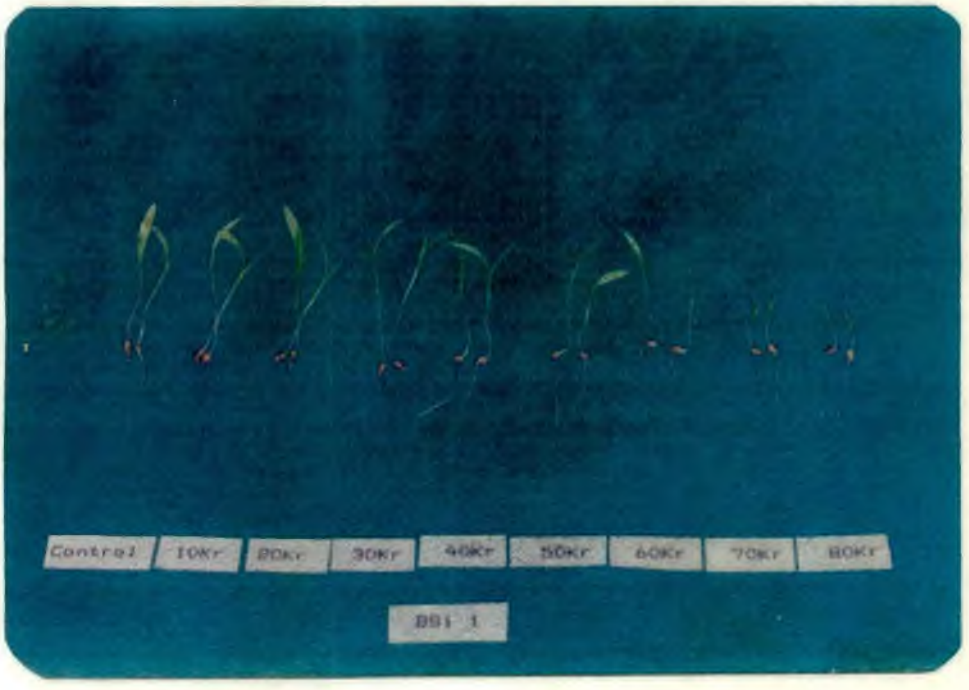
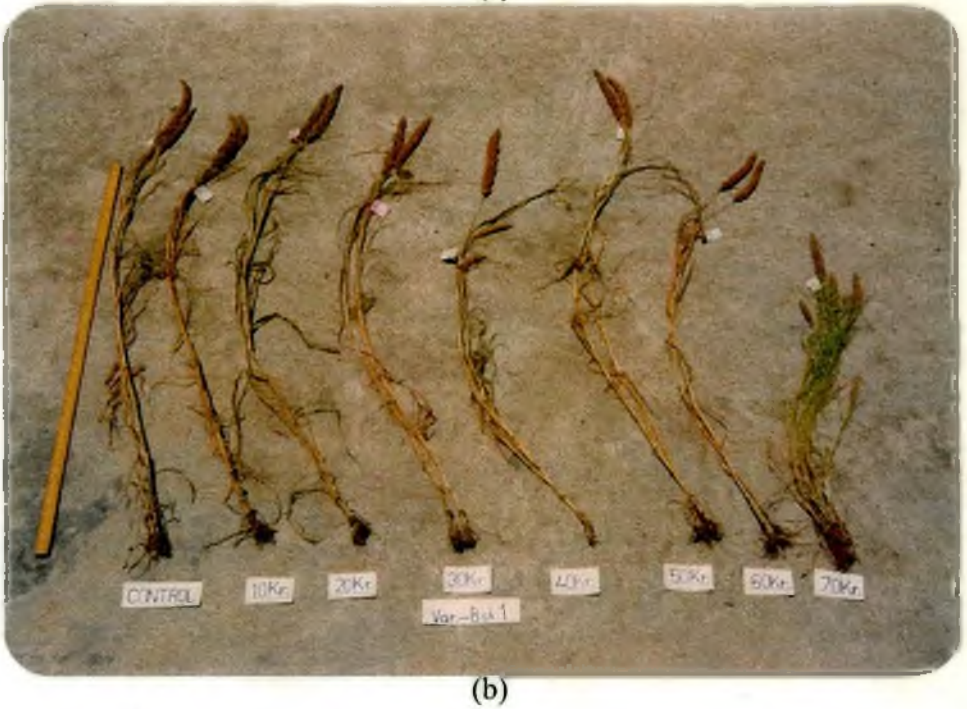


(a)



(b)

Plate 1. a-b: (a) Effect of gamma irradiation on height at seedling stage in BSi1 [Control $^{(L)}$ — higher dosages $^{(R)}$]. (b) Effect of gamma irradiation on height (harvested plants) in BSi1 [Control $^{(L)}$ — higher dosages $^{(R)}$]

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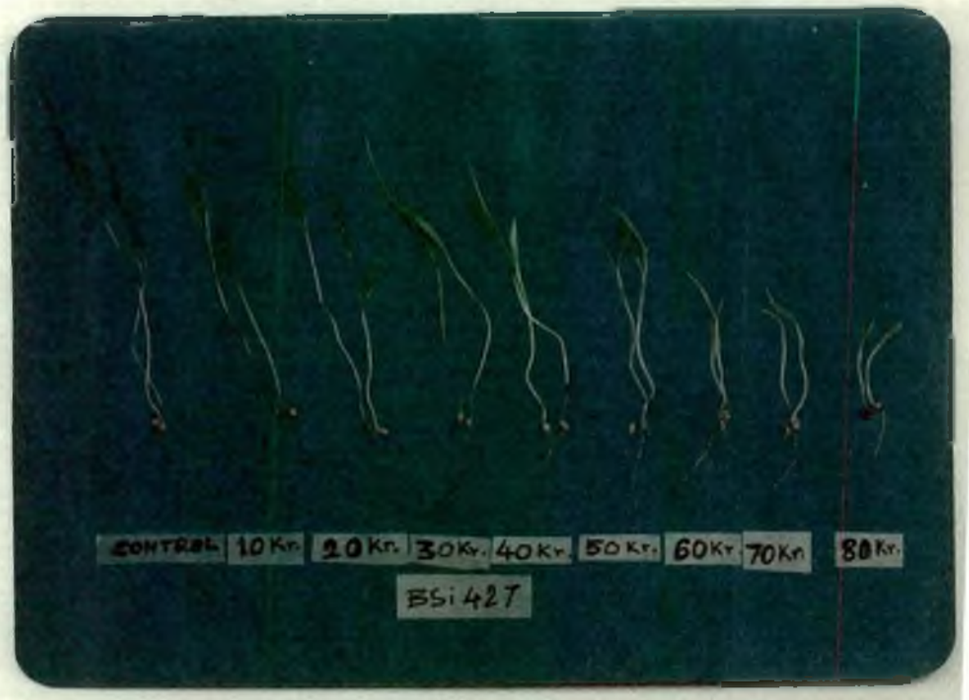
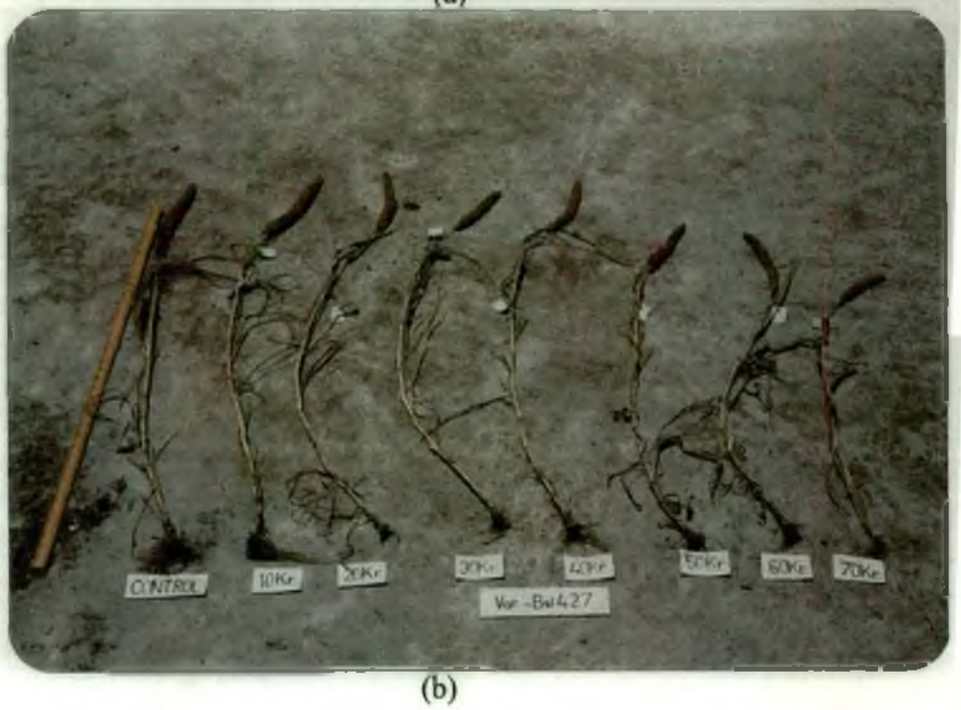


(a)



(b)

Plate 2. a-b: (a) Effect of gamma irradiation on height at seedling stage in BSi427 [Control $^{(L)}$ — higher dosages $^{(R)}$]. (b) Effect of gamma irradiation on height (harvested plants) in BSi427 [Control $^{(L)}$ — higher dosages $^{(R)}$]

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(a)

(b)

Plate 3. a-b: (a) Effect of gamma irradiation on height at seedling stage in BSi467 [Control $^{(L)}$ — higher dosages $^{(R)}$]. (b) Effect of gamma irradiation on height (harvested plants) in BSi467 [Control $^{(L)}$ — higher dosages $^{(R)}$]

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(d) Dry weight of seedlings (7-day-old): The analysis of variance (Table 7) shows that there was no significant difference among varieties, dosages of gamma treatment and their interaction effects in respect of dry weight of 7-day-old seedlings.

Table 8 indicates that the three varieties responded differently in accumulation of dry weight of 7-day-old seedlings. None of the varieties showed dosage dependent relationship (Fig. 4). In BSi1, except 20 Kr, there was an increase in dry weight; different dosages increased dry weight in different degrees. In BSi427 dry weight increased at 10 Kr, gradually decreased up to 60 Kr and again increased at 70 Kr; but the increase was below the level of parent. In BSi467, except at the two higher dosages of 60 and 70 Kr, the dry weight decreased at all dosages. At 60 and 70 Kr dry weight increased up to the parent level. In BSi1 and BSi427 the highest extent of increase being recorded as 138.50 and 107.69 percent of the control respectively was at 10 Kr. In BSi467 the highest extent of increase being recorded as 119.42 percent of control was at the highest dosage of 80 Kr.

(e) Pollen sterility: The analysis of variance for pollen sterility in Table 9 shows that highly significant difference was observed among varieties and dosages of gamma radiation in respect of pollen sterility. The varieties and dosages interaction effect was also found highly significant. The variety BSi427 was found sensitive and the highest dosage of 80 Kr was found the most effective in increasing pollen sterility in all the three varieties as evident from Table 10. Table 10 also indicates that the pollen sterility was affected differently in the three varieties as a result of gamma treatments. The increase in pollen sterility over the parent persisted throughout the dosages in all the three varieties; the different dosages increased pollen sterility in different degrees (Fig. 5). In BSi1 the sterility percentage was 11.46 in parent; the sterility increased to percentage 71.36 at 40 Kr; it was 622.69 percent increase of the control (Plate 4).

In BSi427 the pollen sterility was 24.92 in parent; the sterility increased at different dosages in different degrees. In this variety the highest extent of increase in sterility was 69.32 at 80 Kr which was 278.17 percent increase of the control (Plate 5).

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Table 7. ANOVA among seedling dry weights in gamma irradiated material of three varieties, BSi1, BSi427and BSi467 of foxtail millet in M_1 generation.

Sources of variation	df	SS	MS	F Value
1. Replication	2	1.057	0.528	11.4252
2. Treatments: i) Factor A(Varieties)	2	0.255	0.127	2.7560
ii) Factor B (Gamma radiation)	8	0.560	0.070	1.5142
iii) Interaction (AB)	16	0.709	0.044	0.9588
3. Error	52	2.404	0.046	

Table 8. Effect on seedling dry weight of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.

Gamma rays (Kr)	BSi1		BSi427		BSi467	
	Mean Seedling dry wt. (mg)	Percent of Control	Mean Seedling dry wt. (mg)	Percent of Control	Mean Seedling dry wt. (mg)	Percent of Control
0	0.99	100.00	1.30	100.00	1.20	100.00
10	1.37	138.38	1.40	107.69	1.10	91.67
20	0.90	90.91	1.27	97.69	0.90	75.00
30	1.31	132.32	1.23	94.61	1.17	97.50
40	1.04	105.05	1.23	94.61	1.07	89.17
50	1.03	104.04	1.23	94.61	1.17	97.50
60	1.13	114.14	1.20	92.31	1.13	94.17
70	1.13	114.14	1.30	100.00	1.37	114.17
80	1.22	123.23	1.17	90.00	1.43	119.17

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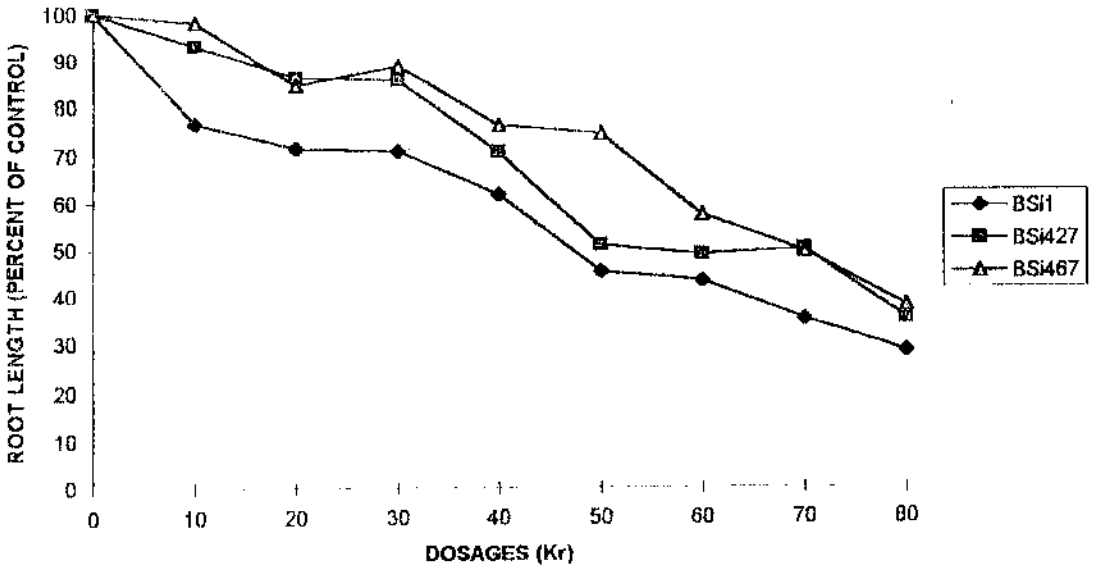

Fig.3. Effect of Gamma rays on root length in BSi1,BSi427 and BSi467 in M_1 generation.

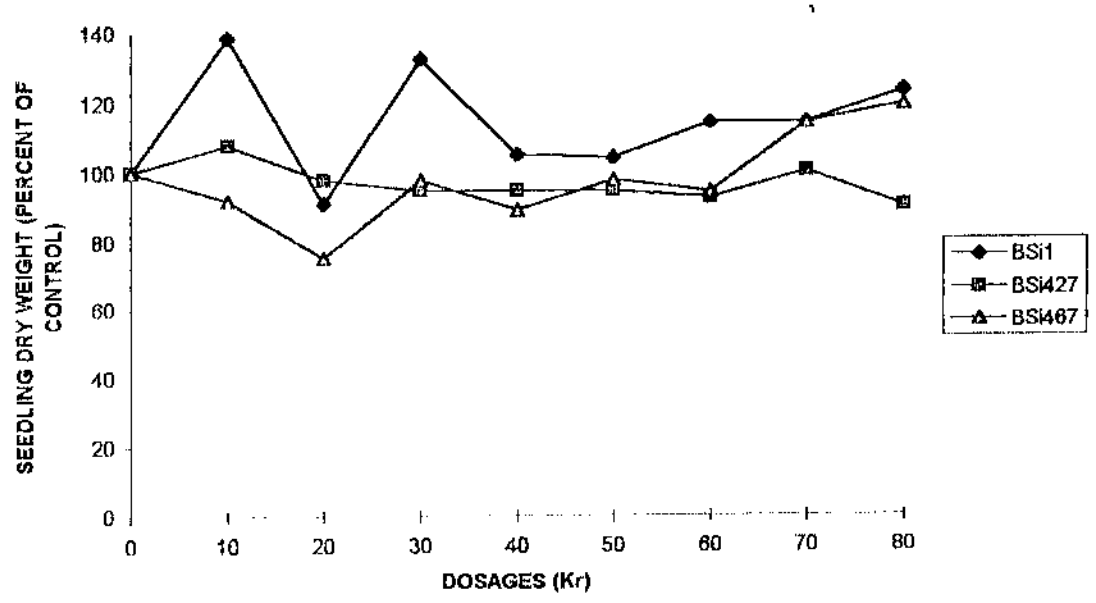

Fig.4. Effect of Gamma rays on seedling dry weight in BSi1,BSi427 and BSi467 in M_1 generation.

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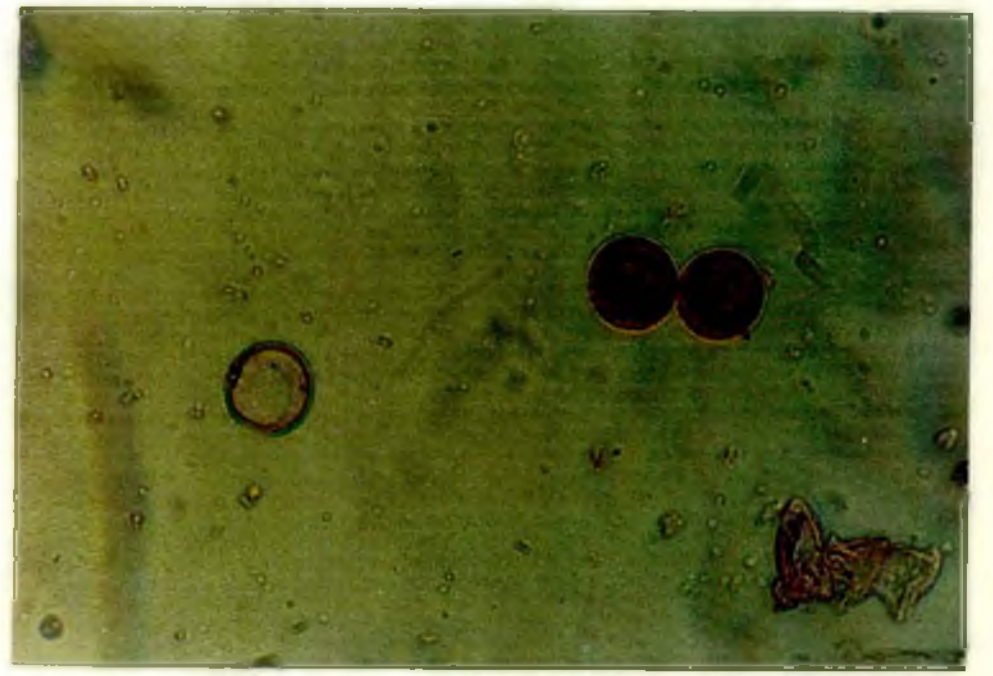
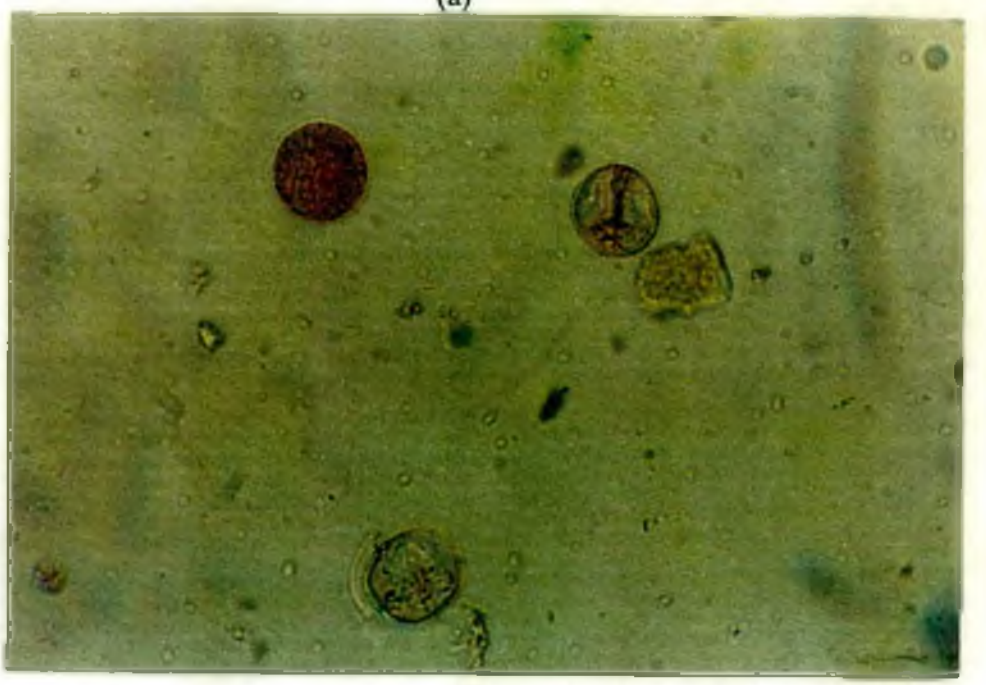


(a)



(b)

Plate 4. a-b: (a) Pollen stainability of control in BSi1. (b) Pollen stainability at 40 Kr in BSi1.

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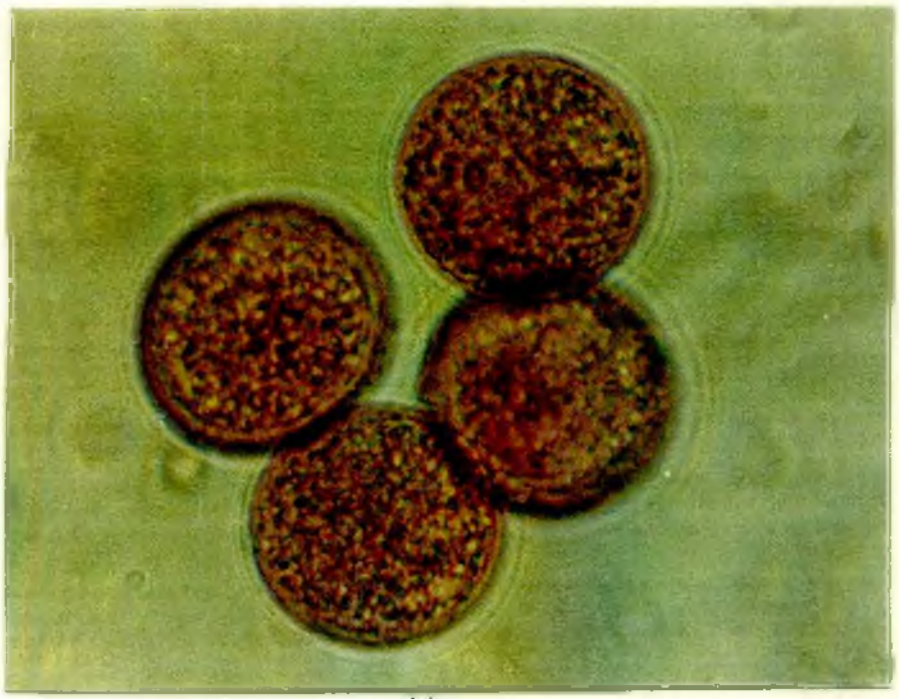

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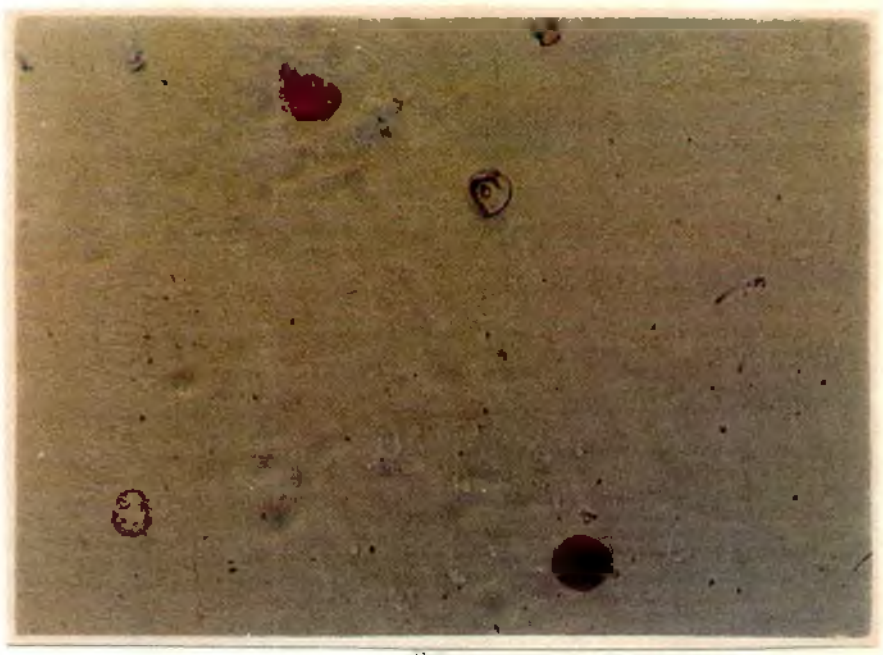

(b)

Plate 5. a-b: (a) Pollen stainability of control in BSi427. (b) Pollen stainability at 80 Kr in BSi427

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In BSi467 the pollen sterility in parent was 13.53; it increased to 82.80 percent at the highest dosage of 80 Kr. The maximum extent of increase in sterility was 611.97 percent increase of the control at the highest dosage of 80 Kr. The increase did not follow dosage dependent relationship (Plate 6).

Comparison of varieties and different dosages of gamma rays indicates differential response of the varieties to different gamma treatments. In BSi1 mid level dosage which is 40 Kr induced higher pollen sterility; whereas in other two varieties highest dosage of 80 Kr induced high pollen sterility. As far as pollen sterility is concerned, BSi427 was found more sensitive to gamma radiation as compared to other two varieties.

(f) Grain fertility: Grain fertility was recorded from 10 randomly selected plants from each replication and from central part of the main panicle. The analysis of variances for grain fertility in Table 11 shows that significant difference among varieties and highly significant difference among dosages were found in respect of grain fertility. The varieties and dosages interaction effect was found insignificant. The variety BSi427 was found sensitive and the dosage of 70 Kr was found the most effective in reducing grain fertility (Table 12). The decrease in grain fertility did not follow a dosage dependent relationship in any of the three varieties (Fig. 6). The second highest dosage of 70 Kr reduced grain fertility substantially in all the three varieties. The highest reduction in fertility was recorded in BSi467; it was 37.25 percent of the control in BSi467 followed by a reduction 26.34 percent of the control in BSi1 and 19.90 percent of the control in BSi427 at 70 Kr.

Comparison of varieties and different dosages of gamma radiation indicates that the second highest dosage of 70 Kr was more effective in affecting seed fertility and the variety BSi427 was found more sensitive to gamma radiation than the other two varieties as far as grain fertility is concerned.

4.1.1. Quantitative characters

The effect of gamma radiation on quantitative characters such as: (a) days to panicle emergence, (b) days to maturity, (c) plant height, (d) panicle length, (e) tillers per plant and (f) yield per plant in M_1 generation was studied. The data recorded were analysed for

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Table 11. ANOVA for grain fertility in gamma irradiated material of three varieties, BSi1, BSi427and BSi467 of foxtail millet in M_1 generation.

Sources of variation	df	SS	MS	F Value
1. *Replication*	2	622.391	311.195	2.3494
2. Treatments:				
i) Factor A(Varieties)	2	846.901	423.450	3.1968*
ii) Factor B (Gamma radiation)	7	33837.911	4833.987	36.4941**
iii) Interaction (AB)	14	2700.795	192.914	1.4564
3. Error	46	6093.136	132.459	

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)

Table 12. Effect on grain fertility of three varieties, BSi1, BSi427and BSi467 of foxtail millet following gamma irradiation in M_1 generation.

Gamma rays (Kr)	BSi1		BSi427		BSi467	
	Grain Fertility (%)	Percent of Control	Grain Fertility (%)	Percent of Control	Grain Fertility (%)	Percent of Control
0	95.21	100.00	93.59	100.00	97.18	100
10	90.80	95.37	85.08	90.91	91.22	93.87
20	79.20	83.18	79.69	85.15	79.48	81.79
30	68.98	72.45	69.92	74.71	67.72	69.68
40	59.98	63.00	67.87	72.52	53.61	55.16
50	38.10	40.02	32.59	34.82	66.18	68.10
60	43.85	46.06	47.35	50.59	64.39	66.26
70	25.08	26.34	18.62	19.90	36.18	37.23

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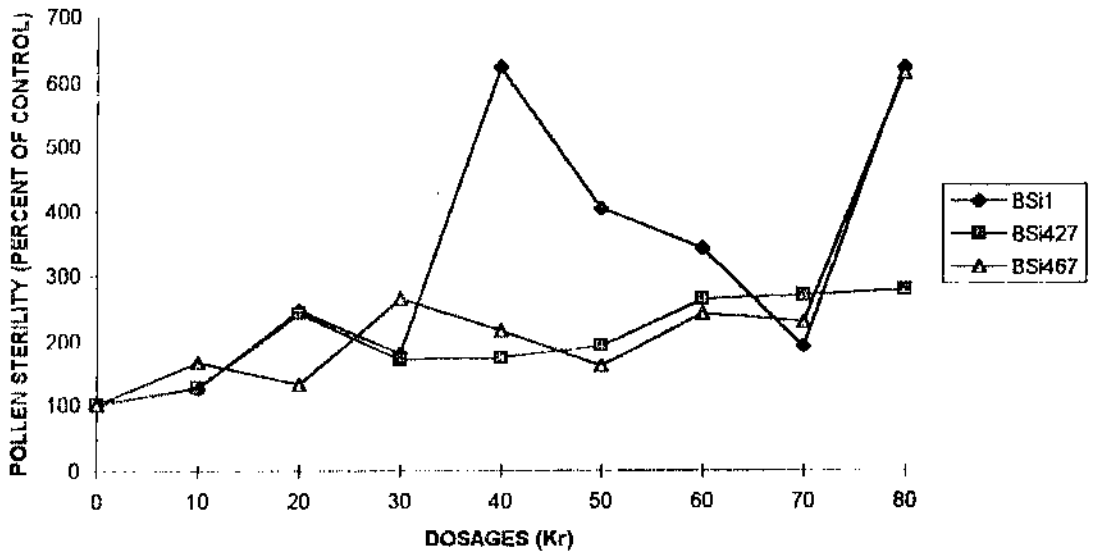

Fig.5. Effect of Gamma rays on pollen sterility in BSi1,BSi427 and BSi467 in M_1 generation.

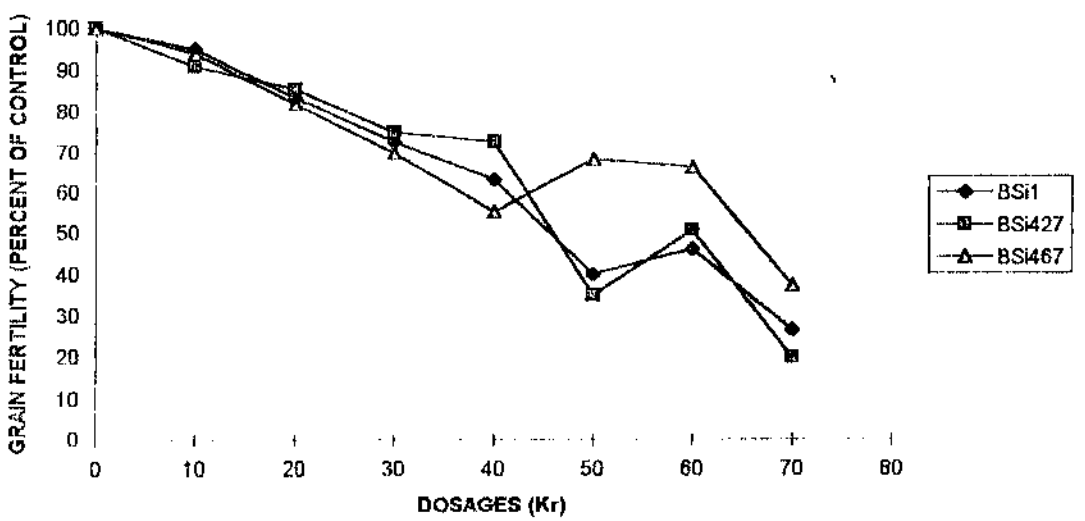

Fig.6. Effect of Gamma rays on grain fertility in BSi1,BSi427 and BSi467 in M_1 generation.

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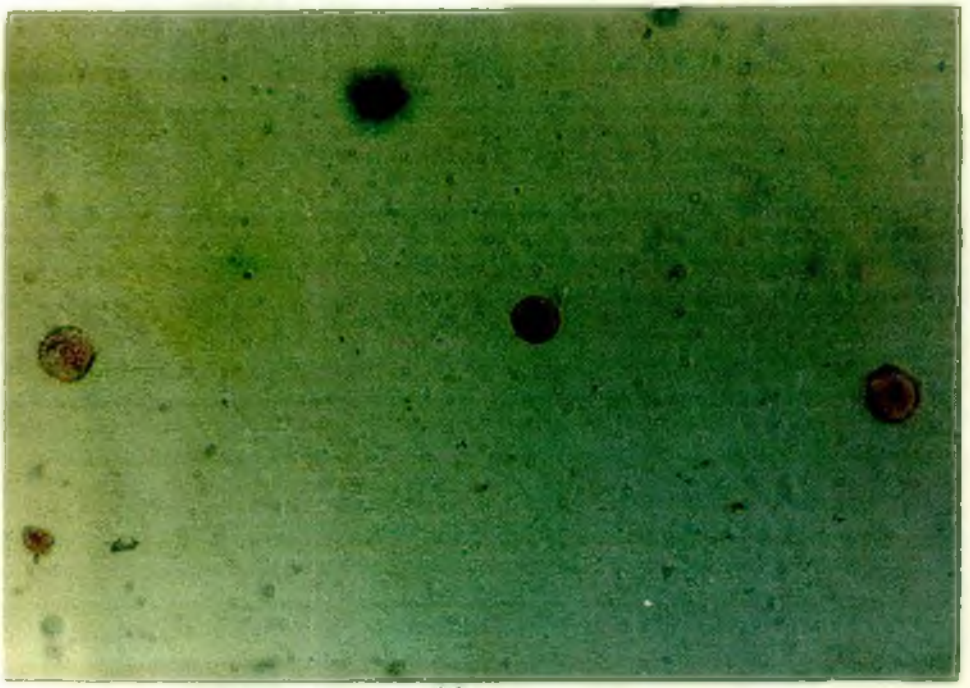
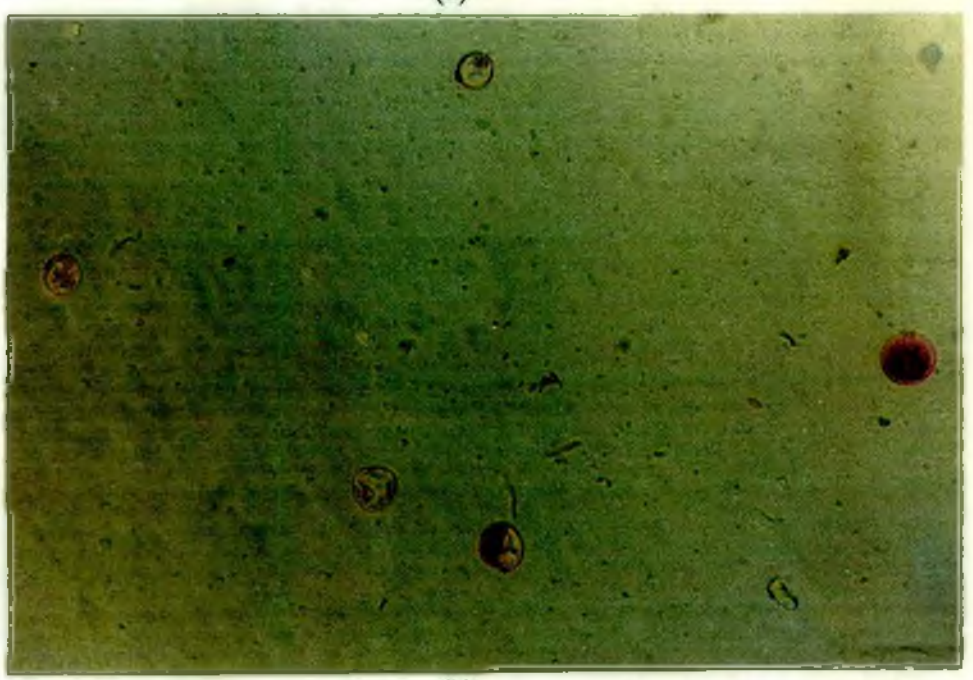


(a)



(b)

Plate 6. a-b: (a) Pollen stainability of control in BSi467. (b) Pollen stainability at 80 Kr in BSi467.

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range, mean, standard deviation and coefficient of variation for each character and are presented in Tables 13-30.

(a) Days to panicle emergence : Mean and variability for panicle emergence in the three varieties are presented in Tables 13 - 15.

BSi1

Range: Gamma radiation induced wide range in days to panicle emergence in BSi1 (Table 13). The range in days to panicle emergence in control (parent) was 79 to 94; the range was shifted in both the directions in most of the dosages, maximum enlargement being recorded from 57-100 at the second highest dosage of 70 Kr followed by the range 58-101 at 50 Kr. Shifting of the range in both the directions indicates that panicle emergence occurred early as well as late as a result of gamma irradiation.

Mean: The mean number of days to panicle emergence shifted only in positive direction. Delay in panicle emergence with the increase of gamma dosages was observed. The maximum mean number of days for panicle emergence was 91.35 at 60 Kr compared to 83.97 days in parent.

Standard deviation and coefficient of variation: In BSi1 except at 20 Kr, both standard deviation and CV increased in all the dosages. The highest standard deviation and CV as 13.54 and 15.86 respectively was at 70 Kr compared to standard deviation and CV 3.60 and 4.28 respectively in parent.

BSi427

Range: In BSi427 the range increased in both the directions. Wide range recorded from 56 to 92 days was at 40 Kr followed by the range from 75 to 96 at 60 Kr compared to the range from 77 to 91 days in parent (Table 14). The shifting in the range towards negative direction indicates that the flowering time shortened as a result of gamma irradiation.

Mean: Except at 10 Kr, the mean number of days to panicle emergence shifted in positive direction in all the dosages. At 10 Kr the mean shifted towards negative direction (Table

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Table 13. Range, mean, standard deviation and coefficient of variation for days to panicle emergence following gamma irradiation in BSi1 in M_1 generation.

Gamma rays (Kr)	Days to panicle emergence				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (Control)	79-94	83.97 ± 0.46	-	3.60	4.28
10	78-99	84.53 ± 0.53	+0.56	4.07	4.81
20	79-95	84.82 ± 0.42	+0.85	3.27	3.85
30	79-100	85.15 ± 0.60	+1.18	4.62	5.43
40	78-102	88.23 ± 0.74	+4.26	5.72	6.48
50	58-101	85.23 ± 1.07	+1.26	8.28	9.71
60	80-102	91.35 ± 1.45	+7.38	7.38	8.08
70	57-100	85.33 ± 3.91	+1.36	13.54	15.86

Table 14. Range, mean, standard deviation and coefficient of variation for days to panicle emergence following gamma irradiation in BSi427 in M_1generation.

Gamma rays (Kr)	Days to panicle emergence				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (Control)	77-91	81.88 ± 0.33	-	2.56	3.13
10	76-94	81.47 ± 0.40	-0.41	3.08	3.78
20	76-98	83.37 ± 0.54	+1.49	4.20	5.04
30	76-89	81.97 ± 0.31	+0.09	2.37	2.92
40	56-92	82.23 ± 0.61	+0.35	4.73	5.75
50	77-96	84.10 ± 0.48	+2.22	3.74	4.45
60	75-96	85.00 ± 0.64	+3.12	4.75	5.59
70	75-95	84.83 ± 0.59	+2.45	4.27	5.04

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14). The mean days to panicle emergence varied from 81.47 to 85.00 days in different treatments compared to mean days 81.88 in parent.

Standard deviation and coefficient of variation: Except the dosage of 30 Kr, the standard deviation and coefficient of variation increased in all the dosages.

BSi467

Range: Although a slight shifting in negative direction in range values at 30, 50 and 60 Kr was observed, the range did not markedly increase in all the dosages compared to parent (Table 15).

Mean: The mean days to panicle emergence shifted in positive direction ranging from 90.68 to 94.38 days in different treatments (Table 15). The positive shift in mean shows that flowering time increased as a result of gamma treatments.

Standard deviation and coefficient of variation: Except at 10 and 20 Kr, the standard deviation and CV increased in all the dosages.

(c) Plant height : Gamma radiation induced wide range in plant height in all the three varieties (plates 1b, 2b and 3b). Mean and measures for variation on plant height in three varieties are presented in Tables 16-18.

BSi1

Range: In BSi1 the range in control was 80-135; the range shifted in both the directions in all the dosages except at a lower dosage of 20 Kr. At 20 Kr the range shifted in positive direction (Table 16). The maximum negative shifting of the range recorded from 49 to 111 was at the second highest dosage of 70 Kr followed by the range 62-119 at 40Kr. The negative shifting of the range indicates that the height of the irradiated population reduced.

Mean: The reduction in mean plant height was observed. The mean plant height in control was 113.02 cm; it shifted in the positive direction at the two lower dosages of 10 and 20 Kr and in negative direction in all other dosages, maximum reduction (90.33 cm) being recorded at the second highest dosage of 70 Kr.

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Table 15. Range, mean, standard deviation and coefficient of variation for days to panicle emergence following gamma irradiation in BSi467 in M_1 generation.

Gamma rays (Kr)	Days to panicle emergence				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (Control)	84-101	90.60 ± 0.56	-	4.31	4.76
10	84-97	90.68 ± 0.44	+0.08	3.41	3.76
20	84-100	90.75 ± 0.54	+0.15	4.19	4.61
30	80-102	92.48 ± 0.72	+1.88	5.60	6.05
40	84-103	90.93 ± 0.63	+0.33	4.86	5.35
50	82-103	92.83 ± 0.67	+2.23	5.22	5.62
60	83-105	93.87 ± 0.79	+3.27	5.27	5.61
70	86-103	94.38 ± 1.30	+3.78	5.80	6.15

Table 16. Range, mean, standard deviation and coefficient of variation for plant height following gamma irradiation in BSi1 in M_1 generation.

Gamma rays (Kr)	Plant height (cm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (Control)	80-135	113.02 ±1.39	-	10.78	9.53
10	80-135	115.28 ± 1.51	+2.26	11.71	10.16
20	85-140	114.27 ± 1.40	+1.25	10.87	9.51
30	75-134	110.12 ± 1.79	-2.9	13.89	12.61
40	62-119	101.60 ± 1.76	-11.42	13.67	13.45
50	70-131	106.47 ± 1.79	-6.55	13.89	13.04
60	70-121	96.35 ± 3.11	-16.67	13.92	14.45
70	49-111	90.33 ± 5.88	-22.69	20.37	22.55

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Standard deviation and coefficient of variation: Standard deviation and CV in control were 10.78 and 9.53 respectively; the two parameters increased in all the dosages. The highest standard deviation and CV recorded as 20.37 and 22.55 respectively were at the second highest dosage of 70 Kr (Table 16).

BSi427

Range : In BSi427 the range of height in parent was from 79-120; it enlarged in both the directions at the lowest dosage of 10 Kr and at the second highest dosage of 70 Kr. Besides, all other dosages show negative shifting in the range. The highest negative shifting in the range recorded from 40 to 115 was at 60 Kr (Table 17). The negative shifting in range indicates the tendency of reduction in plant height following gamma irradiation.

Mean: The mean plant height in parent was 100.28 cm; it reduced in all the dosages except at 50 Kr. Maximum reduction in height (83.04 cm) was at the second highest dosage of 70 Kr. The negative shifting in mean plant height indicates that gamma treatments reduced plant height.

Standard deviation and coefficient of variation: In parent standard deviation and CV were 15.41 and 15.37 respectively. Both standard deviation and CV decreased at 10, 20, 30, and 50 Kr; the two parameters increased at the dosages of 40, 60, and 70 Kr. The decrease and the increase in the above two parameters indicate that gamma treatments not only decrease but also bring about variation in plant height (Table 17).

BSi467

Range: The range in parent was from 100-168; the range shifted in negative direction at the higher dosages of 50, 60, and 70 Kr. The maximum negative shifting in range recorded from 55-160 was at the second highest dosage of 70 Kr (Table18).

Mean: The mean plant height in parent was 133.97 cm. Except at 20 Kr, the mean was reduced in all the dosages. At 20 Kr the mean shifted in positive direction. The highest reduction in mean plant height recorded as 111.48 cm was at the second highest dosage of

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Table 17. Range, mean, standard deviation and coefficient of variation for plant height following gamma irradiation in BSi427 in M_1generation.

Gamma rays (Kr)	Plant height (cm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	79-120	100.28 ±1.99	-	15.41	15.37
10	75-122	97.07 ± 1.33	-3.21	10.28	10.59
20	63-118	96.06 ± 1.46	-4.23	11.32	11.79
30	70-116	96.67 ± 1.29	-3.61	10.02	10.37
40	51-117	94.18 ± 2.09	-6.10	16.16	17.16
50	50-110	85.20 ± 1.64	-15.08	12.69	14.89
60	40-115	84.29 ± 2.02	-15.99	15.08	17.89
70	50-122	83.04 ± 2.81	-17.24	20.44	24.62

Table 18. Range, mean, standard deviation and coefficient of variation for plant height following gamma irradiation in BSi467 in M_1generation.

Gamma rays (Kr)	Plant height (cm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	100-168	133.97 ± 1.97	-	15.28	11.40
10	103-160	131.27 ± 1.72	-2.70	13.30	10.13
20	108-160	139.17 ± 1.79	+5.20	13.86	9.96
30	100-169	128.50 ± 2.00	-5.47	15.45	12.03
40	100-161	127.68 ± 2.17	-6.29	16.80	13.15
50	80-169	130.00 ± 2.49	-3.97	19.26	14.82
60	93-160	130.45 ± 1.93	-3.52	14.67	11.25
70	55-160	111.48 ± 7.48	-22.49	34.29	30.76

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70 Kr (Table 18). The negative shifting of mean plant height indicates the reduction of plant height as a result of gamma irradiation.

Standard deviation and coefficient of variation: Standard deviation and CV in parent was 15.28 and 11.40 respectively; both the parameters not only increased but also decreased in different dosages (Table 18). The highest standard deviation and CV recorded as 34.29 and 30.76 respectively were at the second highest dosage of 70 Kr.

(d) Panicle length : Measures for variation and mean for panicle length are presented in Tables 19 to 21.

BSi1

Range : In BSi1 the range for panicle length in parent was from 11 to 26 cm. But the range caused by all the treatments could not exceed that of the parent (Table 19).

Mean: The mean panicle length in parent was 18.45 cm; it increased only at the lowest dosage of 10 Kr and decreased in all other dosages; The highest reduction in mean (14.76 cm) was recorded at the second highest dosage of 70 Kr. The positive shifting and the negative shifting in mean indicate that gamma radiation induced variability in panicle length (Table 19).

Standard deviation and coefficient of variation: Standard deviation and CV in parent were 3.11 and 16.86 respectively; the two parameters increased as well as decreased in different dosages. The highest standard deviation and CV 3.74 and 25.39 respectively were at 70 Kr (Table 19).

BSi427

Range: In BSi427 the range for panicle length in parent was from 15 to 30; the range shifted to the negative direction in all the treatments except the dosage 40 Kr which exceeded the range values in parent showing a slight tendency to increase the panicle length compared to the parent (Table 20).

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Table 19. Range, mean, standard deviation and coefficient of variation for panicle length following gamma irradiation in BSi1 in M_1generation.

Gamma rays (Kr)	Panicle length (cm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	11 - 26	18.45 ± 0.40	-	3.11	16.86
10	10 - 25	19.17 ± 0.42	+0.72	3.26	16.99
20	11 - 24	18.93 ± 0.32	+0.76	2.50	13.21
30	12 - 25	18.52 ± 0.40	+0.07	3.12	16.83
40	9 - 24	16.96 ± 0.45	-1.50	3.55	20.93
50	10 - 24	18.08 ± 0.36	-0.37	2.79	15.45
60	12 - 22	17.75 ± 0.55	-0.70	2.47	13.90
70	6 - 20	14.75 ± 1.08	-3.70	3.74	25.39

Table 20. Range, mean, standard deviation and coefficient of variation for panicle length following gamma irradiation in BSi427 in M1generation.

Gamma rays (Kr)	Panicle length (cm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	15 - 30	22.38 ± 0.46	-	3.53	15.76
10	14 - 27	21.05 ± 0.38	-1.33	2.92	13.89
20	13 - 29	21.00 ± 0.44	-1.38	3.39	16.12
30	15 - 26	23.17 ± 1.72	+0.79	13.35	57.63
40	12 - 31	22.02 ± 0.41	-0.36	3.19	14.49
50	10 - 28	19.13 ± 0.47	-3.25	3.67	19.19
60	8 - 26	18.25 ± 0.52	-4.13	3.90	21.35
70	7 - 27	18.08 ± 0.53	-4.30	3.84	21.25

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Mean: Except at 30 Kr, the mean panicle length reduced in all the dosages. At 30 Kr the mean slightly increased showing tendency to increase the panicle length. The highest reduction in panicle length recorded as 18.08 cm was at 70 Kr compared to the mean panicle length of 22.38 cm in the parent (Table 20). The negative shifting in mean indicates that the reduction in panicle length occurred as a result of gamma irradiation.

Standard deviation and coefficient of variation: The highest standard deviation and CV recorded as 13.35 and 57.63 respectively was at 30 Kr compared to standard deviation and CV 3.53 and 15.76 respectively in the parent.

BSi467

Range: In BSi467 the range of panicle length in parent was from 15 to 31cm; the range shifted in negative direction in all the treatments except 10 and 40 Kr in which the range shifted in both the directions indicating variability in panicle length caused as a result of gamma irradiation (Table 21).

Mean: The mean panicle length in parent was 21.93 cm; it increased at the lower dosages of 10, 20, 30, and 40 Kr and decreased at the higher dosages of 50, 60, and 70 Kr. The highest reduction in mean (17.95 cm) was at the second highest dosage of 70 Kr (Table 21). The positive shifting in mean indicates that lower dosages of gamma radiation increased panicle length whereas the negative shifting indicates that higher dosages of gamma radiation decreased panicle length.

Standard deviation and coefficient of variation: Except at the second highest dosage of 70 Kr both standard deviation and CV decreased in all the treatments. At 70 Kr the highest standard deviation and CV were 4.96 and 27.64 respectively compared to standard deviation and CV 4.23 and 19.31 respectively in parent (Table 21).

(e) Tiller Number : Mean and measures for variation for tiller number are presented in Tables 22 to 24.

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Table 21. Range, mean, standard deviation and coefficient of variation for panicle length following gamma irradiation in BSi467 in M_1 generation.

Gamma rays (Kr)	Panicle length (cm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	15 - 31	22.38 ± 0.46	-	4.23	19.31
10	14 - 34	21.05 ± 0.38	+1.29	3.23	13.91
20	13 - 31	21.00 ± 0.44	+0.54	3.22	14.34
30	12 - 30	23.17 ± 1.72	+0.62	3.23	14.31
40	12 - 32	22.02 ± 0.41	+0.45	3.56	15.92
50	13 - 29	19.13 ± 0.47	-0.05	3.70	16.90
60	16 - 30	18.25 ± 0.52	-0.57	3.08	14.41
70	8 - 25	18.08 ± 0.53	-3.98	4.98	27.64

Table 22. Range, mean, standard deviation and coefficient of variation for tiller number following gamma irradiation in BSi1 in M1 generation.

Gamma rays (Kr)	Tiller number				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	1 - 3	1.45 ± 0.08	-	0.62	42.56
10	1 - 3	1.78 ± 0.09	+0.33	0.71	39.77
20	1 - 4	1.58 ± 0.09	+0.13	0.69	43.59
30	1 - 5	1.58 ± 0.12	+0.13	0.90	56.83
40	1 - 5	1.92 ± 0.13	+0.47	1.00	52.43
50	1 - 5	1.93 ± 0.14	+0.48	1.06	54.96
60	1 - 7	3.00 ± 0.26	+1.55	1.54	51.25
70	1 - 5	2.58 ± 0.42	+1.33	1.44	55.78

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BSi1

Range: In BSi1 wide range was observed for this character in all the dosages except 10 Kr. The range shifted in positive direction. The highest range recorded from 1 to 7 was at 60 Kr compared to the range from 1 to 3 in parent (Table 22). The positive shifting in the range indicates the tendency of increasing tiller number as a result of gamma irradiation.

Mean: The mean tiller number in control was 1.45; the tiller number increased in all the treatments. The highest mean tiller number recorded as 3.00 was at 60 Kr (Table 22). The positive shifting in mean tiller number indicates that gamma radiation increased tiller number.

Standard deviation and coefficient of variation: Both standard deviation and CV increased substantially in all the dosages compared to the standard deviation and CV 0.62 and 42.56 respectively in the parent (Table 22).

BSi427

Range: In BSi427 the range for tiller number shifted in positive direction in most of the treatments. The highest range was at 10 Kr compared to the range from 1 to 2 in parent (Table 23).

Mean: The mean tiller number in parent was 1.10; the tiller number increased in almost all the dosages except 40 Kr which slightly decreased the mean. The highest mean tiller number was at the second highest dosage of 70 Kr (Table 23). The positive shifting in mean indicates the increasing tendency of the tillering capacity as a result of gamma irradiation.

Standard deviation and coefficient of variation: Both standard deviation and CV increased in almost all the dosages. The highest standard deviation and CV 0.71 and 55.78 respectively were at the dosage of 60 Kr compared to standard deviation and CV 0.30 and 27.27 respectively in parent (Table 23).

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Table 23. Range, mean, standard deviation and coefficient of variation for tiller number following gamma irradiation in BSi427 in M_1 generation.

Gamma rays (Kr)	Tiller number				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	1 - 2	1.10 ± 0.04	-	0.30	27.27
10	1 - 4	1.23 ± 0.08	+0.13	0.59	47.66
20	1 - 3	1.18 ± 0.06	+0.08	0.50	42.23
30	1 - 3	1.12 ± 0.05	+0.02	0.41	36.89
40	1 - 2	1.07 ± 0.03	-0.03	0.25	23.39
50	1 - 2	1.13 ± 0.04	+0.03	0.34	29.99
60	1 - 3	1.27 ± 0.09	+0.17	0.71	55.78
70	1 - 3	1.40 ± 0.09	+0.30	0.62	44.74

Table 24. Range, mean, standard deviation and coefficient of variation for tiller number following gamma irradiation in BSi467 in M_1 generation.

Gamma rays (Kr)	Tiller number				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	1 - 4	1.50 ± 0.10	-	0.81	53.75
10	1 - 7	1.90 ± 0.17	+ 0.40	1.31	69.09
20	1 - 4	1.78 ± 0.12	+ 0.28	0.90	50.25
30	1 - 5	1.93 ± 0.15	+ 0.43	1.12	58.11
40	1 - 5	2.00 ± 0.16	+ 0.50	1.24	61.91
50	1 - 5	1.90 ± 0.13	+ 0.40	1.03	54.10
60	1 - 9	2.47 ± 0.21	+ 0.97	1.61	65.32
70	1 - 5	2.43 ± 0.33	+ 0.93	1.53	62.99

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BSi467

Range: The range in parent was from 1 to 4; the range enlarged in positive direction in almost all the treatments. The highest enlargement in range recorded from 1 to 9 was at 60 Kr (Table 24).

Mean: The mean tiller number increased markedly in all the treatments but different dosages increased the tiller number in different degrees. The highest mean tiller number recorded as 2.47 was at 60 Kr compared to the mean tiller 1.50 in parent (Table 24). The positive shifting in mean in all the dosages indicate that gamma radiation was effective in increasing tillering capacity.

Standard deviation and coefficient of variation: Both standard deviation and CV increased in all the dosages. The highest standard deviation recorded as 1.61 was at 60 Kr and the highest CV of 69.09 was at 10 Kr compared to standard deviation and CV 0.81 and 53.75 respectively in the parent.

(f) Days to maturity : Mean and measures for variation on days to maturity in the three varieties are presented in Tables 25 - 27.

BSi1

Range: The range shifted only in positive direction in all the dosages indicating delay in maturity period induced by gamma treatments. The highest range for maturity recorded from 120 to 143 days was at 20 Kr followed by the range from 121 to 143 days at 50 Kr while the range for maturity period in parent was from 120 to 128 days (Table 25).

Mean: Except at 10 Kr the mean days for maturity shifted in positive direction in all the dosages. At 10 Kr the mean showed a slight shift in negative direction indicating early maturity induced by gamma radiation. The positive shift in mean in all other dosages indicates that gamma treatments delayed maturity also (Table 25).

Standard deviation and coefficient of variation: Standard deviation and CV increased in all the dosages.

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Table 25. Range, mean, standard deviation and coefficient of variation for days to maturity following gamma irradiation in BSi1 in M_1generation.

Gamma rays (Kr)	Days to maturity				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0kr (Control)	120-128	122.80 ± 0.29	-	2.25	1.83
10	120-139	122.42 ± 0.31	-0.38	2.44	1.99
20	120-143	125.05 ± 0.74	+2.25	5.69	4.55
30	120-141	128.78 ± 0.82	+5.98	6.37	4.95
40	121-141	128.42 ± 0.87	+5.62	6.75	5.26
50	121-143	130.77 ± 0.86	+7.97	6.67	5.10
60	121-142	131.42 ± 1.36	+8.62	6.95	5.29
70	123-132	127.17 ± 0.79	+4.37	2.73	2.15

Table 26. Range, mean, standard deviation and coefficient of variation for days to maturity following gamma irradiation in BSi427 in M_1generation.

Gamma rays (Kr)	Days to maturity				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0kr (Control)	115-126	120.23 ± 0.31	-	2.39	1.99
10	115-136	119.95 ± 0.46	-0.28	3.56	2.96
20	115-142	123.17 ± 0.73	+2.94	5.65	4.58
30	115-141	125.73 ± 0.84	+5.50	6.47	5.15
40	116-144	128.77 ± 1.08	+8.54	8.34	6.48
50	116-144	131.87 ± 1.04	+11.64	8.03	6.09
60	121-143	135.16 ± 0.91	+14.93	6.77	5.01
70	121-144	135.89 ± 0.67	+15.66	4.89	3.60

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BSi427

Range: In BSi427 the range increased only in positive direction indicating delay in maturity period in irradiated populations. Maximum range recorded from 116-144 days was at 40 and 50 Kr while the range in parent was from 115 to 126 days (Table 26).

Mean: Except at 10 Kr, the mean number of days to maturity shifted in positive direction in all the dosages indicating late maturity of the irradiated populations. At 10 Kr the mean showed a slight shifting in negative direction. The highest mean number of days recorded as 135.89 was at the second highest dosage of 70 Kr followed by the mean days 135.16 at 60 Kr whereas the mean number of days to maturity in parent was 120.23 (Table 26).

Standard deviation and coefficient of variation: Both standard deviation and CV increased; the two parameters increased by different dosages in different degrees compared to standard deviation and CV 2.39 and 1.99 respectively in the parent (Table 26).

BSi467

Range: In BSi467 except at 50 Kr, the range did not increase substantially in all the dosages. At 50 Kr the range shifted in negative direction showing tendency to earliness in maturity period in the irradiated populations compared to range 124 -144 days in the parent (Table 27).

Mean: The mean days to maturity was 134.03 in parent. The mean days to maturity shifted in positive direction in all the dosages. Different dosages increased the time in different degrees (Table 27).

Standard deviation and coefficient of variation: In parent standard deviation and CV were 6.97 and 5.20 respectively. Both standard deviation and CV decreased in all the dosages (Table 27).

(f) Yield per plant : Three varieties differed in their response to gamma radiation. The results are presented in Tables 28 - 30.

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Table 27. Range, mean, standard deviation and coefficient of variation for days to maturity following gamma irradiation in BSi467 in M_1 generation.

Gamma rays (Kr)	Days to maturity				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (Control)	124-144	134.03 ± 0.90	-	6.97	5.20
10	124-143	139.67 ± 0.43	+5.64	3.34	2.39
20	126-142	137.95 ± 0.58	+3.92	4.49	3.25
30	129-145	140.53 ± 0.26	+6.50	2.00	1.43
40	130-143	139.45 ± 0.25	+5.42	1.92	1.38
50	118-142	138.40 ± 0.38	+4.37	2.93	2.12
60	124-142	139.00 ± 0.39	+4.97	2.59	1.86
70	138-142	139.00 ± 0.32	+4.97	1.41	1.02

Table 28. Range, mean, standard deviation and coefficient of variation for grain yield following irradiation in BSi1 in M1 generation.

Gamma rays (kr)	Grain yield per plant (gm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	3.2 0 - 10.50	6.76 ± 0.25	-	1.93	28.54
10	1.00 - 21.09	7.16 ± 0.63	+0.40	4.91	68.33
20	0.56 - 13.85	6.54 ± 0.50	- 0.22	3.91	59.78
30	0.20 - 17.98	3.81 ± 0.46	- 2.88	3.57	93.71
40	0.08 - 17.98	2.77 ± 0.42	- 3.99	3.26	117.53
50	0.02 - 14.75	4.34 ± 0.49	- 2.42	3.81	87.82
60	0.01 - 16.40	3.02 ± 0.70	- 3.74	4.09	135.38
70	0.01 - 4.70	2.48 ± 0.53	- 4.28	1.83	73.67

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BSi1

Range: In BSi1 the range in control was from 3.2 to 10.5; the range increased in all the dosages except at the second highest dosage of 70 Kr. At 70 Kr the range was narrow and shifted in negative direction. The highest range recorded from 1.00 to 21.09 was at the lowest dosage of 10Kr (Table 28). The positive shifting of the upper limit of the range in almost all the treatments indicates the possibility of increasing yield per plant as a result of gamma irradiation.

Mean: The mean yield reduced in all the dosages and shifted in negative direction except at 10 Kr. At 10 Kr the mean yield increased slightly compared to the mean yield 6.76 in parent (Table 28). The negative shifting in mean yield indicates the reduction in yield as a result of gamma irradiation.

Standard deviation and coefficient of variation: Except at 70 Kr, both standard deviation and CV increased in all the dosages. Different dosages increased the above two parameters in different degrees. The highest standard deviation recorded as 4.91 was at 10 Kr and the highest CV as 135.38 was at 60 Kr compared to standard deviation and CV 1.93 and 28.54 respectively in the parent (Table 28).

BSi427

Range: In BSi427 range caused by all the treatments did not exceed the upper limit of the range from 5.6 to 17.4 in parent. The range for yield shifted in negative direction ranging from 0.05 to 14.84 in all the treatments indicating least chance for increasing per plant yield over parent following gamma irradiation (Table 29).

Mean: The mean yield per plant decreased in all the treatments. The highest reduction in mean yield recorded as 1.06 was at the second highest dosage of 70 Kr. Dosage wise reduction in mean yield was observed (Table 29). The negative shifting in mean indicates that gamma radiation did not increase yield per plant.

Standard deviation and coefficient of variation: Except two higher dosages of 60 and 70 Kr, standard deviation increased in all the dosages. The highest increase in standard

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Table 29. Range, mean, standard deviation and coefficient of variation for grain yield following gamma irradiation in BSi427 in M1generation.

Gamma rays (Kr)	Grain yield per plant (gm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	5.6 - 17.40	9.63 ± 0.35	-	2.73	28.38
10	0.9 - 14.84	7.43 ± 0.47	- 2.20	3.66	49.33
20	0.58 - 13.95	5.67 ± 0.44	- 3.96	3.41	60.16
30	0.27 - 13.50	4.79 ± 0.43	- 4.84	3.34	69.62
40	0.17 - 10.41	3.74 ± 0.36	- 5.89	2.78	74.32
50	0.09 - 13.65	2.86 ± 0.36	- 6.77	2.82	98.52
60	0.03 - 8.65	1.60 ± 0.27	- 8.03	2.03	126.48
70	0.05 - 3.81	1.06 ± 0.13	- 8.57	0.96	90.58

Table 30. Range, mean, standard deviation and coefficient of variation for grain yield following gamma irradiation in BSi467 in M_1generation.

Gamma rays (Kr)	Grain yield per plant (gm)				
	Range	Mean ± SE	Shift in mean	Standard deviation	Coefficient of variation (%)
0 (control)	4.09 - 12.07	8.08 ± 0.24	-	1.88	23.27
10	0.62 - 14.70	4.88 ± 0.35	- 3.20	2.74	56.23
20	0.24 - 16.70	3.96 ± 0.39	- 4.12	2.99	75.46
30	0.11 - 20.46	5.09 ± 0.57	- 2.99	4.45	87.45
40	0.29 - 18.73	3.21 ± 0.40	- 4.87	3.10	96.54
50	0.21 - 12.08	2.64 ± 0.30	- 5.44	2.30	87.16
60	0.04 - 16.10	2.87 ± 0.42	- 5.21	3.17	110.49
70	0.05 - 18.41	2.61 ± 0.96	- 5.47	4.42	168.92

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deviation recorded as 3.66 was at the lowest dosage of 10 Kr compared to standard deviation of 2.73 in the parent. Compared to parent CV also increased in all the dosages, highest CV recorded as 126.48 was at 60 Kr (Table 29).

BSi467

Range: In BSi467 the range was wide. The range shifted in both the directions and the highest range recorded from 0.11 to 20.46 was at 30 Kr (Table 30). The marked positive shifting in the upper limit of all the dosages indicates that per plant yield enhanced as a result of gamma irradiation.

Mean : The mean yield in parent was 8.08; the mean yield reduced substantially more or less gradually in all the dosages. The highest reduction in mean yield recorded as 2.61 was at the second highest dosage of 70 Kr (Table 30). The negative shifting in mean indicates the reduction in yield following gamma irradiation.

Standard deviation and coefficient of variation: Both standard deviation and CV were increased by the different treatments in different degrees. The highest standard deviation recorded as 4.45 was at the dosage of 30 Kr and the highest CV as 168.92 was at the second highest dosage of 70 Kr compared to standard deviation and CV 1.88 and 23.27 respectively in the parent.

4.2. M_2 generation

Individual plants harvested from all the treatments in M_1 generation were sown in plant to progeny rows to raise M_2 generation. Studies in M_2 were confined to scoring of chlorophyll and viable mutants and estimating their frequencies and spectrum.

4.2.1. Chlorophyll mutations

Chlorophyll mutations delineate the genetic damage caused to the treated material by mutagens. Among the different systems of classification of chlorophyll mutations in different plants species, the system suggested by Gaul (1964) in barley are adopted in the present study.

Table 31. Frequency of chlorophyll mutants following gamma irradiation in BSi1 in M_2 generation.

Gamma rays (Kr)	Number of M_1 families scored	Number of M_1 families mutated	Number of M_2 plants/populations scored	Number of chlorophyll mutants observed	Frequency of chlorophyll mutants based on		Mutagenic effectiveness	Mutagenic efficiency
					M_1 families (%)	M_2 plants (%)		
0	30	0	1215	0.00	0.00	0.00	0.00	0.00
10	169	163	18826	743	96.45	3.95	0.395	0.429
20	145	27	18810	137	18.62	0.73	0.036	0.035
30	113	94	9530	218	83.19	2.29	0.076	0.074
40	115	75	8946	303	65.22	3.39	0.084	0.085
50	86	55	4489	194	63.95	4.32	0.086	0.070
60	27	25	1482	155	92.59	10.46	0.174	0.186
70	12	12	735	50	100.00	6.80	0.097	0.089
80	2	2	215	31	100.00	14.42	0.180	0.166

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Table 32. Frequency of chlorophyll mutants following gamma irradiation in BSi427 in M_2 generation.

Gamma rays (Kr)	Number of M_1 families scored	Number of M_1 families mutated	Number of M_2 plants/populations scored	Number of chlorophyll mutants observed	Frequency of chlorophyll mutants based on		Mutagenic effectiveness	Mutagenic efficiency
					M_1 families (%)	M_2 plants (%)		
0	30	0	1225	0	0.00	0	0	0.000
10	180	29	17549	134	16.11	0.76	0.076	0.050
20	156	121	8912	315	77.56	3.53	0.176	0.174
30	159	137	25410	477	86.16	1.88	0.063	0.063
40	115	109	11937	479	94.78	4.01	0.100	0.125
50	108	108	6218	1017	100.00	16.35	0.327	0.269
60	56	13	3154	77	23.21	2.44	0.040	0.046
70	52	46	1843	209	88.46	11.34	0.162	0.139

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4.2.2. Frequency of chlorophyll mutations : The frequency of all types of chlorophyll mutants induced by gamma rays in the three varieties, BSi1, BSi427 and BSi467 is presented in Tables 31 to 33 and in figure (Fig. 7). The result shows that dosage dependent relationship was not observed in the frequency of chlorophyll mutants when calculated per hundred M_1 family and per hundred M_2 plants in all the three varieties.

In BSi1 the highest frequency both on M_1 family and M_2 plants basis was at 80 Kr (Table 31).

In BSi427 the highest frequency of chlorophyll mutants per hundred M_1 family and per hundred M_2 plants was at 50 Kr (Table 32).

In BSi467 frequency of chlorophyll mutants did not follow dosage dependent relationship when frequency was calculated per 100 M_1 family and per 100 M_2 plants (Table 33). The highest frequency of chlorophyll mutants calculated per 100 M_1 family was at 30 Kr and per 100 M_2 plants was at 60 Kr (Table 33).

4.2.3. Spectrum of chlorophyll mutants: In the present study a wide spectrum of chlorophyll mutants induced by gamma radiation was observed in all the three varieties. The spectrum of chlorophyll mutants in the present study comprised albina, xantha, viridis, tigrina, striata and albo viridis (Plate 7 and 8a). The spectrum and frequency of each type calculated on M_1 family and M_2 plants basis in the three varieties are presented in Tables 34, 35 and 36 and in figures (Fig. 8, 9 and 10).

BSi1

Albina: In BSi1 no albina was observed in higher dosages. The frequency on M_1 family basis followed a dosage dependent trend except the dosage of 40 Kr which declined the frequency (Table 34). The highest frequency of albina on M_1 family basis was at 50 Kr and on M_2 plants basis was at 40 Kr.

Xantha: The frequency of xantha did not show dosage dependent relationship when frequency was calculated both on M_1 family and M_2 plants basis. The highest frequency of xantha calculated both on M_1 family and on M_2 plants basis was at 80 Kr (Table 34).

Table 33. Frequency of chlorophyll mutants following gamma irradiation in BSi467 in M_2 generation.

Gamma rays (Kr)	Number of M_1 families scored	Number of M_1 families mutated	Number of M_2 plants/populations scored	Number of chlorophyll mutants observed	Frequency of chlorophyll mutants based on		Mutagenic effectiveness	Mutagenic efficiency
					M_1 families (%)	M_2 Plants (%)		
0(control)	30	0	1230	0	0.00	0.00	0.000	0.000
10	191	143	42239	402	74.87	0.95	0.095	0.108
20	199	191	23726	1092	95.97	4.60	0.223	0.219
30	164	158	21435	752	96.34	3.50	0.117	0.108
40	182	162	16038	1083	89.01	6.75	0.169	0.145
50	142	105	9127	241	73.94	2.64	0.053	0.078
60	59	49	3238	275	83.05	8.49	0.141	0.238
70	10	7	486	16	70.00	3.29	0.047	0.052

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Table 34. Spectrum of chlorophyll mutants following gamma irradiation in BSi1 in M_2 generation.

Gamma rays (Kr)	albina(%)		Xantha(%)		Tigrina(%)		Viridis(%)		Striata(%)		Alboviridis(%)	
	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.59	0.02	13.61	0.16	95.86	3.67	4.73	0.07	1.78	0.02	0.00	0.00
20	0.69	0.01	5.52	0.37	10.34	0.12	4.83	0.23	0.00	0.00	0.00	0.00
30	2.65	0.29	4.42	0.33	69.03	0.84	39.82	0.70	8.85	0.13	0.00	0.00
40	1.75	0.38	6.14	0.23	55.26	1.70	22.81	1.06	0.88	0.01	0.00	0.00
50	3.49	0.11	10.46	1.16	38.37	1.02	34.88	2.00	1.16	0.02	0.00	0.00
60	0.00	0.00	11.11	0.81	88.88	7.83	11.11	1.75	3.70	0.07	0.00	0.00
70	0.00	0.00	8.33	0.27	100.00	5.85	25.00	0.41	16.67	0.27	0.00	0.00
80	0.00	0.00	100.00	7.44	100.00	5.58	50.00	0.93	50.00	0.47	0.00	0.00

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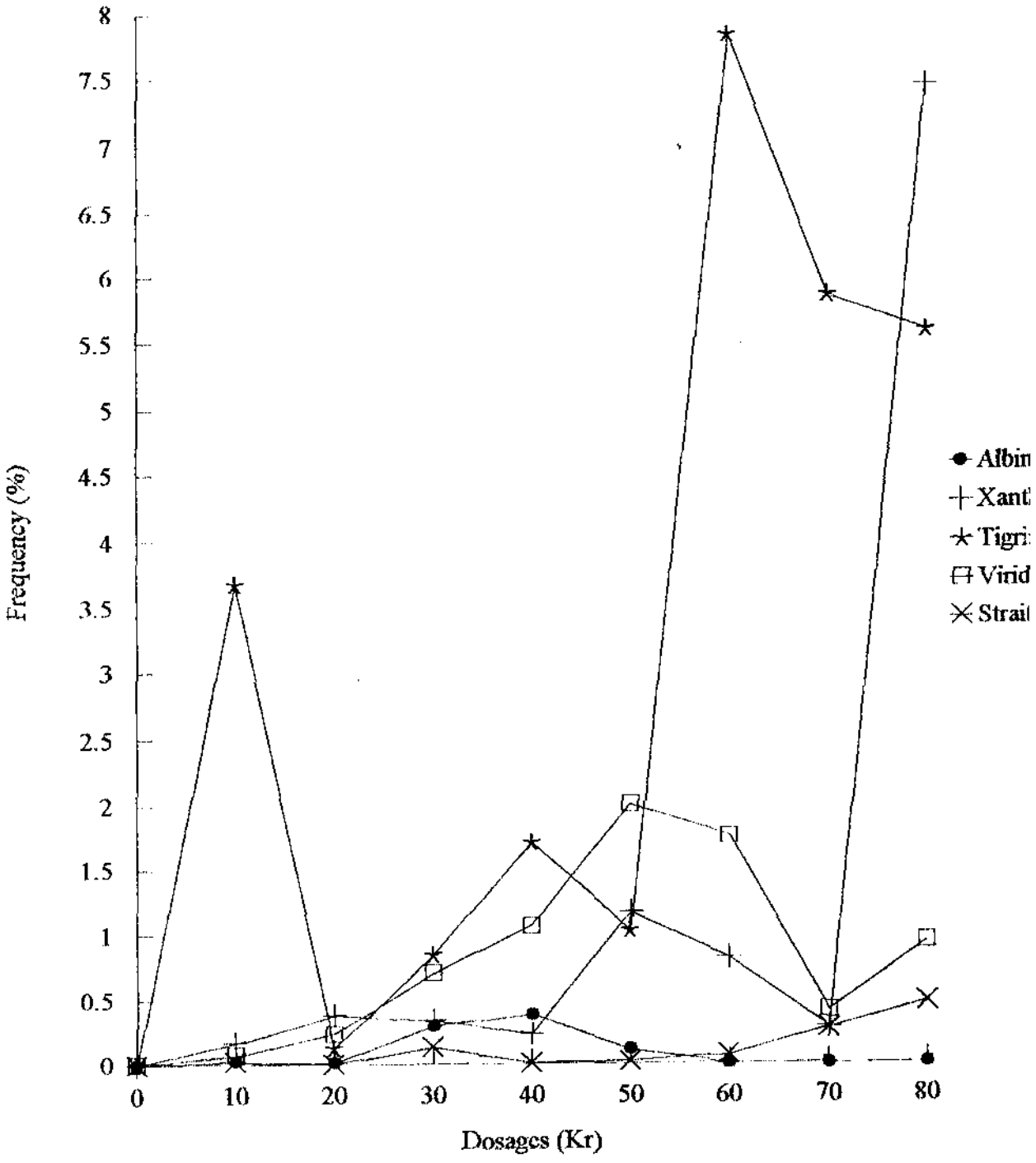

Fig.8. Spectrum of chlorophyll mutants in BSi1.

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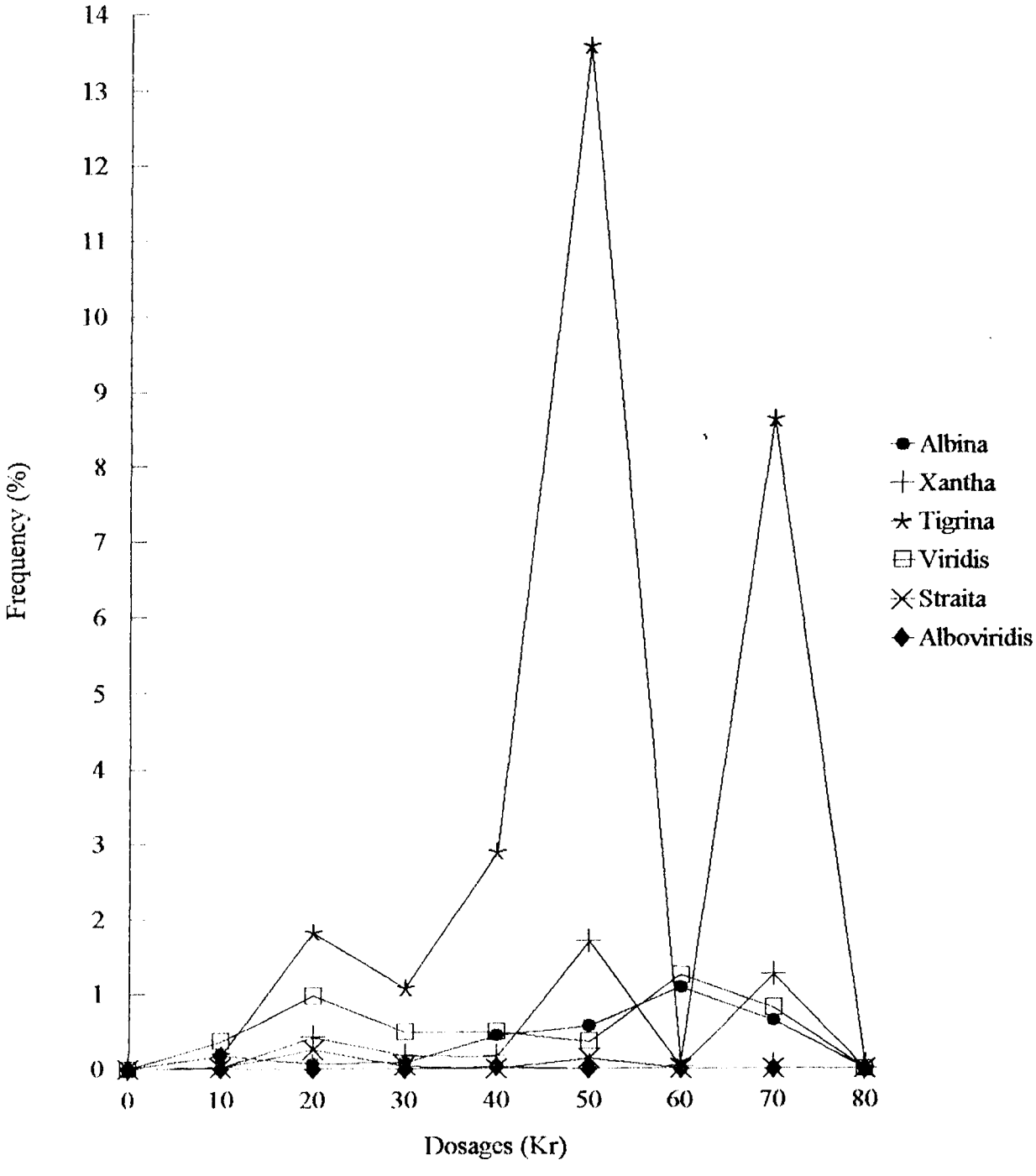

Fig 9: Spectrum of chlorophyll mutants in BSi427.

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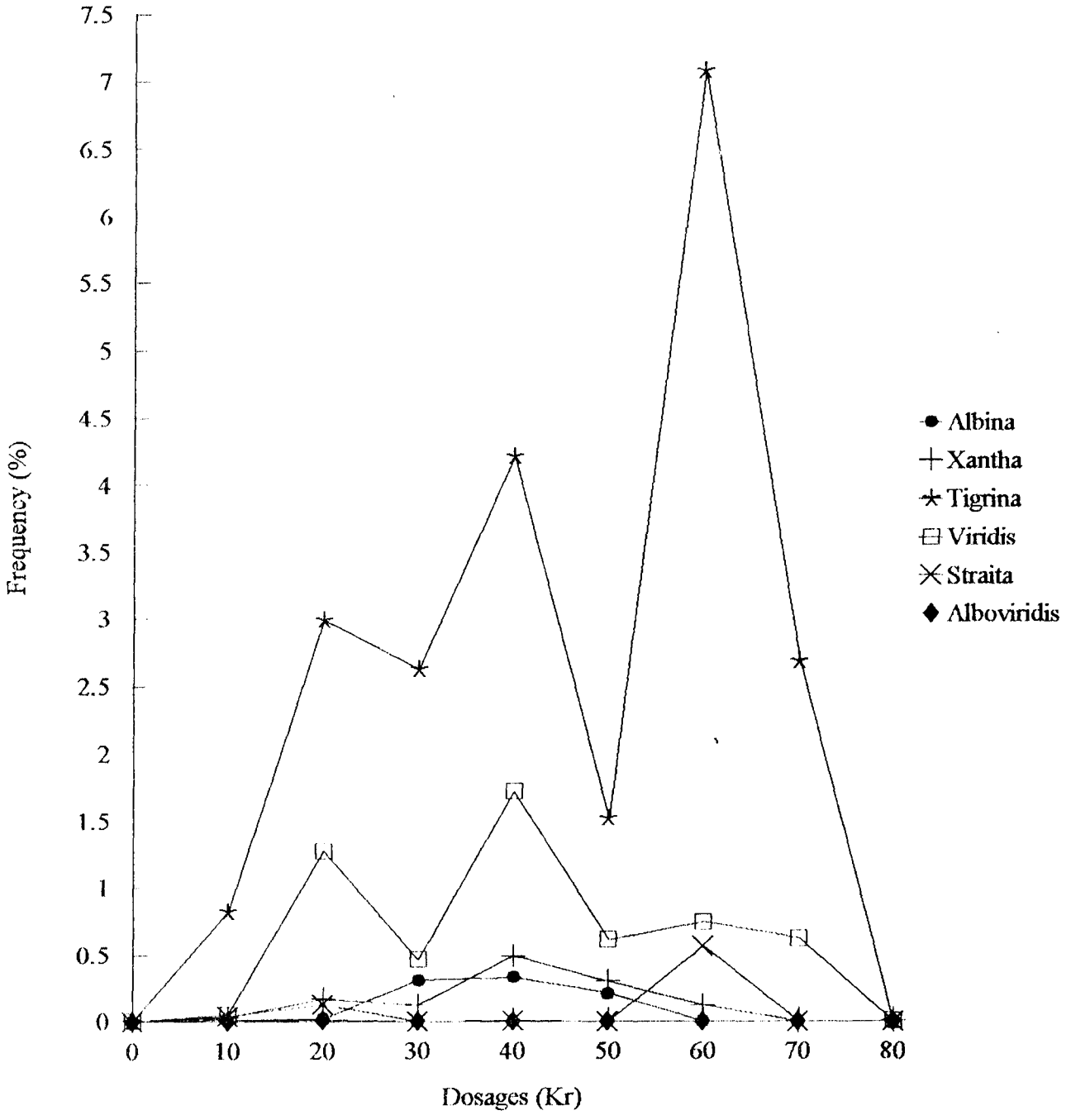

Fig.10. Spectrum of chlorophyll mutants in BSi467.

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Plate 7. a-b: (a) Chlorophyll mutants in BSi1as a result of gamma irradiation. (b) Chlorophyll mutants in BSi467as a result of gamma irradiation.

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(a)

(b)

Plate 8. a-b: (a) Chlorophyll mutants in BSi427 as a result of gamma irradiation. (b) Chlorophyll variant in BSi427 as a result of gamma irradiation.

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Tigrina: The frequency of tigrina increased with the increase of dosages when frequency was calculated on M_1 family basis and reduced at higher dosages on M_2 plants basis. On M_1 family basis the highest frequency of tigrina was at the two higher dosages of 70 Kr and 80 Kr and on M_2 plants basis the highest frequency was at 60 Kr (Table 34).

Viridis: The frequency of viridis did not follow dosage dependent relationship. The highest frequency on M_1 family basis was at the highest dosage of 80 Kr and on M_2 plants basis was at 50 Kr (Table 34).

Striata: No striata was observed at the dosage of 20 Kr. The frequency did not show a dosage dependent relationship at lower dosages; frequency gradually increased with the increase of dosages from 50 Kr, highest frequency both on M_1 family and M_2 plants basis was at the highest dosage of 80 Kr (Table 34).

Alboviridis: No alboviridis was observed in any of the dosages.

BSi427

Albina: In BSi427 the frequency of albina did not show a dosage dependent relationship when calculated on both M_1 family and M_2 plants basis. The highest frequency of albina on the basis of both M_1 family and M_2 plants was at 60 Kr (Table 35).

Xantha: The highest frequency of xantha on M_1 family basis was at 20 Kr and on M_2 plants basis was at 50 Kr (Table 35).

Tigrina: The frequency of tigrina did not show dosage dependent relationship. The highest frequency both on M_1 family and M_2 plants basis was at the dosage of 50 Kr (Table 35).

Viridis: Dosage dependent relationship in the frequency of viridis was not observed when frequency was calculated both on M_1 family and M_2 plants basis. The highest frequency of viridis on M_1 family basis was at 30 Kr and on M_2 plants basis was at 60 Kr (Table 35).

Table 35. Spectrum of chlorophyll mutants following gamma irradiation in BSi427 in M_2 generation.

Gamma rays (Kr)	albina(%)		Xantha(%)		Tigrina(%)		Viridis(%)		Striata(%)		Alboviridis(%)	
	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.11	0.18	0.56	0.02	10.56	0.18	3.89	0.37	1.11	0.01	0.00	0.00
20	0.64	0.07	14.74	0.43	52.56	1.81	24.36	0.97	16.03	0.26	0.00	0.00
30	3.14	0.09	8.81	0.18	72.33	1.07	36.48	0.50	3.77	0.04	0.00	0.00
40	2.61	0.45	3.48	0.17	56.96	2.89	8.70	0.50	0.00	0.00	0.87	0.03
50	3.70	0.58	12.04	1.69	100.00	13.57	11.11	0.37	10.19	0.14	0.00	0.00
60	5.36	1.08	1.79	0.03	5.36	0.10	16.07	1.24	0.00	0.00	0.00	0.00
70	3.85	0.65	11.53	1.25	82.69	8.63	11.54	0.81	0.00	0.00	0.00	0.00

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Striata: No striata was observed at the dosages of 40, 60 and 70 Kr. The frequency of striata did not show dosage dependent relationship when calculated on both M_1 family and M_2 plants basis. The highest frequency both on M_1 family and M_2 plants basis was at 20 Kr (Table 35).

Alboviridis: Alboviridis was observed only at the dosage of 40 Kr. The frequency of alboviridis on M_1 family basis was 0.87 percent and on M_2 plants basis was 0.03 percent (Table 35).

BSi467

Albina: In BSi467 no albina was observed at the two higher dosages of 60 and 70 Kr. The frequency of albina showed more or less dosage dependent relationship when calculated on both M_1 family and M_2 plants basis except the dosage of 50 Kr which declined the frequency (Table 36).

Xantha: No xantha was observed at the second highest dosage of 70 Kr. The frequency of xantha did not follow dosage dependent relationship. The highest frequency calculated on both M_1 family and M_2 plants basis was at 40 Kr (Table 36).

Tigrina: Dosage dependent relationship in the frequency of tigrina was not observed when frequency was calculated on M_1 family and M_2 plants basis. The highest frequency on M_1 family basis was at 30 Kr and on M_2 plants basis was at 60 Kr (Table 36).

Viridis: The frequency of viridis both on M_1 family basis and M_2 plants basis did not follow a dosage dependent relationship. The highest frequency on M_1 family basis was at 20 Kr and on M_2 plants basis was at 40Kr (Table 36).

Striata: No striata was observed at 30, 50 and 70 Kr of gamma radiation. The highest frequency both on M_1 family basis and M_2 plants basis was at 60 Kr (Table 36).

Alboviridis: The only dosage of 20 Kr induced alboviridis the frequency of which on M_1 family basis was 1.00 and on M_2 plants basis was 0.01 (Table 36).

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Table 36. Spectrum of chlorophyll mutants following gamma irradiation in Bsi 467 in M_2 generation.

Gamma rays (Kr)	Albina(%)		Xantha(%)		Tigrina(%)		Viridis(%)		Striata(%)		Alboviridis(%)	
	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants	M_1 family	M_2 plants
0(control)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.52	0.01	4.19	0.03	69.63	0.82	4.71	0.05	2.62	0.04	0.00	0.00
20	0.50	0.02	12.06	0.17	88.44	2.99	48.74	1.27	7.53	0.13	1.00	0.01
30	1.83	0.31	0.61	0.12	90.24	2.62	20.73	0.46	0.00	0.00	0.00	0.00
40	2.20	0.33	20.88	0.49	82.42	4.21	44.51	1.72	0.55	0.006	0.00	0.00
50	1.41	0.21	4.23	0.30	58.45	1.52	11.27	0.61	0.00	0.00	0.00	0.00
60	0.00	0.00	6.78	0.12	79.66	7.07	25.42	0.74	8.47	0.56	0.00	0.00
70	0.00	0.00	0.00	0.00	50.00	2.68	30.00	0.62	0.00	0.00	0.00	0.00

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Table 37. Frequency of viable mutants following gamma irradiation in BSi1 in M_2 generation.

Gamma rays (Kr)	Number of M_1 families scored	Number of M_1 families mutated	Number of M_2 plants/populations scored	Number of viable mutants observed	Frequency of viable mutants based on	
					M_1 families (%)	M_2 plants (%)
0 (control)	30	0	1120	0	0.00	0.00
10	169	67	26038	103	39.64	0.40
20	144	61	11994	83	42.36	0.69
30	111	46	5802	50	41.44	0.86
40	112	62	6264	104	55.36	1.66
50	92	32	2854	59	34.78	2.07
60	29	13	595	19	44.83	3.19
70	11	6	337	30	54.55	8.90
80	2	2	56	2	100.00	3.57

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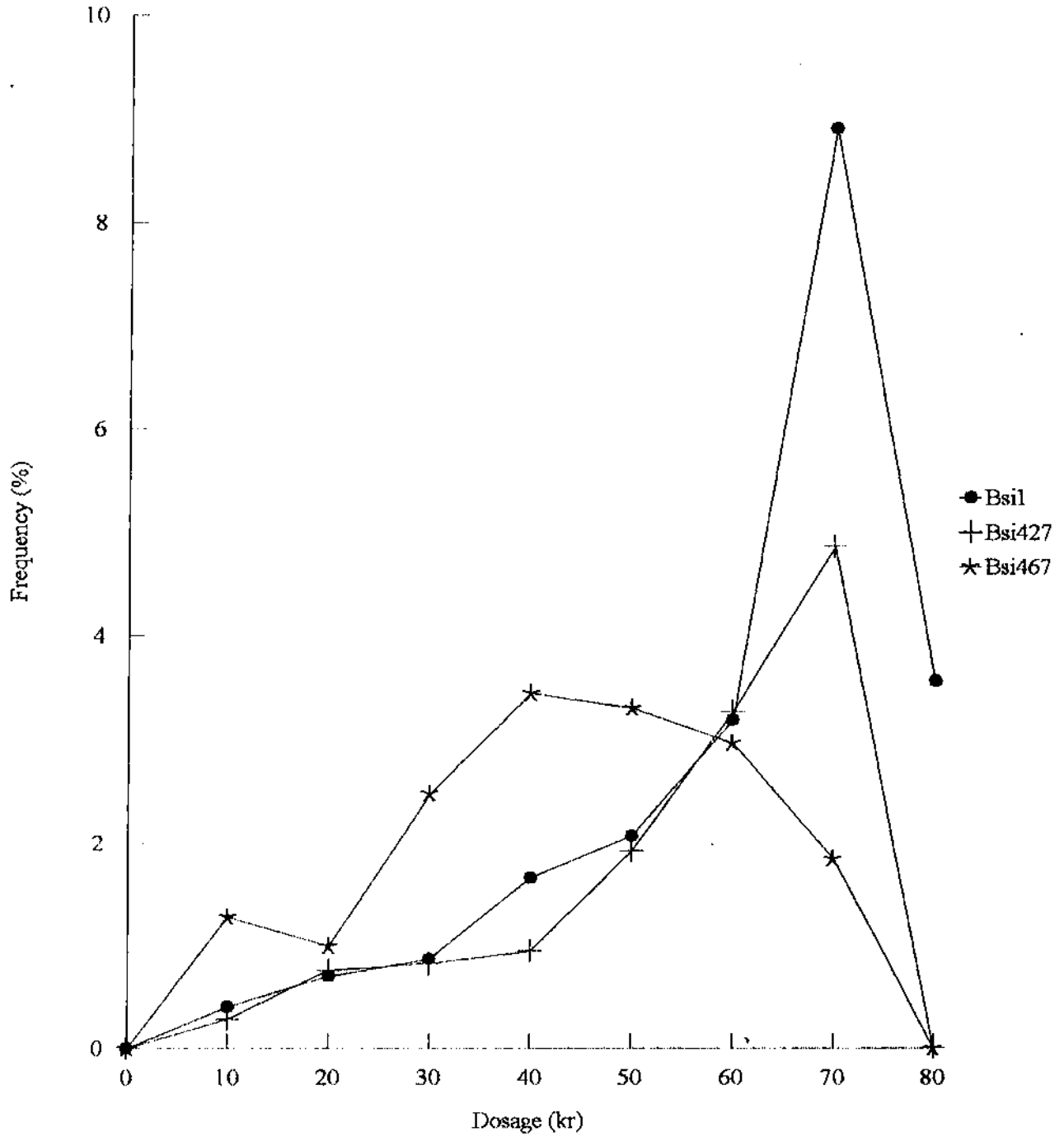

Fig.11. Frequeny of viable mutants based on M2 population (%) in three varieties.

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4.2.4. Frequency of viable mutants : The morphological mutants which reached the flowering stage were recorded as viable mutants. The viable visible mutants (macromutations) in M_2 generation were identified on the basis of segregation in progeny rows. The visible mutants included a large number of plants which carried mutations for more than one character. The identification of viable mutant was based on single character at a time. The frequencies of viable mutants in the three varieties are presented in Tables 37, 38 and 39 and figure (Fig. 11).

Table 37 shows that in BSi1 dosage dependent relationship was not observed in the frequency of viable mutants when calculated on M_1 family basis. The highest frequency of viable mutants on M_1 family basis was at the highest dosage of 80 Kr. A dosage dependent relationship was observed when calculated on M_2 plants basis except at the highest dosage of 80 Kr which declined the frequency.

In BSi427 a somewhat dosage dependent relationship for the frequency of viable mutants was observed when calculated on M_1 family basis except at the dosage of 40 Kr which declined the frequency. The frequency shows dosage dependent relationship when calculated on M_2 plants basis. The highest frequency of viable mutants was observed at the second highest dosage of 70 Kr (Table 38).

In BSi467 the frequency of viable mutants was not proportional to the dosages both on M_1 family and M_2 plants basis. On M_1 family basis from the dosage of 40 Kr the frequency gradually decreased with the increase of dosages. The highest frequency on M_1 family basis was at the dosage of 30 Kr and on M_2 plants basis was at the dosage of 40 Kr (Table 39).

4.2.5. Spectrum of viable mutants : A wide spectrum of viable mutants was observed in the present investigation which consisted of colour mutation (both plant and seed), plant growth or stature, panicle (shape, size, compactness, Awn etc.) and maturity. The different types of viable mutants recorded in the study were broadly grouped under four categories affecting (i) colour, (ii) growth or stature, (iii) panicle and (iv) maturity. A brief description of these viable mutants are given below:

Table 38. Frequency of viable mutants following gamma irradiation in BSi427 in M_2 generation.

Gamma rays (Kr)	Number of M_1 families scored	Number of M_1 families mutated	Number of M_2 plants/populations scored	Number of viable mutants observed	Frequency of viable mutants based on	
					M_1 Families (%)	M_2 plants (%)
0 (control)	30	0	1210	0	0.00	0.00
10	180	45	26203	74	25.00	0.28
20	154	62	15527	117	40.26	0.75
30	159	67	15579	128	42.14	0.82
40	118	46	10642	100	38.98	0.94
50	104	50	5011	96	48.07	1.92
60	56	28	2723	89	50.0	3.27
70	54	31	1380	67	57.41	4.86

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Table 39. Frequency of viable mutants following gamma irradiation in BSi467 in M_2 generation.

Gamma rays (Kr)	Number of M_1 families scored	Number of M_1 families mutated	Number of M_2 plants/populations scored	Number of viable mutants observed	Frequency of viable mutants based on	
					M_1 families (%)	M_2 Plants (%)
0 (control)	30	0	1225	0	0.00	0.00
10	190	65	12608	160	34.21	1.27
20	201	89	26577	263	44.28	0.99
30	164	86	8455	210	52.44	2.48
40	182	82	7973	275	45.05	3.45
50	141	52	4320	143	36.88	3.31
60	57	18	1520	45	31.58	2.96
70	10	3	272	5	30.00	1.84

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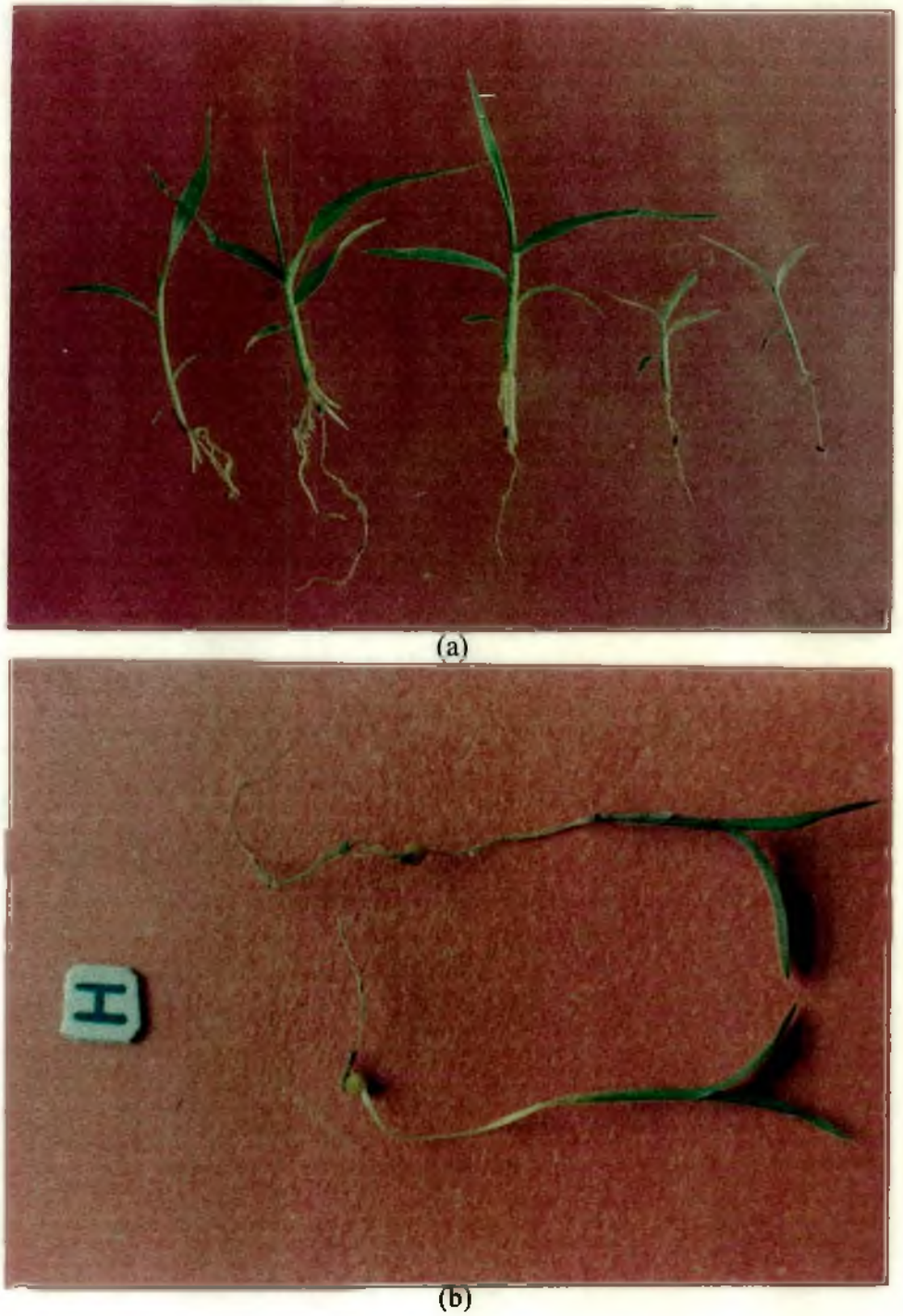

Plate 9. a-b: (a) Effect of gamma irradiation on stem colour: BSi467 control showing purple stem (L); mutants showing green stem (R) at seedling stage. (b) Effect of gamma irradiation on stem colour: BSi427 control showing green stem (lower); mutants showing purple stem (upper). Note that irradiation produced opposite effect in the two varieties; in BSi467 purple changed to green while in BSi427 the green mutated to purple colour.

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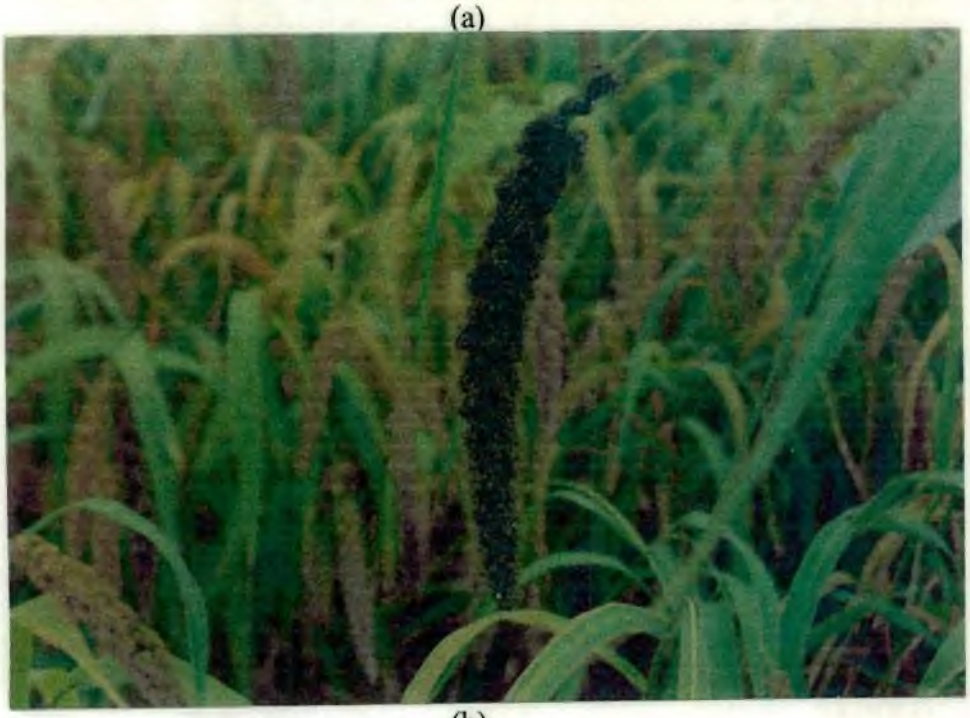
(a)



(b)

Plate 10. a-b: (a) Beautifully shaped five ash coloured seeded panicles in purple coloured stem background in BSi1 (experimental field view). (b) Black seeded panicle in purple coloured stem background in BSi1 (experimental field view).

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(a)

(b)

Plate 11. a-b: (a) Black seeded panicle in green coloured stem background in BSi427 (experimental field view). (b) Beautifully shaped four orange coloured seeded panicles in BSi427 (experimental field view).

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(a)

(b)

Plate 12. a-b: (a) Green stem colour and cream seeded panicle in BSi467 as a result of gamma irradiation (experimental field view). (b) Variation in seed colour in BSi1, BSi427 and BSi467 as a result of gamma irradiation.
(upper line, BSi1; middle line BSi467 and the lower line, BSi427). In all the three rows seeds of the control are shown on the extreme right. First row: Black, cream and ash × normal size Second row: cream, ash, orange and yellow × normal size Third row: Orange, black, yellow and ash × normal size

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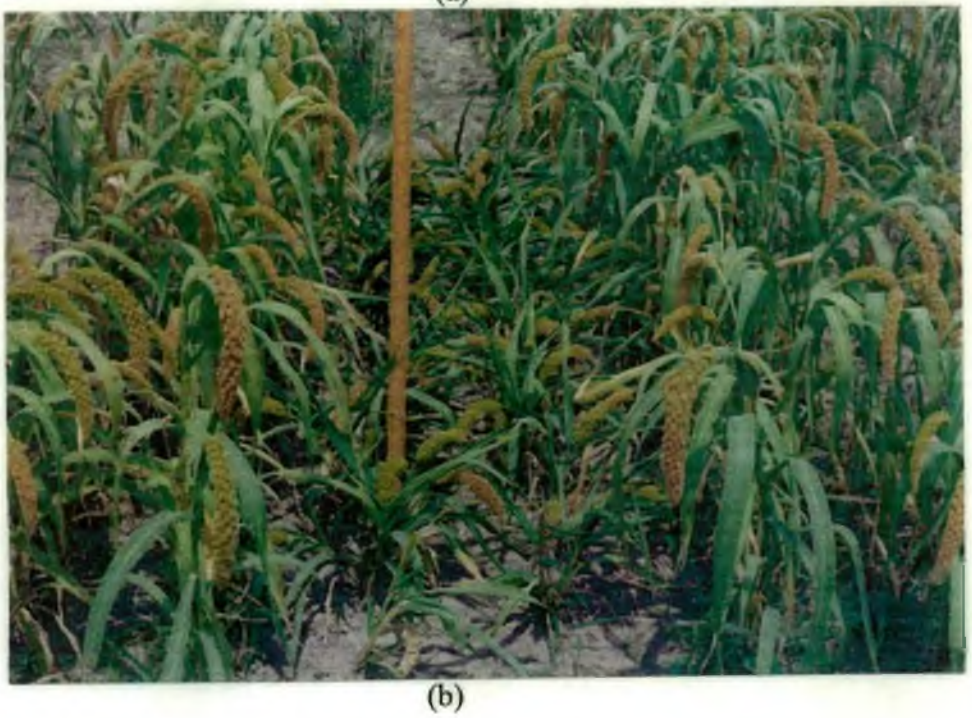
(a)



(b)

Plate 13. a-b: (a) Flowering dwarf mutants of BSi427 grown in experimental field. Control (left); dwarf mutant (right). (b)Dwarf mutants of BSi427 at half maturity stage.Control (left and right); dwarf mutants (middle) × 12.

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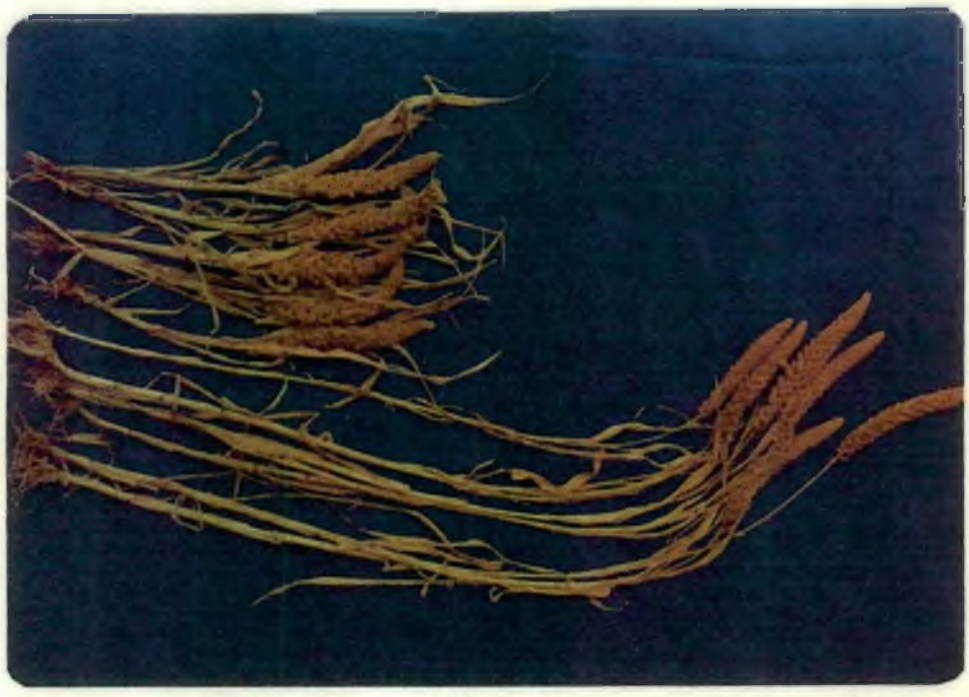

(a)

(b)

Plate 14. a-b: (a) A few harvested plants of dwarf mutant of BSi427. Control (lower); dwarf mutants (upper). (b) A magnified view of dwarf mutant of BSi427 (single harvested plant. Control (lower); dwarf mutant (upper) × 7.5.

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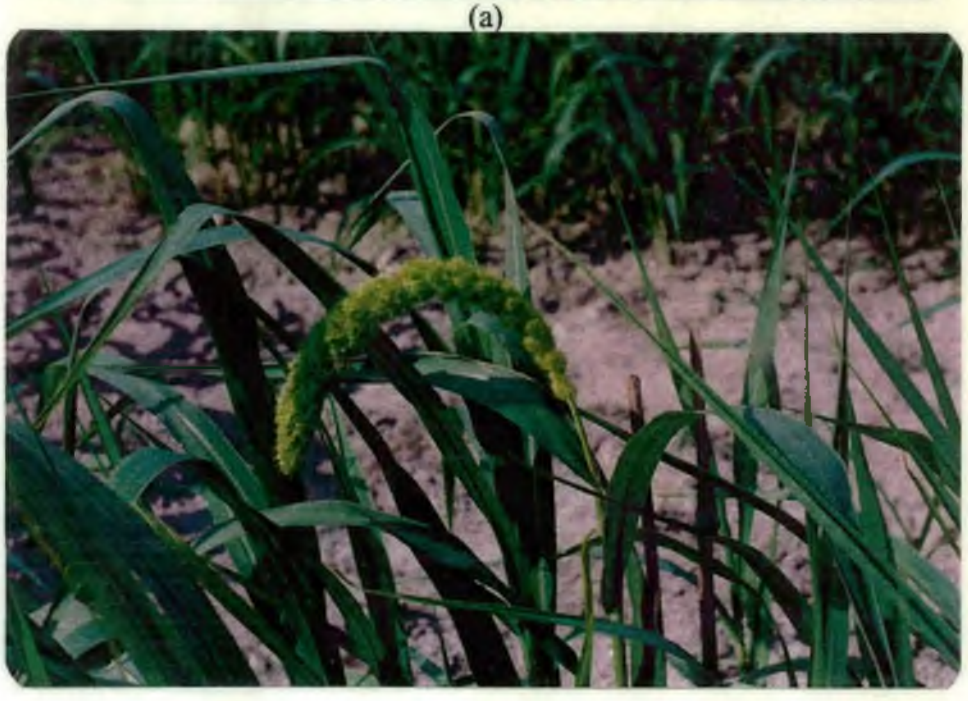
(a)



(b)

Plate 15. a-b: (a) Extreme tall and short mutants in BSi467 (experimental field view). (b) Early mutant in BSi427 (experimental field view).

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(i) Colour mutants: *Gamma radiation induced a spectrum of changes in grain colour and* also brought about change in plant colour in all the three varieties (Plate 9). The grain colour mutants observed in BSi1 were cream, black and ash and stem or plant colour mutant was purple. The grain colour mutants induced in BSi427 were orange, black, yellow and ash and plant or stem colour mutant was purple. In BSi467 four different grain colour such as cream, ash, orange, and yellow, and green coloured mutant plant were induced (Plates 9, 10, 11 and 12).

(ii) Growth or stature mutants : Gamma radiation induced extreme tall (heigher than the level of tall parent), short, extreme dwarf, profuse tillering and broad leaf mutants in the three varieties (Plates 13, 14 and 15a). In BSi1 the extreme tall mutant of 171 cm was isolated at the dosage of 40 Kr compared to the height in control ranging from 118 to 163 cm in M_2 generation. In BSi427 the extreme tall mutant recorded as 159 cm was at the dosage of 40 Kr compared to the height in control ranging from 105 to 130 cm and in BSi467 the extreme tall mutant recorded as 188 cm was at the dosage of 30 Kr compared to the height in control ranging from 122 to 176 cm in M_2 generation. Extreme dwarf mutants of height ranging from 44 to 47 cm were isolated in BSi427 at the dosage of 40 Kr. Broad leaf, narrow leaf and mutants with greater number of tillers, though not frequent, were isolated in all the three varieties; the maximum productive tiller number was from 4 to 6 compared to average unicum parent (BSi427) and parents having average two tillers (BSi1 and BSi467).

(iii) Panicle Mutants: A large variation in the panicle character showing changes in shape (branched tip, finger like, blunt tip, bulky, prominent secondary branch etc.), size, and compactness and also awn character(large, medium, rudimentary and awnless) was induced by gamma radiation in all the three varieties (Plates 16 and 17).

(iv) Mutation affecting maturity: Gamma radiation induced both late and early flowering and maturity in all the three varieties (Plate 15b). Of course, early type was more frequent than the late trait. The early types were at least 7 days earlier in BSi427, 15 days earlier in BSi1 and 20 days earlier in BSi467 than their respective parent.

Table 40. Spectrum of viable mutants following gamma irradiation in BSi1 in M_2 generation.

Gamma rays (Kr)	Coloured Mutants(%)		Mutation affecting stature (%)		Mutation affecting panicle (%)		Mutation affecting maturity (%)	
	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants
0(control)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	28.99	0.28	5.33	0.06	2.37	0.02	1.78	0.05
20	22.22	0.41	9.02	0.15	6.94	0.10	0.69	0.03
30	27.03	0.65	6.3	0.13	1.80	0.03	2.70	0.05
40	38.39	0.9	8.04	0.17	6.25	0.14	9.82	0.43
50	25.0	1.23	3.26	0.11	6.52	0.21	15.21	0.53
60	34.48	1.85	3.45	0.17	6.90	0.34	10.35	0.84
70	45.45	2.97	9.09	0.89	0.00	0.00	36.36	5.04
80	50.0	1.79	0.00	0.00	50.0	1.79	0.00	0.00

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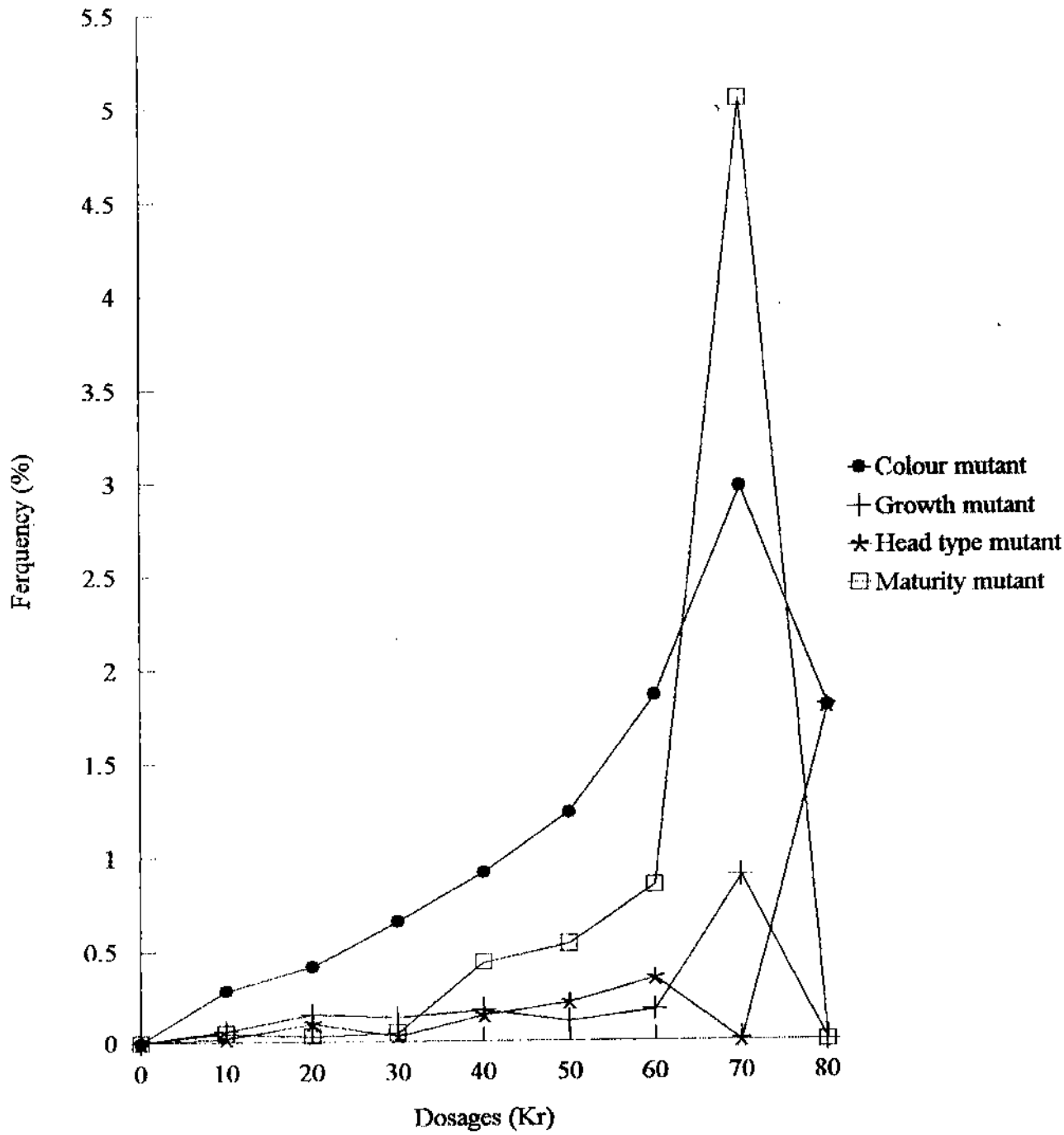

Fig.12. Spectrum of viable mutants in BSi1.

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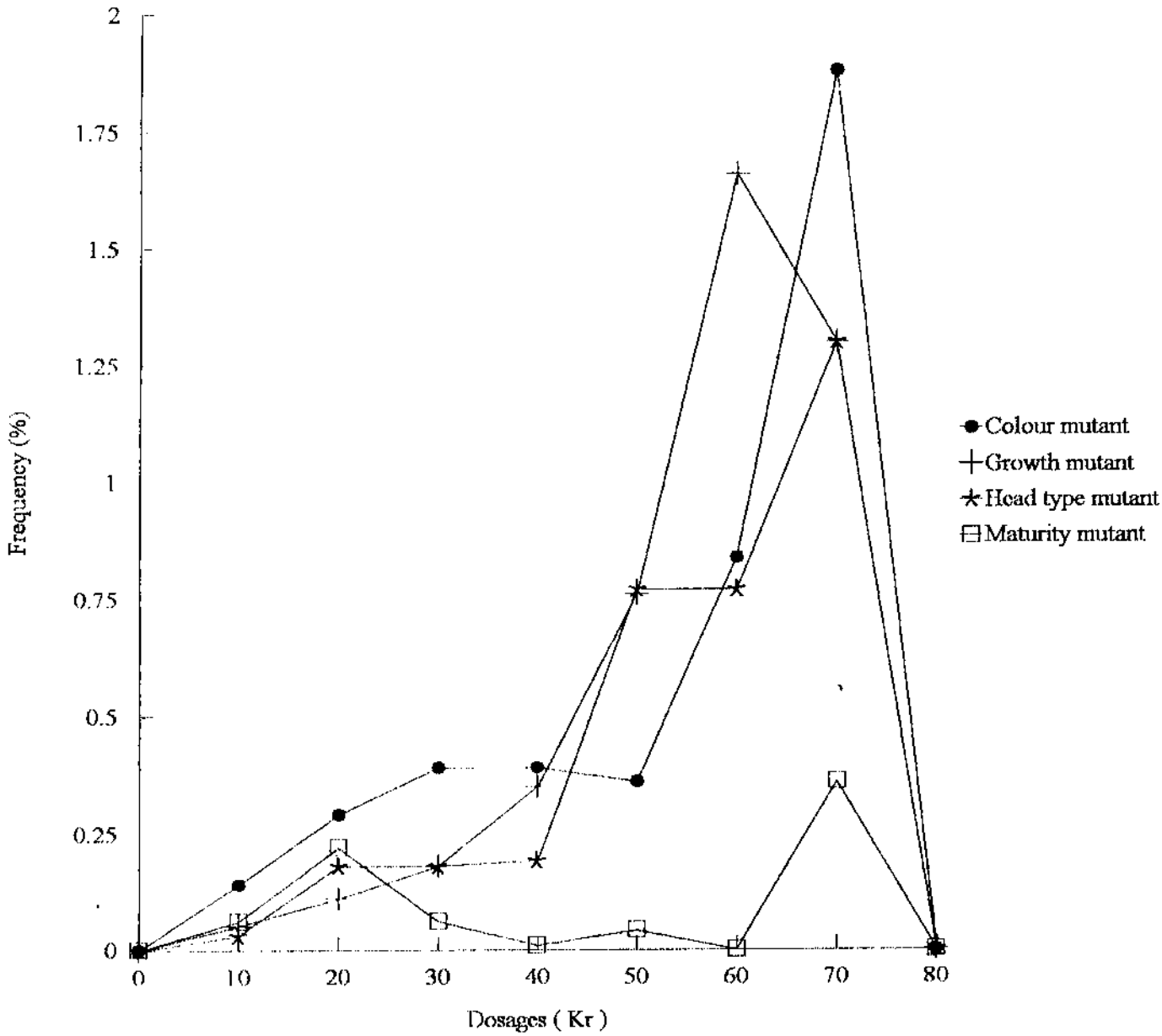

Fig. 13. Spectrum of viable mutations in Bsi427.

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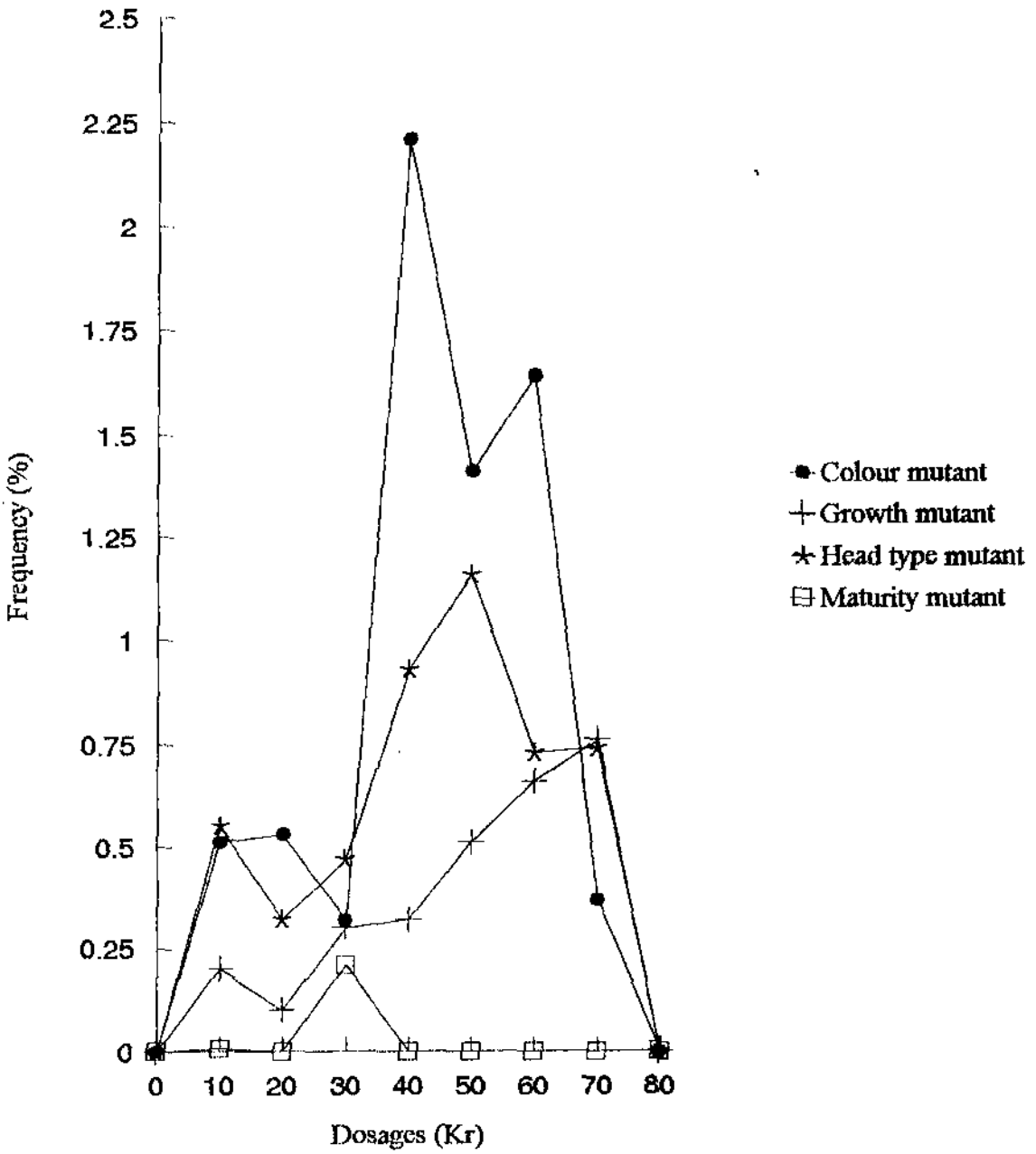

Fig. 14. Spectrum of viable mutants in BSi467.

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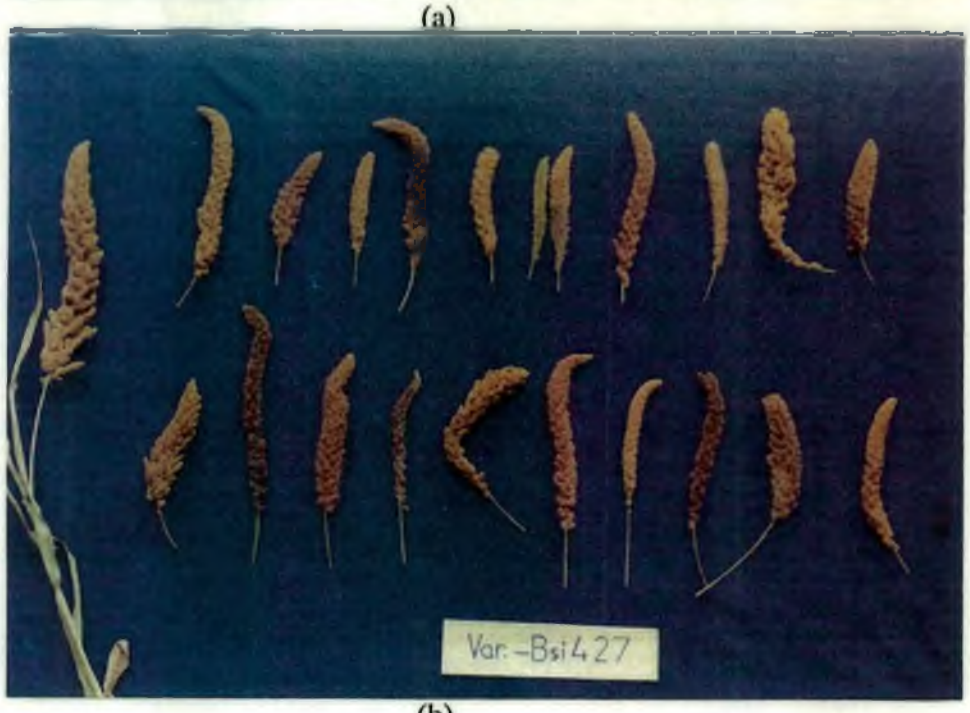
(a)



(b)

Plate 16. a-b: (a) Variation in panicle characters observed in BSi1. Characters include: shape, size, length, lobe arrangement and tip. Control (extreme right); mutants (all others to the left). (b) Variation in panicle characters observed in BSi427. Characters include: shape, size, length, lobe arrangement and tip. Control (lower right); all others to the left and material on the upper row are mutants.

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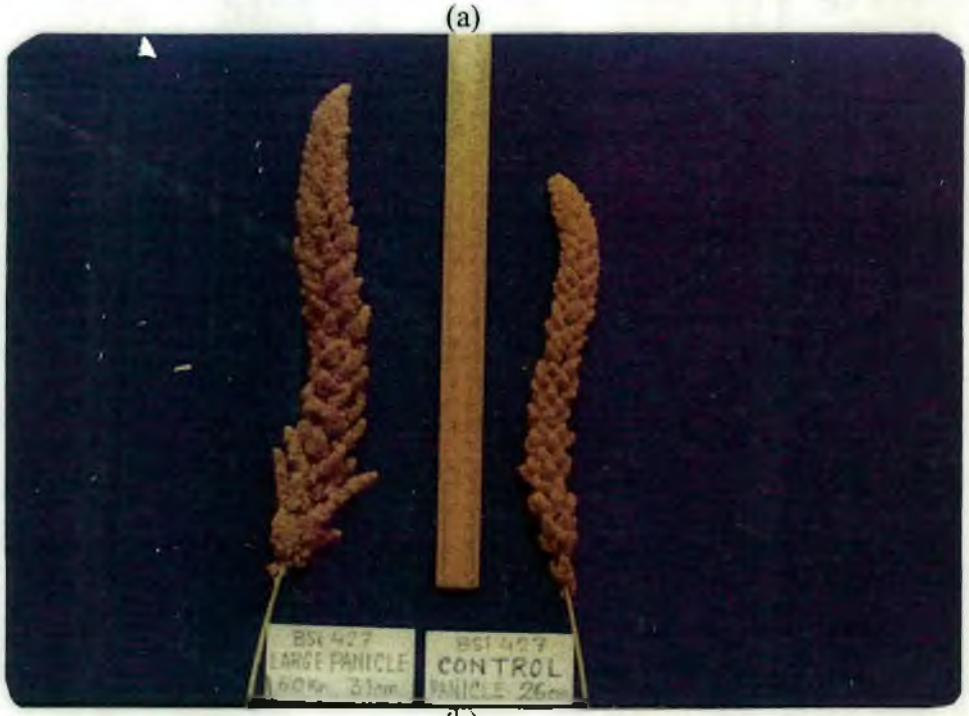
(a)



(b)

Plate 17. a-b: (a) Variation in panicle characters observed in BSi467. Characters include: shape, size, length, lobe arrangement and tip. Control (lower right); all others to the left and material on the upper row are mutants. (b) Large sized panicle in BSi427. Mutant (left); control (right) × 4.6.

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The spectrum of viable mutants and their relative frequencies in the three varieties are presented in Tables 40, 41 and 42 and figures (Fig. 12, 13 and 14). Almost similar mutants were observed in different treatments within variety and also among varieties.

It is evident from the Table 40 that in BSi1 dosage dependent relationship for the frequency of all types of viable mutants was not observed on M_1 family basis. On M_2 population basis the frequency of only colour mutations showed dosage dependent relationship except the highest dosage of 80 Kr. Frequency for panicle and maturity were in different degrees at different dosages. The second highest dosage of 70 Kr did not induce mutations for panicle character and mutation for maturity was not induced at the highest dosage of 80 Kr. Colour mutations were more predominant than all other types of mutants and frequencies of all types of viable mutants were higher at the higher dosages both on M_1 family and M_2 plants basis.

In BSi427 except at the dosage of 50 Kr, frequency of colour mutation showed dosage dependent relationship. Stature mutation did not show dosage dependent relationship both on M_1 family and M_2 population basis. The highest frequency for stature was at 60 Kr. Frequency for panicle character and frequency for maturity did not follow dosage dependent relationship. The highest frequency for panicle character was at 50 Kr on M_1 family basis. The highest frequency for maturity was at the second highest dosage of 70 Kr; the dosage 60 Kr did not induce mutation for maturity. Frequencies for colour mutations were more predominant than all other types of viable mutants. The highest frequency for colour, stature, panicle and maturity was at 70, 60, 50 and 20 Kr respectively on M_1 family basis (Table 41).

In BSi467 frequencies for all types of viable mutants did not show dosage dependent relationship both on M_1 family and M_2 population basis. Mutation for maturity was confined to the two lower dosages of 10 and 30 Kr. Frequencies of colour mutation were predominant than all other viable mutants. The highest frequency for colour mutation was at the dosage of 30 Kr on M_1 family basis and on M_2 population basis was at the dosage of 40 Kr (Table 42). The highest frequency for different types of viable mutants was at

Table 41. Spectrum of viable mutants following gamma irradiation in BSi427 in M_2 generation.

Gamma rays (Kr)	Mutation affecting colour(%)		Mutation affecting stature (%)		Mutation affecting panicle (%)		Mutation affecting maturity (%)	
	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants
0(control)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	14.44	0.14	7.22	0.05	10.00	0.03	11.67	0.06
20	16.23	0.29	9.09	0.11	6.49	0.18	14.94	0.22
30	23.27	0.39	14.47	0.18	12.52	0.18	4.37	0.06
40	24.58	0.39	14.41	0.35	9.33	0.19	0.85	0.009
50	11.54	0.36	21.16	0.76	24.99	0.77	1.92	0.04
60	28.57	0.84	28.57	1.66	21.43	0.77	0.00	0.00
70	33.33	1.88	20.36	1.30	22.22	1.30	9.26	0.36

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Table 42. Spectrum of viable mutants following gamma irradiation in BSi467 in M_2 generation.

Gamma rays (Kr)	Mutation affecting colonr(%)		Mutation affecting stature (%)		Mutation affecting panicle (%)		Mutation affecting maturity (%)	
	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants	based on M_1 family	based on M_2 plants
0(control)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	14.74	0.51	11.58	0.20	18.42	0.55	0.53	.007
20	29.85	0.53	12.44	0.10	11.94	0.32	0.00	0.00
30	35.98	0.32	14.64	0.30	15.25	0.47	1.22	0.21
40	32.42	2.21	10.44	0.32	20.88	0.93	0.00	0.00
50	29.08	1.41	14.19	0.51	19.86	1.16	0.00	0.00
60	19.30	1.64	14.04	0.66	14.03	0.73	0.00	0.00
70	10.00	0.37	20.00	0.74	20.00	0.74	0.00	0.00

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different dosages. The dosages inducing the highest frequency of stature, panicle and maturity on M_1 family basis were 70, 40 and 30 Kr respectively (Table 42).

4.2.6. Mutagenic effectiveness and efficiency: Estimates of mutagenic effectiveness (based on chlorophyll study) and efficiency (based on reduction on grain fertility) of different dosages of gamma rays in the three varieties are presented in Tables 31, 32 and 33

In BSi1 the effectiveness and the efficiency were not proportional to the dosage of gamma rays. Although comparatively higher dosage of 60 Kr and the highest dosage of 80 Kr showed tendency of more efficiency and effectiveness, the lowest dosage of 10Kr was found to be the most effective and efficient (Table 31).

In BSi427 the mutagenic effectiveness and the efficiency were also not proportional to the dosages. The mid level dosage of 50 Kr was found to be most effective and efficient (Table 32).

In BSi467 the effectiveness and the efficiency did not increase with the increase of dosages. Comparatively lower dosages showed more effectiveness and efficiency, the lower dosage of 20 Kr was recorded most effective. However, dosage of 60Kr was found to be most efficient (Table 33).

In the present investigation genotypic differences by treatment with gamma radiation were observed while inducing chlorophyll and viable mutants. No parallel trend of chlorophyll and viable mutations production was observed except BSi1. In BSi1 at the highest dosage of 80 Kr chlorophyll and viable mutants were of high frequency. Gamma treatments showed differences in specificity while inducing spectrum of chlorophyll and viable mutants. Same dosage was not effective and efficient in all the three varieties.

On comparison of chlorophyll and viable mutations in the present study, gamma treatments induced more chlorophyll mutations than viable mutations except in the variety BSi427 in which 10 Kr induced a reverse trend on M_1 family basis. Of the chlorophyll spectrum tigrina appeared with higher frequency followed by viridis in all the three varieties, the inducing dosage being different; alboviridis appeared with least frequency in

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BSi427 and BSi467. Of the viable mutations spectrum, coloured mutations, being induced by different dosages appeared with higher frequency in all the three varieties. Of great interest was the fact that viable mutants were more frequent at higher dosages in BSi1 and BSi427, the picture was different in respect of the third variety in which the higher the dosage, the less was the mutation frequency on M_2 plants basis.

4.2.7. Potency of gamma rays : The potency of mutagenic treatments for inducing all types of chlorophyll and viable mutations as measured by the frequency (%) was in the following pattern:

Chlorophyll mutations

(i) On the basis of segregating progeny

Varieties	Gamma Treatments (Kr)							
BSi1	80	> 70	> 10	> 60	> 30	> 40	> 50	> 20
	(100)	(100)	(96.45)	(92.59)	(83.19)	(65.22)	(63.95)	(18.62)
BSi427	50	> 40	> 70	> 30	> 20	> 60	> 10	
	(100)	(94.78)	(88.46)	(86.16)	(77.56)	(23.21)	(16.11)	
BSi467	30	> 20	> 40	> 60	> 10	> 50	> 70	
	(96.34)	(95.97)	(89.01)	(83.05)	(74.87)	(73.94)	(70.00)	

(ii) On M_2 plants basis

Varieties	Gamma Treatments (Kr)							
BSi1	80	> 60	> 70	> 50	> 10	> 40	> 30	> 20
	(14.42)	(10.46)	(6.80)	(4.32)	(3.95)	(3.39)	(2.29)	(0.73)
BSi427	50	> 70	> 40	> 20	> 60	> 30	> 10	
	(16.35)	(11.34)	(4.01)	(3.53)	(2.44)	(1.88)	(0.76)	
BSi467	60	> 40	> 20	> 30	> 70	> 50	> 10	
	(8.49)	(6.75)	(4.60)	(3.50)	(3.29)	(2.64)	(0.95)	

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Viable mutations

(i) On the basis of segregating progeny

Varieties	Gamma Treatments (Kr)							
BSi1	80	> 40	> 70	> 60	> 20	> 30	> 10	> 50
	(100)	(55.36)	(54.55)	(44.83)	(42.36)	(41.44)	(39.64)	(34.78)
BSi427	70	> 60	> 50	> 30	> 20	> 40	> 10	
	(57.41)	(50.0)	(48.07)	(42.14)	(40.26)	(38.98)	(25.0)	
BSi467	30	> 40	> 20	> 50	> 10	> 60	> 70	
	(52.44)	(45.05)	(44.28)	(36.88)	(34.21)	(31.58)	(30.00)	

(ii) On M_2 plants basis

BSi1	70	> 80	> 60	> 50	> 40	> 30	> 20	> 10
	(8.90)	(3.57)	(3.19)	(2.07)	(1.66)	(0.86)	(0.69)	(0.40)
BSi427	70	> 60	> 50	> 40	> 30	> 20	> 10	
	(4.86)	(3.27)	(1.92)	(0.94)	(0.82)	(0.75)	(0.28)	
BSi467	40	> 50	> 60	> 30	> 70	> 10	> 20	
	(3.45)	(3.31)	(2.96)	(2.48)	(1.84)	(1.27)	(0.99)	

4.2.8. Response of the three varieties : The response of three varieties to gamma treatments in producing chlorophyll and viable mutations as measured by frequency (%) was in the following pattern:

For chlorophyll mutations

(i) On the basis of segregation progeny:

BSi1	>BSi467	>BSi427
(620.02)	(583.18)	(486.28)

(ii) On M_2 plants basis:

BSi1	>BSi427	>BSi467
(46.36)	(40.31)	(30.22)

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For viable mutations

(i) On the basis of segregation progeny:

BSi1 > BSi427 > BSi467

(412.96) (301.86) (274.44)

(ii) On M_2 plants basis:

BSi1 > BSi467 > BSi427

(21.34) (16.30) (12.84)

The chlorophyll and viable spectra in the present investigation as measured by the frequency (%) were in the following order:

Chlophyll spectrum

(i) On the basis of segregating progeny:

Varieties	Spectrum (%)					
BSi1	Tigrina>	Viridis>	Xantha>	Striata>	Albina >	Alboviridis
	(557.74)	(193.18)	(159.59)	(83.04)	(9.17)	(0.00)
BSi427	Tigrina>	Viridis>	Xantha>	Striata>	Albina >	Alboviridis
	(380.46)	(112.15)	(52.95)	(31.10)	(20.41)	(0.87)
BSi467	Tigrina>	Viridis>	Xantha>	Striata>	Albina >	Alboviridis
	(518.84)	(185.38)	(48.75)	(19.17)	(6.46)	(1.00)

(ii) On M_2 plants basis:

BSi1	Tigrina>	Xantha>	Viridis>	Striata>	Albina >	Alboviridis
	(26.61)	(10.77)	(7.15)	(0.99)	(0.81)	(0.00)
BSi427	Tigrina>	Viridis>	Xantha>	Albina>	Striata >	Alboviridis
	(28.25)	(4.76)	(3.77)	(3.10)	(0.45)	(0.03)
BSi467	Tigrina>	Viridis>	Xantha>	Albina>	Striata >	Alboviridis
	(21.91)	(5.47)	(1.23)	(0.88)	(0.74)	(0.01)

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Viable Spectrum

(i) On the basis of segregating progeny:

Varieties	Spectrum			
BSi1	ColouredM	>Panicle M	>Maturity M	>Stature M
	(271.56)	(80.78)	(76.91)	(44.49)
BSi427	ColouredM>	Stature M>	Panicle M>	Maturity M
	(151.96)	(115.28)	(106.98)	(43.01)
BSi467	ColouredM>	Panicle M>	Stature M>	Maturity M
	(171.37)	(120.38)	(97.33)	(1.75)

(ii) On M_2 Plants basis:

BSi1	ColouredM>	Maturity M>	Panicle M>	Stature M
	(10.09)	(6.97)	(2.63)	(1.68)
BSi427	Stature M>	Coloured M>	Panicle M>	Maturity M
	(4.41)	(4.29)	(3.42)	(0.75)
BSi467	ColouredM>	Panicle M>	Stature M>	Maturity M
	(6.99)	(4.9)	(2.83)	(0.22)

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4.3. M_3 generation

Studies in M_3 generation were confined to (i) Study of micro mutations, (ii) breeding behavior of macro mutatnts and (iii) evaluation of useful macro mutants.

4.3.1. Micromutation

Variability for polygenic characters such as (i) days to panicle emergence, (ii) plant height, (iii) panicle length, (iv) number of tillers, (v) days to maturity, (vi) grain yield per plant, and (vii) 1000-grain weight was studied in all the three varieties. The data collected were subjected to statistical analysis for range, mean, standard deviation, coefficient of variation, skewness and Kurtosis for all the characters in different treatments. Frequency curves were also drawn with appropriate class intervals. The results are presented below in Tables 43-67.

The ANOVA (Table 43) shows that differences due to varieties were highly significant for all the characters. Except for days to flowering and number of effective tillers, all dosages of gamma radiation differed significantly in bringing about changes in the above characters; their interactions were also found significant. Tables 44-46 show that effects of mutagenic dosages were different in the three varieties. It is evident from Table 44 that only 50 Kr in BSi1 and 70 Kr in BSi427 decreased flowering time. In respect of plant height except two lower dosages of 10 and 20 Kr, the mean plant height decreased at all other dosages in BSi1. All dosages decreased mean plant height in BSi427, whereas all dosages increased mean plant height in BSi467 (Table 45). In case of panicle length except at 70 Kr, all dosages increased panicle length in BSi1 and except 10 and 30 Kr, all other dosages increased panicle length in BSi467, whereas in BSi427 except the lowest dosage of 10 Kr and the second highest dosage of 70 Kr, all other dosages decreased the panicle length (Table 45). All the dosages of the mutagen did not increase substantially the mean effective tiller number in the three varieties (Table 45). Table 46 shows that lower dosages of 10, 20 and 30 Kr increased the mean grain yield but none of the dosages increased the mean grain weight in BSi1. In BSi427 all the dosages decreased the mean of both grain yield and grain weight. In BSi467 none of the dosages increased grain yield. However, except 40 and 50 Kr, all dosages increased the mean grain weight.

Table 43. ANOVA for different quantitative characters of gamma irradiated materials of three varieties, BSi1, BSi427, and BSi467 of foxtail millet in M_3 generation.

Source of variation	df	Mean Sum of squares						
		Days to flowering	Days to maturity	Plant height (cm)	Panicle length(cm)	Number of tillers per plant	500 grain weight (gm)	Yield per plant (gm)
Replications	2	23.925	0.121	48.588	3.065	0.022	0.000	0.697
Varieties	2	488.614**	993.260**	5188.114**	35.384**	0.113*	0.519**	58.413**
Error (A)	4	18.549	0.287	22.701	0.589	0.011	0.000	0.298
Mutagen dosages (B)	7	20.228	0.467**	87.695**	1.156**	0.009	0.002**	2.158**
Variety X Dosage(AXB)	14	25.192	0.256**	27.486**	1.645**	0.007	0.001**	1.299**
Error (b)	42	21.825	0.062	6.186	0.305	0.005	0.000	0.414
CV(%)		5.33	0.21	2.57	4.12	6.43	1.72	16.75

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)

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Table 44. Effect on days to maturity and flowering of three varieties, BSi1, BSi427 and BSi467 of foxtail millet following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	BSi1		BSi427		BSi467	
	Days to flowering	Days to maturity	Days to flowering	Days to maturity	Days to flowering	Days to maturity
0 (control)	84.76	114.14	86.34	118.97	91.78	126.51
10	84.63	114.30	85.89	118.83	91.86	126.82
20	85.05	114.48	86.87	119.32	91.70	126.75
30	85.22	114.09	88.49	119.83	92.58	127.21
40	84.32	114.43	88.80	119.64	92.90	126.95
50	71.93	114.36	87.92	119.27	92.81	127.35
60	85.12	114.42	88.50	119.79	92.59	127.34
70	86.12	114.34	85.88	119.23	92.98	127.81

	Days to flowering	Days to maturity
LSD(0.01)	-	0.548
CV(%)	5.33	0.21

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Table 45. Effect on plant height, panicle length and tiller number of three varieties, BSi1, BSi427 and BSi467 of foxtail millet following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	BSi1			BSi427			BSi467		
	Plant height (cm)	Panicle length (cm)	Tiller No.	Plant height (cm)	Panicle length (cm)	Tiller No.	Plant height (cm)	Panicle length (cm)	Tiller No.
0 (control)	97.81	11.99	1.33	89.40	14.86	1.08	108.3	12.56	1.01
10	99.91	12.48	1.43	89.02	15.53	1.06	114.6	12.45	1.05
20	97.89	12.18	1.78	85.48	14.49	1.02	119.5	13.75	1.07
30	96.82	12.07	1.10	80.05	13.90	1.03	110.8	12.38	1.00
40	94.72	12.71	1.09	80.35	13.43	1.07	108.6	13.62	1.02
50	89.08	12.62	1.15	78.98	14.51	1.08	109.2	13.72	1.02
60	90.70	12.11	1.33	79.95	14.49	1.01	114.2	14.14	1.02
70	92.87	11.49	1.11	82.02	15.87	1.03	114.0	14.58	1.01

	Plant height	Panicle length	Tiller number
LSD(0.010)	5.479	1.217	--
CV(%)	2.57	4.12	6.43

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Table 46. Effect on grain yield and grain weight of three varieties, BSi1, BSi427 and BSi467 of foxtail millet following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	BSi1		BSi427		BSi467	
	Grain yield (gm)	Grain weight (gm)	Grain yield (gm)	Grain weight (gm)	Grain yield (gm)	Grain weight (gm)
0 (control)	2.99	0.84	8.47	1.18	3.40	0.95
10	3.26	0.80	5.64	1.14	3.10	0.96
20	3.01	0.83	5.76	1.10	3.15	0.99
30	3.10	0.81	5.05	1.08	2.83	0.97
40	2.98	0.82	4.66	1.08	2.86	0.93
50	2.77	0.80	4.87	1.08	3.02	0.95
60	2.67	0.82	5.15	1.09	2.66	0.96
70	2.95	0.82	5.57	1.13	2.36	0.96

	Yield per plant (gm)	Grain weight (gm)
LSD(0.01)	1.417	0.022
CV(%)	16.75	1.72

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(i) Days to panicle emergence : Gamma radiation delayed flowering in the three varieties. Mean and variability for panicle emergence in three varieties are presented in Tables 47,48 and 49.

Range : In BSi1 the range was 81.0 - 93.0 days in control; the range reduced towards negative direction in all the treatments (Table 47).

In BSi427 the range in control was 67.0 - 93.0 days; the range in all the mutagenic treatments was below the level of control (Table 48).

Table 49 shows that in BSi467 gamma treatments practically did not increase the range for days to panicle emergence compared to control (88.0 - 95.0 days).

Mean : In BSi1 the mean number of days for panicle emergence was 84.77 in control, the flowering delayed in all the mutagenic treatments. However, at lower dosages of 10 and 40 Kr the flowering took place earlier compared to the control (Table 47).

In BSi427 the mean days to panicle emergence was 86.34 in control. Except the lowest dosage of 10 Kr and the second highest dosage of 70 Kr all mutagenic treatments delayed flowering time. At 10 and 70 Kr the mean shifted to the negative side that is the flowering took place earlier compared to the control (Table 48).

In BSi467 the mean days to panicle emergence was 91.78 in control. Except the dosage of 20 Kr all the mutagenic treatments delayed flowering time. At 20 Kr flowering took place earlier compared to the control (Table 49).

Standard deviation and CV : *Standard deviation and CV increased in the irradiated* populations of all the three varieties.

In BSi1 except at 10 Kr, both standard deviation and CV increased in all the treatments. At 10 Kr both standard deviation and CV declined below the level of standard deviation (2.12) and CV (2.50) of control. The highest standard deviation and CV 3.14 and 4.00 respectively were at 50 Kr (Table 47).

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In BSi427 standard deviation in control was 3.72. The highest standard deviation and CV recorded as 4.13 and 4.67 respectively were at 60 Kr (Table 48).

In BSi467 except at 10 and 70 Kr, standard deviation and CV increased (Table 49).

Frequency distribution (skewness and kurtosis) : In BSi1 the skewness of the frequency distribution for days to panicle emergence (Table 47) shows that except 10 Kr, almost all mutagenic treatments were moderately positive skewed in comparison to highly positive skewed distribution of control. The positive skewness values indicate that except 10 Kr, all the treatments including control tended to induce early flowering. The kurtosis value of control was also higher than that of all other mutagenic treatments and highly leptokurtic indicating more concentration of data of the character around mean. Similar trend was noticed at 20 Kr. Most of the mutagenic treatments followed platykurtic distribution (Fig. 15).

In BSi427 the highly negative skewed distribution of control, moderately negative skewed distribution of the treatment of 60 Kr and slightly negative skewed distribution of the treatments of 30 and 40 Kr indicate the tendency of the treatments towards late flowering. The positive skewness values of the treatments of 10, 20, 50 and 70 Kr indicate the tendency towards early flowering (Table 48). The kurtosis value of control was higher than that of all other mutagenic treatments and highly leptokurtic indicating the higher concentration of data for the character around the mean. Most of the mutagenic treatments followed platykurtic distribution (Fig. 16).

In BSi467 the skewness was slightly negative in control and less than that of all other mutagenic treatments indicating tendency to late flowering. The positive skewed distribution shows that all the mutagenic treatments tended to early flowering (Table 49). The kurtosis values show that all the mutagenic treatments and control followed leptokurtic distribution. The higher kurtosis values of the control and the treatment of 20 Kr indicate the higher concentration of the data of the character around the mean (Fig. 17).

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Table 47. Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for days to panicle emergence in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Days to panicle emergence					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	81.00 -93.00	84.77±0.22	2.12	2.50	0.99	2.34
10	80.00 -89.00	84.63±0.19	1.79	2.12	-0.33	0.02
20	80.00 -92.00	85.06±0.23	2.17	2.55	0.68	1.55
30	81.00 -90.00	85.22±0.24	2.23	2.62	0.13	-0.34
40	78.00 -90.00	84.32±0.28	2.65	3.14	0.01	-0.03
50	79.00 -91.00	85.27±0.36	3.41	4.00	0.13	-0.93
60	79.00 -91.00	85.12±0.33	3.15	3.70	0.09	-0.54
70	82.00 -91.00	86.12±0.23	2.17	2.52	0.56	0.23

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Table 48. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to panicle emergence in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Days to panicle emergence					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0	67.00 - 93.00	86.34±0.39	3.72	4.31	-1.35	7.37
10	80.00 - 95.00	85.89±0.34	3.26	3.80	0.52	0.30
20	81.00 - 95.00	86.87±0.36	3.38	3.89	0.68	0.23
30	80.00 - 95.00	88.49±0.41	3.90	4.41	-0.05	-0.82
40	81.00 - 94.00	88.80±0.37	3.51	3.95	-0.07	-1.03
50	79.00 - 94.00	87.92±0.41	3.84	4.37	0.06	-0.76
60	80.00 - 95.00	88.50±0.44	4.13	4.67	-0.29	-1.03
70	80.00 - 94.00	85.88±0.39	3.69	4.30	0.50	-0.51

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Table 49. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to panicle emergence in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Days to panicle emergence					
	Range	Mean±SE	Standard deviation	Co-efficient of variation	Skewness	Kurtosis
0 (control)	88.00 - 95.00	91.78±0.13	1.24	1.35	- 0.14	2.37
10	89.00 - 96.00	91.86±0.13	1.27	1.38	1.02	1.43
20	89.00 - 95.00	91.70±0.13	1.19	1.30	0.61	2.04
30	90.00 - 98.00	92.58±0.16	1.53	1.65	1.13	1.43
40	89.00 - 98.00	92.90±0.17	1.63	1.75	0.90	1.36
50	89.00 - 97.00	92.81±0.13	1.26	1.36	0.26	1.18
60	89.00 - 97.00	92.59±0.15	1.42	1.53	0.55	0.88
70	91.00 - 97.00	92.98±0.13	1.24	1.33	0.63	1.10

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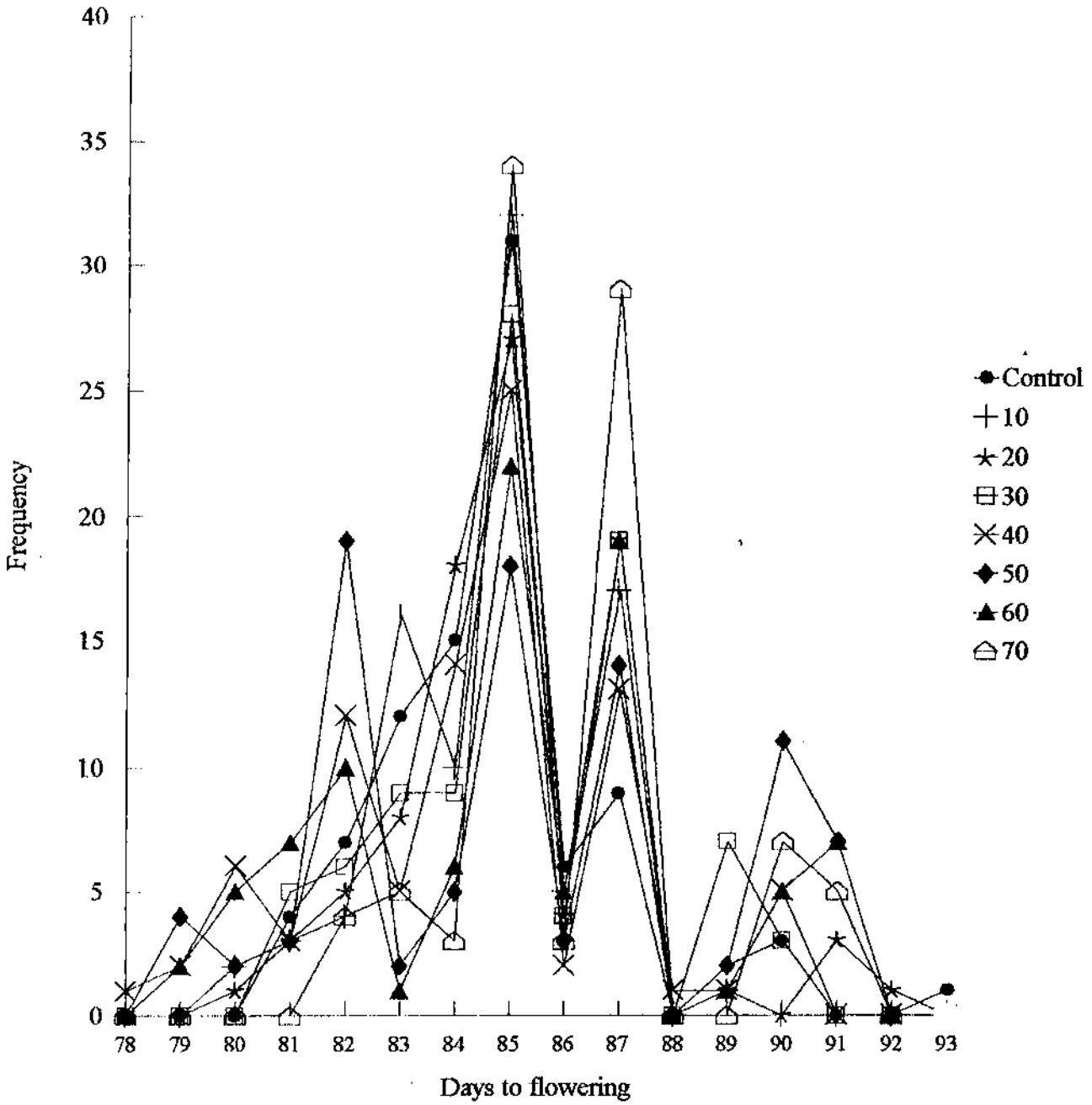

Fig. 15. Frequency curves of induced variability for days to flowering in BSi1.

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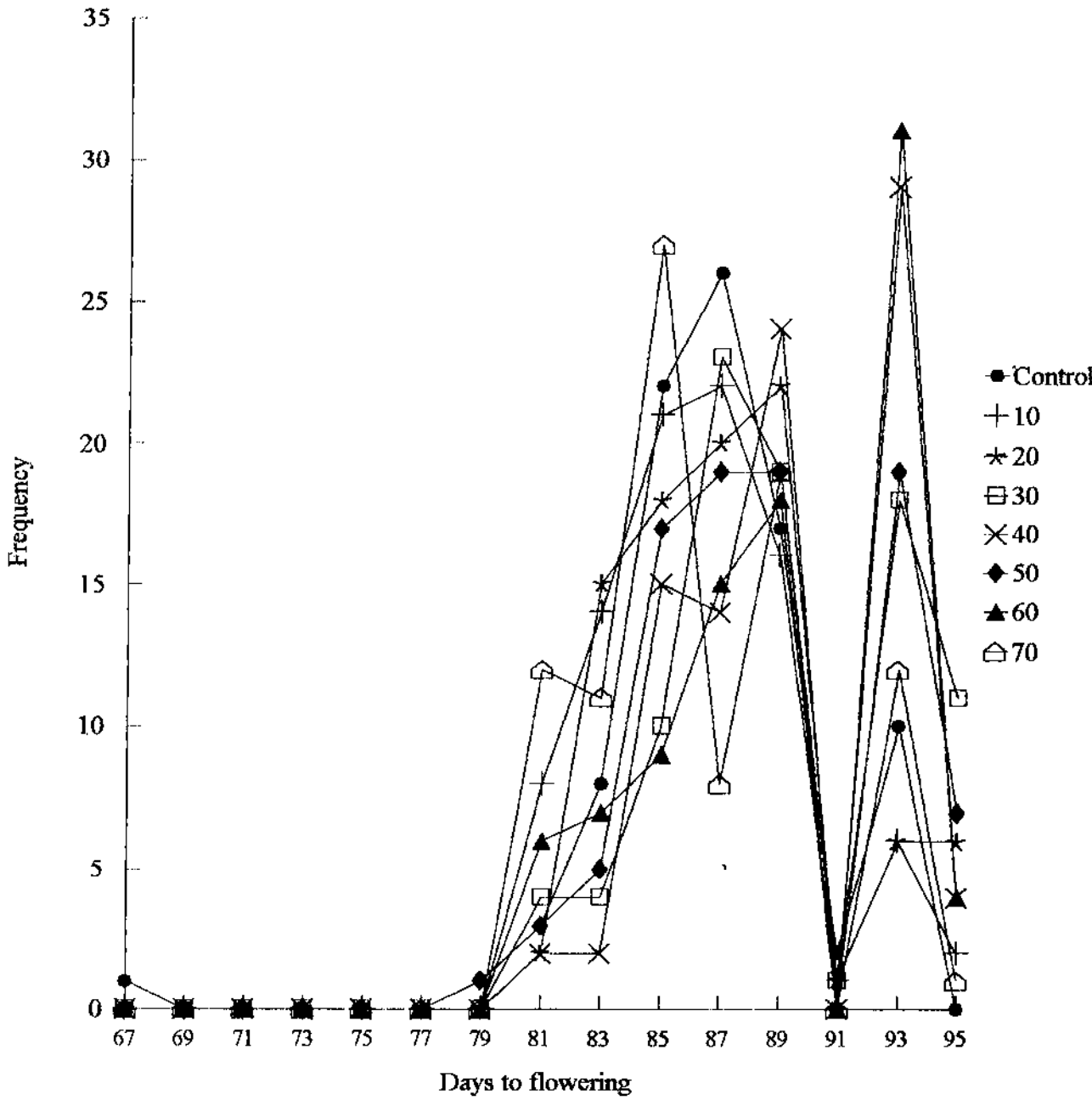

Fig.16. Frequency curves for induced variability for days to flowering in BSi427.

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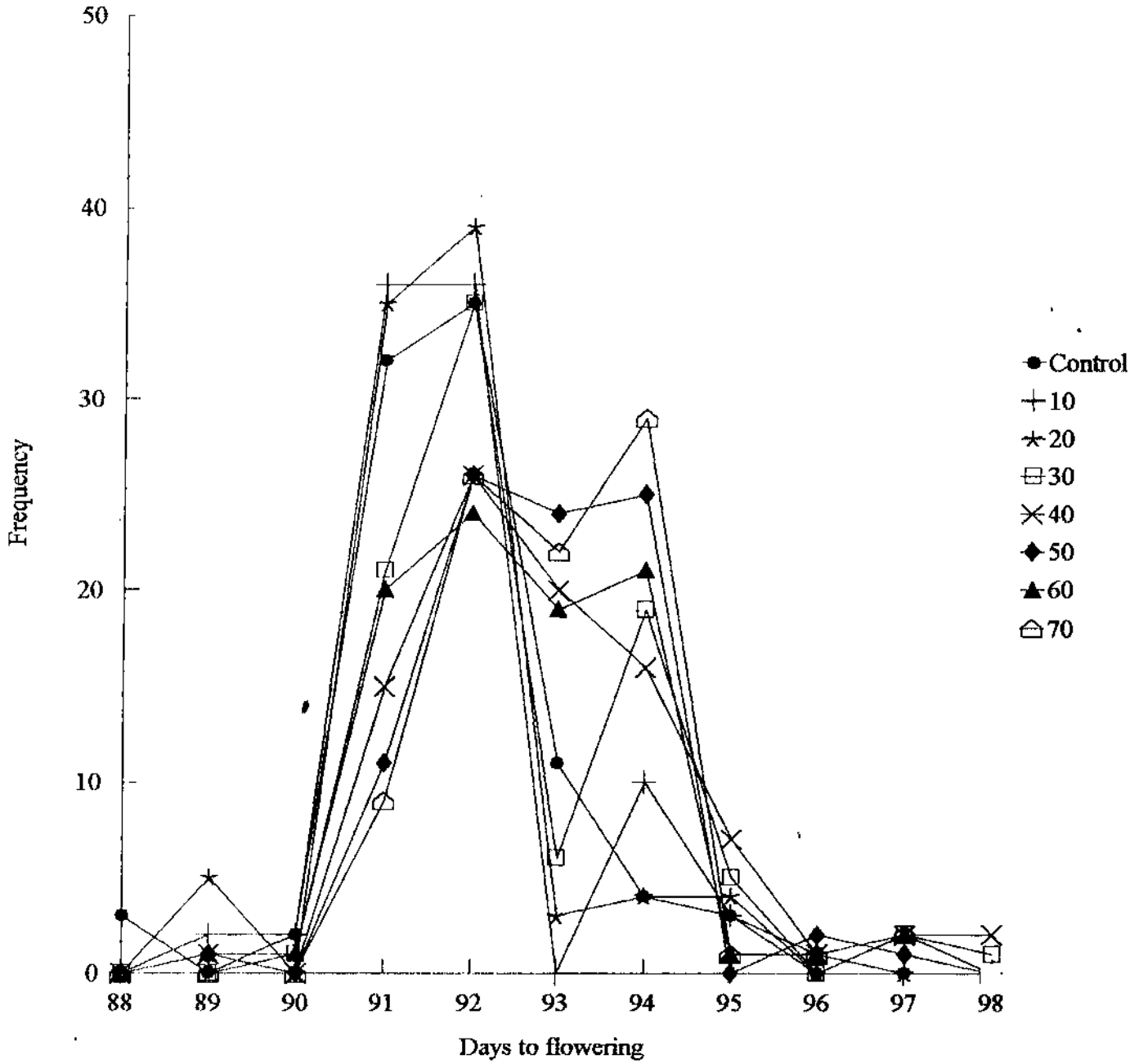

Fig.17. Frequency curves of induced variability for days to flowering in BSi467.

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(ii) Plant height : The three varieties differed in their response to gamma treatment. *High variation was observed for this character.* Mean, range, standard deviation , coefficient of variation skewness and kurtosis are presented in Tables 50 - 52.

Range : *In BSi1 the range was not wide in all the treatments* as compared to the control. Except 40 Kr, the range shifted towards positive direction in all the treatments. At 40 Kr the height ranged from 60 cm to 121 cm and shifted in both the derections (Table 50).

In BSi427 the range shifted in both positive and negative directions in different dosages, the highest enlargement was at 30 Kr. The height at 30 Kr ranged from 30.0 to 100.0 cm (Table 51).

In BSi467 the range shifted only in positive direction in all the treatments. In control the range was from 78.0 to 127.0 cm; the range enlarged maximum at 60 Kr in which the height ranged from 88.0 to 150.0 cm (Table 52).

Both tall and short plants were obtained in all the three varieties due to positive and negative shifting in the range.

Mean : The mean values shifted towards negative direction in most of the treatments in BSi1, in all most all the treatments in BSi427 and towards positive direction in all the *treatments in BSi467.*

In BSi1 the mean height ranged from 89.08 to 99.91 cm in different treatments compared *to 97.81 cm in control. Except 10 and 20 Kr, gamma radiation* reduced mean plant height in all the mutagenic treatments. At 10 and 20 Kr the mean height was 99.91 and 97.81 cm respectively (Table 50).

In BSi427 all the mutagenic treatments reduced the mean plant height which ranged from 78.98 to 89.02 cm in different treatments compared to 89.40 cm in control (Table 51).

In BSi467 all the mutagenic treatments increased mean plant height which ranged from 108.57 to 119.51 cm in different treatments compared to 108.30 cm in control. The maximum increase in mean height was at 20 Kr (Table 52).

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Standard deviation and coefficient of variation : In each variety compared to control both standard deviation and CV for plant height increased considerably in most of the treatments. This increased variability indicates that a significant improvement of the character would be achieved through proper selection method.

In BSi1 except at 10 and 60 Kr, both standard deviation and CV increased substantially at all dosages. Maximum standard deviation recorded as 11.93 and CV as 12.60 were at 40 Kr (Table 50).

In BSi427 except 30 and 70 Kr, most of the mutagenic treatments show decrease in standard deviation. At 30 and 70 Kr the above parameter was 10.20 and 9.21 respectively compared to standard deviation recorded as 8.98 in control. Compared to CV as 10.04 in control the highest CV recorded as 12.74 was at 30 Kr (Table 51).

In BSi467 except 20 and 40 Kr, both standard deviation and CV decreased in all the treatments. The highest standard deviation recorded as 13.44 and CV as 12.38 were at 40 Kr (Table 52).

Frequency distribution (skewness and kurtosis) : In BSi1 the skewness of the frequency distribution for plant height shows that except 10 Kr, frequencies of all other treatments were less skewed than control. The negative skewness values of most of the mutagenic treatments and control indicate the tendency to increase the plant height. On the otherhand, the positive skewness values of 50, 60 and 70 Kr indicate the tendency to decrease the plant height as data for plant height concentrated to the side of lower values (Table 50). The kurtosis value of control (1.96) was higher than all other mutagenic treatment and leptokurtic. The negative kurtosis values of most of the treatments except 10, 30 and 40 Kr indicate the platykurtic distribution of plant height (Fig. 18).

In BSi427 skewness of the frequency distribution in control and in most of the mutagenic treatments were moderately positive indicating the tendency of the treatments to decrease the plant height. The treatment 20 and 30 Kr show negatively skewed distribution indicating the tendency to the increase of the plant height (Table 51). Kurtosis values show that most of the mutagenic treatments followed leptokurtic distribution. The treatment 60 Kr and control followed platykurtic distribution. The higher kurtosis value of

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Table 50. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for plant height in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Plant height (cm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	62.00-116.00	97.81±0.92	8.76	8.96	-0.69	1.96
10	74.00-117.00	99.91±0.86	8.15	8.16	-0.77	0.53
20	75.00-120.00	97.89±1.00	9.49	9.69	-0.003	-0.31
30	66.00-120.00	96.82±1.09	10.31	10.65	-0.22	0.21
40	60.00-121.00	94.72±1.26	11.93	12.60	-0.29	0.29
50	70.00-108.00	89.08±0.96	9.08	10.19	0.12	-0.65
60	75.00-109.00	90.70±0.81	7.65	8.43	0.10	-0.80
70	75.00-113.00	92.87±0.99	9.37	10.09	0.08	-0.83

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Table 51. Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for plant height (cm) in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Plant height (cm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	71.00-110.00	89.40±0.95	8.98	10.04	0.18	-0.46
10	74.00-112.00	89.02±0.76	7.23	8.12	0.66	0.95
20	58.00-107.00	85.48±0.95	8.97	10.49	-0.14	0.21
30	30.00-100.00	80.04±1.08	10.20	12.74	-1.50	5.66
40	62.00-114.00	80.34±0.88	8.34	10.38	0.92	2.67
50	54.00-103.00	78.98±0.90	8.50	10.76	0.07	0.63
60	62.00-100.00	79.94±0.79	7.48	9.36	0.15	-0.16
70	61.00-110.00	82.02±0.97	9.21	11.23	0.20	0.28

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Table 52. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for plant height (cm) in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Plant height (cm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation	Skewness	Kurtosis
0 (control)	78.00 - 127.00	108.30±1.18	11.18	10.32	-0.51	-0.31
10	93.00 - 141.0	114.58±1.11	10.49	9.16	0.35	-0.45
20	95.00 - 138.0	119.51±1.18	11.21	9.38	-0.25	-0.96
30	87.00 - 130.0	110.77±1.04	9.90	8.94	-0.16	-0.69
40	88.00 - 130.0	108.57±1.42	13.44	12.38	-4.33	30.87
50	91.0 - 131.0	109.17±0.94	8.92	8.17	0.36	-0.15
60	96.0 - 135.0	114.18±0.93	8.80	7.71	0.19	-0.41
70	88.0 - 150.0	114.00±1.15	10.88	9.54	0.55	0.36

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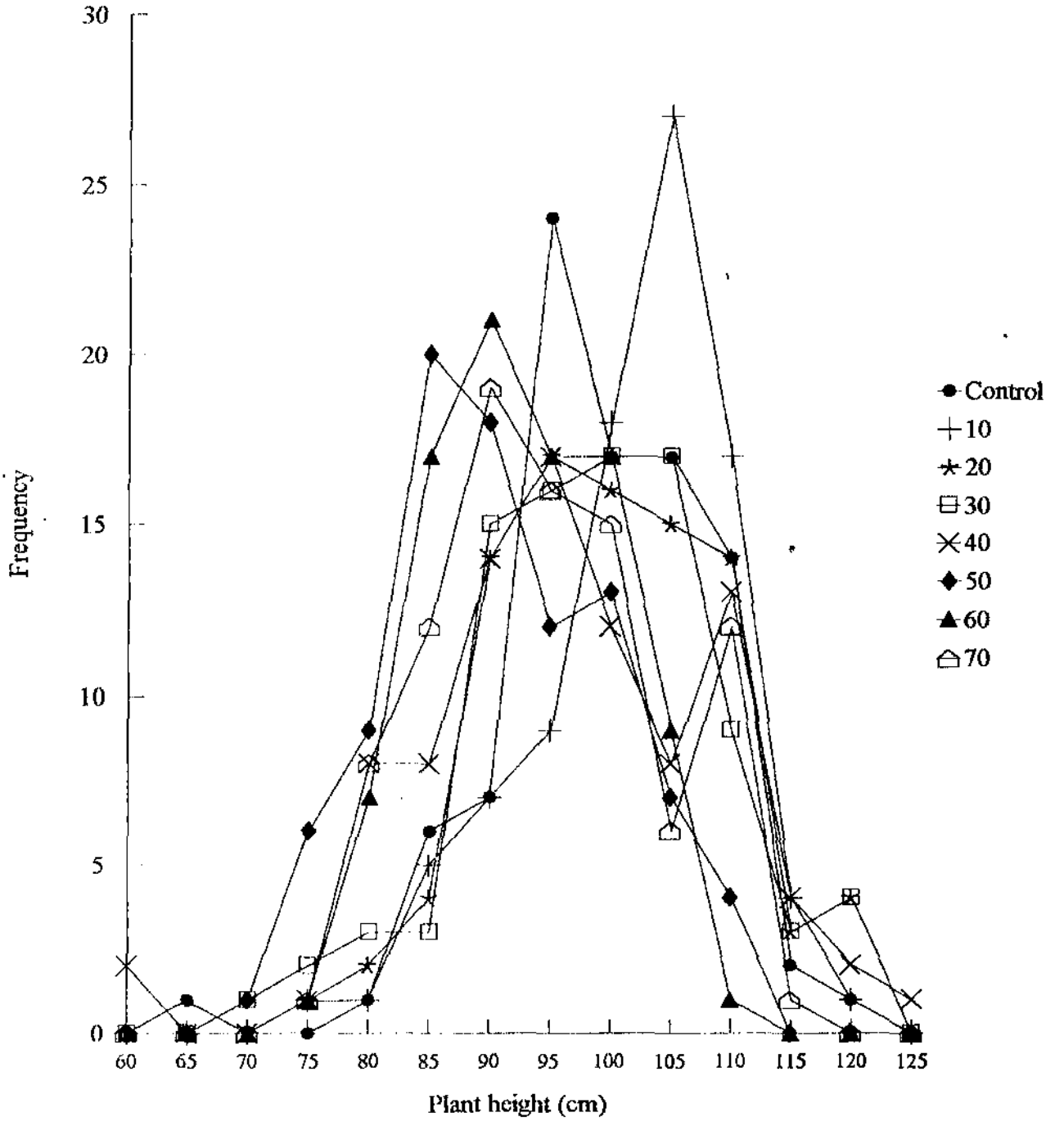

Fig.18. Frequency curves of induced variability for plant height in BSi1.

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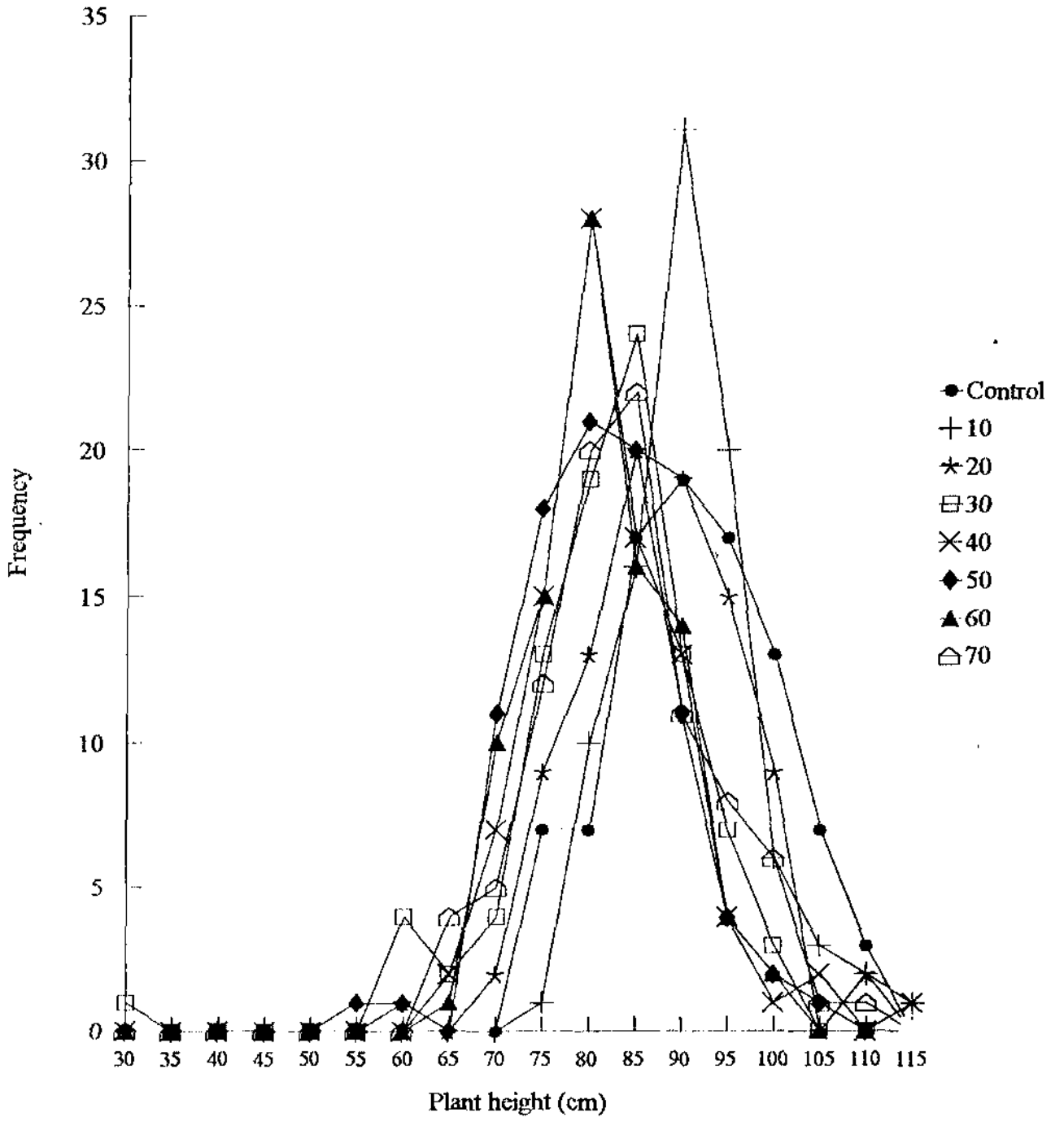

Fig.19. Frequency curves of induced variability for plant height in BSi427.

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the treatment 30 Kr (5.66) and of the treatment 40 Kr (2.67) indicate more concentration of data around the mean (Fig. 19).

In BSi467 the negative skewness of the treatments 20,30 and 40 Kr and control indicate the tendency of the treatments to increase the plant height. The positive skewed distribution of the treatments of 10, 50, 60 and 70 Kr indicate their tendency to decrease the plant height (Table 52). Most of the mutagenic treatments including control show platykurtic distribution. The kurtosis value of the treatment of 40 Kr (30.87) indicates the highly leptokurtic distribution of plant height and more concentration of the data around the mean (Fig. 20).

(iii) Panicle length : With respect to panicle length the three varieties showed different response to gamma radiation. Mean, range, standard deviation, kurtosis and skewness are presented in Tables 53-55.

Range : The range in most of the mutagenic treatments of the three varieties was wider than that of the control. It shifted in both the directions in two varieties and only in positive direction in one variety.

In BSi1 range shifted in positive direction only. The range in control was 6.0 to 18.0 cm; the highest range recorded from 9.0 to 21.0 cm was at 10 Kr (Table 53).

In BSi427 except at 30 and 40 Kr, the range shifted towards positive direction in all the treatments but did not exceed the upper level of range in control. At 30 and 40 Kr the range shifted in both the direction (Table 54).

In BSi467 the range was wider compared to control and shifted towards positive direction at the higher dosages of 50, 60, and 70 Kr. The range in control was 10.0 to 18.0 cm; it enlarged maximum 9.0 to 24.0 cm at 20 Kr (Table 55).

Mean : In BSi1 except the second highest dosage of 70 Kr, the panicle length increased substantially in all the mutagenic treatments. At 70 Kr compared to 11.99 cm in control the panicle length was 11.49 cm (Table 53).

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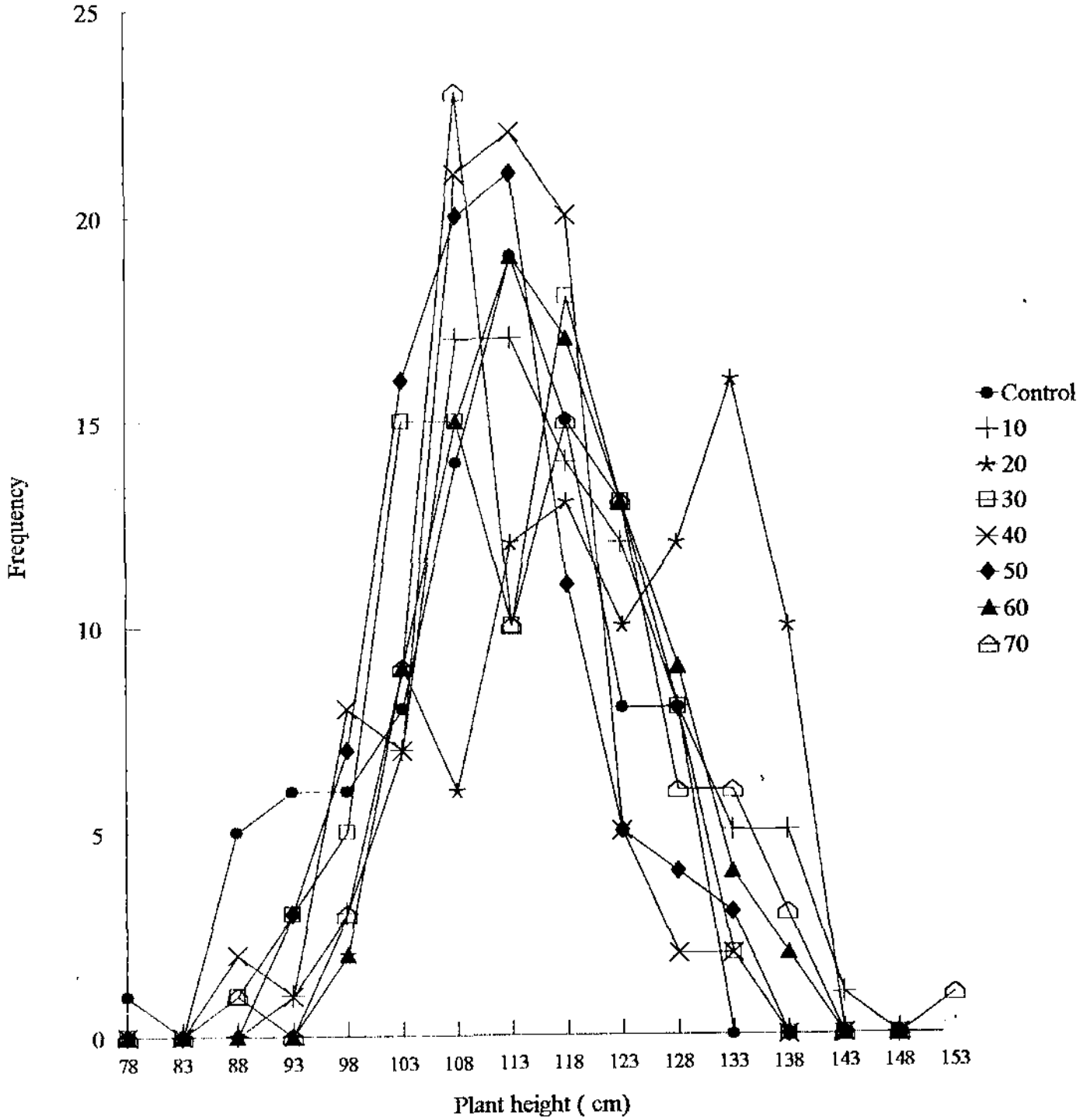

Fig.20. Frequency curves of induced variability for plant height in BSi467.

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In BSi427 panicle length increased only at lower and higher dosages of gamma treatment. The highest mean panicle length recorded as 15.87 cm was at 70 Kr. All other mid level dosages decreased the panicle length (Table 54).

In BSi467 except 10 and 30 Kr, mean panicle length increased in all the treatments. The highest mean panicle length recorded as 14.58 cm was at the second highest dosage of 70 Kr compared to 12.56 cm in control (Table 55).

Standard deviation and coefficient of variation : Compared to control increase as well as decrease in standard deviation and CV for panicle length following gamma irradiation was observed in the three varieties.

In BSi1 most of the mutagenic treatments showed decrease in standard deviation and CV compared to control. In control standard deviation and CV were recorded as 2.25 and 18.76 respectively; the above parameters decreased at lower dosages. The highest standard deviation recorded as 2.76 and the highest CV as 21.87 were at 50 Kr (Table 53)

In BSi427 the highest standard deviation recorded as 3.42 was at 70 Kr and CV as 22.43 was at 20 Kr compared to standard deviation recorded as 3.10 and CV as 20.86 in control (Table 54).

In BSi467 both standard deviation and CV increased in all the mutagenic treatments. Compared to standard deviation recorded as 1.81 and CV as 14.41 in control, the highest standard deviation was recorded as 2.68 at 20 Kr while the highest CV of 19.66 was at 10 Kr (Table 55).

Frequency distribution (skewness and kurtosis) : In BSi1 the skewness of frequency distribution for panicle length at 10 and 40 Kr were higher than control. Except 70 Kr, frequency distribution of all the mutagenic treatments were positively skewed indicating their tendency to decrease the character. The slight negative skewness value of 70 Kr indicate its tendency to increase the character (Table 53). The kurtosis values of the treatments of 10 and 40 Kr were higher than control and followed leptokurtic distribution

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Table 53. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for Panicle length in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Panicle length (cm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	6.00-18.00	11.99±0.24	2.25	18.76	0.64	1.04
10	9.00-21.00	12.48±0.24	2.23	17.95	1.02	2.46
20	8.00-17.00	12.18±0.23	2.17	17.90	0.44	-0.22
30	8.00-18.00	12.07±0.21	1.98	16.40	0.30	0.20
40	8.00-21.00	12.71±0.25	2.38	18.73	0.87	1.61
50	7.00-20.00	12.62±0.29	2.76	21.87	0.35	-0.19
60	8.00-17.00	12.11±0.24	2.29	18.91	0.23	-0.64
70	7.00-16.00	11.49±0.20	1.87	16.28	-0.01	-0.52

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Table 54. Range, mean, standard deviation, Coefficient of variation, skewness and kurtosis for panicle length (cm) in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Panicle length (cm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	9.00 - 29.00	14.86±0.33	3.10	20.80	1.12	3.77
10	*9.00 - 25.00*	*15.53±0.33*	*3.08*	*19.83*	*0.25*	*-0.02*
20	9.00 - 24.00	14.49±0.34	3.25	22.43	0.53	0.09
30	8.00 - 22.00	13.90±0.30	2.88	20.72	0.46	0.09
40	7.00 - 23.00	13.43±0.28	2.69	20.03	0.66	1.14
50	9.00 - 22.00	14.51±0.31	2.98	20.54	0.53	0.14
60	9.00 - 24.00	14.49±0.33	3.14	21.67	0.83	0.80
70	9.00 - 25.00	15.87±0.36	3.42	21.55	0.48	-0.29

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Table 55. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for panicle length (cm) in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Panicle length (cm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation	Skewness	Kurtosis
0 (control)	10.00 - 18.00	12.56±0.19	1.81	14.41	0.75	0.52
10	9.00 - 21.00	12.46±0.26	2.45	19.66	1.13	1.29
20	9.00 - 24.00	13.74±0.28	2.68	19.51	0.75	1.37
30	9.00 - 18.00	12.38±0.23	2.17	17.53	0.87	0.28
40	9.00 - 21.00	13.62±0.25	2.33	17.10	0.61	0.65
50	10.00 - 19.00	13.72±0.23	2.16	15.74	0.42	-0.45
60	10.00 - 19.00	14.14±0.22	2.06	14.57	0.20	-0.59
70	10.00 - 20.00	14.58±0.23	2.21	15.16	0.34	-0.50

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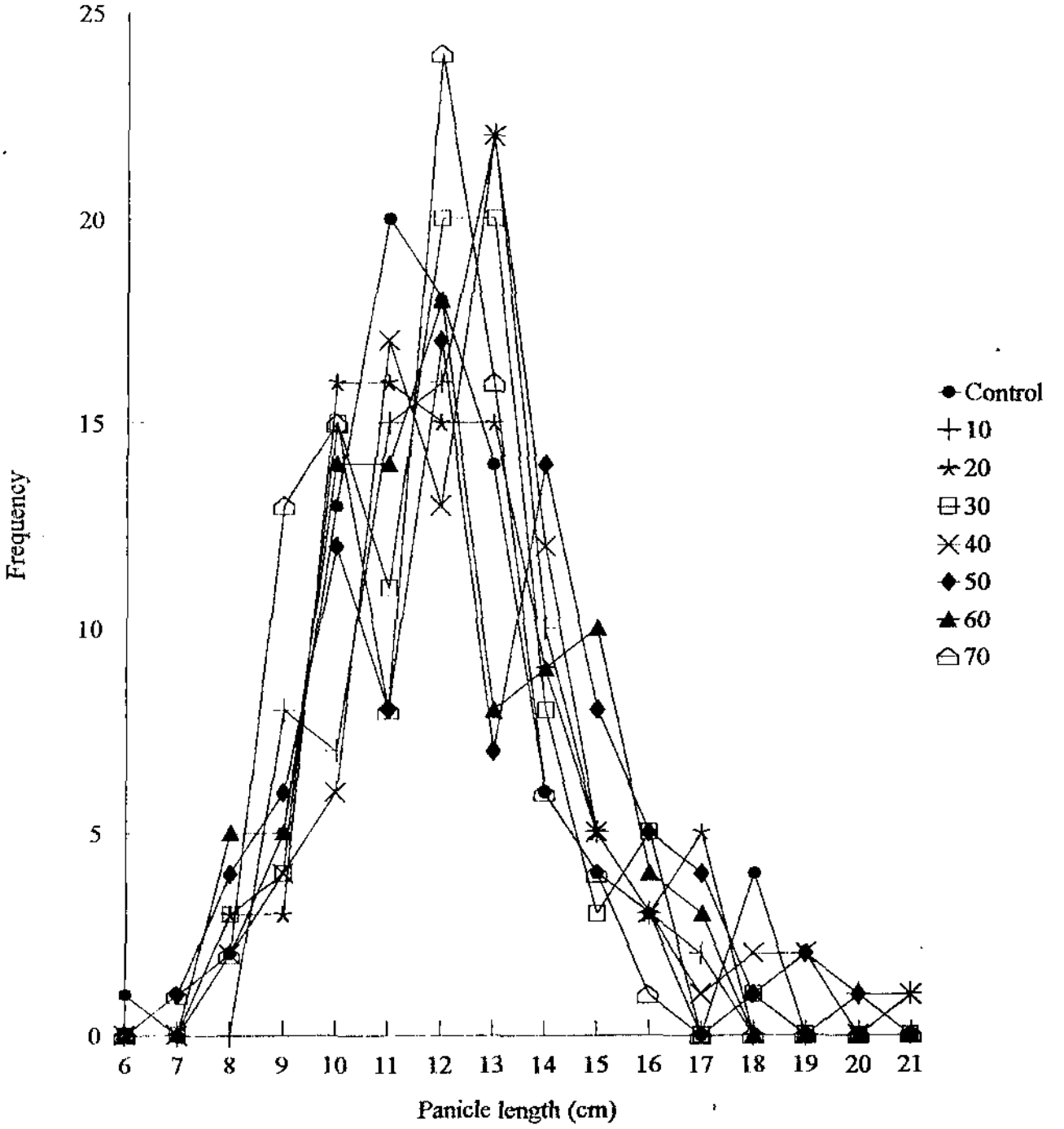

Fig. 21. Frequency curves of induced variability for panicle length in BSi1.

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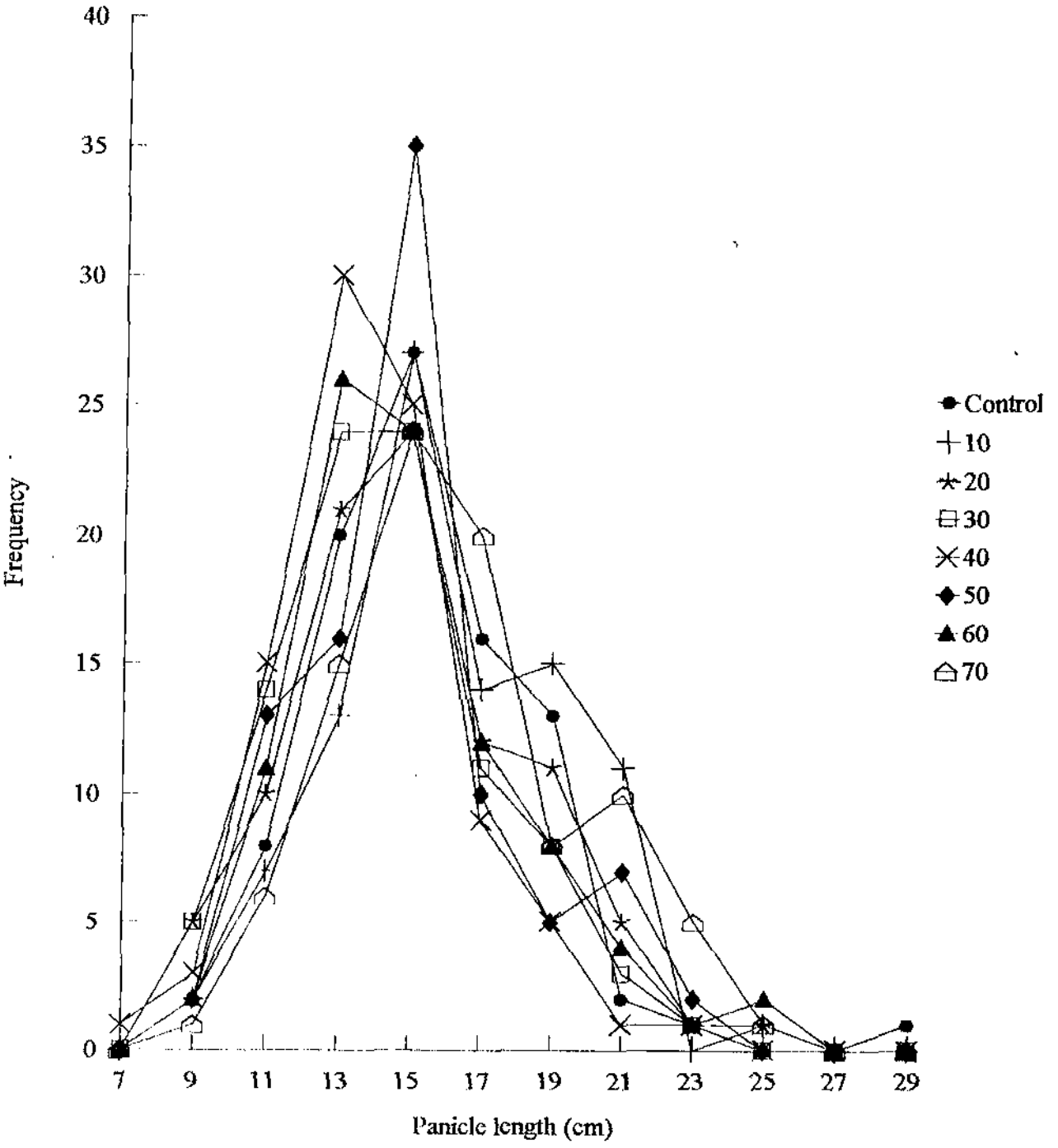

Fig.22. Frequency curves of induced variability for panicle length in BSi427.

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like control, 30 Kr also followed leptokurtic distribution. Besides, all other treatments followed platykurtic distribution (Fig. 21).

In BSi427 frequency distribution in control and in all the treatments show positive skewness The positive skewness indicates that all the mutagenic treatments and control tended to decrease the panicle length (Table 54). In control kurtosis was also higher than all other mutagenic treatments and followed leptokurtic distribution. The negative kurtosis values of 10 and 70kr indicate their platykurtic frequency distribution of panicle length (Fig. 22).

In BSi467 all the mutagenic treatments and control show positive skewness indicating their tendency to decrease the panicle length (Table 55). The positive kurtosis of the treatments of 10, 20, 30 and 40 Kr show that they followed leptokurtic distribution like control. The treatments of 50, 60 and 70 Kr followed platykurtic distribution (Fig. 23).

(iv) Number of Tillers : The mean tiller number did not increase in gamma irradiated populations in all the three varieties. Mean, range, standard deviation, CV, skewness and kurtosis are presented in Tables 56, 57 and 58.

Range : The range for tiller number was not wide in irradiated populations of all the three varieties compared to their respective controls. With a little exception, range of all the mutagenic treatments in the three varieties were below the level of parent.

In BSi1 the range for tiller number in control was 1.0 - 3.0; the range was followed by almost all mutagenic treatments except the dosage of 50 Kr. At 50 Kr the upper limit of range was 4.0 (Table 56).

In BSi427 the tiller number in control ranged from 1.0 to 4.0; the range was not exceeded by any range of the mutaganic treatments. The tiller number in different mutagenic treatments ranged from 1.0 to 3.0 (Table 57).

In BSi467 the range for tiller number in control was 1.0 to 2.0; the range was same in all the mutagenic treatments except the dosage 30 Kr. At 30 Kr population did not show potentiality for tillering (Table 58).

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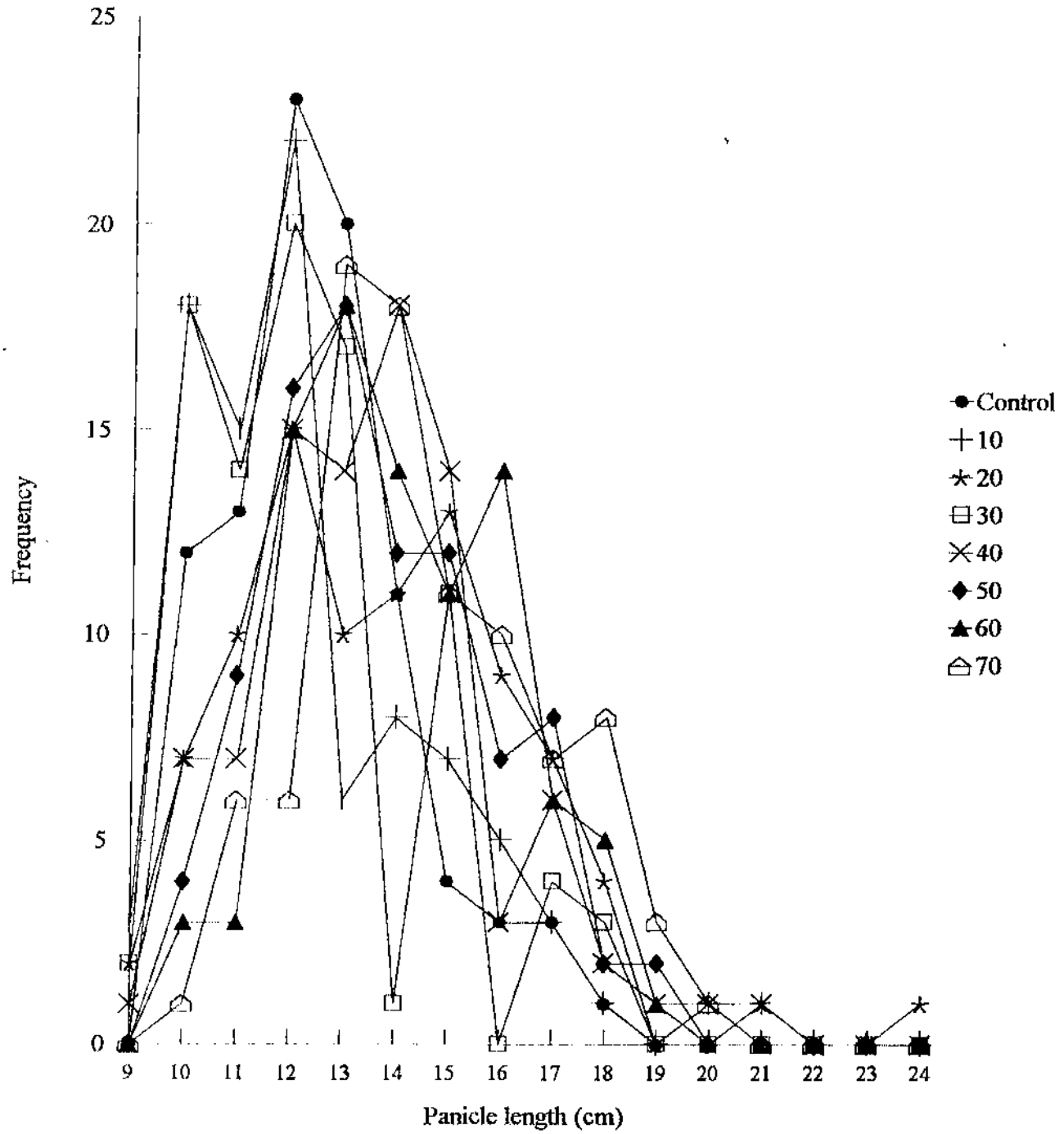

Fig.23. Frequency curves of induced variability for panicle length in BSi467.

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Mean : In BSi1 the mean tiller number per plant did not increase in all the mutagenic treatments. The mean tiller number per plant in control was 1.33; the tiller number ranged in different treatments from 1.09 at 40 Kr to 1.18 at 20 Kr (Table 56).

In BSi427 the mean tiller number per plant was not affected by gamma irradiation. The potentiality of all the treatments in producing tiller number was similar to control. Mean tiller number per plant in control was 1.08; the mean tiller ranged from 1.01 to 1.08 in different treatments (Table 57).

In BSi467 the mean tiller number per plant did not increase substantially following gamma irradiation. The mean tiller number per plant in control was 1.01; the tiller number ranged from 1.0 to 1.08 in different treatments (Table 58).

Standard deviation and CV : With respect to tiller number the three varieties differed in their response to gamma irradiation. In two varieties variation decreased, in other variety variation increased compared to their respective controls.

In BSi1 CV in control was 45.11. Both standard deviation and CV decreased in all mutagenic treatments compared to control (Table 56).

In BSi427 standard deviation and CV were recorded as 0.37 and 34.26 respectively in the control; the above two parameters decreased in all the mutagenic treatments (Table 57).

In BSi467 standard deviation and CV recorded as 0.11 and 10.89 respectively were in control. Except in the dosage of 30 Kr, both standard deviation and CV increased considerably in all the mutagenic treatments compared to control. At 30 Kr there was no deviation (Table 58).

Frequency distribution (skewness and kurtosis) : The skewness of the frequency distribution for tiller number in BSi1 shows that all the mutagenic treatments and control were positively skewed indicating their tendency to decrease the tillering capacity (Table 56). All the treatments like control followed leptokurtic distribution showing concentration of data around the mean.

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Table 56. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for tiller number in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Tiller number					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	1.00-3.00	1.33±0.06	0.60	45.11	1.63	1.61
10	1.00-3.00	1.14±0.04	0.38	33.33	2.65	6.73
20	1.00-3.00	1.18±0.04	0.41	34.75	2.19	4.15
30	1.00-3.00	1.10±0.04	0.34	30.91	3.57	13.35
40	1.00-2.00	1.09±0.03	0.29	26.61	2.94	6.78
50	1.00-4.00	1.14±0.05	0.49	42.98	3.93	16.84
60	1.00-3.00	1.13±0.05	0.43	38.05	3.37	10.99
70	1.00-3.00	1.11±0.04	0.35	31.53	3.29	11.14

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Table 57. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for tiller number in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Tiller number					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	1.00 - 4.00	1.08±0.04	0.37	34.26	6.16	43.42
10	1.00 - 2.00	1.06±0.02	0.23	21.70	3.95	13.88
20	1.00 - 2.00	1.02±0.02	0.15	14.71	6.59	42.41
30	1.00 - 2.00	1.03±0.02	0.18	17.48	5.29	26.59
40	1.00 - 3.00	1.07±0.04	0.33	30.84	5.21	27.33
50	1.00 - 3.00	1.08±0.04	0.34	31.48	4.71	22.57
60	1.00 - 2.00	1.01±0.01	0.11	10.89	9.49	90.00
70	1.00 - 2.00	1.03±0.02	0.18	17.48	5.29	26.55

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Table 58. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for tiller number in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Tiller number					
	Range	Mean±SE	Standard deviation	Coefficient of variation	Skewness	Kurtosis
0 (control)	1.00 - 2.00	1.01±0.01	0.11	10.89	9.49	90.00
10	1.00 - 2.00	1.06±0.02	0.23	21.70	3.95	13.88
20	1.00 - 2.00	1.08±0.03	0.27	25.00	3.21	8.47
30	1.00 - 1.00	1.00±0.00	0.00	0.00	0.00	0.00
40	1.00 - 2.00	1.02±0.02	0.15	14.71	6.59	42.41
50	1.00 - 2.00	1.02±0.02	0.15	14.71	6.59	42.41
60	1.00 - 2.00	1.02±0.02	0.15	14.71	6.59	42.41
70	1.00 - 2.00	1.01±0.01	0.11	10.89	9.49	90.00

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In BSi427 frequency distribution for tiller number shows that all the mutagenic treatments and control were positively skewed indicating their tendency to decrease the tillering capacity (Table 57). All the mutagenic treatments followed leptokurtic distribution like control indicating concentration of data around mean.

In BSi467 skewness of the frequency distribution for tiller number shows that all the mutagenic treatments including control were positively skewed indicating their tendency to decrease the tillering capacity (Table 58). Except 30 Kr, all the mutagenic treatments followed leptokurtic distribution indicating concentration of data around mean. The frequency distribution for tiller number at 30kr was mesokurtic indicating the data equal to mean

(v) Days to Maturity : Gamma radiation practically did not induce variability for the character in the three varieties. Mean and variability for days to maturity in the three varieties are presented in Tables 59-61.

Range : The range in control in three varieties. BSi1, BSi427 and BSi467 were 112.0 - 116.0, 117.0 -122.0 and 124.0 - 129.0 days respectively. Except at 10 Kr in BSi427 range was narrow and shifted only in positive direction in all the mutagenic treatments in the three varieties. At 10 Kr the range was in negative direction indicating its tendency to induce variability for the character.

Mean : The mean number of days for maturity in control of the three varieties, BSi1, BSi427 and BSi467 were 114.14, 118.97 and 126.51 respectively. There was no marked shift in mean in any treatments. Positive shift in mean of all the treatments indicate their tendency to late maturity compared to their control.

Standard deviation and CV : Both standard deviation and CV increased in all the mutagenic treatments in two varieties and in most of the mutagenic treatments in the other variety compared to those of their respective control.

In BSi1 standard deviation and CV were 0.86 and 0.75 respectively in control; both the parameters increased at 10, 20 and 60 Kr and reduced at 30, 40, 50 and 70 Kr (Table 59).

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Table 59. Range, *mean*, *standard deviation*, Coefficient of variation, skewness and kurtosis for days to maturity in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Days to maturity					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	112.00-116.00	114.14±0.09	0.75	0.86	0.05	-0.47
10	112.00-116.00	114.30±0.10	0.80	0.91	-0.08	-0.54
20	113.00-116.00	114.48±0.10	0.80	0.92	-0.02	-0.78
30	113.00-116.00	114.09±0.08	0.67	0.76	0.01	-0.88
40	113.00-116.00	114.43±0.09	0.77	0.88	-0.05	-0.68
50	113.00-116.00	114.36±0.09	0.73	0.84	0.06	-0.57
60	113.00-116.00	114.42±0.10	0.80	0.91	-0.13	-0.84
70	113.00-116.00	114.34±0.08	0.70	0.80	0.12	-0.39

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Table 60. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to maturity in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Days to maturity					
	Range	Mean±SE	Standard deviation	Coefficient of variation	Skewness	Kurtosis
0 (control)	117.00 - 122.00	118.97±0.13	1.19	1.00	0.96	0.31
10	115.00 - 122.00	118.83±0.15	1.46	1.23	0.68	0.25
20	117.00 - 123.00	119.32±0.15	1.44	1.21	0.81	-0.12
30	117.00 - 122.00	119.83±0.14	1.31	1.09	0.22	-0.74
40	117.00 - 123.00	119.64±0.13	1.21	1.01	0.37	-0.21
50	117.00 - 123.00	119.27±0.14	1.30	1.09	0.34	-0.10
60	117.00 - 123.00	119.79±0.16	1.53	1.28	0.15	-0.97
70	117.00 - 122.00	119.23±0.13	1.26	1.06	0.52	-0.59

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Table 61. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for days to maturity in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Days to maturity					
	Range	Mean±SE	Standard deviation	Coefficient of variation	Skewness	Kurtosis
0 (control)	124.00 - 129.00	126.51±0.11	1.07	0.85	0.36	- 0.17
10	125.00 - 129.00	126.82±0.10	0.91	0.72	0.73	0.31
20	125.00 - 128.00	126.74±0.08	0.74	0.58	0.12	- 0.59
30	125.00 - 129.00	127.21±0.09	0.81	0.64	- 0.03	- 0.15
40	125.00 - 129.00	126.96±0.09	0.83	0.65	- 0.03	- 0.69
50	126.00 - 128.00	127.34±0.07	0.64	0.50	- 0.45	- 0.65
60	126.00 - 129.00	127.34±0.08	0.80	0.63	- 0.02	- 0.50
70	126.00 - 129.00	127.81±0.08	0.72	0.56	- 0.08	- 0.32

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In BSi427 both standard deviation and CV increased in all the mutagenic treatments compared to standard deviation and CV 1.19 and 1.00 respectively in control (Table 60).

In BSi467 all the treatments reduced standard deviation and CV compared to 1.07 and 0.85 respectively in control (Table 61).

Frequency distribution (skewness and kurtosis) : In BSi1 at 70 Kr skewness of frequency distribution for days to maturity was positive and higher than control; the distribution was also positively skewed at 30 and 50 Kr indicating their tendency to early maturity compared to control and the remaining treatments (Table 59). Kurtosis values show that all the treatments and control followed platykurtic distribution indicating deviation of the data from the mean (Fig. 24).

In BSi427 skewness was positive in control and higher than that of all other mutagenic treatments. The distribution of all treatments was positive but did not exceed the level of control. The positive skewness indicate the tendency to early maturity (Table 60). Except control and 10 Kr. all treatments followed platykurtic distribution (Fig. 25).

In BSi467 at 10 Kr skewness was positive indicating its tendency to early maturity. The remaining treatments show negative skewness indicating tendency to late flowering (Table 61). All the mutagenic treatments and control followed platykurtic distribution (Fig. 26).

(vi) Grain yield per plant : Gamma radiation induced considerable variability for yield components such as plant height, panicle length and a little variability for tiller number, but gamma radiation did not increase ultimate yield in all the three varieties with a few exception at lower dosages in the variety BSi1.

The statistical parameters such as mean, range, standard deviation, CV, skewness and kurtosis are presented in Tables 62, 63, and 64.

Range : In BSi1 the range for grain yield per plant enlarged towards positive direction in all the mutagenic treatments except the dosage 60 Kr compared to the range 1.84 - 5.36 in control. The positive increase in range indicates that there was scope of selection for per plant yield (Table 62).

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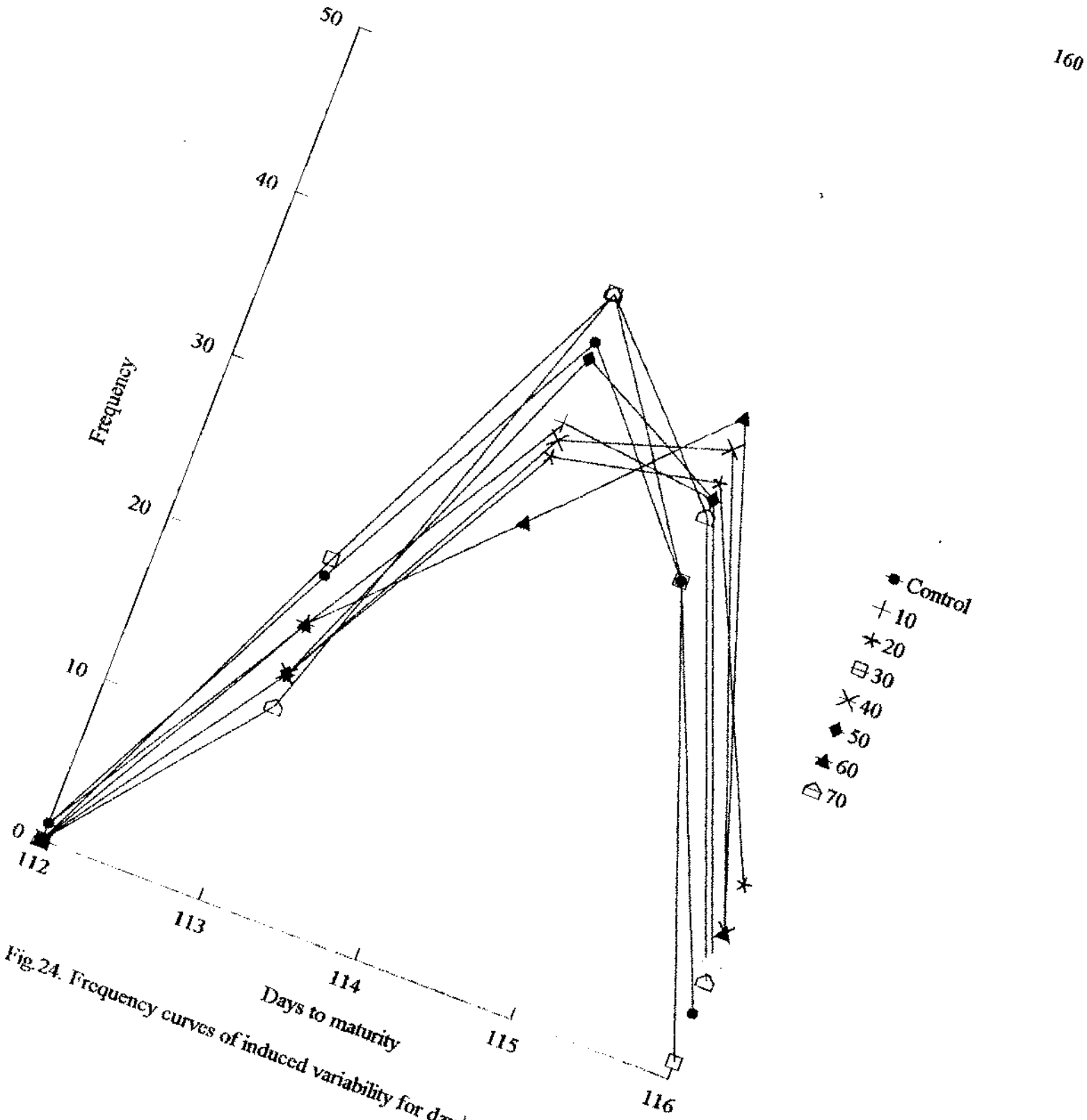

Fig.24. Frequency curves of induced variability for days to maturity in BSiL

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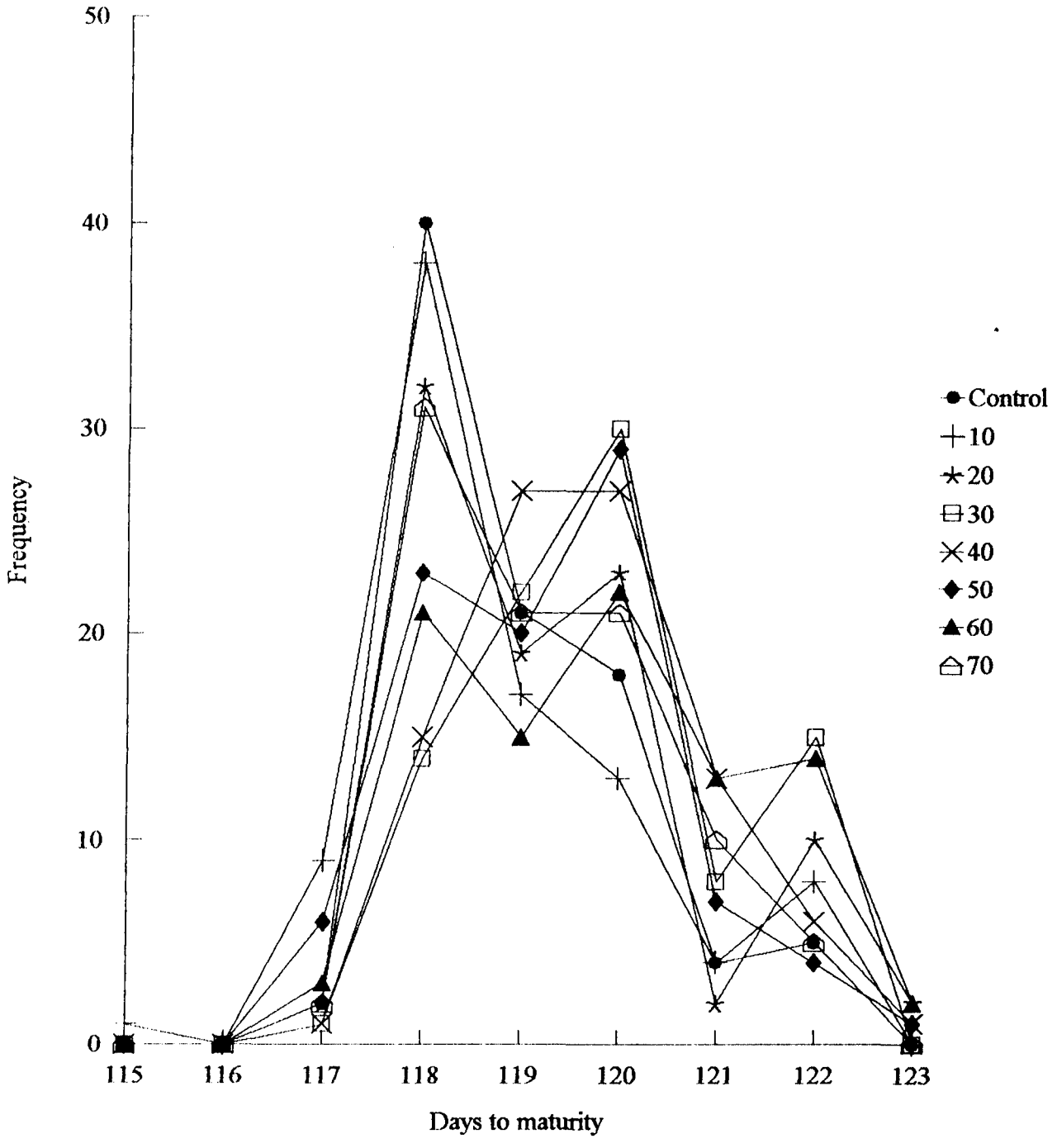

Fig.25. Frequency curves of induced variability for days to maturity in BSi427.

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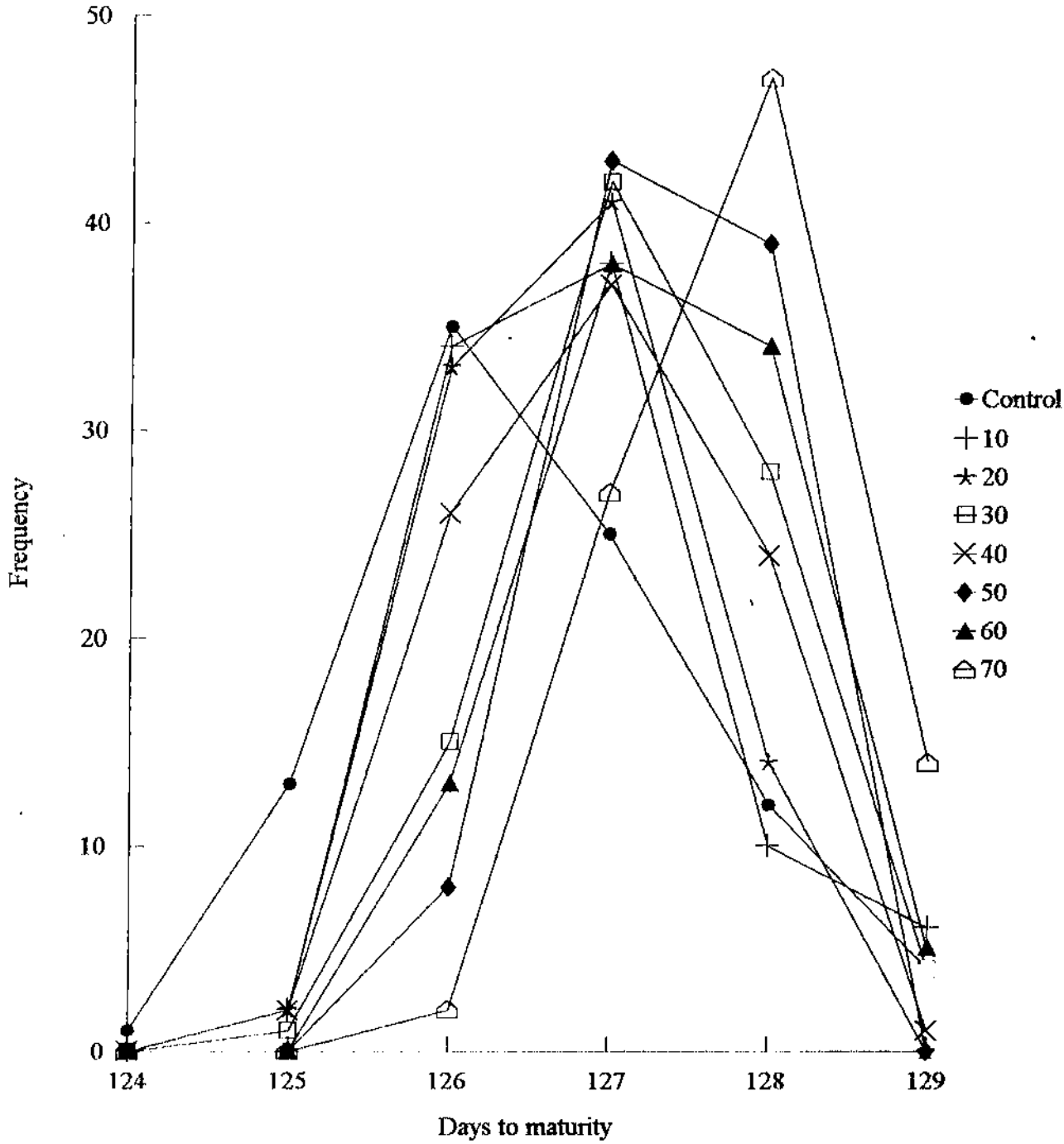

Fig.26. Frequency curves of induced variability for days to maturity in BSi467.

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In BSi427 the range for grain yield was from 4.38 to 19.78 in control. The range was not exceeded by any range of the mutagenic treatments (Table 63).

In BSi467 the range in control was from 1.39 to 5.70 gm. In some treatments the range slightly enlarged towards positive direction (Table 64).

Mean : In BSi1 the mean yield per plant was 2.99 gm in control; the yield increased at 10, 20 and 30 Kr but decreased at all heigher dosages (Table 62).

In BSi427 all the gamma treatments reduced considerably the mean, range and standard deviation compared to that of control (Table 63).

Only the CV increased in all the mutagenic treatments; the highest CV was at 30 Kr compared to that of 28.10 in control (Table 63).

In BSi467 all the gamma treatments showed reduction in mean yield compared to that of 3.40 gm in control (Table 64).

Standard deviation and coefficient of variation : In BSi1 Both standard deviation and CV increased in all the mutagenic treatments compared to 0.72 and 24.08 respectively in control. The highest standard deviation recorded as 1.43 and CV as 47.99 were at 40 Kr (Table 62).

In BSi427 standard deviation was 2.38 in control; the standard deviation decreased in all the treatments. Coefficient of variation increased in all the treatments compared to CV recorded as 28.10 in control (Table 63).

In BSi467 both standard deviation and CV decreased in all the mutagenic treatments compared to standard deviation and CV 1.14 and 33.53 respectively in control (Table 64).

Frequency distribution (skewness and kurtosis) : In BSi1 the skewness of the frequency distribution for yield per plant shows that most of the mutagenic treatments were highly positive compared to the positive skewed distribution of control indicating their tendency to decrease the yield (Table 62). Kurtosis was higher at 40,50 and 70 Kr

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Table 62. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain yield per plant in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Grain yield (gm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	1.84-5.36	2.99±0.09	0.72	24.08	0.76	0.89
10	1.48-6.30	3.26±0.14	1.07	32.32	0.71	0.51
20	1.38-6.94	3.01±0.14	1.10	36.78	1.11	1.92
30	1.24-6.20	3.10±0.15	1.17	37.74	0.93	0.23
40	1.23-8.39	2.98±0.19	1.43	47.99	1.70	3.58
50	1.10-6.49	2.77±0.14	1.08	38.99	1.28	2.14
60	1.36-4.77	2.66±0.11	0.82	30.83	0.71	-0.11
70	1.13-7.78	2.96±0.16	1.25	42.23	1.32	2.85

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Table 63. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for yield per plant (gm) in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Yield per plant (gm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	4.38 - 19.78	8.47±0.31	2.38	28.10	1.85	7.70
10	2.60 - 13.98	5.64±0.28	2.19	38.83	1.38	2.58
20	2.22 - 11.11	5.76±0.28	2.13	36.98	0.73	-0.11
30	2.60 - 12.96	5.05±0.30	2.29	45.35	1.87	3.39
40	2.08 - 10.77	4.66±0.24	1.85	39.70	1.38	1.52
50	2.19 - 10.38	4.87±0.23	1.82	37.37	0.96	0.92
60	2.38 - 10.56	5.15±0.26	2.03	39.42	0.64	-0.23
70	2.72 - 15.27	5.57±0.28	2.16	38.78	2.10	6.71

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Table 64. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain yield per plant in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	Grain yield per plant (gm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation	Skewness	Kurtosis
0 (control)	1.39 - 5.70	3.40±0.15	1.14	33.53	0.43	- 0.85
10	1.63 - 5.15	3.10±0.12	0.96	30.97	0.74	- 0.26
20	1.75 - 5.44	3.15±0.12	0.91	28.89	0.63	- 0.26
30	0.91 - 5.33	2.83±0.12	0.92	32.51	0.32	0.11
40	1.27 - 5.35	2.86±0.11	0.86	30.07	0.49	- 0.14
50	1.71 - 5.94	3.02±0.12	0.91	30.13	0.93	0.73
60	1.51 - 4.23	2.66±0.09	0.69	25.94	0.27	-0.77
70	1.08 - 3.95	2.36±0.09	0.72	30.51	0.51	-0.47

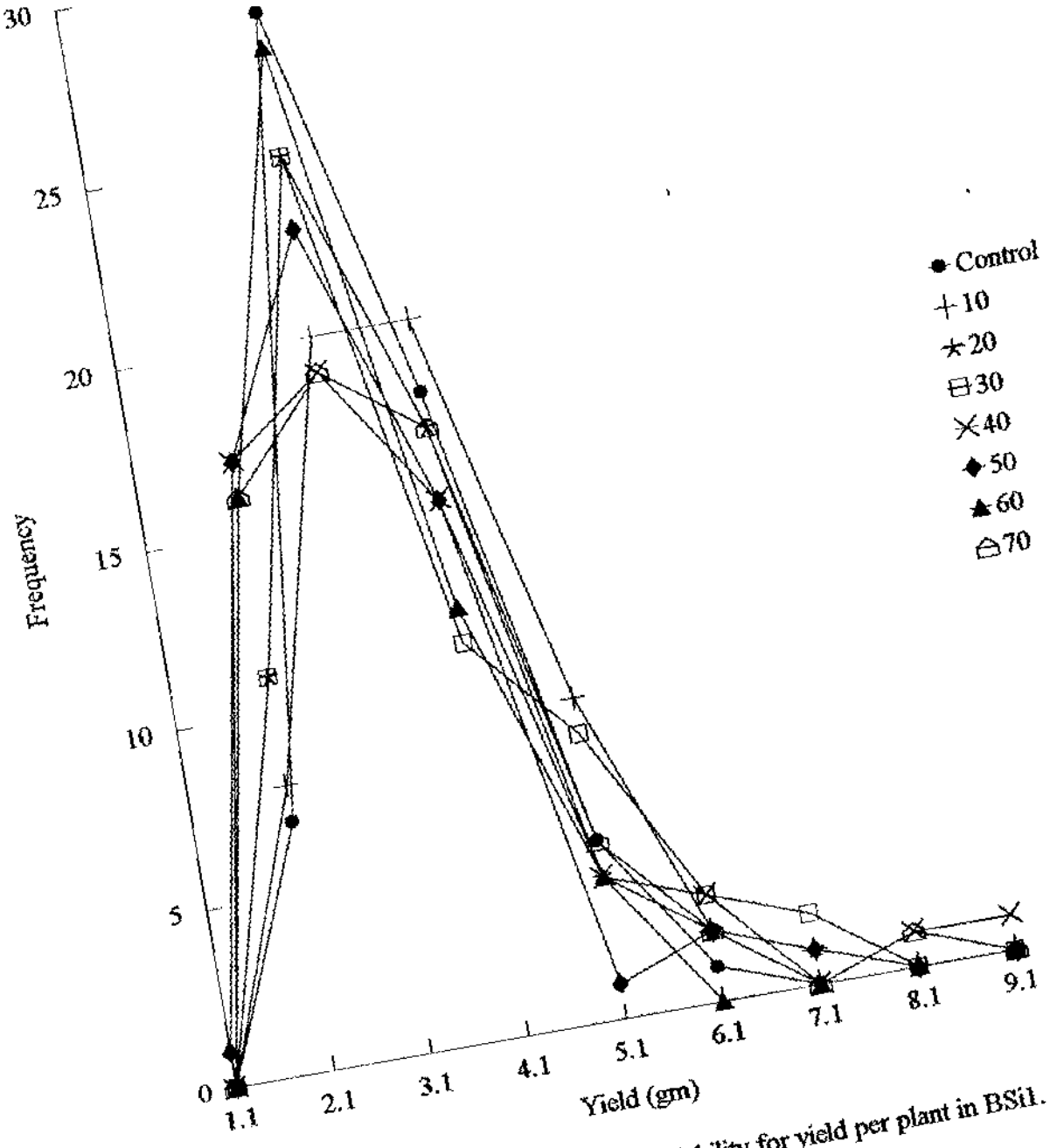

Fig. 27. Frequency curves of induced variability for yield per plant in BSi1.

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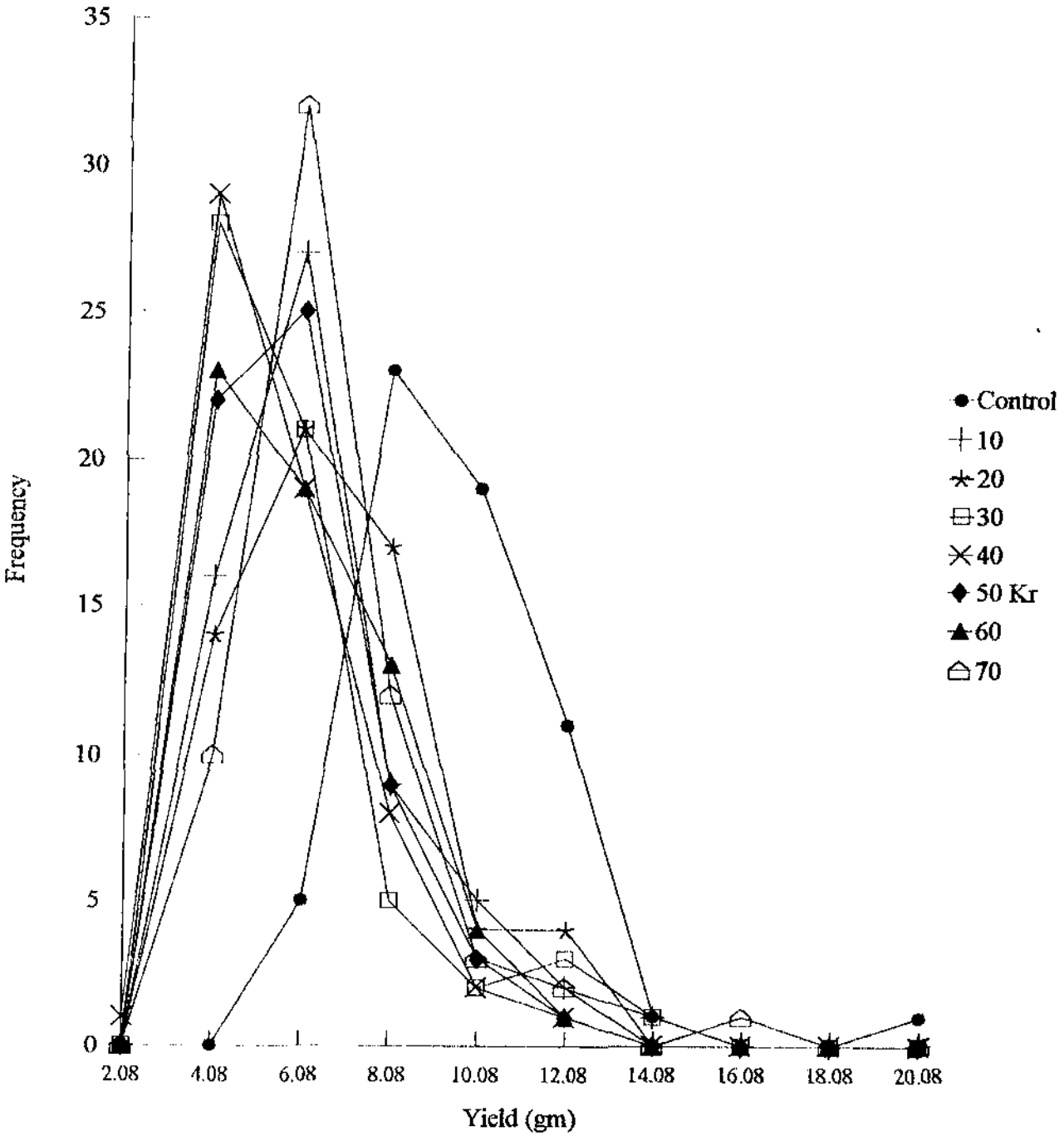

Fig.28. Frequency curves of induced variability for yield per plant in BSi427.

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than control. Except 60 Kr, all the mutagenic treatments and control followed leptokurtic distribution. The frequency at 60 Kr followed platykurtic distribution (Fig. 27).

In BSi427 frequency distribution of all the mutagenic treatments were positively skewed. Positive skewness of control and of all the treatments indicate their tendency to decrease the yield (Table 63). Except the treatments of 20 and 70 Kr, all the mutagenic treatments followed leptokurtic distribution. Frequency of the treatments of 20 and 70 Kr followed platykurtic distribution. Kurtosis was more at control (7.70) and at the treatment of 70 Kr (6.7); the kurtosis at control and at 70 Kr reflected the higher concentration of data around the mean (Fig. 28).

In BSi467 the skewness of the distribution for yield shows that all the mutagenic treatments and control were positively skewed indicating their tendency to decrease the yield (Table64). Except the treatments of 30 and 50 Kr all other mutagenic treatments and control followed platykurtic distribution. The frequency of the treatments of 30 and 50 Kr followed leptokurtic distribution (Fig. 29).

(vii) Weight of 500 seeds (test weight)

Gamma radiation did not induce substantially variability for grain weight in the three varieties. The statistical parameters such as mean, range, standard deviation, CV, skewness and kurtosis are presented in the Tables 65, 66 and 67.

Range : In BSi1 the range in control was 0.76 –0.97; the range shifted only in negative direction in all the mutagenic treatments (Table 65).

In BSi427 the range in control was 1.07-1.80; the range decreased considerably in all the mutagenic treatments towards negative direction (Table 66).

In BSi467 all most all the mutagenic treatments show a tendency to increase the range towards positive direction but none of them enlarged more than the range 0.86-1.13 in control (Table 67).

Mean : In BSi1 the mean test weight was 0.84 gm in control; the test weight decreased in all the mutagenic treatments (Table 65).

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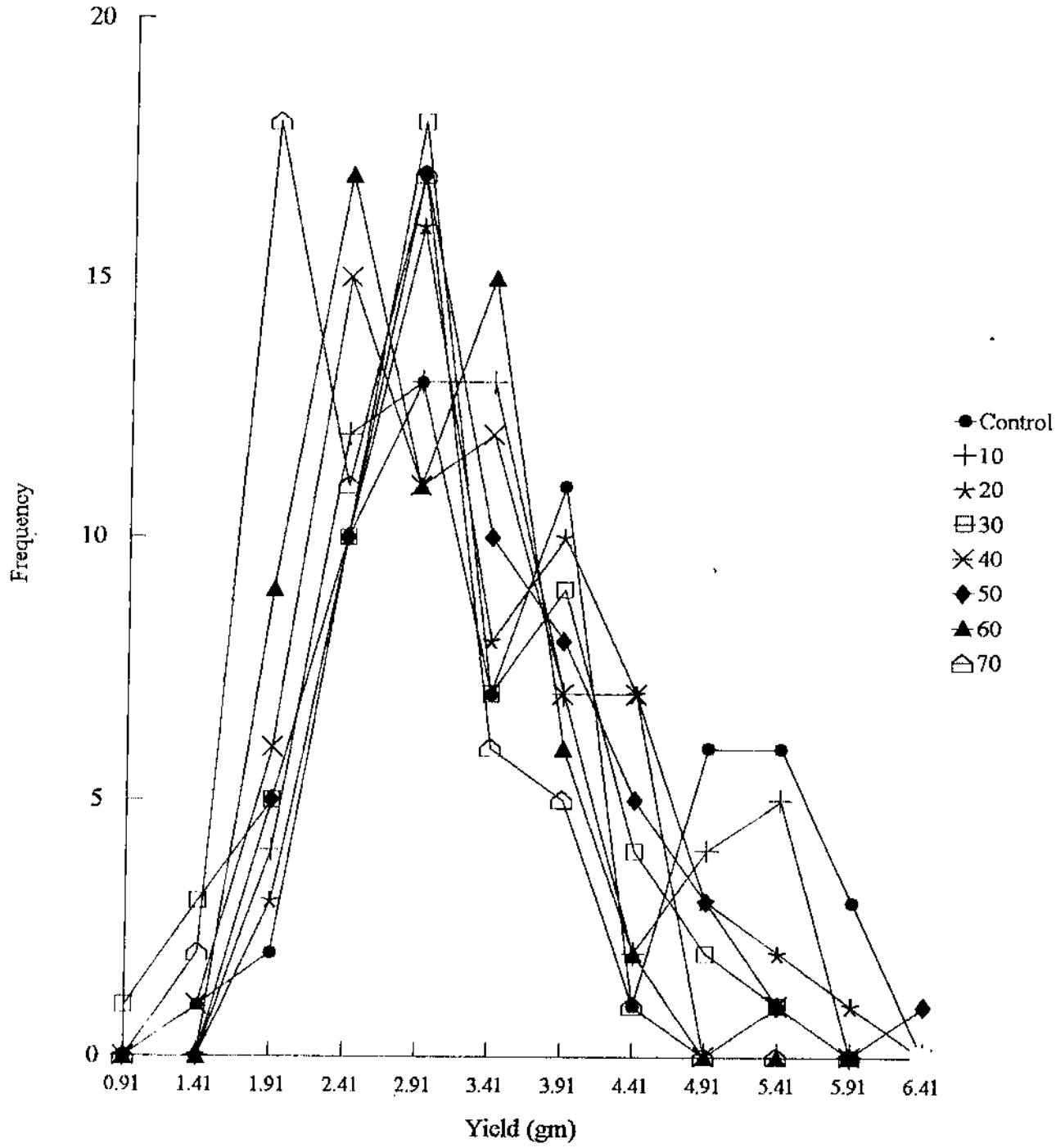

Fig.29. Frequency curves of induced variability for yield per plant in BSi467.

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In BSi427 lower mean test weight was recorded in all the mutagenic treatments compared to 1.18 gm in the control (Table 66).

In BSi467 the mean test weight was 0.96 gm in control; the test weight increased to 0.99 and 0.97 gm at two lower dosages of 10 and 20 Kr respectively indicating slight possibility for improvement of the character following gamma irradiation (Table 67).

Standard deviation and CV : In BSi1 highest CV recorded as 7.32 was at 40 and 60 Kr compared to CV recorded as 5.95 in control (Table 65).

In BSi427 both standard deviation and CV decreased in all the mutagenic treatments compared to standard deviation and CV 0.13 and 11.02 respectively in control (Table 66).

In BSi467 except at the dosage of 50 Kr, standard deviation and CV did not increase practically in almost all the mutagenic treatments. The dosage of 50 Kr shows a slight increase in standard deviation and CV 0.06 and 6.32 respectively compared to standard deviation and CV 0.05 and 5.21 respectively in control (Table 67).

Frequency distribution (skewness and kurtosis) : In BSi1 except at 40 and 70 Kr, the skewness of the frequency distribution for grain weight in all the mutagenic treatments and control were positively skewed indicating their tendency to decrease the grain weight. The negative skewness of the treatments of 40 and 70 Kr indicate their tendency to increase the grain weight (Table 65). The treatments of 20, 50, 60 and 70 Kr followed platykurtic distribution and the treatments of 10, 30 and 40 Kr followed leptokurtic distribution reflecting concentration of data around the mean (Fig. 30).

In BSi427 except the treatments 40 and 50 Kr, skewness of the frequency distribution of all the mutagenic treatments and control were positive. Frequency distribution of the treatments of 40 and 50 Kr were negatively skewed indicating their tendency to increase the grain weight (Table 66). Kurtosis in control was high (21.94) compared to that of all other mutagenic treatments and followed leptokurtic distribution reflecting the higher concentration of data around the mean. The treatments of 10, 40 and 60 Kr followed

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Table 65. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain weight in BSi1 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	500 grain weight (gm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0(control)	0.76-0.97	0.84±0.01	0.05	5.95	0.82	0.60
10	0.74-0.90	0.80±0.01	0.04	5.00	0.76	0.74
20	0.74-0.92	0.83±0.01	0.05	6.02	0.32	-0.66
30	0.76-0.92	0.81±0.01	0.04	4.94	1.07	1.20
40	0.63-0.94	0.82±0.01	0.06	7.32	-0.63	1.33
50	0.72-0.89	0.80±0.01	0.04	5.00	0.28	-0.28
60	0.73-0.93	0.82±0.01	0.06	7.32	0.17	-0.97
70	0.73-0.89	0.82±0.01	0.04	4.88	-0.07	-0.15

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Table 66. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain weight in BSi427 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	500 grain weight (gm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	1.07 -1.80	1.18±0.02	0.13	11.02	4.39	21.91
10	1.05 -1.23	1.14±0.01	0.04	3.51	0.13	0.95
20	1.04 -1.20	1.10±0.01	0.04	3.64	0.31	-0.96
30	0.99 -1.18	1.08±0.01	0.05	4.63	0.11	-0.34
40	0.97 -1.21	1.08±0.01	0.05	4.63	-0.01	1.10
50	0.94 -1.18	1.08±0.01	0.06	5.56	-0.19	-0.40
60	0.97 -1.22	1.09±0.01	0.05	4.59	0.20	0.68
70	1.06 -1.24	1.13±0.01	0.05	4.42	0.16	-0.36

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Table 67. Range, mean, standard deviation, coefficient of variation, skewness and kurtosis for grain weight in BSi467 following gamma rays treatments in M_3 generation.

Gamma rays (Kr)	500 grain weight (gm)					
	Range	Mean±SE	Standard deviation	Coefficient of variation (%)	Skewness	Kurtosis
0 (control)	0.86-1.13	0.96±0.01	0.05	5.21	1.35	3.76
10	0.87-1.08	0.96±0.01	0.05	5.21	0.63	0.002
20	0.87-1.08	0.99±0.01	0.05	5.05	-0.12	-0.49
30	0.90-1.13	0.97±0.01	0.05	5.15	1.18	1.85
40	0.86-1.06	0.93±0.01	0.05	5.38	0.54	0.37
50	0.84-1.07	0.95±0.01	0.06	6.32	-0.02	-0.37
60	0.88-1.12	0.96±0.01	0.05	5.21	1.30	4.21
70	0.86-1.04	0.96±0.01	0.05	5.21	-0.03	-0.24

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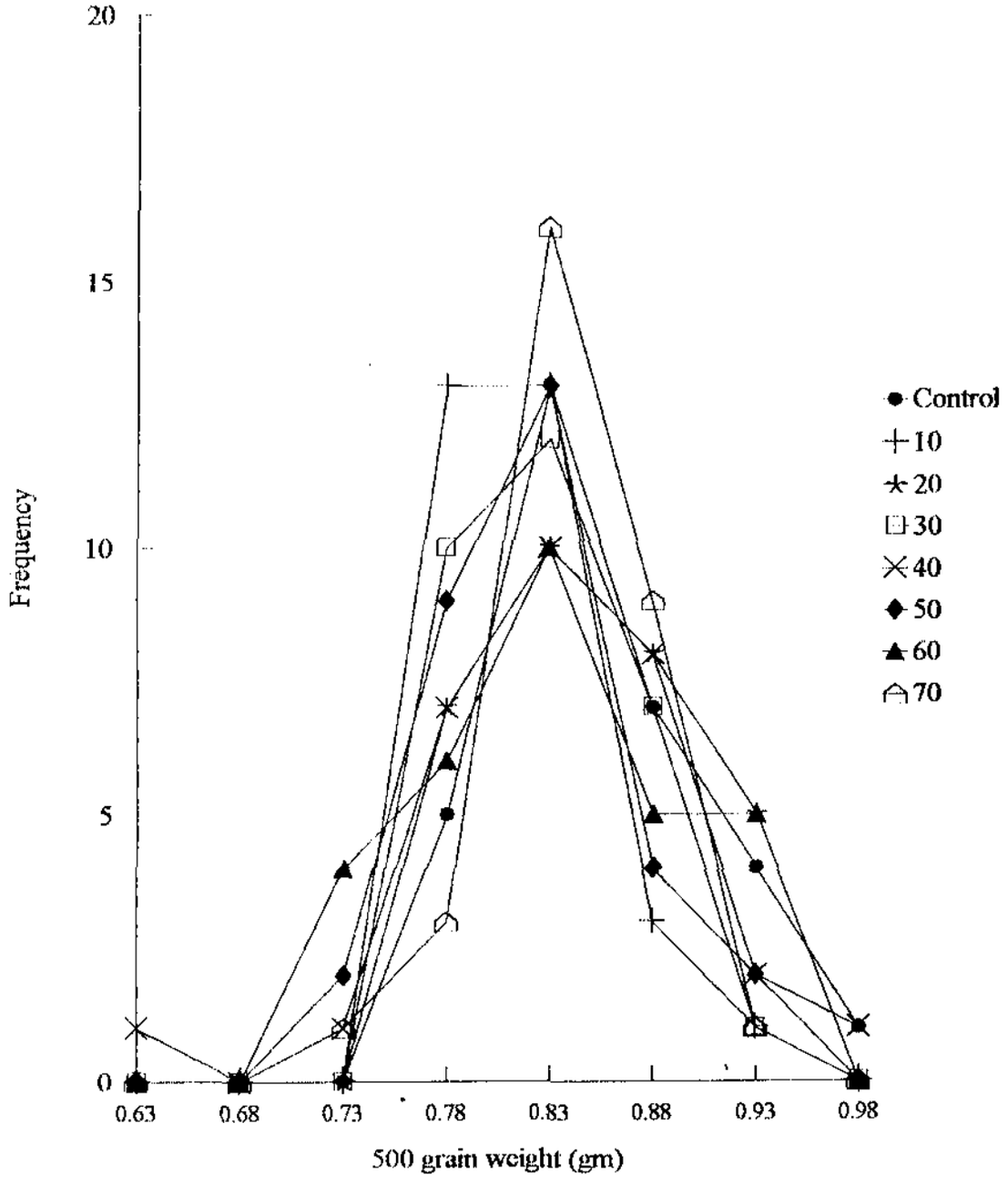

Fig. 30. Frequency curves of induced variability for grain weight in BSi1.

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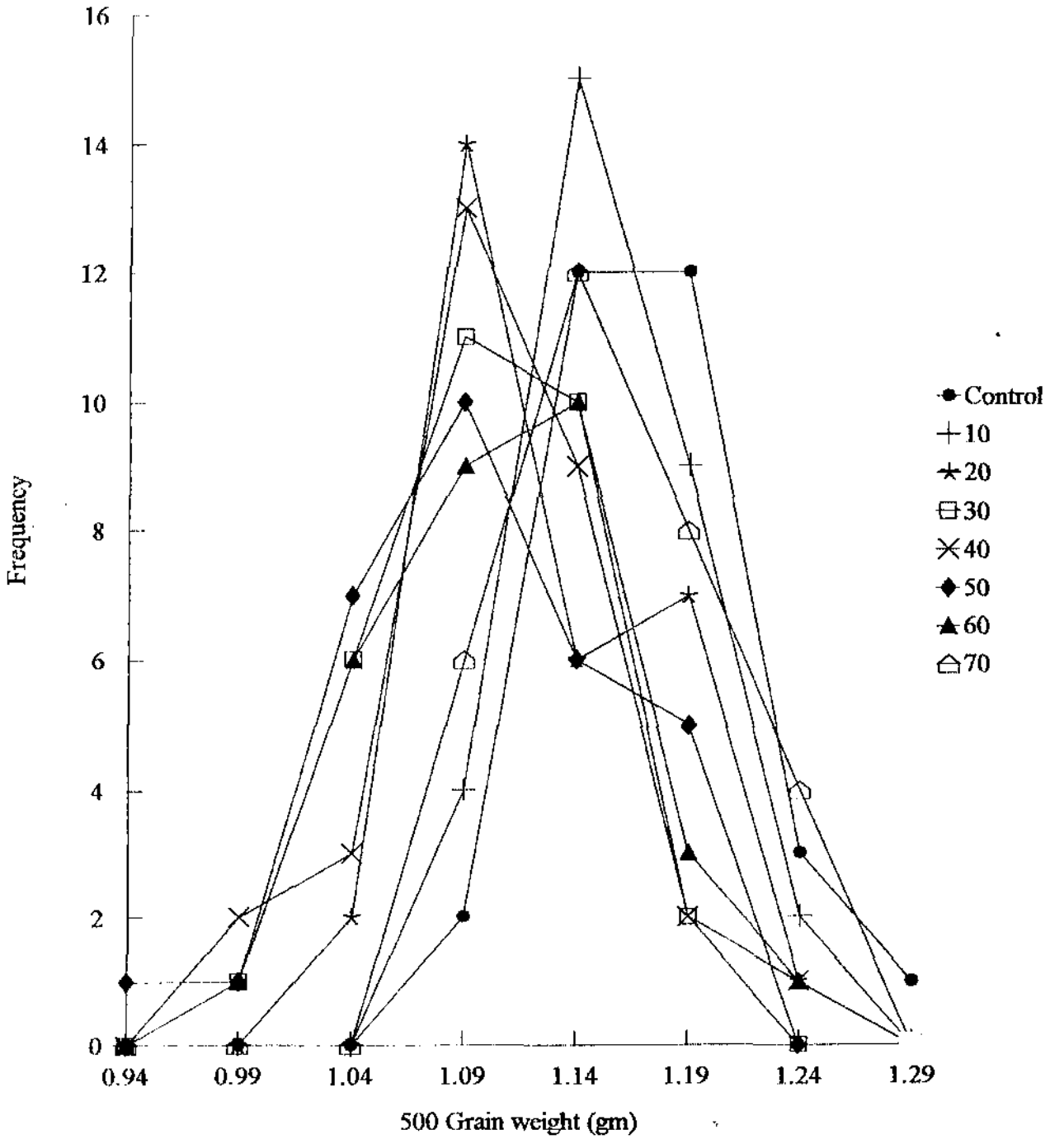

Fig.31. Frequency curves of induced variability for grain weight in BSi427.

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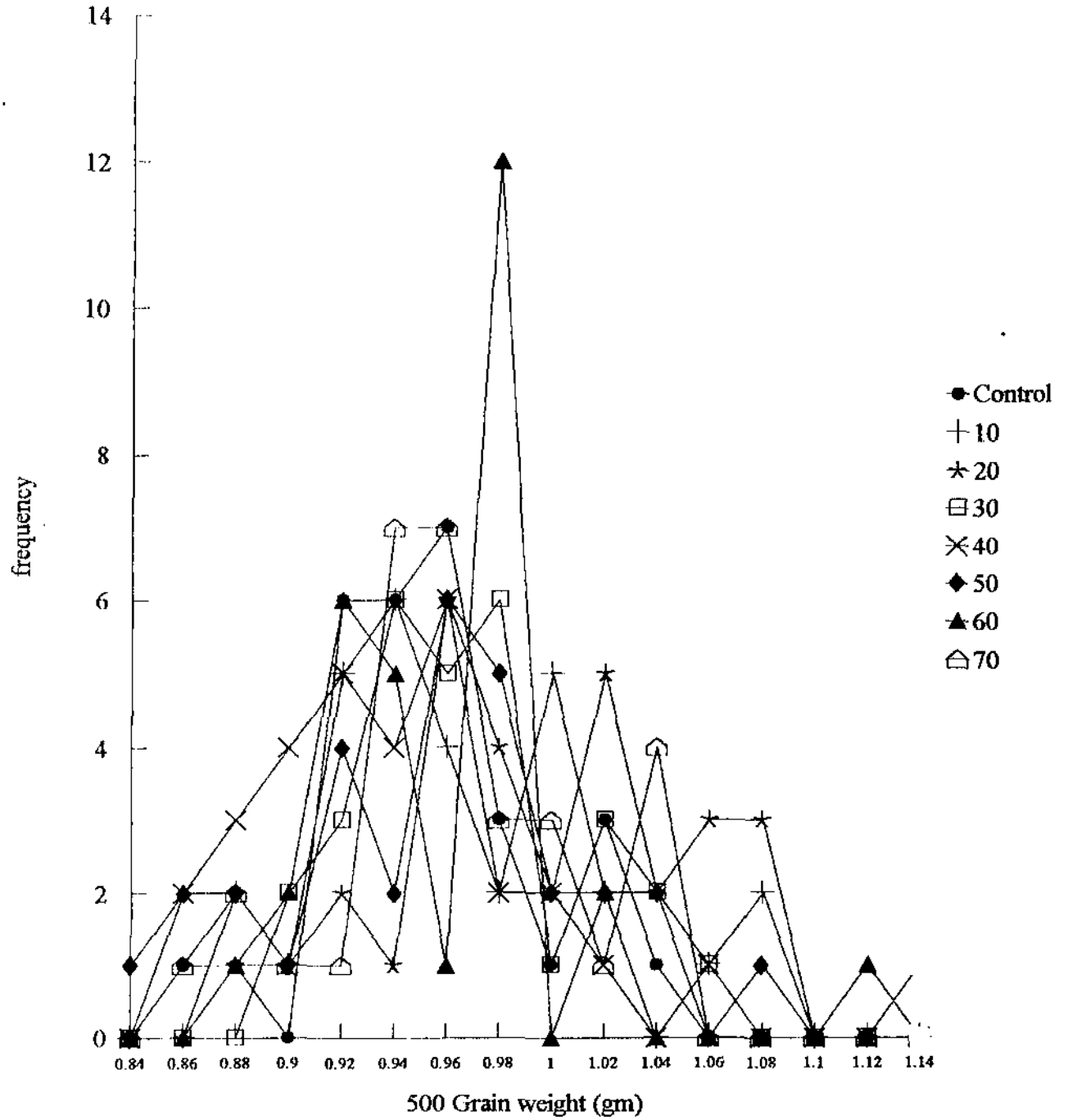

Fig. 32. Frequency curves of induced variability for grain weight in BSi467.

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leptokurtic distribution like control. Other treatments followed platykurtic distribution (Fig. 31).

In BSi467 skewness of the distribution indicates that except treatments of 20, 50 and 70 Kr, all the mutagenic treatments and control were positively skewed. The treatments of 20, 50 and 70 Kr show slightly negative skewness indicating their tendency to increase the grain weight (Table 67). The kurtosis in control was 3.76. The highest kurtosis value (4.21) was at 60 Kr. Except the treatments of 20, 50 and 70 Kr, control and all the treatments followed leptokurtic distribution. The treatments of 20, 50 and 70 Kr followed platykurtic distribution. The small kurtosis value at 10 Kr (0.002) was nearly to zero indicating its tendency to mesokurtic distribution (Fig. 32).

4.3.2. Breeding behaviour of viable mutants

Four categories (colour, panicle character, stature and maturity) of viable mutants isolated in the three varieties in M_2 generation were grown to raise M_3 to study their breeding behaviour. A total of 347 viable mutants in BSi1, 432 mutants in BSi427 and 679 mutants in BSi467 were grown. All the viable mutants were not found to breed true. The majority of BSi1 mutant lines (263), almost half of BSi427 lines (205) and little more than a quarter of BSi467 lines (201) were found to be segregating for the character (Table 68).

4.3.3. Variants in M_1 generation

Gamma radiation induced two types of variants : (i) chlorophyll variant (striata) in BSi427 (Plate 8b), the inducing dosage was 30 Kr and the frequency was 0.64% and (ii) colour variant (seed colour) in BSi467 (Plate 18), the inducing dosage was 20 Kr and the frequency was 1.005%. The two types of variants were grown in M_2 and M_3 generation to study their breeding behaviour. Both types of variants were found to be of parental type. The change of the two types of variants resulted from endospermic mutation and not from the mutation in the embryonal tissue (Table 69).

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Table 68. Breeding behaviour of viable mutants in M_3.

Variety	Category of Mutants	Number of mutants studied	Breeding behaviour	
			Non segregating line	Segregating line
BSi1	Four categories (colour, stature, panicle & maturity)	347	84	263
BSi427	Four categories (colour, stature, panicle & maturity)	432	227	205
BSi467	Four categories (colour, stature, panicle & maturity)	679	478	201

Table 69. Variants in M_1 generation.

Variety	Variant character	No. of population studied in M_2	No. of population studied in M_3	Character found
BSi427	Chlorophyll mutant (striata)	915	540	No striata
BSi467	Seed colour (orange)	2495	802	No orange colour

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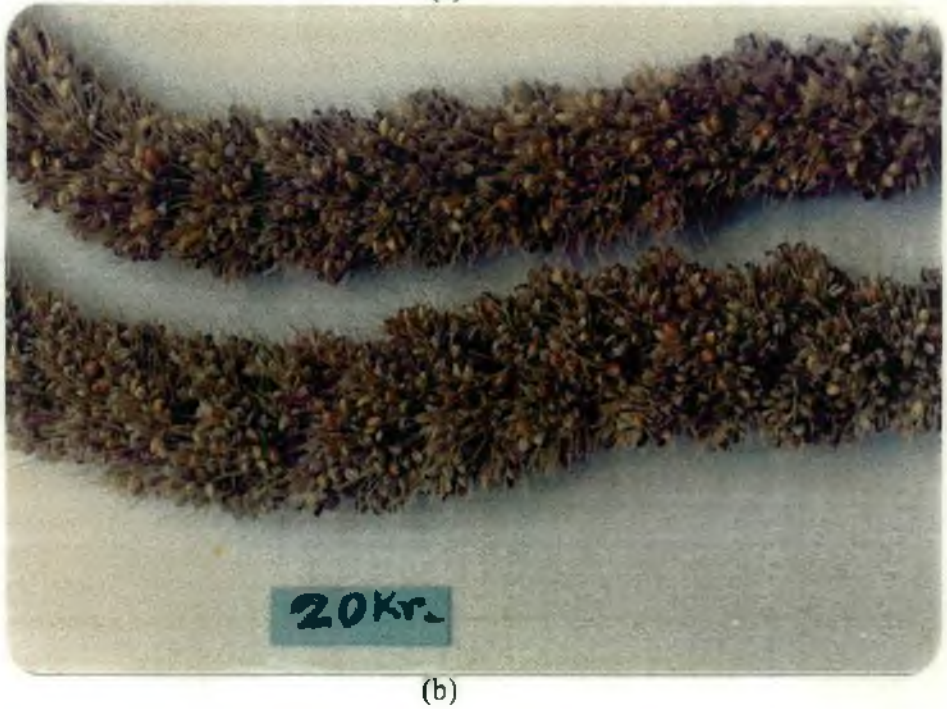
(a)



(b)

Plate 18. a-b: (a) Seed colour variant at 20 Kr in BSi467. Control (lower); variant (upper) in M_1. (b) Seed colour variant at 20 Kr in BSi467 in $M_1 \times 1.75$.

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4.3.4. Evaluation of useful *macro mutants*

A total of 40 early mutants in BSi1, 17 early mutants in BSi467, five dwarfs (dwarf mutant of wheat phenotype), five early and ten large-sized head high yielding mutants in BSi427 were isolated in M_2 generation.

In BSi1 early mutants were isolated at dosages of 10, 20, 30, 40, 50 and 60 Kr, maximum numbers being recorded at 30 and 40 Kr.

In BSi467 early mutants were confined to lower dosages only; one at 10 Kr and all others were at 30 Kr.

In BSi427 early types were obtained at 10, 20, 30 and 40 Kr; dwarfs were obtained only at 40kr and high yielding types at higher dosages of 60 and 70 Kr.

Among these mutants, five dwarfs, two early and seven large-sized head mutants in BSi427, 20 early mutants in BSi1 and 16 early mutants in BSi467 were found to possess desirable agronomic characters. The breeding behaviour and other agronomic characteristics of these useful mutants were studied in M_3 and M_4 generations.

The results of the useful macromutants are presented in Tables 70-96.

4.3.4.1 Early type : In BSi427 it is evident from Table 70 that except for 1000-grain weight in M_3, mean squares for all the characters were found highly significant both in M_3 and M_4 generations indicating high variation among induced mutants and parents. Table 71 indicates that mutant-2 was comparatively shorter, low yielding with smaller number of grains per panicle. In the mutant-2 compared to parent maturity occurred earlier in M_3 by 10 days and in M_4 by 14 days concomitant with higher grain weight. In both generations all the mutants produced a greater number of tillers than that of the parent. The variety-environment interaction for days to maturity and yield per plant were found insignificant indicating that the mutants were not influenced by the change of environment. Highly significant variation among entries was also found for the above characters (Table 72). Table 73 shows that the mutants matured at least 12 days earlier than their parent.

Table 70. ANOVA for different characters in two early mutants and their parent, BSi427 in M_3 and M_4 generations.

Source of variation	df	Mean Square							
		Days to flowering	Days to maturity	Plant height(cm)	Panicle length (cm)	No. of tillers per plant	Yield per Plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Replication	2	5.444	6.778	14.343	0.081	1.474	3.683	0.024	727495.357
		(2.778)	(0.778)	(53.614)	(1.361)	(0.111)	(2.812)	(0.031)	(271089.005)
Variety	2	221.778**	104.111**	278.943*	24.724**	32.068**	18.540*	0.072	8339393.287*
		(312.444**)	(192.111**)	(370.899**)	(30.781**)	(8.964**)	(9.794*)	(0.071**)	(3876980.171**)
Error	4	11.278	5.778	17.757	1.171	0.598	1.715	0.015	672011.784
		(0.444)	(0.444)	(5.318)	(1.584)	(0.051)	(1.577)	(0.004)	(47572.823)

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)
(Figures within parenthesis indicate the values in M_4.)

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Table 71. Mean values of different quantitative characters in two early mutants and their parent, BSi427 in M_3 and M_4 generations.

Variety/mutant	Days to Flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Grains per panicle	Weight of 1000 grains (gm)
Mutant1	73.67	117.0	68.60	12.60	7.333	6.01	3029.0	2.23
	(75.67)	(110.70)	(70.13)	(13.67)	(4.20)	(5.18)	(2763.0)	(2.09)
Mutant2	78.33	116.0	68.33	15.20	2.667	4.62	1261.0	2.50
	(71.67)	(109.70)	(72.67)	(17.47)	(1.47)	(4.92)	(1222.0)	(2.38)
Parent (BSi427)	90.33	126.7	85.17	18.33	1.033	9.45	4593.0	2.49
	(91.00)	(124.00)	(90.53)	(20.03)	(1.00)	(8.17)	(3441.0)	(2.34)
LSD(0.01)	12.62	9.04	15.85	4.07	2.91	4.92	3082.0	-
	(2.49)	(2.51)	(8.67)	(4.73)	(0.85)	(-)	(819.9)	(0.24)
LSD(0.05)	(-)	(-)	(-)	(-)	(-)	(2.85)	(-)	(-)
CV (%)	4.16	2.00	5.69	7.04	21.02	19.56	27.69	5.14
	(0.84)	(0.58)	(2.96)	(7.38)	(10.17)	(20.62)	(8.81)	(2.94)

(Figures within parenthesis indicate the values in M_4 generation.)

Table 72. ANOVA of combined analysis for days to maturity and yield per plant in two early mutants and their parent, BSi427.

Source of variation	df	Days to maturity		Yield per plant (gm)	
		MS	F value	MS	F value
Year (A)	1	117.556	31.1176**	1.650	0.5081
Error	4	3.778		3.247	
Variety(B)	2	289.500	93.0536 **	27.338	16.6113**
Interaction (A x B)	2	6.722	2.1607	0.996	0.6053
Error	8	3.111		1.646	

(** Significant at 1% level of probability.)

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Table 73. Mean values for days to maturity and yield per plant (over two years) in two early mutants and their parent, BSi427.

variety/mutant	Days to maturity	Yield per plant (gm)
Early mutant1	113.80	5.59
Early mutant2	112.80	4.77
Parent (BSi427)	125.30	8.81
LSD (0.01)	3.417	2.485
CV (%)	1.50	20.07

Table 74. Correlation coefficients among different characters in two early mutants and their parent, BSi427 in M_3 and M_4 generations.

	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Panicle length (cm)					
No. of tillers per plant	-.8764** (-.8646)				
Yield per plant (gm)	.6276 (.7103)	-.3260 (-.3671)			
Weight of 1000 grains (gm)	.6824 (.7241)	-.6866 (-.7218)	.0818 (.3101)		
Grains per panicle	.4254 (1970)	-.1727 (.1004)	.8167* (.7370)	.0026 (-.2249)	

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)
(Figures within parenthesis indicate the values in M_4 generation.)

Table 75. ANOVA for different quantitative characters in twenty early mutants and their parent, BSi1 in M_3 and M_4 generations.

Source of variation	df	Mean Square							
		Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per Plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Replication	2	24.778 (21.635)	1.714 (26.587)	34.721 (136.477)	2.392 (10.162)	0.795 (0.106	0.105 (3.210)	0.035 (0.017)	1397425.370 (1037504.932)
Variety	20	60.683** (45.678**)	18.086** (31.244**)	833.372** (394.155**)	32.462** (16.501**)	0.371** (0.060)	6.222** (2.576)	0.018* (0.013**)	3461428.754** (854176.252)
Error	40	3.544 (3.535)	2.914 (3.704)	14.745 (69.297)	1.158 (2.355)	0.098 (0.070)	1.061 (1.870)	0.009 (0.005)	712788.686 (547394)

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)
(Figures within parenthesis indicate the values in M_4 generation.)

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Table 76. Mean values for different characters in twenty early mutants and their parent, BSi1 in M_3 generation.

Variety/Mutant	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per Plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Early Mutant 1	87.33	120.0	117.3	18.47	1.33	7.88	1.87	5071.0
Early Mutant 2	90.00	119.7	116.3	19.13	1.47	9.39	1.79	6334.0
Early Mutant 3	76.33	113.3	68.07	9.60	2.60	4.43	1.60	3861.0
Early Mutant 4	84.00	119.3	112.8	19.80	1.40	8.54	1.85	6097.0
Early Mutant 5	74.67	113.7	69.40	9.87	1.80	3.77	1.87	1886.0
Early Mutant 6	90.00	120.3	115.5	18.60	1.00	7.36	1.85	4597.0
Early Mutant 7	88.67	120.0	110.0	17.33	1.20	6.38	1.79	3555.0
Early Mutant 8	90.33	119.3	114.5	18.47	1.13	8.13	1.84	5284.0
Early Mutant 9	89.33	119.3	116.6	18.73	1.27	8.39	1.75	6097.0
Early Mutant 10	86.67	118.7	114.4	18.33	1.07	7.61	1.84	4825.0
Early Mutant 11	87.00	119.7	112.9	18.00	1.40	6.71	1.78	4314.0
Early Mutant 12	87.33	119.3	113.9	17.93	1.27	7.13	1.81	5342.0
Early Mutant 13	84.67	119.7	112.2	20.53	1.27	6.69	1.85	4593.0
Early Mutant 14	86.00	120.3	110.9	17.60	1.60	4.73	1.89	3352.0
Early Mutant 15	86.67	120.0	112.2	18.33	1.40	6.84	1.85	3968.0
Early Mutant 16	87.33	118.3	118.6	18.33	1.33	6.89	1.94	4741.0
Early Mutant 17	88.00	119.3	112.3	17.00	1.07	5.70	1.91	3439.0
Early Mutant 18	87.67	120.7	115.6	17.80	1.47	5.83	1.80	4816.0
Early Mutant 19	86.00	120.3	114.4	18.00	1.60	6.81	1.87	3813.0
Early Mutant 20	76.67	116.3	66.33	8.87	1.87	5.01	1.67	3435.0
Parent (BSi1)	88.67	125.3	111.7	18.09	1.60	7.61	1.83	4919.0
LSD(0.01)	5.20	3.77	8.48	2.38	0.69	2.27	0.16	1864.0
CV (%)	2.19	1.43	3.57	6.30	21.77	15.25	5.29	18.79

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Table 77. Mean values of different quantitative characters in twenty early mutants and their parent, BSi1 in M_4 generation.

Mutant/variety	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant(gm)	Weight of 1000 grains (gm)	Grains per panicle
Mutant 1	89.33	117.33	91.13	15.40	1.00	3.72	1.65	2295.58
Mutant 2	89.67	116.67	99.27	16.07	1.07	4.78	1.57	3127.15
Mutant 3	78.00	110.00	70.73	9.20	1.00	1.89	1.51	1337.32
Mutant 4	86.00	118.33	99.07	17.83	1.50	3.43	1.67	2137.55
Mutant 5	76.67	109.00	70.20	10.07	1.20	1.61	1.56	1158.03
Mutant 6	87.67	117.33	98.40	15.73	1.40	3.65	1.63	2320.31
Mutant 7	86.67	115.33	100.50	16.83	1.00	4.80	1.68	2915.36
Mutant 8	90.00	117.33	97.93	15.47	1.00	3.84	1.68	2388.38
Mutant 9	87.00	115.33	95.60	15.40	1.07	3.24	1.68	2021.75
Mutant 10	87.00	117.00	101.30	16.00	1.03	4.50	1.69	2725.11
Mutant 11	86.67	116.00	105.87	15.23	1.07	3.46	1.71	2105.96
Mutant 12	86.00	116.00	101.40	16.63	1.00	3.36	1.63	2114.51
Mutant 13	86.67	116.33	100.03	17.10	1.00	3.48	1.59	2237.36
Mutant 14	85.33	117.00	96.30	16.63	1.00	4.15	1.69	2467.90
Mutant 15	87.33	116.67	99.73	16.03	1.00	5.26	1.73	3112.45
Mutant 16	88.67	115.67	102.77	16.13	1.00	3.82	1.75	2225.34
Mutant 17	87.00	115.67	98.00	16.27	1.00	3.28	1.69	1984.57
Mutant 18	87.33	115.00	96.10	16.07	1.00	3.36	1.76	1969.93
Mutant 19	86.67	116.67	101.37	15.87	1.03	3.97	1.71	2381.83
Mutant 20	77.67	110.33	85.80	10.67	1.17	3.05	1.59	1976.24
Parent (BSi1)	91.00	124.67	105.57	17.30	1.27	5.31	1.67	3309.10
LSD (0.01)	4.15	4.25	18.38	3.39	-	-	0.157	-
CV (%)	2.18	1.66	8.75	10.01	24.24	36.83	4.30	32.16

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Correlation coefficient among different characters (Table 74) shows that in M_3 generation yield per plant had significant positive correlation only with grains per panicle. Positive but insignificant association between yield per plant and panicle length, between yield per plant and 1000 grain weight, between panicle length and 1000 grain weight, and between panicle length and grain per panicle were also observed in both generations. Positive association between the above character pairs indicate that selection by using panicle length as one of the criteria for the improvement of yield would be fruitful as these characters were found to be closely associated with panicle length.

In M_3 and M_4 generations mean squares in BSi1 for all the characters except in tiller number, yield per plant and grain per panicle were found highly significant (Table 75) indicating high variation among induced mutants and their parent. Tables 76 and 77 show that in mutants 3 and 5 compared to parent maturity occurred earlier in M_3 by at least 12 days and in M_4 by 14 days. In all other mutants maturity occurred earlier in M_3 by at least 5 days and in M_4 by 8 days. It was interesting to note that in addition to earliness five mutants produced higher yield and higher number of grains per panicle in M_3 generation. The above tables also show that 12 early mutants also produced high grain weight in both the generations. Combined analysis of variance (Table 78) indicates highly significant variation among the entries for days to maturity and yield per plant. The variety-environment interaction was found insignificant for the above characters; it indicates that the mutants were not influenced by the change of the environment. Table 79 also shows that compared to parent mutants 3 and 5 matured earlier by 14 days and all other mutants by 7 days.

Correlation Coefficient among different characters (Table 80) shows highly significant positive association between panicle length and yield per plant, between panicle length and 1000 grain weight, between panicle length and grain per panicle, and between yield per plant and grain per panicle in both the generations. Significant positive association between yield per plant and 1000 grain weight and between 1000 grain weight and grain per panicle were also obtained in M_4 generation. Significant positive correlation among the above character pairs suggests that further selection for panicle length may bring about improvement of yield.

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Table 78. ANOVA of combined analysis for days to maturity and yield in twenty early mutants and their parent BSi1.

Source of variation	df	Days to maturity		Yield per plant (gm)	
		MS	F value	MS	F value
Year (A)	1	343.365	24.2647**	291.384	175.8228**
Error	4	14.151		1.657	
Variety (B)	20	46.698	14.1120**	6.634	4.5281**
Interaction (A x B)	20	2.632	0.7953	2.165	1.4775
Error	80	3.309		1.465	

(** Significant at 1% level of probability.)

Table 79: Mean values (over two years) for days to maturity and yield per plant in twenty early mutants and their parent BSi1.

Variety/mutant	Days to maturity	Yield per plant (gm)
Mutant1	118.70	5.80
Mutant2	118.20	7.08
Mutant3	111.70	3.16
Mutant4	118.80	5.98
Mutant5	111.30	2.69
Mutant6	118.80	5.50
Mutant7	117.70	5.59
Mutant8	118.30	5.98
Mutant9	117.30	5.82
Mutant10	117.80	6.05
Mutant11	117.80	5.09
Mutant12	117.70	5.25
Mutant13	118.00	5.09
Mutant14	118.70	4.44
Mutant15	118.30	6.05
Mutant16	117.00	5.36
Mutant17	117.50	4.49
Mutant18	117.80	4.59
Mutant19	118.50	5.39
Mutant20	113.3	4.03
Parent (BSi1)	125.0	6.46
LSD (0.01)	2.77	1.84
CV (%)	1.55	23.13

Table 80. Correlation coefficient among different characters in twenty early mutants and their parent, *BSi1 in* M_3 and M_4 generations.

	Panicle length	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Panicle length (cm)					
No. of tillers per plant	-.5740**				
	(-.0241)				
Yield per plant (gm)	.6654**	-.3510**			
	(.6580**)	(-.1355)			
Weight of 1000 grains (gm)	.3913**	-.3617**	.1204		
	(.6636**)	(-.1404)	(.5130**)		
Grains per panicle	.5464**	-.1384	.7254**	.0540	
	(.6000**)	(-.0985)	(.9837**)	(.3863**)	

(** Significant at 1% level.)
(Figures within the parenthesis indicate the values in M_4 generation.)

Table 81. ANOVA for different quantitative characters in sixteen early mutants and their parent, BSi467 in M_3 and M_4 generation.

Source of variation	df	Mean Square							
		Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Number of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Replication	2	53.431	27.431	128.524	5.311	0.059	1.135	0.027	22061.375
		(182.020)	(5.549)	(364.439)	(4.878)	(0.200)	(3.158)	(0.010)	(495235.329)
Variety	16	102.814	37.990**	363.447**	20.065**	0.070	7.614**	0.128**	2108661.279**
		(80.260**)	(114.877**)	(200.195**)	(15.743**)	(0.083)	(1.959*)	(0.077**)	(385252.285*)
Error	32	57.806	4.369	36.905	1.806	0.076	0.935	0.046	415005.196
		(24.624)	(2.528)	(41.391)	(4.471)	(0.059)	(0.837)	(0.021)	(154357.470)

(** Significant at 1% level, * Significant at 5% level.)
(Figures within parenthesis indicate the values in M_4 generation.)

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Table 82. Mean values for different quantitative characters in sixteen early mutants and their parent, BSi467 in M_3 generation

Variety/mutant	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Mutant 1	88.00	120.00	91.67	15.33	1.00	4.93	2.09	2260.05
Mutant 2	79.33	117.67	109.27	14.80	1.00	2.63	2.70	1326.20
Mutant 3	77.67	119.33	100.53	14.20	1.07	2.87	2.75	1490.73
Mutant 4	66.67	120.00	93.27	12.33	1.33	3.89	2.62	1945.62
Mutant 5	82.67	119.33	96.87	13.60	1.20	4.10	2.64	1823.33
Mutant 6	75.33	119.00	88.07	10.73	1.00	2.45	2.41	1222.13
Mutant 7	85.33	122.33	104.53	16.60	1.33	3.30	2.49	2346.27
Mutant 8	81.67	119.00	98.60	14.60	1.53	3.13	2.42	2080.83
Mutant 9	79.33	116.67	83.87	10.67	1.20	2.28	2.59	1430.90
Mutant 10	86.00	122.00	101.13	15.60	1.00	5.07	2.46	3278.16
Mutant 11	82.00	118.67	99.13	13.93	1.00	3.27	2.98	1421.87
Mutant 12	83.00	122.33	90.47	12.93	1.00	3.70	2.50	2532.83
Mutant 13	82.00	120.67	93.13	15.00	1.07	3.83	2.36	2300.18
Mutant 14	76.33	121.00	91.40	11.93	1.07	3.87	2.72	1737.78
Mutant 15	84.00	122.67	103.27	14.80	1.07	4.71	2.67	1812.60
Mutant 16	89.00	121.67	98.47	15.67	1.13	5.37	2.73	2345.98
Parent (BSi467)	91.33	133.00	133.27	21.93	1.07	9.08	2.32	4654.78
LSD (0.01)	-	4.67	13.58	3.01	-	2.16	0.48	1440.00
CV (%)	9.30	1.73	6.16	9.34	24.53	24.02	8.38	30.41

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Table 83. Mean values for different quantitative characters in sixteen early mutants and their parent, BSi467 in M_4 generation.

Mutant/variety	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Mutant 1	87.00	115.33	93.17	15.06	1.00	3.09	2.00	2050.50
Mutant 2	88.00	115.33	101.28	16.00	1.29	2.35	2.21	1548.79
Mutant 3	84.33	116.00	97.61	16.96	1.32	4.50	2.43	1627.04
Mutant 4	83.00	115.00	86.67	12.72	1.47	2.98	2.45	1969.21
Mutant 5	90.00	113.00	90.90	12.57	1.13	2.65	2.34	1776.86
Mutant 6	77.00	112.33	79.64	10.36	1.00	1.79	2.37	1333.64
Mutant 7	84.33	113.00	97.77	17.13	1.13	3.16	2.13	1657.08
Mutant 8	81.33	110.67	99.75	13.53	1.20	2.45	2.31	1594.71
Mutant 9	80.00	113.33	84.53	11.97	1.17	1.96	2.27	1359.55
Mutant 10	84.67	114.33	103.75	18.64	1.53	3.50	2.13	1847.39
Mutant 11	80.33	112.00	104.27	15.90	1.13	3.11	2.45	1536.06
Mutant 12	83.33	111.67	101.60	16.10	1.40	3.06	2.38	1599.14
Mutant 13	81.00	111.00	88.37	14.93	1.00	2.08	2.22	1323.81
Mutant 14	79.33	112.00	88.90	11.67	1.13	2.23	2.45	1271.68
Mutant 15	85.33	114.33	93.73	14.93	1.27	3.57	2.36	1619.08
Mutant 16	86.00	114.33	92.97	15.30	1.10	3.71	2.57	1776.84
Parent (BSi467)	99.67	138.00	111.47	17.23	1.00	4.50	2.03	2781.30
LSD (0.01)	4.04	3.56	14.39	4.73	-	2.05	0.32	878.50
CV (%)	5.88	1.38	6.78	14.32	20.39	30.68	6.33	23.29

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Table 84. ANOVA of combined analysis for days to maturity and yield in sixteen early mutants and their parent, BSi467.

Source of variation	df	Days to maturity		Yield per plant (gm)	
		MS	F value	MS	F value
Year (A)	1	948.245	57.5036**	27.841	12.9705*
Error	4	16.490		2.147	
Variety (B)	16	131.956	38.2644**	7.223	8.1540**
Interaction (A x B)	16	20.912	6.0640**	2.350	2.6529**
Error	64	3.449		0.886	

(** Significant at 1% level, * Significant at 5% level)

Table 85. Mean values (combined over two years) for days to maturity and yield per plant in sixteen early mutants and their parent, BSi467.

(Variety/Mutant)	Days to maturity		Yield per plant (gm)	
	Year 1	Year 2	Year 1	Year 2
Mutant 1	120.00	115.30	4.93	3.09
Mutant 2	117.70	115.30	2.63	2.39
Mutant 3	119.30	116.00	2.87	4.50
Mutant 4	120.00	115.00	3.89	2.98
Mutant 5	119.30	113.00	4.10	2.65
Mutant 6	119.00	112.30	2.45	1.79
Mutant 7	122.30	113.00	3.30	3.16
Mutant 8	119.00	110.70	3.13	2.45
Mutant 9	116.70	113.30	2.28	1.96
Mutant 10	122.00	114.30	5.07	3.50
Mutant 11	118.70	112.00	3.27	3.11
Mutant 12	122.30	111.70	3.70	3.06
Mutant 13	120.70	111.00	3.83	2.08
Mutant 14	121.00	112.00	3.83	2.23
Mutant 15	122.70	114.30	4.71	3.57
Mutant 16	121.70	114.30	5.37	3.71
Parent (BSi467)	133.00	138.00	9.08	4.50
LSD (0.01)	4.03		2.04	
CV (%)	1.58		26.86	

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Table 86. Correlation coefficients among different quantitative characters in sixteen early mutants and their parent, BSi467 in M_3 and M_4 generations.

	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Panicle length (cm)					
No. of tillers per plant	.0452 (.1486)				
Yield per plant (gm)	.7220** (.4641**)	-.0200 (.2316)			
Weight of 1000 grains (gm)	.1694 (-.2810)	.0388 (.2136)	-.1849 (-.0501)		
Grains per panicle	.6408** (.2771)	.1161 (.0527)	.7311** (.6524**)	-.3958** (-.4276**)	

(** Significant at 1% level of probability.)
(Figures within the parenthesis indicate the values in M_4 generation)

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In BSi467 except days to flowering in M_3 and tiller number in M_4 generation, highly significant mean squares (Table 81) of all the characters indicate high variation among induced mutants and their parent. Combined analysis of variance (Table 84) also shows high variation among parent and induced mutants for days to maturity and yield per plant. In this variety highly significant variety- environment interaction indicates that the entries (both parent and mutants) were influenced by the change of the environment in respect of both the characters. Tables 82 and 83 indicate that days to maturity in the entries varied from 116.7 to 133.0 days in M_3 and 110.7 to 138.0 days in M_4 generation. In spite of environmental influence in the mutants compared to parent maturity occurred earlier in M_3 by at least 11 days and in M_4 by at least 22 days. Combined analysis over generations (Table 85) shows that the mutants matured earlier by at least 17 days. It is also evident from Tables 82 and 83 that all the mutants produced low yield and all most all the mutants produced high grain weight in both the generations.

Correlation Coefficient among different characters (Table 86) shows that yield per plant has significant positive correlation with panicle length and number of grains per panicle; panicle length has also positive correlation with number of grains per panicle in both the generations. The positive association between the above character pairs suggests that selection for panicle length may bring about improvement of yield as 1000 grain weight and grain per panicle are closely associated with panicle length.

4.3.4.2. Induced dwarf type : Five dwarf mutants were isolated in BSi427. Table 87 shows that in M_2 generation the height of the mutants varied from 44 to 47 cm compared to that of 116.4 cm in the parent. Maturity days of all the induced dwarfs were almost the same as their parent. In M_3 compared to M_2 a little reduction in height of both the parent and dwarfs was observed. The height of dwarfs ranged from 36.6 to 41.4 cm compared to that of 107.0 cm in parent. All the dwarfs were found to produce tiller ranging from 1.0 to 1.6 compared to that of 1.0 in parent. No marked change was observed in maturity period (Table 88). In M_4 generation except days to flowering, days to maturity and harvest index, mean squares for all the characters were found significant (Table 89) indicating high variation among the dwarfs and parent. It is evident from Table 90 that the height of the dwarfs varied from 31.26 cm to 34.31 cm compared to that of 83.50 cm in control. All the

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Table 87. Different quantitative characters in five selected dwarf mutants and their parent, BSi427 in M_2 generation (observed data).

Mutant/Variety	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)
DM1	89.00	124.00	46.00	15.00	1.00	5.16
DM2	90.00	124.00	47.00	16.00	1.00	5.41
DM3	90.00	126.00	47.00	17.00	1.00	7.23
DM4	89.00	125.00	44.00	16.00	1.00	6.17
DM5	89.00	124.00	47.00	14.00	1.00	7.25
Parent (BSi427)	90.00	126.00	116.40	20.50	1.00	12.50

Table 88. Different quantitative characters in five selected dwarf mutants in M_3 generation (mean data)

Mutant/ Variety	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)
DM1	90.00	125.20	36.60	15.60	1.20	4.84
DM2	90.00	124.80	41.40	17.80	1.40	5.96
DM3	90.00	125.80	41.20	16.20	1.20	5.70
DM4	90.14	125.20	39.80	16.80	1.00	5.44
DM5	89.80	124.80	39.00	16.80	1.60	6.39
Parent (BSi427)	90.00	127.00	107.00	21.40	1.00	13.40

Table 89. ANOVA for different quantitative characters in five dwarf mutants and their parent, BSi427 in M_4 generation.

Source of variation	df	Mean Square										
		Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant	weight of 1000 grains (gm)	Grains per panicle	leaf number	Inter nodal length (cm)	Harvest index (HI) in %
Replication	2	0.362	0.395	0.599	0.106	0.112	0.500	0.001	8189.805	1.116	0.040	1.231
Variety	5	1.038	0.442	1302.146**	12.745**	0.148*	6.262**	0.022*	1404057.453**	0.582**	7.320**	4.127
Error	10	0.646	0.236	1.268	0.439	0.027	0.143	0.005	14251.305	0.080	0.052	1.601

(* Significant at 5% level of probability, ** Significant at 1% level of probability.)

Table 90. Mean values of different quantitative characters in five dwarf mutants and their parent, BSi427 in M_4 generation

Mutant/Variety	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle	Leaf No.	Inter nodal length (cm)	Harvest Index(%)
DM1	34.31	14.10	1.430	3.163	2.173	1174.00	9.853	1.367	37.040
DM2	32.62	13.84	1.493	3.023	2.163	1104.00	9.713	1.547	36.687
DM3	32.09	13.24	1.617	2.990	2.137	1101.00	10.18	1.513	36.853
DM4	32.35	13.60	1.457	2.793	2.160	1042.00	10.06	1.520	36.783
DM5	31.26	12.88	1.580	2.633	2.090	984.30	9.870	1.423	36.720
Parent (BSi427)	83.50	18.47	1.000	6.430	2.340	2749.00	8.933	5.297	33.960
LSD(0.01)	2.914	1.715	0.4252	0.9785	-	393.00	0.7319	0.5901	-
LSD(0.05)	-	-	-	-	0.1286	-	-	-	-
CV(%)	2.75	4.62	11.53	10.79	3.30	8.78	2.90	10.83	3.48

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Table 91. Mean values of different quantitative characters in five dwarf mutants and their parent, BSi427 in M_3 and M_4 generation.

Mutant/Variety		Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per Plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
DM1	M_3	90.90	125.50	37.00	15.60	1.20	4.52	2.23	1752.16
	M_4	92.67	127.80	35.80	14.13	1.47	3.16	2.14	1158.24
t value		-3.55**	-5.03**	0.77	1.84	-0.86	4.05**	2.19*	4.51**
DM2	M_3	91.10	125.40	41.30	16.90	1.30	4.70	2.22	1858.71
	M_4	92.40	128.07	32.80	14.40	1.60	3.02	2.16	1103.69
t value		-2.46*	-6.78**	5.04**	2.35*	-0.89	3.44**	1.88	4.82**
DM3	M_3	90.90	125.10	40.20	16.10	1.30	5.03	2.27	2072.11
	M_4	91.73	127.80	33.53	13.27	1.87	2.99	2.14	1102.34
t value		-2.01	-7.22**	4.62**	3.68**	-1.42	5.76**	4.92**	7.12**
DM4	M_3	90.90	125.00	40.80	16.00	1.10	4.69	2.23	2068.27
	M_4	92.00	127.60	35.27	15.93	1.47	2.64	2.15	1009.16
t value		-2.40*	-6.57**	3.40**	0.08	-2.00	5.19**	1.23	5.04**
DM5	M_3	90.70	124.90	39.00	16.80	2.10	6.39	2.29	1485.72
	M_4	91.87	127.67	32.27	12.73	1.73	2.68	2.10	974.92
t value		-2.51*	-7.61**	4.31**	4.32**	0.97	6.10**	3.37**	4.26**
Parent	M_3	90.80	127.00	106.50	21.10	1.00	12.16	2.43	5127.71
(BSi427)	M_4	91.80	127.20	87.90	19.40	1.00	7.19	2.34	3066.42
t value		-1.56	-0.17	7.03**	1.52	-	4.39**	1.71	4.86**

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dwarfs were low yielding with smaller number of grains per panicle; they were with greater tiller number, with greater leaf number and smaller inter-nodal length compared to that of parent. It is apparent that the short stature of the dwarfs might be due to shorter inter-nodes. Mean square for harvest index was found insignificant (Table 90).

Table 91 shows that in DM1 other than plant height, panicle length, tiller number, "t" values were significant for all characters in parent and dwarfs. In DM2 except tiller number and 1000 grain weight "t" values for all other characters were significant. In DM3 except days to flowering and tiller number "t" values for all other characters were significant. In DM4 other than panicle length, tiller number and 1000 grain weight "t" values were significant for all characters. In DM5 except tiller number "t" values for all other characters were significant. In parent other than days to flowering, days to maturity, panicle length, tiller number and 1000-grain weight "t" values were significant for all characters. Significant "t" values indicate that parent and dwarfs (DM2, DM3, DM4 and DM5) were all influenced by the change of the environment. In DM1 "t" value for plant height was insignificant to show that as far as plant height of this mutant is concerned it is not influenced by environment. Table 91 also shows that the reduced height in dwarfs was about two and half times shorter than that of the parent. The five dwarfs did not differ considerably for plant height from one another.

Phenotypic and genotypic coefficient of variations were the highest for plant height followed by yield per plant (Table 92). Except tiller number, the differences between GCV and PCV were small in all the traits. In tiller number differences between GCV and PCV were higher indicating vulnerability of this trait to the environmental influence. High values of heritability (H_b) were obtained for all the characters. The traits also showed moderate to high estimates of genetic advance (GA). High heritablity (H_b) estimates associated with high estimates of GA particularly for plant height and yield per plant indicate that this characters are governed to a great extent by additive genes enabling phenotypic selection of this traits possible.

Correlation coefficient among different characters (Table 93) shows that yield per plant has significant positive correlation with panicle length, 1000-grain weight and number of grains per panicle. Significant positive correlation between panicle length and 1000-grain

Table 92. Genetic parameters for different characters in five dwarf mutants and their parent, BSi427 in M_4 generation.

Characters	Genotypic variance	Environmental variance	Phenotypic variance	GCV	PCV	Heritability (H_b)	G.Ad (5%)	G.Ad (%)
Plant height (cm)	433.63	1.27	434.89	50.76	50.84	99.71	42.83	54.89
Panicle length (cm)	4.10	0.44	4.54	14.11	14.85	90.34	3.97	5.08
No. of Tillers per plant	0.04	0.03	0.07	14.05	18.18	59.74	0.32	0.41
Yield per plant (gm)	2.04	0.14	2.18	40.74	42.14	93.45	2.84	3.64

Table 93. Correlation coefficient among different characters in five dwarf mutants and their parent, BSi427.

	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Panicle length (cm)					
No. of Tillers per plant	-.7768**				
Yield per plant (gm)	.9344**	-.6156*			
Weight of 1000 grains (gm)	.8288**	-.6825**	.7867**		
Grains per panicle	.9618**	-.7305**	.9758**	.7702**	

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Table 94. ANOVA for different quantitative characters in seven high yielding mutants and their parent, BSi427 in M_3 generation.

Source of variation	df	Mean Square							
		Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Number of tillers	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Replication	2	0.792	1.625	47.908	1.143	0.000	1.292	2114514.440	0.001
Variety	7	7.690**	0.280	47.873**	2.165	0.001	1.504	796651.105	0.072**
Error	14	1.030	0.673	7.203	1.525	0.001	1.881	353245.523	0.003

(** Significant at 1% level of probability.)

Table 95. Mean values of different quantitative characters in seven high yielding mutants and their parent, BSi427 in M_3 generation.

Variety/mutant	Days to flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	No. of tillers per plant	Yield per plant (gm)	Weight of 1000 grains (gm)	Grains per panicle
Mutant 1	94.67	129.67	89.33	18.67	1.00	8.67	2.05	4485.53
Mutant 2	95.33	129.67	91.80	18.93	1.00	9.18	1.99	4423.83
Mutant 3	94.67	130.00	91.60	18.77	1.00	9.37	2.00	4615.15
Mutant 4	94.00	133.33	93.20	18.47	1.00	10.03	2.00	4693.55
Mutant 5	95.33	129.67	87.23	17.50	1.00	8.76	2.00	4548.80
Mutant 6	95.33	129.67	90.13	17.87	1.03	9.03	2.03	3479.63
Mutant 7	92.33	129.67	86.20	16.40	1.00	10.26	2.33	3652.46
Parent (BSi427)	91.00	130.33	80.83	17.67	1.03	8.12	2.35	3589.73
LSD(0.01)	2.467	-	6.522	-	-	-	0.133	-
CV(%)	1.08	0.63	3.02	6.85	2.96	14.94	2.49	14.20

Table 96. Comparative increase (percent) in yield of seven high yielding mutants over their parents, BSi427 in M_2 and M_3 generation.

Variety/Mutant	M_2 generation		M_3 generation	
	Observed yield (gm)	Percent of control	Mean yield (gm)	Percent of control
Parent (BSi427)	13.40 (mean)	100.00	8.12	100.00
Mutant1	20.30	151.49	8.68	106.90
Mutant2	20.30	151.49	9.18	113.05
Mutant3	17.40	129.85	9.37	115.39
Mutant4	18.00	134.33	10.03	123.52
Mutant5	21.50	160.45	8.76	107.88
Mutant6	15.50	115.67	9.03	111.21
Mutant7	14.60	108.96	10.26	126.35

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weight, between panicle length and grains per panicle and between grain weight and grains per panicle were also observed. The significant correlation coefficient among the above characters suggests that selection for panicle length may bring about improvement of yield. By increasing panicle length, grains per panicle could be increased as the character is closely associated with its length.

4.3.4.3. High yielding mutants : Seven high yielding mutants were isolated in BSi427. Table 94 shows that mean squares for days to flowering, plant height and 1000-grain weight were significant indicating a good deal of variation among mutants and their parent for the above characters. Table 95 shows that high yielding mutants took more number of days to flowering (92-95) compared to that of 91.0 days in parent. All the mutants and parent took more or less same period for maturity. Thousand-grain-weight in the parent was slightly higher than of all other mutants. Table 96 shows that the yield of all the mutants in M_2 was higher (observed yield on plant basis) than their parent (mean yield). In M_3 generation the yield reduced considerably. In spite of yield reduction mutants were superior than their parent in mean yield.

Since the productivity is the ultimate result of interaction between yield contributing factors and environment, it will be too early to predict whether these mutants would retain their high productivity trait in succeeding generations.

Due to lack of facilities grain protein content was not studied.

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Chapter 5
DISCUSSION

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5. DISCUSSION

Unlike major cereals such as rice, wheat, barley mutation studies have been few and far between in major millets like sorghum, bajra and ragi. Mutation studies by means of ionizing radiation and chemical mutagens have been few in foxtail millet (Bhat et al. 1961; Srirangasayi et al. 1971; Gupta and Yashvir, 1975; Channabyra Gowda, 1978; Sarker, 1993). Nayar and Seetharam (1972) were the first among millet breeders to indicate the possible role of induced mutations in 'ragi' improvement.

Three genotypes of foxtail millet, namely BSi1, BSi427 and BSi467 with distinct morphological features were chosen in the present investigation to understand the mutational effects of physical mutagen on this crop species and to isolate mutants of important agronomic characters.

Various physiological effects in M_1 generation are caused by physical and chemical mutagens (Gaul, 1970). The nature and intensity of the effects depend largely on the type and the dosage of mutagens, pre and post treatments, environmental conditions, genetic background, nuclear volume, chromosome size, ploidy level, age and radio sensitivity of the treated materials.

Among the criteria commonly used as indices of radio sensitivity in M_1 plants, effects in relation to germination and survival, seedling growth, pollen sterility, seed fertility and induction of both chlorophyll and viable mutations in M_2 were studied. Polygenic mutations in M_3 were also studied during the present investigation in order to evaluate the possible role of radio sensitivity in inducing useful mutants.

5.1. Studies in M_1 generation

5.1.1. Germination : Subba Rao et al. (1968), Goud et al. (1970) and Shashidhara et al. (1990) found reduced germination with increasing dosage in sorghum; such observation was made in wheat and barley by Bhaskaran and Swaminathan (1961); in pearl millet by Burton et al. (1974) and Sandhu (1981); in ragi by Kumar et al.(1959), Mahishi (1977), by Srikantaradhya (1979) and by Tikka and Desai (1989); in prosomillet by Mansurova et al. (1958); in foxtail millet by Bhat et al. (1961), by Srirangasayi et al. (1971) and by

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Gowda (1978). Reduced germination was also recorded by Islam (1987) in *Panicum miliaccum* seeds treated with different dosages of gamma rays and EMS.

All these results are in conformity with the present work but it is difficult to reconcile the present results with 100 percent germination reported by Singh and Godward (1974) in *Eleusine coracana* at all dosages with beta rays, X-rays and gamma rays; 100 percent germination in TN treated pearl millet has also been reported by Burton et al. (1974).

5.1.2. Seedling growth (both root and shoot), seedling dry weight, pollen sterility and grain fertility : In the present investigation gamma treatments affected the growth of both roots and shoots, pollen and seed fertility. Such observation has been also made by Goud et al. (1969, 1970) in ragi and sorghum; by Kumar et al. (1969), by Sreekantaradhya (1971, 1979) and Mahishi (1977) in finger millet.

During the study marked varietal differences as a result of irradiation with regard to both root and shoot growth were seen. Seven-day-old seedlings of the three varieties did not differ in their dry weight. Such varietal differences in respect of seedling growth have been reported by Goud et al. (1967, 1969) in paddy and ragi; by Goud et al. (1969) in sorghum; by Shandu (1981) in pearl millet; by Kumar et al. (1969) in finger millet; by Owen (1967) in thermal neutron exposed paspalum seeds. The final survival of the population was also affected to a great extent by higher dosages which is in accord with the findings of Goud et al. (1969) in sorghum and of Singh and Godward (1974) in finger millet.

The differential response of the varieties to gamma treatments in respect of both pollen sterility and grain fertility was observed. The extent of higher pollen sterility was about 71.36 percent at 40 Kr in one variety whereas in the other two varieties higher pollen sterility was recorded at the highest dosage of 80 Kr. In case of grain fertility the highest dosage of 70 Kr caused the highest sterility in all the three varieties. In a study of mutagenic response of *Panicum miliaceum* to different dosages of gamma rays and EMS, Islam (1987) reported that pollen sterility increased with the increase in dosages and grain fertility was more affected by gamma rays than EMS. Shashidhara (1990) also reported a linear decrease of pollen fertility with increasing dosages in a study of induced variability for different traits in M_1, M_2 and M_3 generations of sorghum by MMS and gamma rays. Ekberg (1969) and others observed that chromosomal aberrations were

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mainly responsible for radiation induced sterility. Pollen sterility in M_1 may be the result of mutations, chromosomal aberrations, cytoplasmic abnormalities and physiological disturbances. All these singly or together influence pollen sterility in M_1 generation.

5.1.3. Quantitative characters: Along with the studies of M_1 effects, studies in relation to quantitative characters in M_1 indicated that gamma radiation has been very effective in releasing variability for all the quantitative characters which are in contrast with the observations reported by Islam (1987) in *Panicum meliaceum*. Islam used both gamma rays and EMS in which none of the mutagenes at the dosage used by him created variability for the quantitative characters studied in M_1, whereas Goud (1967) reported EMS as very effective in releasing variability for quantitative characters in wheat in M_1; in ragi reported by Goud et al. (1971) and in sorghum by Shashidhara et al. (1990). Sreekantaradhya (1971) reported gamma rays and EMS as effective in creating wide variability for quantitative characters such as plant height, finger length, finger breadth and finger numbers in ragi in M_1.

The increase in range and shifting in both the directions clearly indicate that though not all the dosages but most of the dosages of gamma radiation released polygenic variability in the present investigation and it was very evident in the case of characters such as: (a) days to flowering, (b) plant height, (c) tiller number and (d) yield per plant (BSi1 and BSi467). The range of flowering shifted in both directions in BSi1 and BSi427 indicating both early and late tendency of flowering. Mahishi (1977) in finger millet, Islam (1987) in *Panicum maliaceum*, Shashidhara et al. (1990) in sorghum reported that gamma radiation and EMS treatments caused delayed flowering. The positive shifting of the range for maturity in the two varieties indicated late maturing while negative shifting at the dosage of 50 Kr indicated the possibility of an induced early maturing character in the other variety (BSi467). Although a narrow range for plant height was observed in BSi467, the wide range of the above character in the other two varieties indicated the possibility of creation of both tall and dwarfness. Islam (1987) reported reduction in plant height following gamma rays and EMS treatment, whereas Shashidhara et al. (1990) reported that gamma rays and MMS increased plant height in sorghum.

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Although dosages of 10, 20 and 30 Kr in BSi1, 10 Kr in BSi427 and 10, 20, 30 and 40 Kr in BSi467 increased panicle length, substantially the range of the character did not enlarge in all the three varieties thereby minimizing the possibilities of enlargement of panicle length in the present investigation. However, the positive shifting of the range of the character at the dosage of 40 Kr in BSi427 and dosages of 10 and 40 Kr in BSi467 in M_1 indicated the possibility of enlargement of panicle length following gamma treatments. Similar to the results reported by Sreekantaradhya (1971) in finger millet.

The wide range and increased mean for tiller number in all the three varieties indicated gamma radiation as very effective in increasing tiller number. Similar observation was made by Goud (1967) in hexaploid wheat in his mutagen treated population.

Mean and range of grain yield per plant in BSi427 reduced and shifted in negative direction. Compared to this, the other two varieties showed a wider range in grain yield both in positive and negative direction. This variability offered scope for selecting promising individuals for grain yield per plant. This is in agreement with the observations on gamma irradiated panicum by Budarov (1969). In UV treated maize and sorghum seeds, similar results were reported by Padmakar and Chaturvedi (1987). Shashidhara et al. (1990) obtained similar results in their MMS treated sorghum seeds.

5.1.4. Variants in M_1 : Chlorophyll variant (striata) with a frequency of 0.64% in the M_1 plant population at a dosage of 30 Kr in BSi427 was observed during the present study. The present finding is in agreement with the data published by Chanchal Kapoor (1967). He observed chlorophyll streaks in about 35% of his chemical mutagen treated M_1 population in sorghum. Srirangasayi et al. (1971) also reported chlorophyll chimera in M_1 generation in his chemical mutagen treated foxtail millet. Sarker (1993) observed plants with crinkle peduncle in his EMS and gamma rays treated foxtail millet M_1 population. He also reported a large number of plants of highly sterile ear heads.

Besides chlorophyll chimera, an interesting seed colour variant with a frequency of 1.005% in the M_1 plant population was observed in BSi467 at a dosage of 20 Kr in the present investigation. Although many M_1 abnormalities related to ear head characters and chlorophyll streaks were reported earlier in other millets including a few in foxtail millet, such seed colour variants have not been reported in any of the millets including foxtail

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millet. The variants were tested for their breeding behaviour. None of the variants followed any segregating pattern but bred true to type. The breeding behaviour suggests that the change may have been due to endospermic mutation and not due to mutation in the embryonal tissue.

5.2. Studies in M_2 generation

5.2.1. Frequency and spectrum of chlorophyll mutations: In the past few studies on induced chlorophyll mutations in millets were done. Although radiation induced chlorophyll mutations have been studied by Goud et al. (1969) in *Eleusine coracana* and in *Sorghum vulgare* by Goud et al. (1970) and Ramula (1970, 1972), study was only confined to *Setaria italica* (Gupta and Yashvir 1975). In such studies both radiation and chemical mutagens were used. The results in the present study clearly indicate that the response of the three varieties was not uniform as indicated in the frequencies of chlorophyll mutations in the three varieties being 46.36% in BSi1, 40.31% in BSi427 and 30.22% in BSi467 on M_2 plant population. Moreover, gamma dosages generated chlorophyll mutations in different frequencies, the highest dosage (80 Kr) being found to induce higher frequency in BSi1 (14.42%). Mid-level dosage of 50 Kr induced higher frequency in BSi427 (16.35%) and the dosage of 60 Kr in BSi467 (8.49%) on M_2 population. The response of the two varieties (BSi427 and BSi467), to 50 Kr was radically different. The variety BSi427 showed maximum frequency of chlorophyll mutation whereas the variety BSi467 showed low frequency of mutation even lower than that produced at 40 Kr (figure 7).

The present findings are in accord with those of Gustafsson (1963) in barley and Goud et al. (1970) in gamma irradiated sorghum but are in contrast with those reported by Gupta and Yashvir (1975) in *Setaria italica*. It may be mentioned that the latter irradiated their material with 10, 20, 30 and 40 Kr of gamma rays. They reported chlorophyll mutation frequency at 40 Kr to be 4.22% in MU-1 and 4.69% in MU-2. At 40 Kr the readings as recorded in the present study were : 3.39% (BSi1), 4.01% (BSi427), and 6.75% (BSi467). Goud et al. (1970) reported a chlorophyll mutation frequency as high as 6.23% on M_2 plant population at 40 Kr gamma radiation in sorghum, although this value is lower than that obtained in the present study. Whether such a difference could be attributed to a

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difference in the physiological condition of seed of different genotypes would be difficult to say, it is however, obvious that such differences are attributable to different genotypes of the material used in the present investigation.

During the present study a wide spectrum of chlorophyll mutations was observed in the three varieties as also reported by Sharma (1965) in sorghum, by Gupta and Yashvir (1975) in *Setaria italica* and by Channabyre Gowda (1978) in *Setaria italica*, by Sing et al. (1974) in pearl millet, by Srikantaradhya and Madhavamenon (1979) in finger millet, by Sandhu (1981) in pearl millet and by Islam (1987) in proso millet using gamma radiation.

The different kinds of chlorophyll mutations and their order obtained in the present work were somewhat different from those reported by earlier workers. The differential response may have arisen as a result of variation of genotypes which distinguished them for the material used by earlier workers.

5.2.2. Efficiency and effectiveness of mutagen : During the present study the effectiveness and efficiency of gamma treatments was not proportional to the dosages and same dosage did not produce the same effect and efficient in the three varieties. In BSi1 lower dosage was found to be the most effective and efficient. In BSi427 the mid-level dosage 50 Kr was found to be most effective and efficient while in other variety, BSi467 lower dosage was effective but comparatively higher dosage was found to be the most efficient. These findings are in agreement with the observations made by Gupta and Yashvir (1975) in *Setaria italica*, by Islam (1987) in *Panucum meliaceum* and by Gowda (1978) in their gamma irradiated and EMS treated materials. These differences may be attributed to the differences in the genotypes and sensitivity of different genotypes to mutagenic treatments at various levels of ionising radiation and chemical mutagens.

5.2.3. Frequency and spectrum of viable mutation : In the present study differential response of the genotypes regarding viable mutations was also observed, the highest frequency being recorded to be 21.34% in BSi1, 16.30% in BSi467 and 12.84% in BSi427 based on M_2 plant population. Besides, gamma dosages generated viable mutations of different frequencies. The second highest dosage of 70 Kr was found to induce higher frequency in BSi1 (8.90%) and in BSi427 (4.86%). Unexpectedly the moderate dosage of 40 Kr induced higher frequency in BSi467 (3.45%) per 100 M_2 plant population. A wide

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spectrum of viable mutations was also observed in the three varieties as has been recorded by Sharma (1965) in his chemical mutagen treated sorghum. Gowda (1978) reported wide spectrum of viable mutants in gamma rays treated foxtail material in comparison to EMS treated material. A wide spectrum of viable mutants in mutagen treated proso millet was also reported by Konstantinov et al. (1987) and in pearl millet by Sandhu (1981). The spectrum in the present work consisted broadly of colour, maturity, panicle and stature type of mutants. The order and frequency of different kinds of viable mutants obtained in the present work were different in the three varieties. Coloured type mutant was more frequent in BSi1 and in BSi467 stature type of mutant was more frequent. Such varietal differences in mutation generating ability are well known (Goud, 1967). Varietal differences in viable mutation yielding ability were also reported by Pilnikova et al. (1971) and Islam (1987) in mutagen treated proso millet varieties.

Useful mutants (dwarf, high yielding and early types) obtained in the present work are in agreement with the observations reported by Srirangasayi et al. (1971) in chemical mutagen treated *Setaria italica* variety and by Konstantinov et al. (1974) in panicum millet.

If the different irradiation dosages are compared, it will reveal that 10 and 20 Kr have the least effect on generating mutation while 80 Kr has not been a potent dosage in the sense that it killed almost the entire population in BSi427 and BSi467.

5.3. Studies in M_3 generation

5.3.1. Polygenic mutations (micro mutation) in M_3 : Effect of seven dosages of gamma irradiation on seven quantitative characters such as: (a) days to flowering, (b) days to maturity, (c) plant height, (d) panicle length, (e) tiller number, (f) grain yield and (g) thousand grain weight in the three varieties were studied. How affected the characters in the three varieties are discussed as follows :

BSi1

(i) **Days to flowering** : All dosages affected the character. Except at 10 and 20 Kr all other dosages of gamma irradiation delayed flowering. At the dosages of 10, 40, 50

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and 60 Kr, the range shifted towards negative direction offering scope of early line selection.

(ii) **Days to maturity** : Except at 30 Kr, all dosages of gamma irradiation induced late maturity. At 30 Kr a little tendency of earliness was observed.

(iii) **Plant height** : Except at 10 and 20 Kr, all other dosages reduced plant height. At 40 Kr the range shifted towards negative direction offering scope of selection of short stature plant type.

(iv) **Panicle length** : All dosages affected the character. Except at the dosage of 70 Kr, all other dosages increased panicle length offering high scope of selection of lines with large panicle.

(v) **Tiller number** : All dosages influenced tiller number. Except for 50 Kr, this influence of all other dosages was in the negative direction. From breeding point of view reduction in tiller number is not desirable. At 50 Kr the tiller number increased offering scope of selection. Rao and Goud (1973) reported also a number of promising lines with a greater number of tiller in *Setaria* but unlike in the present study they obtained enhancement of tiller number in all their treatments.

(vi) **Grain yield** : All dosages affected grain yield. The dosages of 10, 20 and 30 Kr increased grain yield while the remaining higher dosages decreased it. The enhancement of grain yield at the lower dosages offers scope of selection of the character. Bhatia and Swaminathan (1962) reported increased mean for grain yield in wheat, similar to the result reported by Brock (1965) and Goud (1967).

(vii) **Thousand grain weight** : The character responded negatively at all dosages. The negative response of the character offers no chance of selection for improving this character.

BSi427

(i) **Days to flowering** : Except at 10 and 70 Kr, all dosages delayed flowering.

(ii) **Days to maturity** : All dosages affected the character. The dosage of 10 Kr induced earliness in the character. In BSi1 30 Kr influenced the character towards earliness. The other remaining dosages were similar to both the varieties regarding late maturity.

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(iii) **Plant height** : Except at 10 Kr, all other dosages reduced plant height and negative response of the character offers scope of selection of short or dwarf type plants.

(iv) **Panicle length** : All dosages influenced the character. Except for 10 and 70 Kr, the influence of all other dosages was in negative direction. The dosage of 10 and 70 Kr increased panicle length offering high scope of selection of mutant lines with large sized panicle.

(v) **Tiller number** : Except at 50 Kr, in BSi1 in which tiller number showed enhancement, to all dosages BSi427 was similar to BSi1 in respect of reduction in tiller number.

(vi) **Grain yield** : Unlike BSi1 in which the grain yield showed improvement, in BSi427 there was reduction in yield (Table 46).

(vii) **Thousand grain weight** : To all dosages BSi427 was similar to BSi1 in respect of reduction in grain weight.

BSi467

(i) **Days to flowering** : The dosage of 20 Kr induced early flowering. In BSi427 two dosages, namely 10 and 70 Kr showed early flowering nature. The remaining other dosages were similar to the two varieties regarding delayed flowering.

(ii) **Days to maturity** : Substantially all dosages delayed maturity. Negative response of the character offers no chance of early line selection.

(iii) **Plant height** : Unlike BSi1 and BSi427 in which plant height reduced, in BSi467 all dosages increased plant height and it was not a selection criterion because greater the height less desirable is the plant type. The greater height in the treated variety (BSi467) is in agreement with the suggestion of Gaul (1965) and Astveit (1966). They indicated that the induced polygenic mutations do not follow any particular direction and that they are at random.

(iv) **Panicle length** : Except for 10 and 30 Kr, all other dosages increased panicle length of BSi467. In BSi467 two dosages, namely 10 and 30 Kr reduced the mean of the character. The dosage of 70 Kr reduced mean panicle length in BSi1. The remaining treatments were similar to the two varieties regarding improvement of panicle length. On the other hand the mean panicle length in the variety (BSi427) was 14.86

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cm, comparatively larger than that of the two varieties, responded negatively in all dosages except at the lowest dosage of 10 Kr and at the second highest dosage of 70 Kr in M_3 population. Bateman (1959) and Goud (1967, 1968) were of opinion that irradiation changes polygenic character such as height, panicle length, tiller number in a way opposite to what character was the present generation. For instance if the panicle length is short in M_0 then, the length increases considerably in M_1 and vice versa. The same results have been obtained in the present study but some lower and higher dosages of treatment did not agree with this trend (Table 45).

(v) **Tiller number** : Except at 30 Kr, substantially the character was not affected by all other dosages. The dosage 30 Kr reduced tiller number.

(vi) **Grain yield** : Grain yield showed improvement at 50 Kr. To all remaining dosages BSi467 was similar to BSi427 in respect of reduction in grain yield.

(vii) **Thousand grain weight** : Except at 20 and 30 Kr, all other dosages decreased grain weight. In this respect the two other varieties (BSi1 and BSi427) were different because the grain weight reduced at all dosages of gamma irradiation.

As discussed earlier that there exits two schools of thought. One school represented by Bateman (1959) and Goud (1967, 1968) is of opinion that if polygenic, expression of a character takes an opposite direction in successive generations while according to the other school by Gaul (1965) and Astveit (1966) "The direction of expression is at random".

5.3.2. Breeding behaviour and breeding value of viable mutants (macromutants) : A wide variation in quantitative characters as obtained here offering the scope of improvement of quantitative characters through selection supported the suggestion of Gaul (1961). The latter suggested micromutation as a powerful technique to bring about improvement in quantitative characters. Promising macromutants such as dwarf, early and high yielding mutants isolated in M_2 and their superior performance in later generations favour the macromutation technique for improving crops as well. Improvement in quantitative characters through macromutation technique was also adopted by many earlier workers. Joshi (1968) obtained progressive bristled ears and dwarf macromutants in gamma irradiated population in bajra. Nayar et al. (1979) obtained a line of open ear head early mutant in gamma and fast neutrons treated populations in finger millet.

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Shivshankar et al. (1973) obtained an early mutant in gamma irradiated population in a ragi variety (HES-927).

Nayar et al. (1974) also obtained some dwarf and ear mutants in gamma, fast neutrons and EMS treated populations in some ragi varieties.

The progressive mutants (dwarf, early and high yielding type) isolated in the present study were tested over two generations and found homogenous and bred true to the characters evaluated for. The height of the dwarf mutant was significantly different from that of the parent, resembling the triple dwarf mutant phenotype of wheat (McINTOSH, 1973). The population was found to be non segregating observed for six generations as of May 20, 1998. The "t" values for plant height were significant indicating that both parent and the dwarfs were influenced by environment.

The reduced height in dwarfs was due to smaller inter-nodal length and was about two and half times shorter than the height of the parent. Whether the dwarfism is genetical needs elaborate study using GA_3. The yield per plant was low but the harvest index was marginally higher than that of the parent. High heritability (H_b) estimates associated with high estimates of Genetic Advance (GA) for plant height and yield per plant indicated high possibility for improvement of above two characters. The fact that these two characters are governed by additive genes further strengthens the above assumption. The significant positive correlation between panicle length and yield per plant in dwarf mutants also indicated the significance of selection of panicle length for the improvement of yield. Mutant with higher yield due to higher harvest index was reported by Nayar et al. (1974) in finger millet. Dineshkumar et al. (1992) also reported higher yield due to higher harvest index in true genetic dwarf foxtail millet. The dwarfism due to reduced internodal length in the present investigation is in agreement with the findings reported by the above workers. More tillering potentiality and greater leaf number in the present study might be due to the action of dwarf gene as reported in foxtail millet by Dineshkumar et al. (1992). According to Brian et al. (1959) and Gale and Marshal (1973) normal indigenous gibberellin in dwarf individuals stimulates lateral growth accounting for higher tiller number. However, it is obvious that the dwarf mutants isolated in the present study exhibited superiority for most of the quantitative characters and their performance is comparable to any good tall variety.

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The high yielding nature (more tillering, higher harvest index) and superior morphological traits of the dwarf mutants make them ideal and suitable for intensive cultivation resulting in higher productivity not available in the existing germplasm collection. The isolated early type mutants were also evaluated and found to be useful mutants with their potentiality for immediate release. Most of the early mutants were of medium height with good morphological traits and they exhibited superiority for quantitative characters such as panicle length and tiller number. The insignificant variety-environment interaction over two generations indicated stability of the character. In BSi467 the significant variety-environment interaction indicated that earliness was influenced considerably by the environment. The combined performance over two generations put strong support in favour of earliness exhibited by all mutants in their maturity by at least 17 days earlier than their parent. It is generally believed that earliness is associated with low yield but one early mutant, mutant2 in BSi1 in the study was found to produce more yield than that of the parent, all other early types showing slightly lower yield. The isolation of progressively early mutants by means of macro mutation technique in the study are in conformity with the findings reported by Shivashankar et al. (1973) and Nayar et al. (1979) in ragi. Significant positive correlation between yield and other quantitative characters indicated that the selection of panicle length for the improvement of yield can be carried out.

One interesting observation was that factors such as plant height, panicle length, grain weight and tiller number which as a rule enhance yield were not significantly different from that of the parent except for height (high yielding type). However, in later generation there may be a scope to select for characters such as panicle length, tiller number, grain weight contributing to increase in yield.

However, isolation of a good number of progressive induced mutants with agronomically desirable traits may have immediate practical value. Such an option is more applicable for crops not exploited so far for intensive breeding work. Gaul (1964) is also of the same view that progressive macromutations occur more frequently in plant species have been subjected to little or no selection pressure. Moreover, the present results strongly support the mutation breeding programme as an effective tool for the improvement of single or more traits in crops like millets where mutation breeding for its improvement has been undertaken.

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Chapter 6
SUMMARY

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6. SUMMARY

The objective of present study has been to evolve varieties of foxtail millet with agronomic characters of economic importance. The varieties used were: BSi1, BSi427 and BSi467. To achieve the objective, the above varieties were treated with various dosages of gamma radiation. The dosages were 10, 20, 30, 40, 50, 60, 70 and 80 Kr. Of the dosages used 20, 30, 40, 60 and 70Kr were found most suitable. The 80Kr was found to kill the population whereas lower dosages, namely, 10 and 20Kr were found to be effective.

Of the general effects in M_1 generation, germination was reduced more at 60 Kr, and BSi467 was found more sensitive expressed in their reduced germination rate. In respect of root and shoot growth 80 Kr reduced the length of roots and of shoots more in BSi1 compared to the other two varieties. The highest increase of accumulation of dry weight of seven-day-old seedlings was at 10 Kr in two varieties (BSi1 and BSi427) whereas in the remaining variety (BSi467) the maximum increase was effected by the highest dosage of 80 Kr. In case of pollen sterility mid-level dosage of 40 Kr induced higher pollen sterility in one variety (BSi1) whereas the highest dosage of 80 Kr induced high pollen sterility in the other two varieties. Regarding grain fertility 70 Kr induced the highest reduction in all the three varieties, and BSi427 was found more sensitive than the other two. Except for dry seedling weight, varietal differences were observed in M_1 generation of all the three varieties.

Gamma radiation created a wide variability for quantitative characters such as days to flowering, days to maturity, plant height, panicle length, tiller number and grain yield in M_1 generation. Both early and late flowering and maturity were observed in all the three varieties. Lower dosages induced early whereas higher dosages late flowering trait. Plant height was reduced considerably in all the three varieties, highest reduction in height having been observed at the second highest dosage of 70 Kr. Both enhancement and reduction in panicle length were observed. Enhancement of the character was observed at lower dosages while higher dosages reduced the same considerably. All dosages except 10 Kr in BSi1 and 40 Kr in BSi427, increased tiller number. Higher tiller number was induced at two higher dosages, namely 60 and 70 Kr in all the three varieties. Except BSi1 gamma radiation did not increase substantially mean grain yield. At 10 Kr treatment BSi1 showed slight but not

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significant improvement. The reduction in 70 Kr treated material, regardless of the variety, was the highest in M_1 generation. Of the two most interesting variants among 20 and 30 Kr treated material in M_1 were: (a) chlorophyll striata variant in BSi427 (30 Kr) and (b) seed colour variant in BSi467 (20 Kr).

In M_2 generation gamma radiation induced a wide spectrum of mutants. The chlorophyll as well as viable mutants were of high frequency. Varietal differences were observed in respect of chlorophyll and viable mutants. The majority of chlorophyll mutants were observed at 50 and 60 Kr. Of the chlorophyll spectrum tigrina appeared with higher frequency followed by viridis in all the three varieties and alboviridis with least frequency in the variety BSi427 and BSi467. The only dosage which induced alboviridis was 20 Kr .

Four categories of viable mutants affecting colour, stature, panicle and maturity were isolated. In addition, a large number of mutants with desirable agronomic characters such as dwarf, early type and high yielding mutants have been recorded in M_2 generation. In later generations they were tested and found to be useful mutants with their potentiality for immediate release. Gamma radiation induced a spectrum of changes in grain colour. Five seed colour mutants namely, cream, black, yellow, orange and ash were isolated. The stem of BSi467 changed from purple to green while that of BSi1 and BSi427 changed from green to purple. In other words, the change was vice versa. However, there were exceptions in that certain individuals did not follow the pattern. Gamma radiation induced extreme tall, extreme dwarf, profuse tillering, broad leaf, narrow leaf and panicle with large variation. The dosage of 40 Kr induced 171 cm tall plants in BSi1 and 159 cm tall individuals in BSi427. The dosage of 40 Kr also induced extremely dwarf mutants of average height of 45 cm in BSi427. The dosage 30 Kr induced extreme 188 cm tall plants in BSi467.

Mutants of both early and late maturing type were isolated in three varieties. Early type was more frequent than late type and the former was confined to lower dosages treatment in the three varieties. Of viable mutants colour mutants were more predominant than all other types of mutants. Higher dosages produced more coloured mutants in BSi1 and in BSi427 and the frequency was least in BSi467 at a lower dosage (30 Kr) treatment. Genotypic differences by treatment with gamma radiation were observed while inducing chlorophyll and viable mutants.

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In M_3 generation both positive and negative influence in mean of seven quantitative characters such as days to flowering, days to maturity, plant height, panicle length, tiller number, grain yield and grain weight were observed in three varieties. Positive influence of flowering and maturity was observed in all the three varieties. Higher dosages reduced plant height in two varieties, BSi1 and BSi427 while in BSi467 the same character showed an increase in all treatments. Gamma radiation regardless of the dosage reduced tiller number and grain weight in all the three varieties. Two lower dosages, namely, 20 and 30 Kr increased grain weight in BSi467. Lower dosages increased grain yield in BSi1. Panicle length showed improvement in two varieties, BSi1 and BSi467 while in other variety, BSi427 it showed reduction. However, the lowest dosage of 10 Kr and the second highest dosage of 70 Kr enhanced panicle length in M_3 generation.

While higher dosage of gamma irradiation induced viable mutants with higher frequency in BSi1 and BSi427 mid-level dosages brought about the same frequency of mutation in BSi467. With lower and mid-level dosages mutants with agronomic characters of economic importance were obtained. The improved characters were : (a) plant height, (b) panicle length and (c) earliness. BSi1 was found to mutate more than the other two varieties in respect of both chlorophyll characters and viability induction. In the light of the results reported here mid-level dosages, 20, 30, 40, 50 and 60 Kr may be recommended as suitable dosages of gamma radiation in inducing desirable mutants in foxtail millet.

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Chapter 7

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7. REFERENCES

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