

**CREATION OF GENETIC VARIATION THROUGH
MUTAGENESIS IN CUMIN (*Cuminum cyminum* L.)**

THESIS

**SUBMITTED TO THE
RAJASTHAN AGRICULTURAL UNIVERSITY, BIKANER
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF**

**DOCTOR OF PHILOSOPHY IN AGRICULTURE
(PLANT BREEDING AND GENETICS)**

BY

SURESH KUMAR YADAV

2006

RAJASTHAN AGRICULTURAL UNIVERSITY, BIKANER
S.K.N. COLLEGE OF AGRICULTURE, JOBNER

CERTIFICATE-I

Dated :----- 2006

This is to certify that **Mr. SURESH KUMAR YADAV** had successfully completed the preliminary examination held on -----**2002** as required under the regulation for Doctor of Philosophy degree.

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This is to certify that this thesis entitled “**Creation of genetic variation through mutagenesis in cumin (*Cuminum cyminum* L.)**” submitted for the degree of **Doctor of Philosophy** in the subject of **Plant Breeding and Genetics** embodies bonafide research work carried-out by **Mr. SURESH KUMAR YADAV** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on **23rd June, 2006**.

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*Last but not the least, I would like to pray the '**JAWALA MATA**' to bestow her best wishes and blessings that made it possible to complete this task.*

Date:

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*I wish to express my deep sense of gratitude to **Dr. I.S. Khairwal**, Project coordinator (AICRP on Pearl millet), Jodhpur, **Dr. P. Pundhir**, Sr. Cotton Breeder, AICRP on Cotton, ARS, Sriganagar, **Dr. O.P. Yadav**, Principal Scientists, CAZRI, Jodhpur, **Dr. B.L. Yadav** Assoc. Prof. (Soil Science), **Dr. V.S. Yadav**, Assoc. Professor, ARS, Durgapura and **Dr. D.K. Yadav**, Sr. Scientists, IARI, New Delhi for providing valuable for execution of present investigation.*

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UNDERTAKING

It is certified that undersigned was in employment of any kind during the semester of research work. This is submitted for onward transmission as required in point No. 15 of thesis checklist.

Yours faithfully

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Kindly find enclosed herewith three copies of thesis entitled **“Effect of some systemic fungicides their translocation, biochemical changes and residue in management of die back of chilli”** submitted by **Mr. Het Ram Bishnoi** student of Ph.D. Plant pathology. Certificate for correction in the thesis and viva voce report are enclosed herewith this thesis may kindly be forwarded to

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(Name and Signature)

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Kindly find enclosed herewith three copies of thesis entitled “**Management of stem canker of tomato (*Lycopersicon esculentum* Mill) incited by *Rhizoctonia solani kuhn*”** submitted by **Mr. Shiv Kumar Khatik** student of M.Sc. (Ag.) Plant pathology. Certificate for correction in the thesis and viva voce report are enclosed herewith this thesis may kindly be forwarded to the dean, PGS, Rajasthan Agriculture University, Bikaner for final approval at an early date.

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INTRODUCTION

India rightly known as the “land of spices” is the largest producer, consumer and exporter of spices. Cumin (*Cuminum cyminum* L.) also called as *zeera* is a *rabi* seed spice crop. It belongs to family Apiaceae syn. Umbelliferae. It is an often cross pollinated diploid species and possesses 14 pairs of chromosomes (Sharma, 1987). Cumin is cultivated mainly in the arid and semi arid tracts, under dry and moderately cool climate. The crop withstands heat or moisture but not heavy rains. Frost, high humidity during flowering and fruiting stage induces diseases and aphids attack.

Cumin is an aromatic small tropical annual bushy herb with semi erect to erect growth habit attaining 15-60 cm in height, stem cylindrical, smooth, angular, sometime hairy, branched from base of the main stem giving a corymbase shape with many branches bearing long finely dissected deep green linear leaves. Alternate, exstipulate with lamina deep green having sheathing base. Flowers are white or pink, small, borne on compound umbels. Plant comes to bearing in 60-90 days. The seed is elongated greenish (yellow brown) fruit (schizocarp) 6 mm long, tapering towards both ends and laterally compressed. The mericarp is concave on one side with longitudinal ridges and minute hairs.

Cumin is believed to be native of Mediterranean and Near East regions. It is mainly cultivated in India, Egypt, Israel, Libya, Iran, Pakistan, Mexico and Japan mainly for its pleasant flavour, which is due to cuminol or cumin aldehyde (19.25- 27.02 per cent) component of the volatile oil present in the seeds (Balakrishna and Pushpakumari, 2001). The mean volatile oil content of

indigenous collections varies from 2.6-3.5 per cent whereas that of exotic collections varies upto 6.0 per cent (Sastry and Sharma, 2001). It is used for flavouring vegetable, pickles, soups, sausages, cheese, seasoning of breads, cakes and biscuits. Cumin oil is also used for perfumery and for flavouring liquors and cordials. Essential oil extracted from cumin seed is widely used in food processing due to its antimicrobial, antioxidative, colouring and flavouring properties (Ogles *et al.*, 1998). Apart from its culinary values, the seeds are extensively used in Ayurvedic medicines as stomachic, diuretic, carminative, stimulative, and astringent (Murthi and Sridhar, 2001).

The cumin seeds contain 17.7 per cent protein, 23.8 per cent fat, 35.5 per cent carbohydrates and 7.7 per cent minerals (Peter, 1996). The important minerals are calcium (6452.3 ± 53.3 mg /kg), potassium (5412.2 ± 12.2 mg/kg), iron (294.4 ± 7.0 mg/kg), zinc (39.3 ± 0.1 mg/kg), manganese (34.7 ± 0.3 mg/kg), phosphorus and sodium (Chien and Potty, 1996). In addition to the above constituents, the seeds also contain vitamins, particularly B₁, B₂, A and C (Pruthi, 1989).

During the year 2004-05, India exported 13750 tonnes of cumin seeds and earned a foreign exchange worth Rs. 10190 lacks (Anonymous, 2005a).

In India, it is grown on 430.8 thousands ha with an annual production of 202.9 thousands tonnes and average productivity of 471 kg/ha (Anonymous, 2005b). Rajasthan and Gujarat are the main growing states contributing 90- 95 per cent of the total area under cumin cultivation as well as production of the country. Rajasthan accounts for more than 40 per cent area and production of cumin in the country. It is successfully cultivated in arid and semi arid regions of Rajasthan *viz.*, Jalore, Barmer, Pali, Ajmer, Jodhpur, Nagour, Tonk and Jaipur. In Rajasthan, during 2004-05, it was grown in an area of 159.5 thousand ha with a production of

69 metric tonnes and average productivity of 433 kg/ha (Anonymous 2005c). In Rajasthan, the area, production and productivity have been highly fluctuating since last ten years (Fig.1.1).

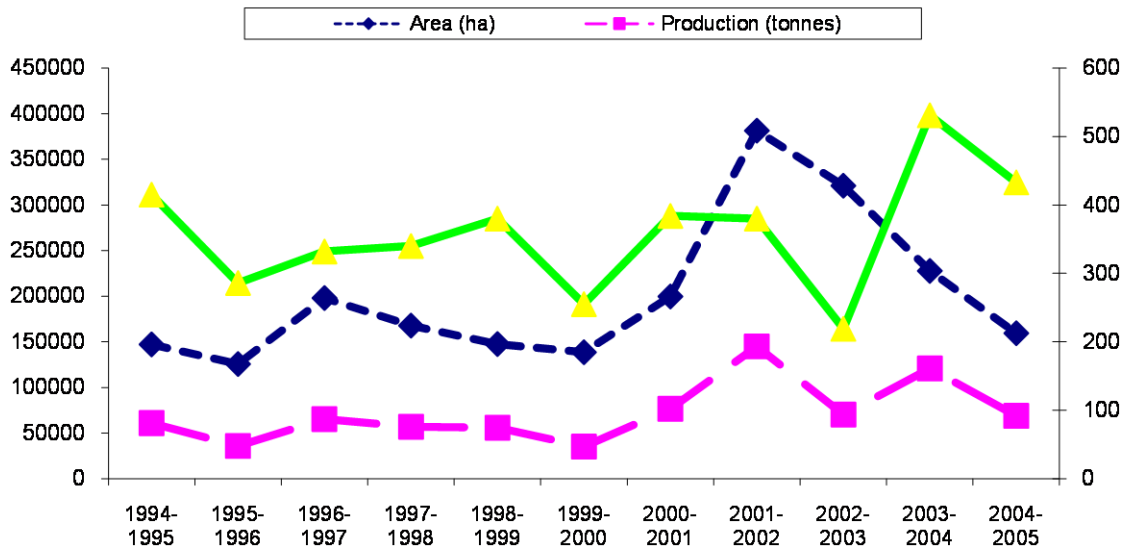
Although Rajasthan accounts for more than 40 per cent of area under cumin cultivation, the average yield level is very low. Partly, it is due to unavailability of high yielding genotypes and partly due to its susceptibility to some of the menacing diseases like *Fusarium* wilt and bacterial blight. Germplasm evaluation studies at Jobner centre of All India Coordinated Spices Improvement Project (ICAR, New Delhi) revealed that inspite of a significant variability for most of the characters, the range of variability was narrow, particularly upper limit for most of the character is low, which limit the scope for improvement of existing collections for yield potential (Sharma, 1994).

Creation of genetic variability is always a major challenge for plant breeder. There are various strategies available for this purpose. Conventionally the most exploited strategy is hybridization whose scope is very limited in cumin due to very small size of flower and it is practically not useful in cumin on account of absence of usable variation in the germplasm for economic characters. Further, being often cross pollinated crop cumin undergoes about 80 per cent self pollination because of vicinity effect (Sharma, 1994). Apart from practical problems in emasculation and pollination, the conventional hybridization strategy is hampered due to non-availability of pure lines in cumin, partially due to operation of some sort of physiological self-incompatibility. Induced mutation has been proved to be a valuable approach in generating genetic variability for breeding improved varieties employing conventional and/or molecular means.

Keeping in view the absence of usable variation in germplasm of cumin, limitations posed by its very small floral structure and promiscuity of mutation

breeding it was thought plausible to approach mutation breeding in this crop and hence the present study was envisaged with a view to undertake application of physical and chemical mutagens to augment genetic variability in cumin with following major objectives.

1. To undertake mutagenesis with different doses of gamma rays and different chemical mutagens *viz.*, EMS, MMS and Sodium Azide on two varieties of cumin.
2. To estimate biological damage caused by various mutagen treatments in M_1 generation on the basis of germination, seedling survival and pollen sterility.
3. To identify different macromutations (chlorophyll and morphological), determine their mutation frequency in M_2 generation and determine effectiveness of various mutagens applied.
4. To estimate induced genetic variation for various quantitative traits among the M_2 progenies of the two varieties of cumin and to identify superior mutant progenies in respect of yield and yield attributes.
5. To evaluate the selected progenies in M_3 generation in respect of yield and yield attributes and to estimate various genetic parameters.



REVIEW OF LITERATURE

The success of any breeding methodology for improving quantitative characters depends primarily on magnitude of usable genetic variability available and its efficient utilization. Therefore, while existence of genetic variability is essential for any crop improvement programme, if not present, then its creation and management becomes central to the crop breeding (Chopra, 1989). The induced mutations have been found quite effective in generating useful variation for polygenically controlled traits (Kumar, 1982). Mutation breeding can, thus, be a valuable supplement to conventional breeding methods in creating variability and particularly for seed yield and its component characters as well as to rectify the minor defects in otherwise agronomically superior variety.

Mutation breeding is a powerful tool to enrich variation particularly for attributes of economic importance in the crops where hybridization is difficult. In cumin, particularly, owing to small flower size and low seed setting in emasculated buds, not much desirable genetic variability could be generated.

There were only few thorough studies about different mutation spectra induced by different mutagens, but they provided convincing evidence that such differences are real, not only with regard to the ratio between gene mutations and chromosomal aberrations (Chopra and Sharma, 1985). Therefore, attempts have been made by many workers to increase the frequency of desirable mutants through induced mutagenesis. In seed spices the important contribution of different workers on induced mutagenesis along with naturally existing variability is reviewed as under:

(a) Work on mutation breeding in cumin

Seeds of anise (*Pimpinella anisum*), cumin (*Cuminum cyminum*) and fennel (*Foeniculum vulgare*) were treated with 1, 5 and 10 kGy gamma rays by El-Geddawy and Rashwan (1993) and revealed that volatile oils were extracted before and after irradiation and individual components were separated from the oils using gas chromatography. Cumin had the highest level of hydrocarbons, while anise and fennel contained the most oxygenated compounds. Irradiation caused a general decrease in total hydrocarbons and an increase in oxygenated compounds at 1 kGy, followed by a decrease between 5 and 10 kGy. Furthermore, the main characteristic components of all three spices were increased at doses between 1 and 5 kGy. The predominant hydrocarbon was camphene; 21.2, 29.8 and 8.8% in anise, cumin and fennel, respectively. Camphene and anethole were the main constituents of anise (21.2 and 74.1%, respectively), while cuminaldehyde and camphene were predominant in cumin (33.6 and 29.8%, respectively).

Sharma (1999) observed significant differences between the progenies for all the traits studied in cumin variety RZ 19 but non-significant “within family” variances for most of the characters except plant height, umbels per plant and umbellets per umbel in M₂ generation. In M₃, the “within family” variances were found non-significant for most of the characters studied.

Koli *et al.* (2000a) irradiated the dry cumin seed (cv. RZ-19) with 20, 30, 40, 50 and 60 kR gamma radiation and observed that the mean for plant height increased marginally at all rates in M₂ whereas variance decreased except at 30 kR. The mean for branches per plant increased except at 20 and 60 kR. The mean and variance increased linearly for umbels per plant, umbellets per umbel and seeds per umbel while the mean for seed yield per plant and 1000 seed weight decreased with all rates of gamma radiation.

Koli *et al.* (2000b) furthering their studies, observed that several M₂ lines showed improvements in days to flowering, days to maturity and test weight.

Koli and Sharma (2002) revealed that gamma rays treatments reduced pollen fertility, plant survival, seeds per umbel and test weight, while an increase was observed for days to flowering, branches per plant, umbels per plant and yield per plant over the control. Based on the observations, 60 kR was concluded to be the LD₅₀ dose, while 40 kR and 50 kR were also effective for creating genetic variability.

(b) Mutation breeding work on other Umbelliferous crops (coriander, fennel and black cumin)

Tewari (1968) observed an apetalous (complete absence of corolla) and two floral mutants (a seedless, sterile and a dwarf) mutants in fennel.

Mehta and Patel (1976) irradiated the seeds of fennel variety PF-35 and S-7-9 by gamma radiation and found one plant in M₂ generation which was carried to the advanced generation by selfing and also reported that one progeny of S-7-9 namely 4-1 at 10 kR dose of gamma-radiation produced 32.44% higher yield than control indicating that the mutation at polygenic level resulted in higher yield in mutant lines.

In a study conducted with gamma radiation derived M_2 generation, Raghuvanshi and Singh (1974) reported highly significant variability for plant height in fenugreek. Two tall plants of more than 106 cm in height were also identified during the investigation.

Fel'dberg (1981) irradiated seeds of coriander of different geographical origin with gamma rays ranging from 0.5 to 12 kR and X-ray doses ranging from 1 to 20 kR. Seeds of Southern origin (India and China) showed the greatest resistance to gamma rays and seeds from Azerbaijan and Ablehnazea were the most sensitive. Mutants with high yield and a high content of essential oil were selected in the M_2 generation.

While working with M_1 generation of coriander variety CO-1 derived from 5, 10, 15, 20 and 25 kR doses of gamma radiation, Punnuswamy and Muthuswamy (1982) reported significant variability for number of primary and secondary branches, number of seed per plant, while height and germination percentage remained unaffected. Another study conducted at Coimbatore centre of "All Indian Co-ordinated spices Improvement Project" with similar doses of gamma-radiation to variety Co-2, indicated a linear decreased in germination percentage along with dose gradient (5 to 25 kR.).

Das and Mallick (1989) observed that treatments of *Coriandrum sativum* and *Foeniculum vulgare* with 3 kR gamma irradiation produced a dwarf, bushy late flowering coriander mutant and a tall early flowering fennel mutant in the M_2 generation.

A wide range of variability for number of primary branches followed by secondary branches was observed in sixty six mutant lines (M_5) of coriander by Khader *et al.* (1989). One line showed high yield/plant than the check variety, indicating the possibility of further yield improvement by mutation breeding.

Sixty six mutant lines (M_5) in coriander were evaluated by Vedamuthu *et al.* (1989) and found that correlation coefficient was significant between seed yield and number of umbellets per umbel, umbels per plant and the number of primary and

secondary branches. All the mutant lines except one, registered higher yield than the check cultivar Co-2 indicating the scope for further improvement of yield through mutation breeding.

Singh *et al.* (1992) exposed air dried seeds of coriander (*Coriander sativum* L.) variety UD-20 to 5, 10, 15 and 20 kR doses of gamma radiation and observed that 10 kR dose increased the level of variation in M₁ generation for various morphological and yield related characters. The study further indicated that there was reduction in germination and plant survival. The LD₅₀ dose was adjudged at 15 kR treatment.

In an investigation, Mitra and Bhowmik (1997) evaluated ten different type of chlorophyll mutations were induced in two cultivars of black cumin (*Nigella sativa*) after gamma irradiation with doses of 50 to 250 Gy or treatment with 0.1 to 0.4% EMS and revealed that mutation frequency was proportional to dose for gamma rays, but not for EMS. Higher doses of gamma rays and lower concentration of EMS were most efficient. Differences in the responses of the two cultivars (Assam Local and KS-1) due to mutagenic treatment indicated variation in their genetic architecture.

Mitra and Bhowmik (1998) irradiated two cultivars of black cumin with 5, 10, 15, 20 and 25 kR of gamma rays and 0.1, 0.2, 0.3, 0.4% EMS to observe mutagenic effects on some biological parameters in M₁ generation. Germination, survival and rate of seedling growth were inversely proportional while pollen and ovule sterility was directly proportional to gamma ray doses and EMS concentration. The effects of gamma rays were higher than EMS and cultivar KS-1 was more sensitive to mutagens under the tested doses and concentration.

Rang and Datta (1998) observed a male sterile mutant of *Nigella sativa* isolated from the fertile M₃ mutant progenies of broad elongated lax pinnae (6 hours 0.25%, ethyle methanesulfonate), which showed chlorophyll deficiency in the shoot apex of the primary axis at the onset of floral bud initiation and produced small yellowish white anthers, which were non-dehiscent and pollenless at anthesis.

Dixit (1999) assessed induced variation in 156 M₃ progenies of coriander variety RCr-20 which were derived from exposure of gamma rays with or without sodium azide or hydroxylamine in M₁ generation and observed significant differences between the progenies but non-significant differences within the progenies for all the characters studied. Variation in respect of various characters were induced to different magnitudes. Umbels per plant (109.23%) recorded maximum increase whereas 100-seed weight (18.30%) recorded minimum increase. The characters *viz.*, plant height, primary branches per plant, umbels per plant and 100-seed weight were relatively more heritable than other characters studied.

In a study on 192 M₂ progenies of coriander variety UD-20, significant 'inter progeny' variances were observed for all the traits (Mahla *et al.*, 1999). However, intra progeny variance was found non-significant for all the traits studied. Umbels per plant recorded maximum increase (372%) followed by seed yield per plant (289%), primary branches per plant (84%), seeds per umbel (66%), umbellets per umbel (43%), plant height (30%), 100-seed weight (28%) and seed setting per umbel (22%).

Sengupta and Datta (1999) studied mutagenic efficiency of gamma radiation and ethyl methane sulfonate (EMS) on coriander varieties NP (D) 95 and TNP (D) 92, based on M₁ biological damages (lethality, injury and sterility) and viable mutation frequency (including, chlorophyll mutations) in the M₂ generation. EMS was more effective than gamma radiation. The threshold doses of gamma radiation (1, 2 and 4 kR) and EMS (0.25%, 4 hours and 0.50%, 4 hours) showed higher mutagenic efficiency than higher doses of treatments.

Datta and Rang (2000) observed seven viable morphological mutants (lax branching, feathery leaf, bushy I, bushy II, lax pinnae, needle leaf and crumpled leaf) and screened in an M₂ population (7956 plants) following mutagen treatments (gamma radiation, ethyl methanesulfonate and H₂O₂, and combined treatments of gamma radiation with EMS and H₂O₂) of the seeds of *N.sativa*. The M₂ segregation pattern showed that the lax branching, feathery leaf, bushy I, bushy II and lax pinnae

mutants were controlled by single pair of recessive genes, while selfed M_3 lines of needle leaf and crumpled leaf mutants indicated that the mutant traits were controlled by 2 pairs of recessive genes. Bushy I and II mutants manifested synchronous flowering and maturity of capsules.

In an attempt to study various seed characters including the essential oil content Khandelwal *et al.* (2000) evaluated 60 M_2 progenies of coriander variety RCr-20 and revealed that seed yield per plant was not significantly correlated with 100-seed weight, 100-seed volume, seed density, seed length, seed breadth, L/B ratio and essential oil content. However, seed breadth was significantly correlated with essential oil and also with seed length.

Datta and Rang (2001) observed that in M_4 generation *chloroxantha* mutants crop possessed significantly higher number of primary branches and capsules per plant and had smaller seeds than normal plants. The chlorophyll content and biological development of *chloroxantha* mutants are briefly discussed.

Datta and Saha (2001) observed that male sterile mutants with distinctive phenotypic markers (dwarf, chlorophyll deficiency, crumpled pinnae, bushy and lax pinnae) were induced in black cumin (*N. sativa* cv. Persian Jewels) following treatments with gamma irradiation (5, 10 and 20 kR) and ethyl methanesulfonate (3 h treatment with 0.25, 0.50 and 1.0% EMS) at M_2 . The male sterile mutant plants were categorized into five (I to V) types based on sterility and morphology. Mutation frequency of the male sterile mutant types was assessed. Male sterile genes were possibly pleiotropic in nature and acted on microspores and pollen seeds. Male sterile plants were non-structural nuclear type and included both male sterile, female sterile mutations (type I and III) and male sterile, female fertile mutations (type II, IV and V). Male sterility was monogenic recessive to male fertility in type IV and V, while type II manifested digenic inheritance pattern.

Sengupta and Datta (2001) isolated there highly productive (leaf and seed yield) mutants, namely, *cone* mutant type I (1 kR of varieties TNP (D) 92 and NP (D) 95 of coriander), *prostrate* mutant type I (NP (D) 95 –1 kR; TNP (D) 92-0.5%, 8

hours EMS treatment) and *lax branching* (NP (D) 95-0.5% EMS, 4 hours; TNP (D) 92-8 kR at M₂ following gamma radiation and EMS treatments. The prostrate mutant type I was concomitantly associated with broader pinnae of decomposed leaves, luxuriant growth and evergreen nature of pinnae, multiple shoot formation, and delayed flowering and maturity. The induced mutation seemed to have affected two or more characters in the macromutations. The pollen fertility recorded in mutants over the generations was high (82 to 86%).

A study was conducted to evaluate extent of induced variation for various quantitative characters in M₂ progenies of coriander variety UD-436 (Swami *et al.*, 2001). These M₂ progenies were originally obtained by treating the seeds with 15, 20 and 25 kR doses of gamma irradiation with or without sodium azide (1 mM) and hydroxylamine (1%) and following selfing of M₁ progeny. The inter-progeny variance was highly significant, whereas the intra-progeny variance was non-significant for all the traits studied. Progenies differing significantly from the control in positive and negative directions were more frequent for all the traits except grain yield per plant and 100-seed weight. Based on mean and coefficient of variation, two progenies, namely 43 and 56 were found promising.

Datta and Sengupta (2002) treated seeds of coriander with gamma irradiation (1, 2, 4, 8 and 10 kR doses) and EMS (0.25, 0.50 and 1.0%) treatments and observed thirteen types of viable macromutants: cone I, cone II, cone II, prostrate I, prostrate I, prostrate III, lax branching, lilac purple, dwarf, early flowering, dusky red, reddish grey and yellowish red. The viable mutation frequency had an inverse relationship with dose and appeared with higher tendency in lower dose treatments. EMS treatment showed a higher frequency of mutations (22.22-57.98% in NP (D) 95 and 13.33-44.18% in TNP (D) 92) than gamma irradiation (13.58-34.1% in NP (D) 95 and 11.11-23.98% in TNP (D) 92). The mutation frequency was higher in NP (D) 95 than TNP (D) 92. Both cultivars recorded maximum viable mutations in 4 kR dose of gamma rays and 0.25% concentration of EMS.

Mahla and Ramkrishna (2002a) estimated the effectiveness and efficiency of gamma rays, Sodium Azide, Ethyl Methane Sulphonate (EMS) and their combinations in fennel c.v. Rf-101 and observed a steady reduction in germination. Subsequent reduction in survival and pollen fertility was observed with the increasing doses of the mutagens. The efficiency of mutagenic treatment increased with the dose of the mutagens. Sodium Azide at 3 mM had maximum efficiency (0.976), followed by EMS at 0.5% (0.76). Magnitude of effectiveness also increased with increase in the dose of the mutagen. Sodium Azide was reported 24 fold effective than EMS and 310 times than gamma rays.

In a study, 270 M₂ progenies of fennel variety RF-101 were evaluated for various quantitative traits (Mahla and Ramkrishna, 2002b). The inter family variance was significant for all the characters studied, whereas Intra family variance was non significant for all the characters except plant height. The range in the treated population was invariably wider than control for all the characters and the mean of each treatment were slightly higher than the control mean in respect of various characters studied. Coefficient of variation among the treatment groups in response of various characters were closely comparable.

Evaluation of induced variation in 99 M₂ progenies of coriander variety RCr-41 in respect of yield and yield attributes was carried out by Punia and Ramkrishna (2002). These progenies were obtained by selfing M₁'s surviving exposure of sodium azide (1 mM), Hydroxylamine (1%) and HA+15 kR dose of gamma rays. It was revealed that for all the characters studied inter-progeny variance was highly significant whereas intra-progeny variance was non-significant for all the characters except for one characters.

An investigation was made to report polygenic variation noted in 150 M₄ progenies of three coriander varieties, namely RCr-41, RCr-436 and RC-20 (Choudhary and Ramkrishna, 2003). The between progeny component of variance was significant for all the characters studied. The inter progeny component of variance was, however, non significant for all the characters studied. One progeny of

RCr-41 and 8 progenies of RCr-436 were found superior out of 63 and 64 progenies evaluated, respectively. Existence of influence of genetic constitution of the parents on the fate of their mutant progenies was indicated. It was inferred that (i) selection for yield made in M₂ generation should be accompanied by identification of inbreeding resistant lines in advance generations and (ii) more genotypes should be included to initiate a mutation breeding programme for polygenic trait improvement in the cross pollinated crop.

Datta *et al.* (2003) observed significant variation for the different characters of black cumin except the seeds per fruit. Accession R.N.-2 had the shortest days to 50% flowering. Among the different accessions, Rajendra Shyama had the highest plant height, number of primary branches per plant, number of secondary branches per plant, number of leaves per plant, number of fruits per plant, number of seeds per fruit and seed yield (8.65 q/ha).

(c) Other breeding work on cumin

Importance of genetic variability in any breeding programme is well known as it provides not only a basis for selection but also some valuable information regarding selection of diverse parents to be used in a hybridization programme. The most important function of heritability estimates in the genetic studies of quantitative characters is their predictive role. Possible advance through selection based on phenotypic values can be predicted only from knowledge at the degree of correspondence between phenotypic and genotypic values. High heritability coupled with high genetic advance have been reported by several workers in mutagenised population.

Mathur *et al.* (1971) observed a wide range of variability for plant height, number of branches per plant, yield per plant and 1000 seed weight, while low range of variability for days to flowering and days to maturity was recorded in a study conducted with 134 indigenous and exotic collections of cumin.

Baswana *et al.* (1983) revealed that in cumin, yield per plant had the highest genotypic and phenotypic coefficients of variation (23.41 and 24.17%, respectively) and high heritability (93.83%).

Solanki and Joshi (1989) evaluated twenty five entries of cumin and reported significant variability for days to flowering, days to maturity, plant height, umbels per plant and seed yield per plot, but the range of variability was narrow for most of the characters studied.

Avatar *et al.* (1991) reported significant variability for wilt incidence, powdery mildew, days to flowering, days to maturity, plant height, primary branches, umbel per plant, umbellets per umbel, seeds per umbel, test weight and yield per plot, however, the range of variability was narrow for days to flowering, plant height, branches per plant, seeds per umbel, test weight, thus limiting the scope for further selection for these traits.

Evaluation of 200 accessions of cumin (*Cuminum cyminum* L.) germplasm including collections from the state of Rajasthan and Gujarat and two exotic collections one each of Egypt and Libiya namely UC-198 and UC-199 (EC-130202 and EC-130203) respectively at Jobner centre of “All India Co-ordinated Spices Improvement Project”, revealed significant variability for seed yield, volatile oil content as well as other morphological characters like branches per plant, umbels per plant and seeds per umbel (Sastry and Sharma, 2001).

In cumin, Sharma (1994) observed that inspite of significant variability in cumin for yield and most of morphological characters, the range of variability was narrow. The upper limit for most of the characters being low, showed limited scope for improvement of cumin for yield and yield related characters.

Dhayal *et al.* (1999) revealed that estimates of genotypic coefficient of variance, phenotypic coefficient of variance, heritability and genetic advance were higher for plant height, number of umbels per plant, number of seeds per umbel, test weight, seed yield per plant on normal soil and number of seeds per umbel and test

weight on saline soil, suggesting the probable role of additive gene effects on character expression in cumin.

Meena (2001) observed significant variability among the 180 accessions of cumin with respect to all the characters *viz.*, day to 50% flowering, days to maturity, plant height, branches per plant, umbellets per umbel, seeds per umbel, 1000-seed weight and seed yield per plant, except umbels per plant. The estimate of heritability was high for all the characters *viz.*, days to 50% flowering, plant height, branches per plant, seeds per umbel, 1000-seed weight and seed yield per plant. While, it was moderate to low for the characters *viz.*, days to maturity and umbellets per umbel. The genetic advance was high for seeds per umbel and seed yield per plant. While, it was moderate to low for branches per plant, plant height, 1000-seed weight, umbellets per umbel, days to 50% flowering and days to maturity.

Singh *et al.* (2001) revealed that under salinity, high estimates of genotypic and phenotypic coefficients of variations, heritability and genetic advance were recorded for seed yield, umbels per plant, seeds per umbel and harvest index in cumin.

MATERIALS AND METHODS

The present investigation was carried out at the Agronomy Farm, S.K.N. College of Agriculture, Jobner, Jaipur (Rajasthan) during *rabi* of 2001-02, 2002-03 and 2004-05. Jobner is located at 75.28⁰ North latitude at 427 metres above MSL and situated 45 km West of Jaipur. This region falls under Agro Climatic Zone III A (Semi Arid Eastern Plain Zone). The climate of the region is typically semi arid which is characterized by extremes of the temperature both during summer and winter with aridity of atmosphere and salinity of rhizosphere. The temperature may go as high as 48 °C during summers while it may fall below freezing point during winters. The average rainfall of the locality is about 400 mm, which is mostly received during July to September. The mean weekly data of temperature, relative humidity, rainfall and evaporation recorded at college meteorological observatory during the period of experimentation are presented diagrammatically (Fig 3.1).

The material for investigation consisted of M₁, M₂ and M₃ generations produced through physical and chemical mutagenesis of two high yielding cumin genotypes, *viz.* RZ 19 and RZ 209. The seeds of these genotypes maintained in isolation were produced from All India Coordinated Seed Spices Improvement Project at S K N College of Agriculture, Jobner, Jaipur.

3.1 MATERIALS

A. Genotypes:

The characteristics of the parental genotypes used for the study are as follow:

- (i) **RZ 19:** It was developed through recurrent single plant progeny selection from collection of Kekri (Ajmer). The plants are erect, medium tall with pink flowers and bold grey pubescent seeds containing 2.7 per cent volatile oil. The genotype is moderately resistant to wilt as well as blight. It matures in 140 to 150 days and produces an average yield of 5.6 q ha⁻¹.
- (ii) **RZ 209:** It was developed through recurrent single plant progeny selection in a local collection from Ahore (Jalore). The genotype is medium tall with medium seed weight and contains 2.7 per cent volatile oil. It is moderately resistant to powdery mildew. It matures in 120 to 130 days and produces an average yield of 6.5 q ha⁻¹.

B. Mutagens:

(i) Physical mutagens

The seeds of both genotypes were treated with 50, 60 and 70 kR doses of gamma rays at Nuclear Research Laboratory, IARI, New Delhi.

(ii) Chemical mutagens

Three chemical mutagens namely, ethylmethane sulphonate (EMS), methylmethane sulphonate (MMS) and sodium azide (SA) were employed in the present study. The doses of these mutagens were arbitrarily chosen after considering their usual range of doses in other crops and M₁'s were raised from the seeds surviving the exposure of the following mutagenic doses:

50 kR Gamma rays	0.2 mM SA
60 kR Gamma rays	0.4 mM SA
70 kR Gamma rays	0.6 mM SA
0.2 % EMS	50 kR gamma rays + 0.2% EMS
0.4 % EMS	50 kR gamma rays + 0.02 % MMS
0.6 % EMS	50 kR gamma rays + 0.2 mM SA
0.02 % MMS	0.2% EMS + 0.02 % MMS
0.04 % MMS	0.2% EMS + 0.2 mM SA
0.06 % MMS	0.02% MMS + 0.2 mM SA

Control

3.2 METHODS

3.2.1 Treatment with chemical mutagens:

The fresh seeds of both the genotypes were treated with different sole and combination treatments of physical and chemical mutagens listed above. Physical treatments were performed at Nuclear Research Laboratory, IARI, New Delhi and chemical treatments were performed at Department of Plant Breeding and Genetics, S.K.N. College of Agriculture, Jobner (Rajasthan). The EMS and MMS solutions were freshly prepared in 0.1 M phosphate buffer adjusted to 7.0 pH. Similarly, SA solution was also freshly prepared in 0.1 M phosphate buffer adjusted to pH 3.0. For proceeding the chemical mutagenesis, the presoaked (6 hours) seeds of both genotypes were immersed in mutagen solution and incubated for 6 h with intermittent shaking. At 6 h the treatment was terminated by thorough washing of the seeds with running water. The treated seed samples were surface dried on a blotting paper and sown in the field immediately. Seeds of the parents treated in the similar way but without mutagens served as control (i.e. only presoaked in water) and were sown along with treated seeds. The dried seeds of both the genotypes treated with gamma rays were sown in the field.

3.3 EXPERIMENTAL METHODOLOGY

The present investigation spanned over three cropping seasons. The M₁ generation was raised during *rabi* of 2001-02, M₂ generation was raised during *rabi* of 2002-03 and M₃ generation during *rabi* of 2004-05. All the three generations were grown in well prepared land. Recommended agronomical and cultural practices were followed to raise a good crop. The post-treatment handling of experimental material in M₁, M₂ and M₃ generations are described below.

3.3.1 M₁ generation:

The treated seeds along with the untreated controls were sown in RBD with three replications in beds of 4.0 m x 2.5 m size by dibbling. Three hundred seeds were sown in each bed in rows separated by 45 cm with an interplant distance of 10 cm.

3.3.1 (a) Observation recorded in M₁ generation

The following observations were recorded in M₁ generation.

(i) Germination

The number of seeds germinated was recorded at 30 days after sowing to estimate germination and as presented in percentage over the control.

(ii) Plant survival

All such plants which reached maturity and produced seeds were counted. The survival percentage was calculated as the proportion of seedlings harvested at maturity to the total seeds germinated.

(iii) Pollen sterility

Pollen sterility was determined by staining the pollens with 1 per cent acetocarmin stain. The pollen seeds fully stained were considered fertile, while the unstained, abnormal shaped and improperly filled pollen seeds were considered sterile. Pollen sterility (%) was measured as the ratio of sterile pollen seeds to the total number of pollens (5 independent observations) observed in the microscopic field (10X). The observations were based on 10 randomly selected buds each taken from different plants in each treated plot and the observations averaged.

3.3.1 (b) Harvesting of M₁ generation

The M₁ generation was harvested on single plant basis. The normal looking M₁'s plant were randomly selected and selfed for advancement to the next generation

for raising M_2 generation. The progeny of each individual M_1 plant formed an M_2 progeny.

3.3.2 M_2 generation

In the M_1 generation, 30-40 normal looking plants were selected and bagged before flowering to avoid outcrossing. The M_2 seeds were harvested only from the bagged M_1 plants. The M_2 progenies along with control were sown in a plot of 0.9 sq m consisting of two rows (each of 2.0 m long). The control was repeated once after every 20 rows of M_2 progenies in the experiment. The M_2 progenies of the two genotypes were sown separately. The distance between plants and rows was maintained at 10 cm and 45 cm, respectively. Although initially 464 progenies of RZ-19 and 464 M_2 progenies of RZ-209 were sown but finally only 210 M_2 progenies of RZ 19 and 251 M_2 progenies of RZ 209 were considered for further observation because a number of M_2 progenies did not germinate well to give rise to enough plants in the row.

3.3.2.1 Observations recorded in M_2 generation

A. Macromutations

(i) Chlorophyll mutations

All the treated as well as control progenies were screened at every stage of plant growth for recording chlorophyll mutations in M_2 generation.

(ii) Morphological mutations

The progenies were screened several times during the entire growth period to detect viable mutations affecting various morphological attributes.

(iii) Mutation frequency

The frequencies of chlorophyll and morphological mutations were calculated as given below (Kharkwal, 1998).

(a) M_2 progeny basis (percentage of mutated M_2 progenies)

$$\text{Mutation frequency (\%)} = \frac{\text{No. of mutated progenies}}{\text{Total no of } M_2 \text{ progenies}} \times 100$$

(b) M_2 population basis (percentage of mutants)

$$\text{Mutation frequency} = \frac{\text{No. of mutated } M_2 \text{ plants}}{\text{Total no of } M_2 \text{ plants}} \times 100$$

(iv) Mutagenic effectiveness and efficiency

Mutagenic effectiveness and efficiency were computed as described by Konzak *et al.* (1965).

$$\text{(a) Mutagenic effectiveness} = \frac{\text{Percentage of families segregating for mutation}}{\text{Duration of mutagenic treatment} \times \text{Concentration of mutagen (\%)} \text{ or radiation dose}}$$

$$\text{(b) Mutagenic efficiency} = \frac{\text{Percentage of families segregating for mutation}}{\text{Biological damage in } M_1 \text{ generation}}$$

B. Micromutation

Observations in M_2 generation were recorded on 10 randomly selected plants in each progeny (family) and mean was calculated for all the characters except days to flowering, days to maturity and test weight. Methods of recording observations in M_2 and M_3 generations (including the control progenies) are described as under.

(i) Days to flowering

The number of days taken from sowing to anthesis of the main umbels in 50 per cent plants in the each progeny was considered as days to flowering.

(ii) Days to maturity

The number of days taken from the date of sowing to the stage when seeds in the main umbel turned brownish on 50 per cent plants of a progeny was considered as days to maturity.

(iii) Plant height (cm)

Height of the plant was measured from ground level to the tip of the main umbel of the randomly selected plant at maturity.

(iv) Branches per plant

Number of branches arising laterally from the main stem were counted at the time of harvesting among the randomly selected plants.

(v) Umbels per plant

The number of umbels bearing atleast 10 seeds were counted at the time of harvest from randomly selected plants in each progeny and mean was recorded.

(vi) Umbellets per umbel

The number of umbellets bearing seeds in the main umbel from randomly selected plants were counted at the time of harvest and mean was recorded.

(vii) Seeds per umbel

The number of seeds from main umbel of the each randomly selected plants were counted at the time of harvest and mean was recorded.

(viii) Seed yield per plant (g)

Total seeds obtained from the harvest of each randomly selected plants were weighed and mean seed yield was calculated per plant and expressed in grams as seed yield per plant.

(ix) Test weight (g)

A random sample of 1000 seeds was drawn from the bulk (produce) of the randomly selected plants from each progeny and weighed.

3.3.3 M₃ generation

The M₃ generation was grown during *rabi* 2004-05 and consisted of selected M₃ progenies. These M₃ progenies were evaluated in Augmented Randomized Complete Block Design (Federer, 1956). The material was divided into 8 blocks each accommodating 40 M₃ progenies of RZ 19 and 10 blocks each accommodating 20 M₃ progenies of RZ 209. Each group of M₃ progeny was assigned to a separate block. Five checks (parents) *viz.* RZ 19, RZ 209, RZ 223, UC 198 and JC 2000-72 were also assigned to each block. In each block, 40 M₃ progenies and 5 check genotypes were grown in plots of single rows after randomization for RZ 19 and 20 M₃ progenies and 5 check genotypes were grown in plots of single rows after randomization for RZ 209. Each row was 4.0 m long and spaced 45 cm and plant to plant distance was maintained at 10 cm.

3.3.4 Analysis of statistical parameters in M₂ generation

The estimation of magnitude of variability such as variance and coefficient of variation (C.V.) was done on family and population basis using the standard statistical procedure outlined by Snedecor and Cochran (1967).

Table 3.1: The skeleton of analysis of variance is given as under:

Source of variation	d.f.	S.S.	Expected M.S.	F. value
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Between progenies	(f-1)	V_{BF}	$\sigma_{WF}^2 + n \sigma_{BF}^2$	V_{BF}/V_{WF}
Within progenies	f (n-1)	V_{WF}	σ_{WF}^2	V_{WF}/V_C
Control	N_c-1	V_C		

Where,

f = Number of progenies

n = number of plants in each progeny

σ_{BF}^2 = Progeny component of variance (Between)

σ_{WF}^2 = Progeny component of variance (Within)

$V_C = \sigma_C^2$ = Within control variance

n_c = Number of plants in control

The observed F-value was compared against the corresponding table value given by Fisher and Yates (1957) for deciding the significance of between progenies and within progenies component of variances.

Analysis of variance in M₃ generation

The mean of the data recorded on M₃ progenies were analysed for variances as per the method suggested by Federer (1956). The ANOVA table with appropriate sources of variation and degree of freedom along with expectation of mean sum of squares are given below:

Table 3.2: The ANOVA table and expected mean squares

Source of variation	d.f.	M.S.	Expected M.S.
Blocks (ignoring accessions and checks)	(b-1)	MS _b	
Entries (check + accessions)	(c+g)-1	MS _v	
Checks	(c-1)	MS _c	
Accessions (ignoring blocks)	g-1	MS _g	$\sigma_e^2 + \sigma_g^2$
Accessions v/s checks	1	MS _{cg}	
Error	(c-1)(b-1)	MS _e	σ_e^2
Total	N-1		

Where,

b = Number of blocks

c = Number of check genotypes in each block

g = Number of accessions in all blocks

σ_g^2 = Genotypic variance (MS_g – MS_e)

σ_p^2 = Phenotypic variance (MS_e)

The respective CD values were determined by the following formulae described for augmented block designs (Sharma, 1998)

(i) CD for testing difference between means of the two check genotypes

$$\sqrt{\frac{2 \times MS_e}{b} \times t}$$

(ii) CD for testing difference between two M₃ progenies means when both are in the same block

$$\sqrt{\frac{2 \times MS_e}{b} \times t}$$

$$\sqrt{2 \times MS_e \times t}$$

- (iii) CD for testing difference between two M_3 progenies means when they are in different blocks

$$\sqrt{\left[\frac{2 \times MS_e \times (c+1)}{c} \right] \times t}$$

- (iv) CD for testing difference between a check genotype and a M_3 progeny mean

$$\sqrt{\left[\frac{MS_e \times (b+1) \times (c+1)}{b \times c} \right] \times t}$$

Where,

MS_e = error variance

b = number of blocks

c = number of checks

t = t value at $p = 0.05$ at error d.f.

The computation of the various statistical parameters for analysis of induced variability was done as follows:

Assuming X_{ij} be the value of the j^{th} plant in a sample drawn from the i^{th} family;

f is the total number of families;

n_i is the number of plants in the i^{th} family and

$N = \sum_{j=1}^f n_i$ is the total number of plants under study,

than various parameters are defined as follows:

(i) **Total of the ith family** $(X_{i.}) = \sum_{j=1}^{n_i} X_{ij}$

(ii) **Family mean**

The mean of a character was calculated based on ten randomly selected plants in a family.

$$\text{Mean of the } i^{\text{th}} \text{ family } (\bar{X}_{i.}) = \frac{1}{n_i} \left(\begin{array}{c} n_i \\ \sum_{j=1} X_{ij} \end{array} \right)$$

(iii) **Population mean**

The character mean was calculated over all the plants studied in a treatment.

$$\text{Population mean } (\bar{X}) = \frac{1}{N} \left(\begin{array}{cc} f & n_i \\ \sum_{i=1} & \sum_{j=1} X_{ij} \end{array} \right)$$

(iv) **Intra family variance**

This refers to the variance for a character among the randomly selected plants of a family.

$$\text{Intra family variance} = \frac{1}{n_i - 1} \left(\begin{array}{c} n_i \\ \sum_{j=1} X_{ij}^2 - \frac{(\sum X_{i.})^2}{n_i} \end{array} \right)$$

(v) **Inter family variance**

It is the variance for a character between different families within a treatment.

$$\text{Inter family variance} = \frac{1}{f-1} \left(\begin{array}{c} f \\ \sum_{j=1} X_{i.}^2 / n_i - \left\{ \frac{1}{N} \left(\sum_{i=1}^f \sum_{j=1}^{n_i} X_{ij} \right)^2 \right\} \end{array} \right)$$

(vi) **Population variance**

This refers to the inter plant variance for a character averaged over all the families of a treatment.

$$\text{Population variance} = \frac{1}{N-1} \left(\sum_{i=1}^f \sum_{j=1}^{n_i} X_{ij}^2 - \left\{ \frac{1}{N} \left(\sum_{i=1}^f \sum_{j=1}^{n_i} X_{ij} \right)^2 \right\} \right)$$

(vii) Intra family co-efficient of variability

Using the intra family variance estimates and family mean values for a particular or a family, the intra family co-efficient of variability was estimated as follows;

$$\text{Intra family CV} = \frac{\sqrt{\text{Intra family variance}}}{\text{Family mean}} \times 100$$

(viii) Test of significance of family variance under treated population

Individual family variance was tested as given below

$$F = \frac{V_1}{V_2}$$

Where,

V_1 = Individual family variance which is to be tested

V_2 = Variance of a family in control population.

(ix) Comparison of control and progeny means

For any character, the progeny mean was compared with control mean to estimate the statistical superiority using ‘t’ test by following formula.

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{S^2 (1/n_i + 1/n_c)}}$$

Where,

$$S^2 = \frac{SSP + SSC}{n_i + n_c - 2}$$

\bar{X} = Mean of progeny

\bar{Y} = Mean of control

SSP = Sum of square due to progeny

SSC = Sum of square due to control

S^2 = Pooled variance

n_i = Size of i^{th} sample

n_c = Size of control

Estimation of genetic parameters for M3 generation

(a) Genotypic co-efficient of variation

Genotypic co-efficient of variation was estimated as per the formula given by Burton (1952).

$$GCV = \frac{\sqrt{\sigma_g^2}}{\bar{X}} \times 100$$

Where,

σ_g^2 = genotypic variance

\bar{X} = population mean

(b) Phenotypic co-efficient of variation

Phenotypic co-efficient of variation was estimated as per the formula given by Burton (1952).

$$PCV = \frac{\sqrt{\sigma_p^2}}{\bar{X}} \times 100$$

Where,

σ_p^2 = phenotypic variance

\bar{X} = population mean

(c) Heritability

Heritability (h^2) in broad sense was estimated as ratio between interfamily variance (σ_{BF}^2) and total phenotypic variance (σ_T^2) using formula suggested by Hanson *et al.* (1956).

$$h^2 \text{ (bs) (\%)} = \frac{\sigma_{BF}^2 \text{ (} \sigma_g^2 \text{)}}{\sigma_T^2 \text{ (} \sigma_p^2 \text{)}} \times 100$$

Where,

$$\sigma_T^2 = \sigma_{BF}^2 + \sigma_{WF}^2$$

$$\sigma_{BF}^2 = \frac{V_{BF} - V_{WF}}{n}$$

σ_{BF}^2 = Inter family variance

σ_{WF}^2 = Within family variance

σ_g^2 = Genotypic variance ($MS_g - MS_e$)

σ_p^2 = Phenotypic variance (MS_e)

(d) Genetic advance expressed as percentage of mean

Genetic advance as percentage of mean was estimated as per the formula given by Johnson *et al.* (1955).

$$GA = \frac{\sigma_T \times h^2_{(bs)} \times k}{\bar{X}} \times 100$$

Where,

k = Selection differential (for 5% selection pressure, k = 2.06)

$h^2_{(bs)}$ = Heritability in broad sense

σ_T = Phenotypic standard deviation

EXPERIMENTAL RESULTS

The present investigations was concerned with carrying out comprehensive mutagenesis, both physical and chemical, and characterizing the segregating generations *viz.*, M_2 and M_3 generations of two genotypes of cumin namely, RZ 19 and RZ 209, in respect of yield and yield attributes. The doses of gamma radiation

were chosen as per previous report of Koli and Sharma (1997). For chemical mutagens, however the three doses were selected as per doses applied on other crops such as coriander and fennel and from other related literature. The irradiated and chemical mutagens treated seeds were directly sown in the field to raise M_1 generation.

4.1 M_1 GENERATION

The M_1 generation of the two varieties resulting from 18 different treatments (12 sole treatments and six combination treatments) were raised separately in RBD with three replications in the field. However, observations were recorded only on germination, plant survival and pollen sterility. The results have been presented in Table 4.1.

(i) Germination

The germination of M_1 progenies of the two genotypes of cumin followed more or less same trend along the doses of various mutagenic treatments. Both, gamma rays as sole treatment or in combination with the chemical mutagens considerably reduced the germination percentage as compared to all the doses of chemical mutagens either applied as sole or in combination with other chemical mutagens. Although, using the present data, precise values for LD_{50} for the chemical mutagens may not be determined, it seemed that EMS at slightly less than 0.6 per cent, MMS slightly less than 0.06 per cent and sodium azide slightly less than 0.6 mM may yield LD_{50} values. Combination treatments of chemical mutagens seemed to have no considerably different effect than their sole treatment. Further, with sole physical and chemical mutagens, the germination reduced linearly with their increasing doses.

(ii) Plant survival

The survival of M_1 progenies of the two cumin genotypes followed more or less same trend as that of germination percentage. Survival was considerably reduced (as low as 40% in RZ 19 and 41.18% in RZ 209) in gamma rays treatments when applied as sole or as low as 56.92% (RZ 19) or 61.19% (RZ 209) when applied in combination with chemical mutagens (Table 4.1). The survival of M_1 progenies resulting from treatments of the three chemical mutagens was more or less similar and decreased with increasing the doses of mutagens (84-63%). Combination treatments comprising of two chemical mutagens had slightly more effect on survival than their individual sole treatments. Collectively, the survival was as high as 85.45% and as low as 40.24%.

(iii) Pollen sterility

Pollen sterility ranged between 10.19 (0.02% MMS) to 21.89 (70 kR gamma rays). As regard sole treatments, all the mutagens showed increasing pollen sterility with increase in their concentration in M_1 progenies of both the genotypes. Gamma rays appeared to cause relatively more sterility than chemical mutagens. These results were consistent in combination treatments also.

4.2 M_2 GERMINATION

In the present study observations were recorded on 210 M_2 progenies of RZ 19 and 251 M_2 progenies of RZ 209. The M_2 progenies of two genotypes were thoroughly evaluated for macro mutational changes during their growth and described as follows:

(i) Macromutational changes

The macro mutational changes were comprised of both chlorophyll and morphological variants in the M_2 progenies of both the cumin genotypes and their

frequencies presented in Table 4.2 and 4.3. Among chlorophyll mutants, *albinos* were rarely seen in the progenies of RZ 209 only and *xantha* were relatively more frequent (up to 11) in the M₂ progenies of the two cumin genotypes (Plate 1).

Among morphological ones, same classes of variants, namely, *bushy*, *miniature*, *loosely branched*, *thick stem*, *deformed* and *drooping type* were commonly seen in the M₂ progenies of both genotypes with inconsistent frequencies (Plate 2a and 2b). However, the total number of macro mutants were comparably same in the M₂ progenies of RZ 19 (96) and RZ 209 (106). On population basis the mutation frequency was consistently higher at the highest dose of sole mutagenic treatments. The combination treatments yielded relatively moderate mutation frequencies.

Employing the results of mutation frequencies on family basis and pollen sterility, the two quantities *i.e.*, mutagenic effectiveness and mutagenic efficiency were calculated for the two genotypes of cumin (Table 4.4 and 4.5). In case of progenies of RZ 19, it may be seen that for gamma rays and EMS, the mutagenic efficiency increased with increasing doses of mutagens but this trend was not consistent with MMS and sodium azide treatments. On RZ 19, the gamma rays of 70 kR appeared most efficient (4.84) followed by 60 kR gamma rays (2.13) or 0.4 mM sodium azide (2.13) and 0.2 per cent EMS with 0.2 mM sodium azide (1.86). Least mutagenic efficiency was seen with 0.6 mM sodium azide. Mutagenic effectiveness were not consistent with the dose of different mutagens. Since the figures of mutagenic effectiveness can be compared between the doses of same mutagen but not between the doses of different mutagens, therefore, on that basis the effectiveness increased linearly in case of gamma rays only but not with other mutagens. In case of progenies of RZ 209, the mutagenic efficiency was maximum with 60 kR gamma rays (7.58) followed by 0.6 mM sodium azide (3.37), 0.2 per cent EMS + 0.2 mM sodium azide (2.5) and 50 kR + 0.2 per cent EMS (2.43). The least mutagenic efficiency was seen with 50 kR + 0.2 mM sodium azide. Results of mutagenic effectiveness were also inconsistent from one mutagen to another.

(ii) *Micromutational changes*

The analysis of variance revealed that differences attributable to between progenies and within progenies of the two genotypes were highly significant for all the characters (Table 4.6). The range, mean and coefficient of variation for M_2 progenies of the two genotypes of cumin arising from different sole and combination mutagenic treatments are presented in Table 4.7 for various characters studied. From the results obtained, following general trend could be noticed:

1. The coefficient of variation (CV) of the mutant progenies was invariably higher than their respective control.
2. By comparing CV of various characters it was revealed that certain traits have shown very high CV such as yield per plant where CV among the M_2 progenies ranged between 47.70 to 74.69 per cent for RZ 209 and 48.71 to 70.14 per cent RZ 19. For characters like branches per plant and umbels per plant the CV ranged between 25-50 per cent. However, for other characters like plant height, umbellets per umbel and seeds per umbel it was less than 20 per cent in both the genotypes.
3. The values of the traits within the progenies of the two genotypes of cumin invariably ranged away from the mean in both, positive and negative direction for all the characters studied.

In Table 4.8 and 4.9 attempts have been made to classified the M_2 progenies of the two genotypes of cumin with respect to their superiority compared to the parent for various characters studied. It may be seen that for both the genotypes a number of progenies were either better than the parent inferior than the parent or at par with the respective parents. In case of RZ 19 large number of progenies (85%) showed significantly higher mean values than the control for seed yield per plant followed by seeds per umbel (79% progenies), branches per plant (74% progenies), plant height (71% progenies), than umbels per plant (29% progenies) and umbellets per umbel (27% progenies). It may further be seen that occurrence of superior or inferior progenies were associated with all the mutagenic treatments in both the genotypes.

In case of RZ 209 also, a large number of progenies showed significantly higher mean value than the parent (78% progenies) followed by umbels per plant (44% progenies), plant height (47% progenies), branches per plant (40% progenies), umbellets per umbel (30% progenies) and seeds per umbel (22% progenies). In this case a large number of progenies had significantly low mean values as compared to the parent for all the characters.

The superior mutant progenies (*i.e.*, those progenies which showed significantly higher mean than the parents) of the two genotypes were analyzed for their distribution into various increasing class intervals (Table 4.10). It may be seen that for all the characters, most of the progenies were invariably frequented around lower mean values whereas progenies with higher mean values were relatively rare.

The comparative assessment of 25 best progenies of RZ 19 selected on the basis of seed yield per plant for their magnitude of other characters have been presented in Table 4.11. It may be seen that the variance of 25 progenies were significant or highly significant than the control variance for all the characters studied. Further, the progenies found superior for seed yield per plant as compared to control were generally associated with significantly high mean values of either all other component characters or for four or for three out of five characters studied.

Days to 50 per cent flowering indicated that the mutant progenies of RZ 19 were no early but generally late without having considerably affected their maturity duration. The test weight was also generally increased.

Similarly for genotype RZ 209 the comparative assessment of 25 best progenies selected on the basis of seed yield per plant for their magnitude of other characters have been presented in Table 4.12. It may be seen that the variances of 25 progenies were significant or highly significant than the control variance for all the traits studied. Whereas, the progenies found superior for seed yield per plant as compared to control were generally associated with significantly high mean values of either all other component characters or for four or for three out of five characters studied.

Days to 50 per cent flowering indicated that the mutant progenies were no early but generally late without having considerably affected their maturity duration. The test weight was also generally increased.

The significance of variance of those progenies which showed significantly higher mean values for various characters were considered (Table 4.13) for the M₂ progenies of the two cumin genotypes. It was clear that for a given character all the superior M₂ progenies showed significant variances. However, when the maximum increase in the mean over their parent was considered, then seed yield per plant was most easily improvable (268.7 per cent for RZ 19 and 198.7 per cent for RZ 209).

However for rest of the characters the progenies of the two cumin genotypes showed variable results as regards the significant increase in their mean value (*i.e.* less than 100%).

4.3 M₃ GENERATION

Individual M₂ plants were selected from high yielding M₂ progenies (those showing significantly higher mean than the control) exhibiting very low or high coefficient of variance as compared to the parent. Thus, 320 M₃ progenies of RZ 19 and 200 M₃ progenies of RZ 209 were raised in augmented complete randomized block design with five checks (including parents). The data were recorded on various quantitative characters on ten competitive plants selected randomly in a progeny were subjected to the variance analysis. The results are briefly presented in Tables 4.14 and 4.15 and described as under.

(i) RZ 19

The mean squares attributable to blocks were significant for all the characters except days to 50 per cent flowering, test weight and branches per plant. The variances attributable to checks were significant for plant height, umbels per plant, umbellets per umbel, seeds per umbel and seed yield per plant and that attributable to M₃ progenies and checks vs M₃ progenies were significant for all the characters studied (Table 4.14). Both genotypic and phenotypic variances were computed for various characters. The differences between the two were least for seed yield per plant followed by umbels per plant, seeds per umbel and plant height.

(ii) RZ 209

The variances attributable to blocks were significant for all the characters. The checks showed significant differences for plant height, umbels per plant, umbellets per umbel, seeds per umbel and seed yield per plant. Similar to that observed for M₃

progenies for RZ 19 in this case also the variances arising due to M₃ progenies and checks vs M₃ progenies were significant for all the characters studied (Table 4.15). The genotypic variances were invariably low as compared to phenotypic variances. However the differences between two were less in case of plant height, umbels per plant and seed yield per plant.

Genetic parameters such as GCV, PCV, heritability and genetic advance were estimated for the two genotypes and present in Table 4.16 and 4.17. The trend of GCV and PCV between the characters were comparable in the progenies of RZ19, in that, seed yield per plant recorded maximum genotypic coefficient variance (37.81%) followed by umbels per plant (29.19%), branches per plant (24.74%) and plant height (14.90%), whereas, that for seeds per umbel, umbellets per umbel were relatively less and least for days to 50 per cent flowering and days to maturity. The heritability in broad sense was maximum for seed yield per plant (93.87%) followed by umbels per plant (88.3%), seeds per umbel (79.4%) and plant height (76.65%). For rest of the characters the magnitude of heritability were moderate. Further, genetic advance as percentage of mean was found maximum for seed yield per plant (75.46%) followed by umbels per plant (53.13%) and branches per plant (27.89%). For days to 50 per cent flowering and days to maturity the genetic advance estimates were extremely low *i.e.*, 1.87 and 1.55, respectively.

For the progenies of RZ 209 also the GCV values were low and maximum for seed yield per plant (36.00%), branches per plant (21.31%), umbels per plant (17.94%) and low for rest of the characters (less than 10.00%). The PCV and GCV values for these characters were relatively close in trend. Heritability in broad sense was high for seed yield per plant (76.41%) followed by plant height (74.7%), umbels per plant (74.09%) and seeds per umbel (63.00%) and moderate to low for rest of the characters. Estimates of genetic advance was high for seed yield per plant (64.82%) but

moderate for umbels per plant (37.77%), branches per plant (25.58%), plant height (23.13%) and low for the rest of characters.

In Table 4.18, an attempt has been made to assess the mean and range of all the M₃ progenies of RZ 19 and RZ 209. Besides, the number of M₃ progenies found significantly higher or lower than the control/parent value have also been shown. It may be seen that for seed yield per plant 19 per cent of the progenies of RZ 19 were still superior as against only 8 per cent in case of RZ 209. Further, in RZ 19 a large number of progenies (40%) showed significantly less mean than control but in RZ 209 there were relatively less inferior progenies (11%). The values of both mean and range for different characters were closely comparable in the M₃ progenies of RZ 19 and RZ 209.

The magnitude of yield of 20 best progenies of cumin genotypes RZ 19 and RZ 209 along with mean of the checks and various CD values have been presented in Table 4.19 and 4.20. It may be seen that, when compared to best check, the yielding potential of these progenies was generally supported by significantly high value of umbels per plant followed by seeds per umbel and plant height whereas branches per plant and test weight did support only progeny 29 with their significantly different magnitude of values. However in case of progenies of RZ 209 their yielding potential was generally supported by significantly high values of umbels per plant, branches per plant and plant height but not at all by umbellets per umbel, seeds per umbel and test weight. Further, progeny 154 of RZ 209 seemed to be early because it had significantly less duration to days to 50 per cent flowering and days to maturity.

SUMMARY

The present investigation was carried out with an objective to induce macro and micro mutational changes in cumin. The experiments were conducted during *rabi* of 2001-02, 2002-03 and 2004-05 with two genotypes of cumin, namely, RZ 19 and RZ 209 at the Agronomy Farm of S.K.N. College of Agriculture, Jobner. Both, sole and combination treatments of gamma rays and three chemical mutagens were employed *viz.*, ethyl methane sulphonate (EMS), methyl methane sulphonate (MMS) and sodium azide (SA). For mutagenesis, the seeds of the two genotypes were treated with gamma rays (50 kR, 60 kR and 70 kR), EMS (0.2, 0.4 and 0.6%), MMS (0.02, 0.04 and 0.06%) and SA (0.2, 0.4 and 0.6 mM) and resulting six combination treatments (50 kR gamma rays + 0.2% EMS, 50 kR gamma rays + 0.02 % MMS, 50 kR gamma rays + 0.2 mM SA, 0.2% EMS + 0.02 % MMS, 0.2% EMS + 0.2 mM SA and 0.02% MMS + 0.2 mM SA) and their M₁ generation raised. The damages in M₁ generation caused by mutagenic treatments were determined by observing reduction in germination, plant survival and pollen viability. In the two genotypes, with sole physical and chemical mutagenic treatments the germination reduced linearly with increase in their doses. The gamma rays severely affected the germination such that even at 50 kR the germination was less than 37%. The LD₅₀ values for chemical mutagens appeared to be slightly less than 0.6% for EMS, 0.06%% for MMS and 0.6 mM for sodium azide. Plant survival also followed the

similar trend where gamma rays considerably affected the plant survival. Chemical mutagens either as sole or as combination treatments were of less severe effect on plant survival than gamma rays. Pollen sterility ranged between 10 to 22 per cent between the treatments. Gamma rays treatments appeared to cause relatively more sterility than chemical mutagens.

In the M_2 generation, 210 progenies of RZ 19 and 251 progenies of RZ 209 were evaluated both for macro (chlorophyll and morphological) and micromutational changes. While chlorophyll mutations were restricted to rare *albino* and few *xantha*, seven different morphological variants were frequently seen in the M_2 progenies of both the genotypes. The efficiency of mutagenic treatments showed that gamma rays at 70 kR were most efficient followed by 0.4 mM sodium azide, 0.2% EMS with 0.2 mM sodium azide on RZ 209 whereas on RZ 19, 60 kR gamma rays were most effective.

In the M_2 generation, analysis of variance revealed that for the progenies of two genotypes, variation attributable to 'between progenies' and 'within progenies' were significant for all the characters studied. Based on range, mean and coefficient of variation (CV), it was noted that the CV of mutant progenies was invariably higher than the control. Mutational changes appeared to occur both in the positive and negative directions for all the quantitative characters studied. Further, based on the magnitude of CV, the characters could be grouped in three categories *i.e.*, those exhibiting (i) greater than 50 per cent, (ii) between 50-20 per cent and (iii) less than 20 per cent CV.

Based on 't' test, a considerable number of progenies had significantly higher or lower mean than the control for all the characters studied. Further, 78% progenies of RZ 209 and 85% of RZ 19 showed significantly higher seed yield per plant as compared to control. The high yielding progenies were generally associated with significantly high values of four to five other traits studied.

In RZ 19 the yield per plant showed maximum increase (268.78%) followed by branches per plant (117.66%), whereas for RZ 209, seed yield per plant could be increased to 198.7% whereas rest of the characters could be increased up to 65 per cent or less. Progeny 19 of RZ 209 and progeny 41 of RZ 19 were identified as promising genotypes along with others.

From superior M_2 progenies, 520 single M_3 progenies were raised and evaluated in augmented complete randomized block design and data analyzed in respect of various characters. Highly significant mean squares were observed for accessions (M_3 progenies of the two cumin genotypes).

Both, the GCV and PCV values were of relatively low order and the differences between the two were also relatively less. The estimates of heritability in broad sense were high for seed yield per plant, umbels per plant, seeds per umbel, plant height and branches per plant in both the genotypes. The estimates of genetic advance in both the genotypes were maximum for seed yield per plant followed by umbels per plants. Out of 320 M_3 progenies of RZ 19, 19 per cent showed significantly high yield per plant than the parent whereas in case of 200 M_3 progenies of RZ 209 evaluated only 8 per cent were superior in seed yield.

DISCUSSION

The different types of plant breeding methods are usually alternatives and should be used to supplement each other in order to solve the problem of crop improvement (Micke, 1995). The mutation breeding, however, has proved itself more than an alternative because more often the products of mutagenesis have been directly released as a variety (Ahloowalia et al., 2004). There are two important opportunities in using mutagenesis, in first it offers the breeder an unselected genetic variation and second is in using it in augmentation of genetic variability for selection and cross breeding. While later opportunity has been a justification in most cases of mutagenesis approach for quantitative trait improvement, lack of usable variation and very small flower of cumin forms it suitable candidate for approaching mutation breeding.

The choice of parent material being subjected to mutagenesis is crucial. A general convention is to use best available genotype as it would need less number of steps or grades for improvement (Ahloowalia et al., 2004). For polygenic traits, this convention would continue as the knowledge regarding influence of genotypes on spectrum of induced mutation is scanty (Micke, 1995). However, some guidance may be taken as from the Brock's hypothesis (Brock, 1965) which suggests that outcome of the mutation would be opposite to the previous history of selection for quantitative characters. In the present study, however, the two genotypes, RZ 19 and RZ 209, the only two released varieties of cumin for Rajasthan, were selected for mutagenesis programme. Further, from the point of view of induction of polygenic variation, an open pollinated population is justified. It was clearly demonstrated in pea by Sharma (1995) that when both hybrid and its pure line parents were subjected to mutagenic treatments, hybrids exposed more micromutational variability than the parents. This was attributed to reshuffling of minor genes through hybridization. Individuals of an open pollinated population offer a similar reshuffling of minor genes, and hence, are likely to open more variability than the inbreds. Inbreds are, however, inevitable when fine genetic analysis is to be carried out through induced mutagenesis.

For a systematic mutation breeding programme it is important to know which mutagens to be used. It is plausible to use several mutagens on account of existence of mutagen specificity (Micke, 1995). In the present study, the inclusion of alkylating agents (EMS and MMS) and diazo compound (SA) alongwith gamma rays were considered justified on account of (1) possible existence of mutagen specificity, if any (2) different modes of action of three types of mutagens (3) feasibility of different combination treatments which may show antagonistic or synergistic effects and (4) possible influence of genotypic background of the test material being used.

As regards mechanism of action of gamma rays there are both, direct as well as indirect effects. In the case of direct effect, energy is transferred to a molecule directly by the radiation. Indirect effect is mediated by

free radical formation; these redicals transfer their energy to other molecules. The free redicals are highly reactive and produce H₂O₂ and organic peroxides, which are highly reactive and are thought to be responsible for a good portion of the biological effects of radiation. Genetic effects of radiation on DNA include, change in a base, e.g., deamination, loss of a base, breaking of hydrogen bonds in DNA, single and double strand breaks in DNA and cross linking of DNA strands (Singh, 2001).

Alkylating agents have one, two or more reactive groups that react with DNA and cause extensive cross-linking of DNA, chromosome breaks, chromosome mutations and gene mutations. They react with phosphatic group in the DNA phosphate-sugar backbone producing semistable trimesters which may cause backbone breaks. Alkylation of the ring N ultimately leads to the removal of the alkylated base i.e., depurination and may lead to backbone breaks. Transition may result due to a mistake in base pairing and produces mispairs. The lethal effects of alkylating agents may be primarily due to the alkylation of proteins (Singh, 2001).

Sodium azide is a potent base substitution mutagen and induces high frequencies of chlorophyll and morphological mutations with negligible frequency of chromosome aberrations when used under acidic conditions. At pH below 4.8, azide yields uncharged hydrozoic acid molecules, which are believed to penetrate cell membrane by greater ease than does the azide ion. The enzyme O-acetylserine sulphydrylase condenses O-acetylserine and azide ion to yield azidoalanine, which is the real mutagenic metabolite (Singh, 2001).

The doses of gamma rays were chosen from the report of Koli and Sharma (2002) who found 60 kR being LD₅₀ in cumin genotype. However, our results contradict his finding. Instead, these doses have caused severe reduction in the germination and also on survival. Therefore, more trials (both laboratory and field) are required to find out the LD₅₀ dose. As regards chemical mutagens, their concentrations were taken on the basis of their usual range applied to other crops in the same laboratory where the present work has been done on fennel, coriander, clusterbean etc. However, with the available results of present study it may be inferred that LD₅₀ values are slightly less than 0.6% for EMS, 0.06% for MMS and 0.6 mM for SA.

The present investigation was carried out with an aim to induce mutations to bring about macro and micromutational changes in respect of yield and yield traits. Macro mutational changes are easily detected on account of their easily discernible phenotype. In the present study, few chlorophyll mutants but many changes in plant types were observed. Among various possible classes of chlorophyll mutants (Amarnath and Prasad, 1998) There appeared only a rare albino and few xantha. This may be attributed to relatively small population of the M₂ progenies i.e. 461 M₂ progenies (including progenies of both the parents). It is suggested that for a given chance of recovery of a gene mutation, progenies from a minimum of 2000 M₁ plants should be used in seed propagated crops (Micke, 1995). Besides, the phenomenon of group mutability (IAEA, 1977) may not be ruled out including the influence of host genetic background. The results of morphological variation revealed that, since such variants were not restricted to any particular mutagen treatment therefore, the possibility of

mutagenic specificity is ruled out. Influence of host genotypes may also be considered. This may seek support from the observations made by Kumawat (2004) who found that of the three genotypes of clusterbean used, the chlorophyll and morphological variants were largely associated only one genotype only. However, by pooling the data it was possible to compute efficiency and effectiveness of mutagenic treatments.

The gamma rays and alkalyting agents have long been used for inducing mutations in plants on account of their proven mutagenic potential, whereas, use of mutagens, such as sodium azide in plant system is relatively recent. The results of present study and those of others support the view of that sodium azide was equally as potent as the above mutagens for the purpose of obtaining induced mutation (Mahla et al., 1999, Mahna et al., 1993, Nandanwar et al., 2001, Kumawat, 2004 and Jain, 2005). It is known that both genetic system and its genotypes have profound influence on the outcome of mutagenic efficiency (Roy, 2000), and hence, characterization of a mutagen on the basis of its effectiveness and efficiency is fundamental to the usefulness of mutagen in a particular crop breeding programme. In the present investigation the influence of the genotypes on mutagenic efficiency and effectiveness was not clear. Effectiveness is defined as number of mutation induced by a unit dose of mutagen while mutagenic efficiency is their frequency in relation to observed biological damage measured in terms of lethality, seedling injury, pollen sterility, mitotic and meiotic chromosomal aberrations. In the present study, only pollen sterility was used to characterize the biological damage. The estimation of efficiency can be influenced by the criteria used for defining the biological damage. On comparative grounds mutagenic efficiency is a better yardstick for comparing the usefulness of mutagens than mutagenic effectiveness (IAEA, 1977). The purpose of using sole and their combination treatments of mutagens was to exploit the mutagenic specificity and widening of spectrum of mutations, if any (IAEA, 1977). However, in the present study, such a specificity was not marked.

The detection of micromutational changes requires a more meticulous approach. Sharma (1995) through a series of studies in pea and lentil has drawn two very important conclusions for efficient recovery of individuals with micro mutation changes. First, the M_1 progenies suffering more biological damage expose out more polygenic variation and second, selection is more effective in M_2 generation then M_3 , although the later is most variable. Following the first conclusion one is able to concentration only on that fraction of M_1 population that has a better prospectus for induction of micromutational changes in M_2 generation. Therefore, the characterization of damage in M_1 is of primary importance. In the present study, however, M_2 progenies exhibiting significant differences for quantitative traits were equally frequent in all the mutagenic treatment and that these M_2 progenies were derived from selfing of normal looking M_1 plants resulting from different mutagenic treatments. The conclusion of Sharma (1995) was one from self pollinated breeding systems whereas, cumin is a cross pollinated crop. Mahla (2000) has also arrived at same inference in fennel. It is also plausible to speculate that even if M_1 individual is suffering a severe biological damage, the haplontic selection

will result in formation of a zygote being developed from union of normal gametes. The progeny of such M_1 would tend to be normal.

The results of statistical analysis in M_2 generation are clearly indicative of induction of micromutational changes in the progenies of two genotypes. However, the occurrence of significant 'within progeny' variance is in contradiction to the findings of Mahla et al. (1999), Dixit (1999), Swami et al. (2001), Poonia and Ramkrishna (2002) on coriander and Mahla and Ramkrishna (2002b) on fennel and may be attributed to increase in heterozygosity resulting from of mutational events. If this speculation is correct then cumin genotypes (used in the present study) even being cross pollinated largely are homozygous. This statement seeks support from the report of Sharma (1994).

The wide range of values of M_2 progenies observed in respect of various traits is not only indicative of induction of polygenic variation but their direction as well (i.e. positive and negative). It has been pointed earlier that, the micromutations of positive and negative directions were induced in equal magnitudes but their phenotypic effects may be unequal resulting in the positive and negative shifts in the progeny mean (Gregory, 1967). The mutagenic treatments resulting both in positive and negative shifts in mean are reported in coriander (Mahla, 1997 and Swami et al., 2001) and fennel (Mahla, 2000). Since superior M_2 progenies had been derived from all the mutagenic treatments, this means the absence of mutagenic specificity for such mutational changes.

The coefficient of variation of various characters were variable from one character to another. This vaguely may indicate to relative number of genes governing a character because more variation would be expected when a character was governed by more number of polygenes and hence enhanced possibility of mutations to occur. Alternatively genes controlling different characters may show differential sensitivity to the environment.

It was also seen that a number of progenies exhibiting superior mean values had significantly higher variance as compared to control. This allows us for possible identification of even better progenies through selection. Based on the mean values certain progenies namely, progeny No. 15, 16, 59, 79, 90, 188 and 205 of RZ 19 and progeny No. 3, 19, 32 and 143 of RZ 209 were found not only high yielding but also had significantly higher values in respect of other characters namely, plant height, branches per plant, umbels per plant and grains per umbel. There is sufficient evidence that induced mutations fit Vavilov's law of homologous series of genetic

variation (Micke, 1995). The progeny No. 15 and 16 (RZ 19) and 3 (RZ 209) were originated from gamma rays treatment, progeny No. 59 (RZ 19) and 19 and 32 (RZ 209) from EMS treatment, progeny No. 79 and 90 (RZ 19) from MMS treatment, progeny No. 143 (RZ 209) from sodium azide treatment, progeny No. 188 and 205 (RZ 19) from combination treatments. High yielding progenies resulting from mutation breeding have been reported by Mehta and Patel (1976) for fennel, Mahla *et al.* (1999) Punia and Ramkrishna (2002) for coriander and Datta *et al.* (2003) for black cumin.

In M_3 generation analysis of variance revealed that M_3 progenies significantly differed among themselves and also as a group from the checks in case of both the genotypes. Phenotypic variances and genotypic variances showed differences of varying degree for different characters. This indicated varying influence of environment on different characters. The estimates of genotypic coefficient of variation and phenotypic coefficient of variation being unit free allow one to compare the variances from one character to another. Heritability in broad sense was very high for M_3 progenies of RZ 19 whereas, that observed for progenies of RZ 209 was high but supported by high heritability values of components traits too. Since heritability in broad sense itself suffers from reliability (Sharma, 1994) the high heritability values observed in the present case may not be dependable one. Also the present data is insufficient to explain very high heritability observed for seed yield for progenies of RZ 19. It is generally argued that meaningful inferences can be made when heritability (broad sense) estimates are considered with estimates of genetic advance because high heritability along with high magnitude of genetic advance would be attributed to additive gene actions which is of fixable nature.

For seed yield per plant about 40 per cent progenies of RZ 19 whereas only 11 per cent of RZ 209 were inferior. Further, 40 per cent

progenies of RZ 19 and about 80 per cent progenies of RZ 209 were at par with the control. Obviously a large number of selected M₂ progenies have under gone inbreeding depression of varying magnitudes. Those found superior may be considered as inbreeding resistant ones. In coriander there is an evidence that while advancing from M₂ to M₄ most M₂ progenies suffered inbreeding depression and were influenced by parent's genotypic background also (Choudhary and Ramkrishna, 2003).

Conclusively a considerable number of progenies were found significantly high in seed yield per plant supported by significantly high values of one or more component characters in progenies of two genotypes and holds enhance promise for further evaluation in the field trials.

It is worth mentioning that one of the checks is RZ 223, is developed through mutation breeding in this department and has recently been identified for release in the 17th Annual workshop of AICRP on seed species. This indicates to the promiscuity of application of mutation breeding in cumin improvement. The successes of mutation breeding has recently been reviewed by Ahloowalia *et al.* (2004) in the crop improvement for yield, quality and disease resistance. Another example of application of mutation breeding is Gujrat cumin-2, which is an induced mutant of MC-43, tolerant to wilt and blight (Ravindran *et al.*, 2001).

Creation of genetic variation through mutagenesis in cumin (*Cuminum cyminum* L.)

Suresh kumar yadav*

ABSTRACT**

An investigation was carried out to induce macro and micro mutational changes in two cumin genotypes using sole and combination treatments of gamma rays and three chemical mutagens namely, EMS, MMS and sodium azide. In the two genotypes, with sole physical and chemical mutagenic treatments, the germination reduced linearly with increase in their doses. The gamma rays severely affected the germination. The LD₅₀ values for chemical mutagens appeared to be slightly less than 0.6 per cent for EMS, 0.06 per cent for MMS and 0.6 mM for sodium azide. Chemical mutagens either as sole or as combination treatments were of less severe effect on plant survival than gamma rays. Pollen sterility

ranged between 10 to 22 per cent. Gamma rays caused more sterility than chemical mutagens.

In the M₂ generation, 210 progenies of RZ 19 and 251 progenies of RZ 209 were evaluated. Chlorophyll mutations were restricted to rare *albino* and few *xantha*. Seven different morphological variants were frequently seen in the M₂ progenies of both the genotypes. The efficiency of mutagenic treatments showed that gamma rays at 70 kR was most efficient on RZ 209 whereas, 60 kR on RZ 19. In the M₂ generation, analysis of variance revealed that variance attributable to 'between progenies' and 'within progenies' were significant for all the characters studied. The coefficient of variation of mutant progenies were invariably higher than the control (parent) and values spread to both, the positive and negative directions for all the quantitative characters studied. Based on 't' test, a considerable number of progenies had significantly higher or lower mean than the control for all the characters studied. The high yielding progenies were generally associated with significantly high values of four to five other traits studied. In RZ 19, the yield per plant showed maximum increase (268.78%) followed by branches per plant (117.66%), whereas for RZ 209, seed yield per plant could be increased to 198.7 per cent.

520 single M₃ progenies were raised and evaluated in augmented complete randomized block design and data were analyzed in respect of various characters. Highly significant mean squares were observed for M₃ progenies of the two cumin genotypes. Both, the GCV and PCV values were of relatively low order and the differences between the two were also less. The estimates of heritability in broad sense and genetic advance were maximum for seed yield per plant and umbels per plant in progenies of both genotypes. In M₃, 19 per cent progenies of RZ 19 and 8 per cent of RZ 209 were found high yielding.

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LIST OF TABLES

Table No.	Particulars	Page No.
4.1	Mean germination, survival and pollen sterility of different genotypes of cumin exposed to graded doses of various mutagenic treatments
4.2	Frequency of chlorophyll and morphological mutants observed in M ₂ progenies of cumin genotype RZ 19.	.....
4.3	Frequency of chlorophyll and morphological mutants observed in M ₂ progenies of cumin genotype RZ 209.	.....
4.4	Estimates of effectiveness and efficiency of the different mutagenic treatments on cumin genotype RZ 19.	.....
4.5	Estimates of effectiveness and efficiency of the different mutagenic treatments on cumin genotype RZ 209.	.....
4.6	ANOVA for different quantitative characters in M ₂ progenies of two cumin genotypes.	.....
4.7	Range, mean and coefficient of variation observed for different quantitative traits in M ₂ generation of two cumin genotypes.	.....
4.8	Distribution of M ₂ progenies of cumin genotype RZ 19 showing significant increase or decrease in the mean performance for various traits in respect of different mutagenic treatments.	.....
4.9	Distribution of M ₂ progenies of cumin genotype RZ 209 showing significant increase or decrease in the mean performance for various traits in respect of different mutagenic treatments.	.....
4.10	Distribution of superior M ₂ progenies of two cumin genotypes in various class intervals.	.....

- 4.11 Magnitude of various yield attributes of top 25 M₂ progenies of
cumin genotype RZ 19 showing significantly higher seed yield
per plant.
- 4.12 Magnitude of various yield attributes of top 25 M₂ progenies of
cumin genotype RZ 209 showing significantly higher seed yield
per plant.
- 4.13 Occurrence of superior progenies with their coefficient of variance
for various characters
-

Table No.	Particulars	Page No.
4.14	Mean squares and variances for different characters in M ₃ progenies of cumin variety RZ 19.	.....
4.15	Mean squares and variances for different characters in M ₃ progenies of cumin variety RZ 209.	.....
4.16	Genotypic and phenotypic coefficient of variation, heritability in broad sense and genetic advance as percentage of mean for different characters in M ₃ mutant lines of cumin variety RZ 19.	.....
4.17	Genotypic and phenotypic coefficient of variation, heritability in broad sense and genetic advance as percentage of mean for different characters in M ₃ mutant lines of cumin variety RZ 209.	.....
4.18	Mean, range and distribution of M ₃ progenies of two cumin genotypes showing significant increase or decrease in the mean performance for various traits.	.....
4.19	Magnitude of yield and yield attributes of 20 M ₃ progenies of cumin genotype RZ 19 sowing significantly higher yield than their parents.	.....
4.20	Magnitude of yield and yield attributes of 20 M ₃ progenies of cumin genotypes RZ 209 sowing significantly higher yield than their parents.	.....

LIST OF FIGURE AND PLATES

Fig/plates No.	Particulars	Page No.
1.1	Area (ha), production (t) and productivity (kg/ha) of seed spices in Rajasthan	.....
3.1	Mean weekly weather parameters recorded for crop season (Rabi 2001-02, 2002-03 and 2004-05)	.....
4.1	Chlorophyll mutants (<i>xantha</i>) of cumin	.....
4.2 (a)	Morphological mutants of cumin	.....
4.2 (b)	Morphological mutants of cumin	.....

LIST OF APPENDICES

Figure No.	Particulars	Page No.
I.	Mean and coefficient of variation (C.V.) of cumin genotype RZ 19 for different characters in M ₂ generation for various mutagen treatments	.....
II	Mean and coefficient of variation (C.V.) of cumin genotype RZ 209 for different characters in M ₂ generation for various mutagen treatments	.....
III	Adjusted mean values for different characters of M ₃ mutant lines (cumin variety RZ 19), check varieties along with CD values	.....
IV	Adjusted mean values for different characters of M ₃ mutant lines (cumin variety RZ 209), check varieties along with CD values	.....

CONTENTS

CHAPTER NO.	PARTICULARS	PAGE NO.
1.	<i>INTRODUCTION</i>	.....
2.	REVIEW OF LITERATURE	.....
3.	<i>MATERIALS AND METHODS</i>	.....
4.	EXPERIMENTAL RESULTS	.....
5.	DISCUSSION	.....
6.	SUMMARY	.....
	BIBLIOGRAPHY	.....
	ABSTRACT (ENGLISH)	.....
	

Table 4.1: Mean germination, survival and pollen sterility of different genotypes of cumin exposed to graded doses of various mutagenic treatments.

Mutagenic treatments	Germination* (%)		Survival * (%)		Pollen Sterility (%)	
	RZ	RZ	RZ	RZ	RZ	RZ
	19	209	19	209	19	209
Gamma rays						
50 Kr	36.99	33.02	69.58	64.20	15.37	15.98
60 kR	27.14	25.41	61.14	58.29	17.58	17.58
70 kR	11.53	13.86	40.24	41.18	20.64	21.89
EMS						
0.2 %	84.95	82.34	84.60	81.85	12.54	11.24
0.4 %	65.40	68.21	79.78	80.88	14.24	13.08
0.6 %	44.73	46.06	72.64	66.37	17.83	17.43
MMS						
0.02 %	82.70	83.97	81.97	79.45	10.19	11.12
0.04 %	59.63	62.50	76.42	75.65	11.89	12.86
0.06 %	43.32	46.47	65.58	63.74	15.24	15.87
SA						
0.2 mM	84.11	81.52	85.45	81.17	12.06	12.34
0.4 mM	70.46	65.63	81.04	79.09	13.43	13.88
0.6 mM	46.69	42.26	71.69	68.49	16.52	16.21
Combinations						
50 kR gamma rays + 0.2% EMS	38.82	30.57	63.04	66.22	17.99	16.49
50 kR gamma rays + 0.02 % MMS	27.43	27.31	56.92	61.19	16.02	15.35
50 kR gamma rays + 0.2 mM SA	33.47	27.85	62.61	65.37	16.82	15.87
0.2% EMS + 0.02 % MMS	81.01	79.76	76.74	74.79	14.24	13.62
0.2% EMS + 0.2 mM SA	77.92	78.53	71.66	72.49	14.70	12.02
0.02% MMS + 0.2 mM SA	79.32	76.36	74.82	72.78	13.76	12.86

Control	71.10	73.60	93.81	94.57	7.89	7.09
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*Data presented for germination and survival are expressed as per cent over the respective control.

Table 4.4: Estimates of effectiveness and efficiency of the different mutagenic treatments on cumin genotype RZ

19.

Mutagenic treatments	Percentage of M₂ families segregating for mutations (Me)	Pollen sterility (%) in M₁ (S)	Mutagenic effectiveness Me/t x c*	Mutagenic efficiency Me/S
Gamma rays				
50 kR	14.29	15.37	0.29	0.93
60 kR	37.50	17.58	0.63	2.13
70 kR	100.00	20.64	1.43	4.84
EMS				
0.2 %	9.09	12.54	7.58	0.72
0.4 %	12.50	14.24	5.21	0.88
0.6 %	31.25	17.83	8.68	1.75
MMS				
0.02 %	9.09	10.19	75.75	0.89
0.04 %	7.14	11.89	29.75	0.60
0.06 %	25.00	15.24	69.44	1.64
SA				

0.2 mM (0.0013%)	10.00	12.06	1282.05	0.83
0.4 mM (0.0026%)	28.57	13.43	1831.41	2.13
0.6 mM (0.0039%)	9.09	16.52	388.46	0.55
Combinations				
50 kR gamma rays + 0.2% EMS	11.76	17.99	0.23	0.65
50 kR gamma rays + 0.02 %	22.22	16.02	0.44	1.39
MMS				
50 kR gamma rays + 0.2 mM SA	-	16.82		-
0.2% EMS + 0.02 % MMS	13.64	14.24	10..33	0.96
0.2% EMS + 0.2 mM SA	27.27	14.70	22.57	1.86
0.02% MMS + 0.2 mM SA	18.18	13.76	142.25	1.32

*t x c stands for product of treatment duration in h and concentration of the mutagen in percentage, respectively.

Table 4.5: Estimates of effectiveness and efficiency of the different mutagenic treatments on cumin genotype RZ

Mutagenic treatments	Percentage of M₂ families segregating for mutations (Me)	Pollen sterility (%) in M₁ (S)	Mutagenic effectiveness Me/t x c*	Mutagenic efficiency Me/S
Gamma rays				
50 kR	25.00	15.98	0.50	1.56
60 kR	66.67	17.58	2.22	7.58
70 kR	-	21.89	-	-
EMS				
0.2 %	5.56	11.24	4.63	0.49
0.4 %	11.11	13.08	4.63	0.85
0.6 %	30.77	17.43	8.55	1.77
MMS				
0.02 %	13.33	11.12	111.08	1.20
0.04 %	12.50	12.86	52.08	0.97
0.06 %	33.33	15.87	92.58	2.10
SA				
0.2 mM (0.0013%)	8.33	12.34	1067.95	0.68
0.4 mM (0.0026%)	9.09	13.88	582.70	0.65
0.6 mM (0.0039%)	54.55	16.21	2331.20	3.37
Combinations				
50 kR gamma rays + 0.2% EMS	40.00	16.49	0.67	2.43
50 kR gamma rays + 0.02 %	30.00	15.35	5.00	1.95
MMS				
50 kR gamma rays + 0.2 mM SA	6.25	15.87	0.12	0.39
0.2% EMS + 0.02 % MMS	19.05	13.62	793.75	1.40
0.2% EMS + 0.2 mM SA	30.00	12.02	24.83	2.50

0.02% MMS + 0.2 mM SA 20.00 12.86 156.49 1.56

*t x c stands for product of treatment duration in h and concentration of the mutagen in percentage, respectively

Table 4.6: ANOVA for different quantitative characters in M₂ progenies of two cumin genotypes.

Source of variation	d.f.	Plant height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Seed yield per plant (g)
Genotype RZ 19							
Between progenies	209	77.25**	11.98**	385.7**	0.92**	74.81**	11.02**
Within progenies	1890	6.82**	2.14**	72.75**	0.27**	19.32**	2.75**
Control	129	0.65	0.02	0.89	0.03	0.54	0.01
Genotype RZ 209							
Between progenies	250	113.1**	14.99**	375.72**	1.51**	89.36**	6.69**
<i>Within progenies</i>	2259	5.97**	1.72**	35.07**	0.42**	14.4**	2.75**
Control	159	0.73	0.28	2.79	0.04	2.29	0.04

**significant at p= 0.01.

Table 4.13: Occurrence of superior progenies with their coefficient of variance for various characters

Variety	Characters	Number of progenies with significantly higher mean values	Number of superior progenies with significantly higher variance	Maximum increase in the mean over the control (per cent)
RZ 19				
	Plant height (cm)	125	118	45.51
	Branches per plant	156	156	117.66
	Umbels per plant	60	60	90.46
	Umbellets per umbel	56	56	26.98
	Seeds per umbel	166	166	60.43
	Seed yield per plant	179	179	268.78
	(g)			
RZ 209				
	Plant height (cm)	99	94	36.04
	Branches per plant	84	78	63.37
	Umbels per plant	110	100	65.56
	Umbellets per umbel	63	63	34.36
	Seeds per umbel	54	41	34.33

Seed yield per plant	195	195	198.71
(g)			

Table 4.18: Mean, range and distribution of M₃ progenies of two cumin genotypes showing significant increase or decrease in the mean performance for various traits.

<i>Characters</i>	Mean	Range	Distribution			Total
			a	b	c	
RZ 19						
Days to 50 % flowering	92.3 (87.7)*	86-99	0	223	97	320
Days to Maturity	113.6 (112.6)	110-119	0	155	165	„
Plant height (cm)	31.0 (28.3)	14.8-39.3	32	30	258	„
Branches per plant	5.0 (4.5)	1.8-8.4	5	44	271	„
Umbels per plant	17.5 (17.3)	5.5-37.6	32	112	176	„
Umbellets per umbel	4.4 (4.2)	3.3-5.7	3	44	273	„
Seeds per umbel	26.7 (23.2)	14.3-35.7	82	33	205	„
Test weight (g)	3.7 (3.5)	2.27-5.30	4	8	308	„
Seed yield per plant (g)	1.14 (1.16)	0.33-3.07	63	132	125	„
RZ 209						
Days to 50 % flowering	91.6 (92.0)	81-94	4	0	196	200
Days to Maturity	112.4 (112.1)	102-118	5	17	178	„
Plant height (cm)	33.1 (31.1)	15.5-45.4	33	9	158	„
Branches per plant	5.1 (5.0)	2.4-11.4	16	0	184	„
Umbels per plant	17.4 (16.9)	8.4-34.0	15	37	148	„
Umbellets per umbel	4.8 (4.6)	2.8-6.8	5	16	179	„
Seeds per umbel	26.8 (26.2)	17.6-33.1	4	39	157	„
Test weight (g)	3.65 (3.52)	3.03-5.4	5	6	189	„
Seed yield per plant (g)	1.09 (0.94)	0.30-3.27	16	22	162	„

*Figures in parenthesis indicate the control value

a=Number of M₂ progenies showing significantly higher mean values than the control

b= Number of M₂ progenies showing significantly lower mean values than the control

c= Number of M₂ progenies at par with the control

Appendix-1

Mean and coefficient of variation (C.V.) of cumin genotype RZ 19 for different characters in M₂ generation for various mutagen treatments

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
50% kR Gamm rays															
1	78	116	30.50**	11.59**	6.10**	26.15**	20.10**	35.37**	4.8**	8.78**	29.50**	16.47**	4.4	2.98**	73.77**
2	76	112	29.00**	9.34**	6.70**	31.50**	43.20**	39.04**	4.8**	8.78**	31.60**	13.61**	3.89	1.53**	41.06**
3	80	116	30.30**	6.23**	5.40**	32.90**	16.60**	34.80**	5.3**	9.11**	27.40	19.33**	4.94	2.38**	36.50**
4	76	113	28.10**	10.93**	4.40**	32.50**	16.20**	41.13**	5.2**	8.11**	28.00**	11.42**	3.77	4.25**	25.66**
5	80	117	25.10*	12.94**	4.80	39.04**	23.70	54.40**	4.9*	15.06**	26.60	17.56**	4.54	2.37**	65.52**
6	79	111	26.30	19.14**	6.20**	19.83**	28.00**	13.88**	4.9**	6.45*	28.60**	17.22**	5.11	5.21**	32.68**
7	81	114	25.40	7.47**	7.50**	33.41**	26.70*	34.06**	5.1	11.13**	28.70**	11.02**	4.04	4.90**	46.96**
60 kR Gamma rays															
8	78	112	26.50*	9.94**	6.50**	19.53**	26.70**	29.91**	5.0	9.43**	29.60**	7.67**	5.15	4.45**	64.41**
9	77	111	29.50**	7.01**	5.60**	17.25**	24.40	29.44**	5.6**	9.22**	29.50**	9.62**	4.56	3.71**	31.99**
10	79	109	30.20**	8.08**	5.70**	16.64**	24.50	31.16**	5.0	9.43**	25.90	23.34**	5.07	4.06**	48.83**
11	79	119	27.70**	5.91*	6.70**	14.16**	35.20**	22.60**	5.5**	9.58**	34.10**	11.27**	4.81	5.04**	42.80**
12	78	116	21.40**	8.30**	4.60**	15.20**	16.50**	24.12**	4.8**	8.78**	27.10	15.89**	4.82	1.60**	39.03**
13	80	117	26.90**	4.78	7.80**	26.89**	28.30**	28.95**	4.8**	8.78**	30.60**	10.81**	5.14	2.34**	38.13**
14	79	112	21.70**	10.20**	6.60**	34.40**	24.50	40.74**	5.0	9.43**	30.00**	6.09**	5.14	3.86**	67.72**
15	79	111	37.60**	4.89**	10.60**	12.73**	47.90**	18.48**	5.0	9.43**	34.50**	8.00**	5.10	6.75**	31.11**
70 kR Gamma rays															
16	75	107	27.90**	12.00**	7.70**	31.84**	28.30**	37.25**	5.1	11.13**	29.70**	11.00**	5.2	5.24**	70.14**
0.2% EMS															
17	81	114	26.00	5.73*	4.20**	15.06**	9.30**	43.32**	5.4**	15.62**	29.20**	22.65**	5.08	1.40**	51.18**
18	80	116	23.30**	12.96**	4.40**	30.68**	18.30**	40.65**	4.9*	11.58**	26.10	17.55**	5.06	1.89*	59.80**
19	81	117	24.70**	6.89**	5.10**	14.47**	19.80**	31.39**	4.4**	11.74**	24.50**	21.87**	4.42	1.63**	50.24**
20	76	114	22.80**	6.13*	5.30**	28.20**	16.90**	39.00**	4.7**	10.28**	23.60**	24.80**	4.33	2.71**	40.51**
21	81	116	24.30**	9.71**	6.30**	32.66**	23.00**	42.35**	4.8**	8.78**	28.70**	6.98**	4.27	3.66**	61.87**
22	78	116	25.20**	6.95**	6.30**	28.05**	20.90**	34.68**	4.9**	6.45*	29.50**	9.75**	4.86	2.98**	51.91**
23	79	111	30.50**	5.18*	5.20**	8.11**	23.90**	26.50**	5.1	11.13**	28.90**	12.58**	5.02	3.57**	49.59**
24	78	112	28.70**	4.36	6.40**	31.42**	28.30**	42.01**	5.1	6.20*	32.20**	9.91**	5.02	3.43**	46.89**
25	78	108	23.60**	7.26**	5.30**	15.53**	17.10**	31.49**	5.1	6.20*	29.40**	11.36**	4.94	2.23**	41.01**
26	80	110	27.00**	6.30**	6.70**	21.17**	26.40**	19.25**	4.6**	11.23**	27.10	15.21**	5.67	3.74**	45.69**
27	78	108	27.50**	6.47**	7.70**	22.95**	24.40	40.99**	5.2**	8.11**	30.70**	12.57**	5.21	3.72**	58.80**
0.4% EMS															
28	78	113	29.70**	13.09**	4.80	19.14**	20.00**	31.80**	5.2*	15.17**	28.40**	11.64**	3.89	2.37**	55.58**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
29	78	112	29.40**	11.25**	5.60**	36.89**	17.40**	24.86**	5.1	6.20*	27.70**	17.53**	4.38	2.25**	44.13**
30	80	120	30.00**	4.71*	5.80**	24.11**	24.50	40.78**	5.0	9.43**	32.80**	5.14**	4.62	3.45**	38.79**
31	78	116	23.70**	5.64	5.70**	24.88**	19.90**	45.04**	4.9*	11.58**	28.00**	17.33**	4.53	2.01	41.63**
32	81	118	24.25**	7.35**	7.50**	25.34**	29.00**	30.19**	5.1	6.20*	30.30**	10.44**	5.15	2.53**	44.34**
33	79	117	31.30**	10.55**	4.80	27.43**	24.40	61.89**	5.0	9.43**	24.60**	22.28**	5.02	2.74**	56.22**
34	79	120	28.50**	6.87**	6.30**	18.40**	32.90**	39.80**	5.1	6.20*	31.00**	10.75**	4.90	4.28**	38.36**
35	79	118	30.90**	4.69*	5.20**	21.83**	21.20**	51.76**	4.6**	15.20**	24.70**	22.18**	5.20	2.69**	32.77**
36	84	119	28.40**	5.30*	5.40**	17.89**	24.90	31.53**	6.4**	8.07**	42.90**	6.45**	4.52	2.75**	41.77**
37	81	116	27.10**	6.14*	5.00	24.94**	27.00*	43.82**	4.6**	15.20**	31.80**	19.99**	4.67	2.65**	38.47**
38	78	110	28.20**	14.16**	7.20**	10.96**	25.30	21.89**	4.7**	10.28**	27.50*	12.97**	3.88	3.38**	35.94**
39	78	109	29.70**	6.36**	5.50**	19.64**	21.00**	36.13**	4.9*	11.58**	23.20**	20.50**	4.17	2.62**	35.65**
40	76	108	26.00.	10.57**	6.80**	24.80**	22.40**	32.27**	5.0	9.43**	26.50	17.09**	4.43	3.84**	42.72**
41	79	110	26.40*	8.60**	6.20**	16.66**	28.10**	18.79**	5.2**	8.11**	29.50**	8.19**	5.16	7.56**	29.35**
42	81	110	22.10**	15.00**	6.50**	18.13**	20.80**	23.64**	5.1	6.20*	28.80**	21.33**	5.30	2.22*	54.55**
43	82	116	31.10**	8.08**	6.60**	17.78**	26.10	27.00**	4.8**	8.78**	30.60**	6.39**	3.84	2.33**	39.85**
0.6% EMS															
44	80	114	29.20**	8.81**	5.60**	22.59**	24.80	40.58**	5.1	6.20*	27.40*	11.57**	5.01	2.30**	37.53**
45	81	108	28.90**	11.70**	5.00	32.66**	32.30**	34.54**	5.1	11.13**	37.70**	24.63**	5.3	3.70**	29.59**
46	79	114	25.60	7.86**	6.00**	11.11**	20.00**	26.77**	4.2**	15.06**	25.60**	7.64**	3.95	2.46**	52.03**
47	76	115	28.40**	4.13	6.70**	33.78**	19.60**	41.67**	5.0	9.43**	29.10**	6.96**	4.93	2.13	37.29**
48	81	114	29.20**	8.20**	6.20**	26.12**	20.70**	30.39**	5.3**	9.11**	30.80**	10.13**	5.28	3.23**	38.96**
49	81	115	27.30**	12.93**	7.50**	27.58**	26.60**	30.65**	5.1	11.13**	28.60**	7.59**	5.01	3.86**	57.60**
50	75	112	25.50	5.39*	7.10**	36.64**	27.50**	38.23**	5.0	13.33**	30.60**	16.10**	4.45	4.52**	72.51**
51	80	115	25.50	6.20*	6.50**	24.33**	31.80**	53.59**	4.5**	11.71**	30.10**	16.38**	3.98	3.98**	52.62**
52	80	114	29.60**	4.83*	5.50**	21.43**	20.10**	27.40**	5.1	11.13**	29.30**	16.65**	4.71	3.46**	50.70**
53	76	114	29.00**	16.81**	5.00	29.81**	16.00**	48.14**	5.3**	9.11**	29.70**	6.74**	4.23	2.62**	30.93**
54	78	116	26.40	12.78**	4.90	22.46**	20.00**	36.74**	4.9*	17.87**	27.20	23.94**	4.60	2.46**	55.79**
55	80	110	30.60**	8.18**	6.90**	25.97**	26.30	46.81**	4.7**	14.36**	26.30	22.10**	5.27	4.48**	53.92**
56	78	110	32.90**	5.06*	5.70**	14.44**	19.70**	36.14**	5.3**	9.11**	31.00**	7.75**	5.16	3.70**	33.83**
57	80	110	25.00**	8.00**	5.10*	26.87**	19.00**	38.99**	5.1	6.20*	29.90**	7.63**	4.18	2.81**	37.37**
58	79	110	25.50	12.16**	6.50**	23.22**	26.10*	21.48**	5.3**	9.11**	31.30**	9.41**	4.27	4.93**	33.76**
59	80	112	27.80**	5.82*	6.30**	23.72**	29.30**	43.89**	5.8**	10.90**	33.40**	16.04**	4.93	4.55**	67.52**
0.02% MMS															
60	77	114	29.60**	5.33*	4.50**	24.00**	28.60**	27.29**	5.0	9.43**	31.50**	14.22**	4.31	3.25**	39.88**
61	80	116	27.90**	7.64**	4.40**	24.43**	22.10**	29.20**	4.9**	6.45*	33.30**	17.85**	4.43	2.65**	54.56**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
62	78	114	28.00**	11.04**	4.70*	22.54**	25.40	34.18**	5.2**	8.11**	30.20**	8.94**	4.28	2.13	73.07**
63	76	113	29.00**	6.90**	4.00**	23.57**	16.90**	33.64**	5.3**	9.11**	28.00**	5.83**	3.83	2.03	42.25**
64	81	115	23.00**	7.67**	4.50**	18.89**	14.60**	41.25**	5.0	9.43**	30.10**	7.42**	5.22	2.96**	57.80**
65	84	120	26.80**	8.21**	6.50**	23.22**	24.10	30.58**	4.9**	6.45*	32.90**	9.97**	5.08	2.76**	41.44**
66	83	115	24.70**	8.33**	6.60**	30.47**	19.40**	35.48**	4.5**	11.71**	23.10**	15.87**	4.66	1.86**	44.76**
67	80	110	23.60**	7.26**	5.70**	23.46**	22.90**	28.26**	5.1	6.20*	29.60**	8.31**	5.16	5.65**	59.82**
68	76	118	33.00**	9.26**	6.00**	13.61**	33.40**	32.25**	4.8**	8.78**	29.60**	17.09**	4.79	4.32**	56.51**
69	77	117	27.90**	5.96*	5.80**	15.84**	23.80**	12.34**	4.8**	8.78**	27.00	9.72**	4.84	2.44**	40.10**
70	76	115	23.75**	6.06*	4.40**	15.89**	14.60**	29.10**	4.7**	14.36**	27.20	17.31**	4.26	1.76**	29.03**
0.04% MMS															
71	82	117	26.10	8.93**	5.30**	25.24**	17.20**	43.32**	5.0	9.43**	30.00**	12.37**	4.28	2.22	56.18**
72	82	113	28.40**	9.27**	5.90**	18.65**	20.40**	38.96**	4.9*	11.58**	28.40**	18.05**	5.05	3.09**	73.63**
73	76	111	28.00**	4.76	5.00	23.09**	19.00**	47.92**	4.9**	6.45*	27.40	17.39**	4.56	2.68**	50.71**
74	76	112	28.60**	9.50**	3.80**	24.18**	10.00**	68.80**	5.0	9.43**	26.90	12.57**	4.58	1.77**	55.85**
75	78	115	29.90**	8.26**	5.40**	15.62**	19.70**	53.56**	5.7**	8.47**	30.90**	14.67**	4.97	3.09**	86.91**
76	76	114	28.90**	8.55**	5.30**	28.20**	20.40**	39.37**	5.0	9.43**	28.90**	17.53**	4.07	2.49**	32.93**
77	81	118	24.60**	8.82**	6.30**	23.72**	25.00	27.33**	4.7**	10.28**	27.40	19.63**	4.74	2.73**	45.14**
78	76	109	23.20**	27.40**	5.20**	28.38**	21.00**	42.00**	5.2*	15.17**	29.40**	6.65**	5.26	3.19**	52.43**
79	79	114	31.60**	7.03**	6.30**	22.51**	30.50**	28.43**	5.0	9.43**	29.20**	8.20**	4.8	4.94**	57.92**
80	81	112	27.50**	7.12**	6.10**	22.46**	22.50**	30.88**	4.9**	6.45*	27.70**	17.61**	5.13	4.53**	70.69**
81	80	109	27.90**	9.01**	7.40**	22.25**	32.10**	18.95**	4.9**	6.45*	30.80**	7.77**	5.00	4.29**	35.44**
82	79	110	29.50**	6.24**	5.70**	24.88**	25.90	31.07**	4.7**	10.28**	28.00**	14.87**	5.23	4.73**	48.19**
83	77	111	29.50**	8.49**	6.80**	30.06**	25.80	23.67**	5.4**	9.56**	30.90**	13.07**	5.26	4.82**	52.87**
84	80	112	29.70**	7.78**	7.00**	29.35**	29.40**	28.01**	5.2**	12.16**	27.70*	21.53**	4.57	3.72**	59.77**
0.06% MMS															
85	82	117	25.20*	14.59**	5.20**	32.43**	23.40**	29.35**	4.7**	10.28**	27.40**	9.61**	4.39	3.02**	57.16**
86	79	116	23.40**	12.12**	4.40**	34.22**	18.30**	76.07**	5.1	14.47**	25.50**	24.89**	4.10	1.53**	73.29**
87	81	120	27.60**	8.05**	5.80**	19.57**	22.20**	38.68**	5.1	11.13**	26.20	23.10**	5.06	4.24**	48.89**
88	76	113	26.10	10.29**	4.60**	25.52**	12.50**	58.58**	5.2**	8.11**	26.50	10.10**	5.28	3.22**	27.91**
89	80	117	30.60**	7.42**	5.00	24.94**	19.50**	34.38**	5.3**	9.11**	33.00**	16.16**	5.25	3.35**	43.60**
90	77	114	31.20**	10.00**	6.20**	23.80**	27.10*	51.17**	5.4**	9.56**	32.90**	17.46**	5.02	5.38**	50.51**
91	78	115	27.30**	15.16**	8.00**	32.27**	38.80**	29.95**	5.6**	9.22**	33.80**	16.43**	5.04	2.83**	42.99**
92	76	117	26.30	15.84**	7.60**	18.81**	31.20**	24.26**	5.2**	8.11**	29.40**	9.10**	5.17	4.48**	62.29**
93	81	118	30.70**	10.19**	7.30**	24.21**	26.50*	30.20**	4.9**	6.45*	31.90**	16.02**	4.50	3.75**	68.98**
94	80	111	28.70**	7.71**	7.50**	28.97**	25.60	29.82**	5.1	6.20*	30.00**	11.76**	3.77	4.04**	63.12**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
95	81	111	29.00**	5.14*	7.00**	20.20**	22.80**	26.14**	5.0	9.43**	29.50**	17.88**	4.03	2.77**	33.18**
96	79	112	26.10	11.34**	7.40**	25.64**	26.20*	25.43**	5.1	6.20*	27.70**	7.62**	4.35	4.73**	51.17**
0.2 mM SA															
97	76	114	25.10*	13.21**	4.70	28.46**	24.00**	23.16**	5.1	6.20*	26.90	11.94**	5.23	2.68**	38.13**
98	80	111	26.20	7.15**	6.10**	19.63**	23.80*	36.62**	5.0	9.43**	30.00**	11.65**	4.85	5.38**	53.66**
99	78	118	26.80**	7.83**	3.70**	22.25**	15.60**	39.42**	4.7**	14.36**	23.50**	29.50**	4.56	2.28**	24.98**
100	80	117	26.30	12.16**	5.50**	33.47**	19.30**	41.38**	5.2**	15.17**	29.20**	20.15**	4.01	4.67**	57.47**
101	77	113	28.40**	6.47**	5.00	18.86**	14.30**	43.86**	5.4**	9.56**	32.90**	19.46**	4.96	2.12	52.21**
102	82	116	26.80**	6.99**	7.30**	31.67**	27.30**	28.11**	5.1	6.20*	29.10**	10.80**	4.62	3.34**	48.18**
103	80	118	29.70**	7.28**	6.50**	8.11**	25.90	17.87**	5.1	6.20*	33.60**	4.90**	5.16	3.50**	40.67**
104	76	117	27.70**	10.22**	4.90	15.06**	18.20**	31.49**	5.2**	12.16**	28.70**	23.23**	4.56	3.17**	56.42**
105	81	116	26.20	3.94	5.70**	23.46**	27.90**	34.23**	4.7**	10.28**	25.50**	12.16**	4.31	2.42**	44.27**
106	81	117	30.85**	3.42	6.30**	21.23**	28.10**	18.33**	5.1	6.20*	32.10**	7.26**	5.16	3.64**	34.93**
0.4 mM SA															
107	80	117	26.10	9.11**	5.90**	48.24**	34.40**	41.41**	4.9**	6.45*	30.30**	11.44**	4.20	3.26**	42.30**
108	84	113	32.00**	8.33**	6.20**	40.80**	26.40	41.62**	5.0	16.33**	34.50**	30.71**	5.17	3.20**	63.15**
109	84	115	20.30**	8.70**	5.60**	46.26**	9.30**	53.42**	4.3**	15.70**	22.70**	16.09**	4.94	1.35**	78.43**
110	58	114	24.40**	8.01**	5.40**	23.42**	20.30**	38.93**	4.7**	10.28**	31.90**	13.09**	4.79	3.18**	51.33**
111	80	119	28.70**	11.85**	5.20**	19.86**	24.00*	25.15**	5.2**	12.16**	28.80**	16.35**	4.54	2.52**	34.35**
112	77	115	31.70**	6.98**	5.20**	26.89**	23.40**	40.80**	5.3**	9.11**	30.40**	19.69**	4.87	3.21**	49.25**
113	79	117	25.80	12.63**	5.80**	32.31**	24.10	30.33**	5.4**	9.56**	32.60**	22.87**	4.4	2.92**	58.27**
114	78	115	28.30**	10.67**	6.80**	19.36**	32.30**	19.53**	5.1	11.13**	30.10**	15.54**	4.81	3.62**	53.93**
115	77	116	29.40**	8.36**	5.90**	14.84**	24.30	26.74**	5.2**	12.16**	30.20**	8.80**	4.87	3.30**	39.57**
116	88	112	26.30	6.48**	7.60**	24.97**	22.40**	42.47**	5.0	13.33**	30.10**	11.97**	5.56	2.82**	48.46**
117	81	115	19.30**	5.49	5.90**	14.84**	24.50	24.20**	5.1	6.20*	30.60**	12.25**	5.11	1.64**	55.93**
118	76	110	28.10**	10.80**	5.40**	12.95**	19.60**	24.55**	5.1	6.20*	30.10**	5.74**	4.35	3.52**	38.27**
119	77	118	26.30	11.34**	5.70**	29.88**	22.40**	39.89**	5.1	6.20*	29.70**	9.79**	4.80	5.45**	42.16**
120	82	114	25.00**	7.30**	6.40**	28.72**	22.50**	19.12**	5.1	6.20*	28.90**	6.20**	4.62	3.83**	65.45**
0.6 mM SA															
121	78	111	28.30**	7.08**	4.50**	15.71**	23.40**	36.44**	5.1	6.20*	31.40**	13.86**	5.14	2.68**	72.75**
122	80	117	28.50**	21.00**	4.00**	23.57**	29.70**	51.38**	4.9*	17.87**	33.40**	14.61**	5.06	2.63**	30.12**
123	87	118	24.70*	30.84**	4.00**	37.27**	31.10**	79.64**	4.5**	18.89**	28.00*	31.13**	4.85	2.18	64.45**
124	80	114	25.90	3.84	6.40**	13.18**	25.10	18.63**	5.0	9.43**	29.30**	7.89**	5.14	3.23**	69.45**
125	81	114	27.60**	8.57**	7.40**	15.86**	30.90**	22.86**	5.1	6.20*	30.00**	13.52**	4.21	2.32**	36.71**
126	78	109	25.10**	10.36**	6.50**	18.13**	35.60**	18.55**	5.5**	15.45**	29.30**	21.77**	5.26	4.33**	58.37**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
127	80	110	29.90**	8.41**	8.10**	19.69**	35.30**	23.78**	5.1	6.20*	31.90**	9.85**	4.96	2.85**	35.87**
128	81	111	28.30**	11.06**	6.00**	19.25**	22.00**	21.53**	5.2**	8.11**	27.40*	14.52**	5.04	3.05**	30.79**
129	77	110	31.80**	8.36**	8.00**	18.63**	28.50**	19.09**	5.0	9.43**	31.70**	9.29**	5.28	3.27**	31.17**
130	80	109	27.00**	15.32**	5.10*	25.23**	18.00**	37.04**	4.9*	11.58**	22.30**	19.72**	5.12	2.55**	51.85**
131	76	108	29.40**	6.45**	5.30**	25.24**	24.40	28.86**	4.9**	6.45*	26.40	12.90**	4.28	4.18**	60.11**
50 kR Gamma rays + 0.2% EMS															
132	78	113	25.90	9.36**	4.50**	36.66**	21.30**	49.29**	4.5**	15.71**	27.70**	12.63**	5.30	1.17**	63.17**
133	76	112	25.00**	7.30**	5.90**	30.37**	28.10**	32.33**	4.9*	11.58**	29.70**	25.20**	4.8	3.71**	53.11**
134	79	116	25.90	8.62**	5.40**	19.91**	26.10*	23.37**	5.2**	12.16**	31.60**	12.23**	4.83	3.38**	42.83**
135	76	115	33.00**	9.90**	5.60**	20.96**	36.00**	48.36**	4.8**	16.43**	28.20**	14.55**	4.92	3.39**	43.32**
136	78	115	29.40**	9.65**	5.10**	19.50**	19.20**	29.24**	5.5**	9.58**	29.80**	4.42**	4.72	2.48**	44.30**
137	76	112	28.40**	9.99**	5.50**	34.55**	24.70	60.95**	4.9**	6.45*	28.30**	13.23**	4.66	2.29**	58.21**
138	79	112	24.00**	6.21*	5.80**	22.70**	19.10**	33.43**	5.2**	8.11**	29.80**	7.55**	4.60	3.63**	59.91**
139	79	113	24.90**	13.04**	5.40**	17.89**	24.50	19.83**	5.2*	15.17**	28.90**	5.98**	4.97	3.54**	31.69**
140	76	110	27.80**	10.43**	4.70**	14.36**	18.30**	29.82**	4.7**	10.28**	28.70**	13.65**	4.17	2.92**	53.87**
141	78	117	26.20	9.14**	5.00	24.94**	20.90**	30.96**	5.1	6.20*	29.90**	10.27**	4.84	2.94**	31.43**
142	81	117	28.20**	6.21**	8.20**	13.85**	32.80**	24.68**	4.9**	6.45*	31.10**	15.34**	4.48	3.95**	73.60**
143	77	107	27.40**	10.91**	5.70**	28.71**	19.40**	36.14**	5.1	6.20*	30.30**	12.74**	4.39	4.08**	62.61**
144	78	108	29.70**	7.11**	7.30**	14.51**	29.50**	10.98**	5.1	11.13**	31.10**	12.45**	4.53	2.59**	52.43**
145	77	109	25.50	6.98**	5.50**	24.62**	19.10**	27.64**	5.3**	15.53**	26.00	25.58**	5.24	2.53**	61.76**
146	81	114	28.10**	5.68*	5.30**	17.90**	20.10**	13.56**	5.6**	19.20**	24.50**	14.69**	4.94	2.97**	67.01**
147	79	111	25.70	8.21**	4.70*	24.67**	15.90**	23.80**	5.0	9.43**	30.20**	9.34**	5.02	3.03**	53.69**
148	77	110	33.70**	5.24**	8.40**	17.92**	35.40**	23.53**	5.7**	8.47**	30.90**	11.86**	5.01	4.30**	48.85**
50 kR Gamma rays + 0.02% MMS															
149	76	111	27.10**	9.28**	4.90	20.29**	20.30**	26.79**	5.0	9.43**	27.60*	17.27**	4.33	2.82**	37.36**
150	77	112	26.90**	13.17**	5.30**	21.88**	31.20**	63.09**	5.5**	12.86**	32.70**	15.46**	4.28	3.40**	52.63**
151	78	115	26.20	18.85**	5.80**	29.08**	25.10	29.18**	5.3**	9.11**	30.70**	21.72**	3.86	2.81**	25.22**
152	79	112	22.30**	16.79**	5.30**	23.62**	16.30**	28.64**	5.0	9.43**	30.10**	11.23**	5.23	2.53**	34.26**
153	75	106	30.40**	6.05**	6.50**	30.12**	31.00**	32.22**	4.6**	11.23**	31.00**	12.90**	4.31	3.29**	40.70**
154	77	109	24.10**	8.63**	6.60**	22.81**	24.00*	30.99**	5.0	9.43**	30.80**	10.01**	4.02	4.20**	54.45**
155	81	111	29.90**	5.10*	5.90**	29.30**	22.40**	35.04**	5.1	6.20*	29.80**	7.21**	4.92	3.23**	52.56**
156	77	108	25.10**	7.38**	5.40**	26.48**	20.90**	22.72**	5.1	14.47**	26.60	15.06**	5.5	2.39**	75.99**
157	81	112	25.60	10.45**	5.50**	19.64**	25.20	26.51**	5.2**	8.11**	28.90**	7.90**	5.19	6.59**	40.76**
50 kR Gamma rays + 0.2 mM SA															
158	79	116	26.00	10.26**	4.60**	23.37**	25.00	43.45**	4.8**	13.18**	25.70**	12.85**	4.82	2.29	91.94**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
159	82	117	29.50**	7.37**	5.40**	26.48**	20.50**	38.22**	5.1	11.13**	30.30**	21.67**	4.46	3.76**	38.05**
160	76	112	25.30	15.59**	5.10*	26.87**	23.20**	35.94**	5.2**	12.16**	29.00**	10.28**	3.84	2.58**	43.74**
161	81	115	26.50	15.63**	5.20*	39.31**	20.70**	48.69**	5.1	6.20*	30.70**	11.80**	5.22	2.49**	39.63**
162	81	112	31.30**	5.01*	5.00	18.86**	17.80**	38.63**	4.5**	11.71**	25.00**	28.84**	5.28	3.34**	26.97**
163	80	109	26.20	8.40**	5.60**	19.20**	20.40**	34.75**	4.9**	6.45*	29.40**	7.38**	5.17	2.53**	46.05**
164	80	113	25.00**	5.96*	7.20**	36.92**	25.70	34.85**	5.1	6.20*	29.30**	10.68**	4.21	2.83**	45.72**
165	76	109	30.60**	6.75**	6.10**	22.46**	25.10	29.12**	5.1	6.20*	25.60**	21.65**	4.19	3.28**	60.75**
166	78	109	27.40**	6.01*	5.40**	9.56**	21.10**	29.25**	5.1	6.20*	28.80**	10.20**	4.47	3.58**	34.64**
0.2% EMS + 0.02% MMS															
167	81	115	24.20**	14.68**	4.60*	38.62**	11.70**	73.42**	4.6**	11.23**	24.90**	11.74**	4.52	2.20	49.85**
168	78	113	24.30**	11.15**	5.20**	19.86**	23.60*	43.54**	4.6**	18.33**	28.80**	32.89**	5.06	2.80**	39.93**
169	82	119	29.50**	4.30	4.50**	30.09**	19.50**	46.33**	5.2**	8.11**	30.00**	17.57**	4.12	2.35**	41.59**
170	77	111	28.90**	12.36**	4.00**	23.57**	22.00**	28.10**	5.0	9.43**	26.30	14.12**	5.00	3.04**	30.85**
171	81	119	25.80	14.13**	5.20**	29.79**	26.40	36.60**	4.9*	11.58**	32.00**	19.98**	5.23	3.33**	39.50**
172	76	115	27.00**	10.33**	4.60**	23.37**	17.70**	43.44**	5.3**	9.11**	28.60**	16.08**	4.35	2.07	43.34**
173	79	119	28.20**	13.14**	5.10	32.61**	23.70**	31.39**	5.4**	9.56**	28.70**	14.97**	4.18	3.55**	51.92**
174	77	114	28.10**	7.59**	3.80**	24.18**	14.70**	53.09**	5.3**	9.11**	29.00**	17.36**	4.49	1.89*	60.47**
175	76	114	24.40**	11.46**	3.90**	28.22**	14.40**	40.52**	4.8**	16.43**	30.70**	20.55**	5.04	1.78**	38.64**
176	76	114	27.60**	9.69**	5.60**	30.58**	17.50**	27.24**	5.6**	9.22**	32.10**	14.72**	5.12	2.79**	30.04**
177	79	120	28.20**	9.72**	5.70**	16.64**	31.40**	26.91**	5.3**	9.11**	31.10**	12.07**	5.21	3.28**	40.70**
178	77	118	27.80**	5.03*	6.50**	30.98**	30.60**	34.63**	5.1	11.13**	28.90**	12.79**	3.94	3.73**	30.04**
179	79	117	23.30**	9.06**	5.10*	23.47**	14.90**	36.00**	4.7**	10.28**	28.50**	5.79**	4.36	2.73**	107.64**
180	83	119	32.20**	6.35**	7.40**	22.25**	28.80**	19.42**	4.9**	6.45*	31.60**	12.94**	5.12	2.51**	64.67**
181	81	116	29.90**	5.78**	6.40**	28.72**	30.60**	27.74**	5.0	9.43**	31.80**	10.14**	5.08	3.37**	25.62**
182	78	114	25.30*	8.13**	5.20**	28.38**	20.50**	38.77**	4.9*	11.58**	29.80**	14.74**	3.81	2.99**	50.48**
183	79	115	22.70**	4.18	5.60**	19.20**	30.30**	49.88**	4.4**	15.89**	28.20**	17.83**	5.02	3.32**	41.06**
184	76	113	27.40**	7.73**	5.90**	18.65**	25.30	24.86**	4.2**	15.06**	27.00	21.74**	4.53	3.29**	35.12**
185	80	110	30.10**	4.27	6.10**	23.76**	23.70**	19.99**	4.9**	6.45*	30.60**	9.65**	4.44	2.74**	41.06**
186	77	107	25.40*	5.93*	5.20**	23.64**	23.10**	26.01**	5.0	9.43**	31.30**	10.65**	5.08	3.30**	29.95**
187	81	110	20.10**	7.58*	6.30**	32.66**	18.60**	32.08**	5.1	6.20*	29.20**	8.51**	4.95	2.48**	58.05**
188	84	119	31.90**	5.62**	8.50**	14.93**	41.60**	23.83**	5.4**	9.56**	35.60**	14.99**	5.09	6.57**	29.64**
0.2% EMS + 0.2 mM SA															
189	76	114	28.80**	7.10**	4.60*	42.50**	24.90	61.33**	5.4**	12.95**	30.40**	14.89**	5.31	1.67**	50.03**
190	76	112	29.90**	7.80**	4.80	23.65**	23.00**	39.26**	4.9**	6.45*	28.40**	12.33**	5.32	2.98**	36.05**
191	79	115	25.80	12.63**	4.70	31.80**	24.00	52.92**	4.9**	6.45*	31.10**	16.91**	4.74	3.31**	47.05**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
192	80	112	23.80**	5.17	5.30**	32.13**	18.60**	41.81**	5.1	6.20*	30.40**	10.65**	5.00	3.79**	46.36**
193	80	116	28.10**	12.38**	5.50**	24.62**	28.60**	36.64**	5.1	6.20*	31.70**	11.90**	3.77	3.88**	42.97**
194	81	121	27.70**	6.15**	6.80**	30.06**	36.20**	35.32**	5.1	6.20*	35.10**	8.22**	4.27	3.98**	33.38**
195	81	116	21.40**	12.50**	5.00	23.09**	22.00**	33.61**	3.7**	13.06**	24.00**	19.14**	4.59	2.87**	55.28**
196	79	122	27.50**	7.32**	6.50**	18.13**	24.70	18.80**	4.5**	11.71**	31.30**	12.24**	4.43	2.67**	44.66**
197	76	110	21.90**	7.60*	4.80	21.52**	12.70**	23.20**	5.1	6.20*	30.30**	13.57**	4.15	2.03	28.32**
198	79	110	24.20**	6.10*	5.70**	20.34**	17.00**	29.74**	4.9**	6.45*	29.20**	9.39**	4.66	3.00**	42.55**
199	80	110	29.80**	5.88**	5.90**	21.81**	26.40*	29.19**	5.1	6.20*	28.10**	19.81**	5.10	3.92**	55.25**
0.02% MMS + 0.2 mM SA															
200	80	115	23.70**	18.66**	3.20**	38.41**	18.90**	67.69**	4.6**	15.20**	22.60**	18.09**	4.97	2.06	46.98**
201	75	110	28.30**	9.72**	4.20**	40.16**	20.00**	35.82**	5.6**	9.22**	32.30**	18.58**	4.14	2.03	69.86**
202	79	112	25.60	11.23**	3.90**	25.50**	18.10**	35.08**	4.8**	8.78**	26.80	13.94**	5.23	2.00	43.84**
203	80	115	26.90**	10.29**	5.20**	21.83**	14.20**	30.39**	4.9**	6.45*	28.20**	17.03**	4.18	1.92**	25.29**
204	86	120	27.50**	10.74**	5.30**	37.79**	22.70**	21.18**	5.3**	9.11**	33.80**	16.72**	4.98	2.94**	22.70**
205	77	118	27.60**	10.69**	7.50**	14.40**	47.10**	19.32**	5.0	13.33**	32.60**	12.29**	4.18	6.03**	34.49**
206	78	116	20.90**	9.69**	3.90**	18.92**	15.20**	44.60**	4.5**	15.71**	23.70**	20.19**	4.68	1.74**	56.33**
207	76	108	27.00**	5.52*	5.00	18.86**	18.90**	32.28**	5.0	9.43**	29.80**	8.49**	5.12	3.01**	34.82**
208	77	109	27.70**	7.43**	5.00	21.08**	18.50**	34.49**	5.1	6.20*	29.90**	9.90**	4.82	3.09**	36.14**
209	82	110	23.80**	12.65**	6.80**	23.81**	22.20**	25.99**	4.8**	8.78**	26.00*	16.72**	5.05	2.54**	52.12**
210	78	109	32.10**	4.51*	8.00**	22.05**	30.60**	20.16**	5.5**	17.67**	29.10**	11.73**	5.05	3.92**	54.60**
Control	76.69	112.77	25.84	3.12	4.87	3.03	25.15	3.74	5.04	3.27	26.74	2.75	4.69	2.05	5.12

Appendix-I1

Mean and coefficient of variation (C.V.) of cumin genotype RZ 209 for different characters in M₂ generation for various mutagen treatments

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
50% kR Gamm rays															
1	75	110	24.20**	5.44	4.80**	29.13**	20.2**	40.61**	5.2	8.11*	29.00*	11.72**	4.38	3.83**	53.00**
2	76	109	28.50	15.45**	7.20**	18.29**	33.3**	21.98**	5.1	11.13**	32.30**	8.26*	4.90	4.69**	50.24**
3	76	108	31.20**	7.97**	6.90**	35.14**	32.6**	28.42**	5.1	6.20	31.60*	14.01**	4.26	4.77**	53.71**
4	76	109	30.70**	3.78	6.30	21.23**	26.1	18.72**	5.1	21.58**	27.80**	20.26**	5.11	3.46**	29.75**
5	75	110	31.10**	4.90*	5.50**	24.62**	27.1*	22.51**	5.1	6.20	28.90*	15.34**	5.03	2.36	50.09**
6	76	116	23.20**	12.33**	6.00	19.25**	27.9**	18.08**	5.3	17.90**	29.10*	9.65*	4.11	3.94**	27.62**
7	76	107	28.70	9.00**	5.50**	24.62**	24.2*	29.85**	5**	9.43**	28.80*	13.58**	4.20	2.83**	63.84**
8	77	111	25.40**	11.01**	7.60**	14.14*	39.9**	18.55**	5*	18.86**	30.20	12.37**	4.81	3.99**	61.91**
60 kR Gamma rays															
9	78	113	23.90**	7.75**	6.80**	18.08**	32.7**	23.34**	5.3	9.11**	32.00**	11.32**	4.98	2.73*	73.21**
10	76	108	23.30**	8.11**	4.70**	20.18*	17.8**	28.38**	5*	13.33**	28.90*	11.59**	4.98	1.68**	76.05**
11	76	111	31.70**	8.15**	4.90**	35.28**	24.7	33.61**	5.1	14.47**	28.80*	10.20*	4.68	1.66**	57.08**
0.2% EMS															
12	76	106	29.10*	8.49**	5.90	21.81**	28.1**	26.50**	5*	13.33**	29.90	14.40**	4.53	3.77**	44.46**
13	77	108	28.00	9.52**	6.00	17.57*	27.4**	19.93**	5.1	11.13**	32.00**	2.95	5.15	3.67**	33.23**
14	78	108	18.90**	8.06*	3.90**	25.50*	11.1**	37.38**	4.8**	8.78*	18.20**	11.23	5.01	3.86**	57.05**
15	75	110	27.90	13.67**	5.00**	21.08*	21.4**	20.57**	5**	9.43**	29.30	10.18*	5.26	3.07**	60.06**
16	76	109	27.70	12.51**	5.70	18.59*	22.3**	24.29**	4.9**	20.29**	29.20	19.43**	4.64	2.89**	79.67**
17	75	107	24.00**	13.89**	7.10**	12.33	26.8	19.73**	5.4*	9.56**	27.20**	8.63	3.8	2.51*	35.53**
18	75	106	29.40**	6.25**	5.40**	15.62	29**	13.00**	5.1	11.13**	31.60**	2.67	4.86	2.94**	49.32**
19	76	110	32.50**	8.24**	7.90**	12.59*	42.5**	37.39**	5**	9.43**	36.80**	9.48**	4.33	6.93**	63.78**
20	75	108	27.70	11.17**	7.10**	16.86**	27.9**	9.17*	6.2**	12.72**	29.60	4.56	5.19	3.77**	23.26**
21	75	108	29.60**	11.51**	5.30**	19.99*	25.2	20.73**	5.4*	9.56**	28.50**	12.62**	5.30	2.68**	47.98**
22	76	109	24.70**	8.33**	6.00	17.57*	26.4	23.02**	5.7**	16.64**	28.20**	7.44	4.46	2.62*	65.95**
23	80	114	29.90**	7.80**	7.00**	24.28**	25.2	19.42**	5.4	23.42**	29.80	20.06**	4.34	3.22**	43.58**
24	77	109	27.50*	11.01**	4.70**	33.34**	17.6**	51.74**	4.9**	11.58**	27.80**	9.10*	3.56	2.33	69.71**
25	76	113	27.90	13.14**	5.90	16.85*	26.1	18.10**	5.2	8.11*	28.70**	13.35**	3.95	3.13**	50.34**
26	77	112	30.30**	5.17*	10.00**	11.55**	35.6**	8.80**	5.5**	12.86**	33.10**	9.71**	4.44	2.86**	38.82**
27	79	120	31.40**	7.54**	8.20**	22.85**	29.3**	3.62	5.3	12.73**	32.10**	10.53**	4.95	2.23	55.94**
28	76	110	26.70**	9.52**	4.80**	16.43	18.8**	18.73**	5.1	6.20	29.70	8.41	3.98	3.49**	111.39**
29	77	116	22.20**	13.40**	4.30**	29.11**	15.7**	57.21**	4.9**	11.58**	26.10**	12.18**	4.42	1.95**	58.83**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
0.4% EMS															
30	79	112	24.95**	9.75**	4.60**	15.20	15.4**	22.12**	5.2	12.16**	29.40	11.80**	5.14	3.69**	36.89**
31	81	114	23.35**	4.04	4.20**	33.30**	12**	23.24*	5**	9.43**	30.30	12.26**	5.22	2.22	62.59**
32	75	108	31.60**	6.54**	8.00**	18.63**	31.5**	14.06**	5**	9.43**	32.20**	11.51**	5.29	4.79**	43.19**
33	75	108	25.70**	7.79**	7.80**	16.88**	30.9**	18.96**	5.2	15.17**	27.20**	9.30*	5.10	3.38**	38.62**
34	75	108	25.70**	7.35**	5.40**	21.74**	24**	13.61**	5.1	11.13**	27.90**	12.12**	4.83	3.13**	62.35**
35	75	107	28.80	8.31**	5.40**	21.74**	27.4*	24.52**	5.3	9.11**	30.00	12.96**	4.94	2.54	50.25**
36	76	108	30.50**	7.61**	7.60**	12.71*	41.4**	18.86**	5.6**	9.22**	31.20*	6.37	4.18	3.72**	36.68**
37	76	109	30.70**	12.10**	5.40**	15.62	27.2*	21.42**	5.1	11.13**	28.00**	17.66**	5.31	3.48**	42.40**
38	76	109	21.40**	7.04*	5.20**	26.89**	22.3**	31.64**	5**	9.43**	30.00	15.56**	4.87	2.38	41.92**
39	76	109	29.50**	6.24**	6.40	21.09**	22.2**	32.26**	5.3	9.11**	24.60**	27.38**	4.65	3.18**	42.17**
40	75	109	30.60**	12.25**	5.90	23.23**	26.2	22.74**	5**	9.43**	29.80	18.23**	4.83	3.27**	60.29**
41	75	109	38.50**	6.62**	9.90**	14.64**	34.3**	11.08**	6.1**	14.35**	36.50**	11.28**	5.15	3.55**	75.86**
42	75	112	32.20**	5.63**	8.30**	18.88**	29.6**	8.46*	5.1	11.13**	31.60**	11.95**	3.91	2.86**	63.11**
43	80	106	26.70**	9.84**	6.00	20.79**	21.4**	28.23**	5.1	6.20	27.90**	19.81**	5.30	2.85**	26.41**
44	76	112	26.00**	10.57**	6.30	39.63**	38**	11.23**	5.1	11.13**	30.40	10.88**	3.93	2.47	46.48**
45	76	113	28.90	11.93**	6.90**	22.09**	20.8**	27.83**	5*	16.33**	29.10	14.89**	5.24	2.73**	41.66**
46	76	114	23.20**	9.70**	4.30**	24.64*	17**	43.40**	5**	9.43**	25.80**	12.63**	4.31	3.43**	60.46**
47	80	121	26.70**	8.84**	5.60*	30.58**	26	6.78	6.2**	14.82**	33.00**	17.32**	4.94	1.82**	41.96**
0.6% EMS															
48	76	105	28.00	9.96**	4.90**	27.97**	15.9**	39.16**	5*	13.33**	28.80**	8.63	4.59	2.38	71.33**
49	77	106	25.70**	6.63*	5.90	20.29**	23.5**	14.77**	5*	13.33**	28.70**	7.35	4.66	3.33**	37.57**
50	80	108	24.90**	13.84**	7.20**	15.77**	30.2**	17.99**	4.9**	15.06**	32.40**	3.62	4.23	3.94**	40.62**
51	76	108	32.50**	5.66**	5.70*	16.64*	21.6**	10.51	5.6**	12.49**	33.00**	8.69*	5.12	3.13**	27.98**
52	76	108	28.10	8.95**	5.50**	19.64*	25.1	24.30**	5.3	12.73**	28.30**	15.45**	4.90	3.28**	66.17**
53	75	107	28.70	6.78**	6.00	19.25**	25.8	26.40**	5.2	15.17**	30.20	14.71**	4.70	3.56**	64.22**
54	76	108	32.50**	6.99**	6.50*	25.38**	23.7**	27.20**	5.8**	15.84**	31.00	18.06**	5.12	2.75**	61.87**
55	76	108	26.50**	8.20**	6.10	19.63**	25	21.75**	5.4*	12.95**	29.50	16.24**	5.11	1.99**	56.70**
56	76	110	25.60**	5.88*	5.90	16.85*	21**	27.49**	5.2	15.17**	22.50**	14.40**	4.74	3.02**	64.14**
57	78	111	27.10**	7.06**	6.10	26.15**	17.8**	45.32**	5.3	15.53**	23.90**	23.04**	5.32	2.82**	59.87**
58	80	116	31.90**	5.00*	7.40**	25.64**	31.3**	22.49**	5.3	12.73**	31.30	14.61**	5.12	5.25**	56.94**
59	76	111	27.50*	5.75*	5.50**	23.08**	27.5**	21.97**	5.3	12.73**	29.00*	14.54**	4.40	2.12*	46.44**
60	76	109	23.55**	10.13**	5.40**	37.24**	20.8**	20.12**	5.1	11.13**	29.40	15.06**	5.28	2.21	48.90**
61	75	108	37.90**	5.62**	6.20	18.31**	31.3**	19.52**	5.2	8.11*	31.50**	8.50*	4.89	2.78**	61.01**
62	75	109	31.80**	11.37**	5.70*	11.84	28.6**	21.12**	4.9**	15.06**	30.70	11.18**	4.86	3.01**	45.37**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
63	76	108	27.30**	7.13**	6.50*	25.38**	22.8**	37.09**	5.2	8.11*	27.40**	19.33**	5.18	2.95**	68.22**
64	75	108	27.70	8.85**	7.80**	16.88**	28.2**	6.21	5.3	12.73**	30.70	8.96*	5.55	2.84**	45.74**
65	76	110	31.10**	3.85	6.00	23.57**	35.2**	16.98**	4.8**	8.78*	32.70**	5.00	4.92	3.38**	61.52**
66	76	110	25.80**	13.02**	6.90**	17.35**	31.1**	16.50**	5.2	12.16**	30.00	9.16*	4.17	3.53**	38.44**
67	76	109	24.10**	7.44**	6.10	16.30*	26.5	19.91**	5.1	6.20	31.40*	13.44**	4.93	3.31**	42.35**
68	76	108	30.70**	5.10*	4.50**	15.71	21.3**	34.43**	5.1	14.47**	23.00**	16.01**	4.04	2.45	61.96**
69	75	108	29.00*	5.14*	4.90**	15.06	25	11.62*	4.6**	11.23**	25.80**	13.15**	5.04	2.65**	53.66**
70	76	108	30.60**	7.89**	8.90**	14.46**	30.1**	7.58	6.1**	14.35**	30.30	4.41	4.05	4.12**	52.06**
71	76	109	27.40**	8.51**	7.90**	28.27**	29.2**	25.62**	5**	9.43**	29.70	9.66*	5.25	4.47**	45.23**
72	76	110	24.10**	7.93**	4.50**	26.19**	19.2**	36.89**	5.1	6.20	29.20	8.81*	5.28	2.90**	45.71**
73	76	110	30.50**	5.83*	7.40**	13.06*	29.9**	3.33	6.4**	10.93**	30.30	3.13	3.87	3.15**	38.97**
0.02% MMS															
74	80	109	26.60**	9.74**	6.10	21.09**	21**	24.90**	5.1	14.47**	26.50**	19.10**	4.25	2.76**	63.79*
75	78	110	21.10**	10.10**	4.80**	19.14*	12.7**	31.51**	4.5**	11.71**	19.10**	14.06*	5.12	1.68**	75.33**
76	81	112	24.20**	12.13**	6.10	16.30*	27.3**	14.24**	5.1	6.20	30.10	8.05	4.56	3.51**	48.20**
77	76	109	26.90**	6.18*	7.10**	19.30**	30.5**	14.52**	5.6**	15.06**	27.90**	9.32*	4.93	3.39**	55.65**
78	76	109	30.20**	5.36*	9.20**	14.31**	24.4*	15.48**	5.4*	9.56**	32.00**	11.69**	4.74	2.90**	42.00**
79	76	110	31.60**	6.19**	6.50	30.12**	26.8	29.58**	5.1	11.13**	29.90	9.25*	4.85	3.38**	91.08**
80	75	108	23.40**	10.70**	5.90	18.65*	24.3**	13.02**	5.3	9.11**	27.90**	5.46	5.25	2.86**	35.39**
81	76	110	28.50	8.79**	5.90	20.29**	28.2**	25.72**	5.2	12.16**	32.00**	9.66*	4.43	2.95**	51.58**
82	76	111	31.20**	8.78**	6.80**	29.25**	32**	20.57**	5.2	8.11*	30.20	13.59**	4.77	3.67**	53.94**
83	75	108	28.70	7.71**	6.40	15.10*	21.1**	18.35**	6.2**	10.20**	29.00*	13.70**	5.11	3.70**	44.42**
84	75	108	29.50**	7.87**	6.20	30.22**	20**	23.92**	5.6**	17.25**	28.10**	15.42**	5.17	2.76**	48.87**
85	77	108	32.40**	10.21**	8.30	26.06**	27.3**	17.19**	5.6**	15.06**	28.90*	15.94**	5.06	2.42	51.40**
86	77	110	27.20**	7.31**	5.70*	16.64*	29.4**	22.63**	5**	9.43**	30.20	11.87**	4.33	3.30**	51.32**
87	78	110	25.60**	9.78**	5.20**	28.38**	24.3*	18.20**	5**	9.43**	29.10	15.49**	5.27	2.86**	48.21**
88	78	108	26.90**	15.32**	7.30**	15.88**	41.1**	15.19**	5.5**	21.43**	34.50**	15.41**	6.23	2.32	54.18**
0.04% MMS															
89	75	108	25.30**	10.71**	6.00	17.57*	24.6	23.01**	5.9**	14.84**	32.70**	12.57**	4.64	2.57**	35.96**
90	80	114	32.10**	7.26**	6.40	18.34**	26	36.58**	5.1	11.13**	29.70	24.64**	4.69	3.10**	48.67**
91	76	108	22.10**	12.70**	5.90	16.85*	23.1**	7.48	5.2	17.67**	27.30**	9.15	5.22	2.34	51.03**
92	76	110	30.00**	7.03**	7.10**	24.35**	28.5**	29.23**	5.1	6.20	30.40	8.66*	4.46	3.89**	48.94**
93	75	108	28.00	6.73**	6.60**	20.45**	24.2*	28.15**	5*	13.33**	25.80**	21.45**	5.02	3.48**	19.76**
94	76	108	28.40	7.64**	5.20**	21.83**	20.1**	31.33**	5.1	6.20	30.50	16.15**	4.75	2.65*	68.88**
95	76	110	33.00**	8.21**	7.80**	15.76**	30.9**	9.08*	5.6**	15.06**	29.80	15.07**	5.14	3.67**	44.44**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
96	75	108	26.70**	9.01**	5.60**	12.49	29.5**	16.55**	5.4*	9.56**	27.20**	11.07*	5.09	2.94**	33.04**
97	76	110	34.50**	8.67**	7.50**	16.92**	32.2**	9.69**	5**	9.43**	26.70**	15.50**	4.66	2.24	42.85**
98	76	110	29.60**	5.33*	8.10**	14.78**	26.5	8.20	7**	13.47**	34.40**	9.71**	4.83	3.33**	45.76**
99	76	108	28.70	9.00**	6.20	19.83**	33.9**	16.30**	5.1	14.47**	31.40*	10.09**	4.56	3.37**	40.93**
100	77	108	29.30**	11.94**	5.00**	33.99**	23.6*	38.33**	5.1	11.13**	28.60**	11.44**	4.19	2.34	43.42**
101	76	115	27.00**	11.71**	7.60**	24.18**	29.1**	25.69**	5.2	12.16**	28.70**	7.54	3.96	4.52**	60.09**
102	76	110	31.70**	8.15**	8.70**	12.18*	28.7**	7.17	5.5**	15.45**	30.90	15.81**	5.14	3.76**	62.79**
103	77	109	21.90**	8.73**	4.80**	21.52*	27.6**	13.36**	5.1	11.13**	30.50	7.92	5.01	2.19	59.63**
104	79	118	27.80	6.52**	7.00**	11.66	37.8**	8.62**	5.4*	17.89**	32.30**	13.06**	5.12	2.07**	43.40**
0.06% MMS															
105	78	108	26.50**	7.17**	4.50**	24.00*	17.2**	45.43**	5.1	14.47**	27.10**	7.06	5.06	2.25	72.83**
106	78	108	28.20	7.62**	5.80	21.19**	23.6**	22.26**	5.2	8.11*	28.30**	7.27	4.90	3.97**	29.75**
107	77	109	25.60**	9.24**	4.70**	24.67**	17.4**	33.97**	5.1	6.20	28.30**	10.00*	5.42	2.39	44.49**
108	76	108	30.70**	8.28**	6.10	19.63**	27.5**	25.21**	5.2	8.11*	33.90**	14.28**	5.34	4.17**	68.77**
109	77	111	29.80**	5.20*	8.40**	15.06**	30.6**	6.20	6.4**	10.93**	30.40	4.70	4.02	2.97**	39.98**
110	75	108	21.20**	6.21	6.70**	19.96**	25.8	9.81*	6.2**	12.72**	27.40**	7.73	4.66	3.50**	64.06**
111	77	110	29.40**	5.12*	5.50**	24.62**	20.3**	21.16**	5.1	6.20	23.00**	7.94	4.86	1.99**	60.39**
112	76	108	30.50**	4.70*	6.60**	19.17**	34.7**	13.17**	5.1	14.47**	31.40**	1.64	5.10	3.66**	58.00**
113	76	108	32.00**	6.25**	5.70*	11.84	27.6**	20.37**	5.2	12.16**	29.80	19.55**	5.21	3.14**	54.28**
114	77	110	29.50**	5.82*	5.80	30.19**	23.3**	28.33**	5*	16.33**	29.70	14.38**	4.4	3.95**	45.83**
115	77	109	29.10*	7.84**	6.40	18.34**	31.8**	16.23**	5**	9.43**	31.10	7.02	5.36	3.39**	53.30**
116	76	105	30.20**	7.62**	7.70**	30.64**	37.9**	9.83**	5.1	11.13**	35.90**	6.88	4.45	3.71**	61.23**
117	76	110	29.20*	14.51**	5.40**	27.88**	27.1*	21.83**	5.4*	9.56**	32.70**	6.61	5.17	3.60**	66.54**
118	76	108	28.50	11.00**	6.70**	12.29	40.8**	11.77**	4.9**	11.58**	28.10**	10.40*	5.20	2.84**	32.77**
119	75	105	20.00**	11.79**	3.90**	28.22*	23**	20.39**	4.8**	16.43**	29.80	3.81	4.41	2.36	39.29**
0.2 mM SA															
120	77	110	26.80**	4.91	5.00**	16.33	18.3**	41.06**	5.1	14.47**	28.70**	7.35	3.68	3.43**	77.44**
121	76	109	32.60**	6.50**	8.30**	17.09**	31.2**	17.48**	5.2	8.11*	31.40*	9.52*	5.06	3.77**	27.77**
122	77	110	32.00**	13.26**	7.40**	18.24**	31.3**	18.45**	5.1	11.13**	32.10**	13.09**	4.38	3.67**	34.18**
123	75	107	28.50	12.62**	6.20	21.23**	28.4**	19.30**	5.1	11.13**	29.60	19.19**	5.07	2.85**	20.66**
124	75	108	30.80**	10.36**	5.00**	13.33	23.3**	33.19**	5.1	6.20	29.20	14.60**	5.05	2.57**	36.10**
125	76	109	26.90**	7.11**	4.40**	21.96*	17.7**	30.49**	5.1	6.20	26.60**	11.51*	3.95	3.50**	35.61**
126	77	111	29.80**	10.94**	5.80	13.60	26.5	11.97**	5.5**	9.58**	29.10*	9.78*	4.64	4.43**	22.91**
127	76	110	29.10*	8.01**	5.30**	21.88**	25	19.23**	5.1	11.13**	30.10	7.90	5.08	3.06**	36.08**
128	75	107	29.50**	6.44**	7.30**	13.00*	34.7**	20.29**	5.3	9.11**	28.60**	11.44**	5.26	3.99**	62.93**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
129	79	113	31.30**	8.92**	6.10	24.98**	30.5**	26.29**	5.3	19.99**	30.60	15.42**	5.33	3.81**	60.64**
130	80	119	30.50**	7.12**	7.20**	19.42**	30.3**	24.99**	5.1	14.47**	30.20	8.94*	4.18	3.82**	57.05**
131	78	115	19.90**	24.67**	4.60**	32.73**	17.4**	23.65**	5.2	12.16**	30.50	6.42	4.56	2.57**	31.52**
0.4 mM SA															
132	78	109	25.30**	6.47*	4.90**	24.43**	18.9**	28.60**	5.2	15.17**	28.40**	8.33	4.84	1.49**	39.35**
133	76	109	30.50**	5.18*	5.20**	12.16	22.7**	25.52**	4.8**	8.78*	26.60**	17.65**	4.68	2.88**	56.85**
134	76	107	22.50**	8.95**	5.20**	25.32**	24.4*	23.76**	5**	9.43**	31.80**	6.76	4.77	4.71**	34.21**
135	76	107	28.80	7.28**	5.70	20.34**	22.5**	22.88**	5.6**	9.22**	29.90	18.35**	4.92	2.97**	40.47**
136	76	108	27.10**	10.93**	5.20**	23.64**	20.4**	39.70**	5*	13.33**	26.00**	13.32**	4.80	2.46	88.98**
137	78	108	27.70*	6.38*	6.30	25.97**	24.8	25.56**	4.9**	11.58**	28.30**	14.53**	5.07	4.06**	20.96**
138	76	110	18.10**	6.61	4.30**	34.75**	10.3**	48.88**	4.9**	6.45	20.60**	21.25**	5.17	1.25**	123.02**
139	75	108	29.10**	5.72*	6.20	14.82*	24.2*	25.23**	5.2	15.17**	25.60**	18.98**	3.88	2.95**	45.63**
140	76	108	25.00**	9.80**	4.80**	19.14*	15.6**	26.38**	5*	13.33**	30.80	16.61**	5.09	2.26	39.06**
141	77	109	32.20**	7.44**	6.20	32.08**	20**	41.83**	5.3	12.73**	22.60**	27.77**	5.16	3.31**	65.26**
142	76	110	28.80	10.58**	7.60**	26.46**	28.1**	14.57**	5.3	15.53**	32.60**	14.76**	4.97	3.83**	28.65**
143	76	109	35.35**	8.54**	8.00**	11.79*	39.8**	22.59**	5.4*	9.56**	38.00**	12.77**	5.23	4.66**	52.62**
144	76	109	28.50	7.44**	7.10**	14.01*	30.1**	4.55	6.6**	7.82**	30.90	7.23	4.81	2.94**	54.29**
145	76	108	20.00**	6.24	4.00**	20.41	20.7**	13.29*	4.6**	21.00**	26.60**	11.38*	5.21	2.97**	44.43**
146	77	111	32.30**	5.27*	6.50*	13.07	27.2*	21.70**	5.1	6.20	29.70	13.66**	5.02	5.10**	36.14**
147	77	109	30.80**	6.81**	6.90**	19.86**	30.3**	9.85*	5.5**	15.45**	30.90	12.62**	5.29	4.49**	64.07**
148	76	108	26.80**	9.11**	7.80**	15.76**	30.9**	13.07**	6**	13.61**	29.40	3.66	5.12	3.67**	32.82**
149	76	110	30.50**	8.36**	5.80	22.70**	25.1	26.19**	5*	13.33**	28.40**	12.77**	4.44	3.84**	83.65**
150	76	110	18.50**	15.13**	5.50**	26.07**	23.9*	35.85**	5.4*	17.89**	28.80*	12.12**	5.06	3.01**	42.50**
151	76	110	30.10**	4.55	5.70	20.34**	28.5**	26.11**	5**	9.43**	28.70*	16.83**	4.67	2.22	69.35**
152	76	113	22.50**	8.18**	4.00**	26.35*	17.1**	33.36**	5.1	11.13**	28.70**	12.73**	4.66	2.13*	44.38**
153	76	109	29.50**	10.26**	7.20**	10.96	25	16.00**	6.4**	10.93**	32.30**	12.30**	5.44	4.25**	63.36**
0.6 mM SA															
154	76	109	28.70	6.16*	5.30**	23.62**	22.9**	29.22**	4.9**	6.45	26.10**	19.74**	4.14	3.86**	31.95**
155	76	108	27.30**	10.79**	4.90**	17.87	19.5**	17.14**	5.1	11.13**	30.20	4.89	4.87	2.67**	31.21**
156	76	108	23.50**	5.40	4.50**	18.89	19.2**	38.65**	4.9**	6.45	28.20**	9.43*	4.72	3.20**	65.97**
157	77	107	24.00**	5.64	4.70**	30.17**	17.3**	35.53**	4.9**	6.45	30.00	8.31	5.23	2.39	81.33**
158	77	107	23.05**	8.08**	4.50**	30.09**	18.6**	46.75**	5.2	8.11*	29.80	7.88	4.25	3.00**	43.42**
159	77	109	29.70**	10.17**	7.60**	32.35**	28.9**	38.48**	5**	9.43**	30.50	8.64*	3.54	4.67**	42.10**
160	76	112	32.40**	6.03**	7.20**	22.49**	31.4**	15.54**	5.3	17.90**	32.50**	6.99	4.14	3.62**	36.28**
161	75	110	26.60**	7.56**	8.20**	14.99**	27.5**	3.93	6.4**	19.76**	28.60**	5.00	5.28	4.06**	40.69**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
162	76	109	28.90	7.55**	5.80	24.11**	30.9**	26.49**	5.1	6.20	31.80**	8.23*	5.11	3.28**	23.83**
163	76	110	28.50	8.31**	5.70	20.34**	26.9*	16.39**	5.1	6.20	29.40	15.56**	4.85	3.04**	41.87**
164	76	112	28.40	13.91**	5.10**	14.47	24.8	21.74**	5.3	19.99**	30.10	16.53**	3.96	3.26**	62.19**
50 kR Gamma rays + 0.2% EMS															
165	79	108	25.60**	10.93**	6.00	22.22**	22.7**	49.67**	5.5**	15.45**	25.00**	24.59**	3.99	3.01**	56.75**
166	75	108	24.20**	5.44	4.40**	11.74	13.5**	22.15*	4.9**	6.45	31.80**	9.58*	4.98	2.82**	29.29**
167	78	110	29.50**	5.36*	5.60*	24.11**	26.6	26.06**	5.1	11.13**	31.30*	7.98	5.12	4.77**	34.36**
168	76	108	26.31**	7.08**	7.80**	22.45**	29.4**	17.06**	5.1	6.20	32.90**	16.11**	4.88	4.38**	47.16**
169	75	106	29.80**	7.21**	4.90**	20.29*	31.9**	26.74**	5.1	11.13**	30.90	21.16**	4.27	3.74**	72.82**
50 kR Gamma rays + 0.02% MMS															
170	76	109	26.00**	5.73*	5.40**	9.56	22.9**	14.03**	5.2	8.11*	30.10	5.95	4.26	4.05**	15.32**
171	76	108	31.10**	9.40**	6.50*	20.83**	29.7**	18.31**	5.1	11.13**	30.20	9.85*	4.48	2.57*	52.16**
172	77	110	32.10**	5.18*	8.00**	14.43**	28.5**	5.55	6.4**	10.93**	29.40	5.12	5.05	3.56**	57.82**
173	76	110	27.80	7.92**	8.20**	20.57**	27.7**	11.67**	5.9**	14.84**	28.10**	13.98**	5.45	2.51	43.08**
174	76	107	28.70	14.04**	6.20	27.20**	30.2**	32.92**	5.2	17.67**	28.30**	12.13**	5.13	2.62**	37.15**
175	75	107	26.60**	11.65**	7.50**	21.08**	27.6**	14.81**	5.5**	15.45**	30.90	9.58*	5.22	2.49	106.49**
176	76	110	30.00**	4.97*	5.30**	25.24**	25.6	36.00**	5.1	11.13**	23.70**	23.54**	4.92	2.55*	47.21**
177	75	109	27.50*	8.95**	5.40**	15.62	26.7	12.49**	5.1	11.13**	30.90	8.69*	5.28	2.04*	73.48**
178	75	107	24.30**	10.63**	4.20**	29.27**	14.5**	42.17**	5.1	6.20	28.70*	16.43**	4.23	2.73*	77.32**
179	76	112	27.00**	11.04**	5.30**	28.20**	21.2**	36.32**	4.9**	11.58**	28.60**	5.76	5.30	1.41**	43.53**
50 kR Gamma rays + 0.2 mM SA															
180	76	110	27.90	11.14**	4.70**	24.67**	24.6	15.83**	5.3	15.53**	29.50	11.33**	5.14	3.57**	41.05**
181	76	110	22.90**	12.08**	6.70**	25.42**	29.4**	27.03**	5.6**	15.06**	27.70**	13.51**	4.9	3.53**	31.52**
182	75	107	27.10**	8.06**	8.80**	8.96	28**	13.15**	6**	11.11**	34.60**	6.70	4.72	5.02**	19.42**
183	76	107	24.30**	7.27*	5.20**	15.17	22.5**	25.34**	5.2	8.11*	33.60**	12.00**	5.10	3.66**	40.01**
184	77	107	21.10**	17.08**	5.10**	21.58*	19.8**	34.07**	5.5**	9.58**	25.90**	12.54**	5.26	1.96**	69.91**
185	76	108	25.45**	9.64**	5.40**	17.89*	24.5	24.73**	5.4*	9.56**	26.90**	7.92	4.92	3.31**	24.51**
186	76	108	25.30**	8.19**	5.00**	13.33	19.7**	34.10**	5.4*	9.56**	25.40**	18.94**	5.01	3.43**	42.76**
187	77	107	29.70**	6.36**	6.60**	17.78**	25.3	23.05**	5.4*	9.56**	24.10**	16.88**	5.11	2.15	35.99**
188	80	112	29.00*	8.75**	7.20**	18.29**	27.3**	9.47*	5.1	11.13**	29.70	11.56**	4.81	5.07**	34.50**
189	76	110	30.30**	6.79**	6.80**	27.56**	32.4**	21.04**	5.2	8.11*	31.30*	9.17*	5.27	4.89**	52.33**
190	76	110	29.60**	5.09*	8.80**	19.17**	29.5**	6.03	6.3**	10.71**	30.80	3.35	4.61	4.18**	68.00**
191	79	111	23.20**	8.81**	4.90**	24.43**	16.4**	31.64**	5.1	11.13**	28.40**	8.66	4.78	2.34	92.60**
192	76	109	30.60**	7.09**	6.50	30.12**	27.1	31.24**	5.1	11.13**	29.70	18.03**	4.32	3.33**	59.79**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
193	77	108	26.80**	6.77**	5.50**	15.45	24.8	13.81**	4.8**	16.43**	27.10**	20.69**	4.15	2.59*	58.65**
194	77	111	26.00**	7.69**	7.60**	23.37**	30**	24.39**	4.8**	16.43**	29.90	13.04**	4.29	3.29**	51.91**
195	77	106	28.50	8.47**	6.90**	17.35**	34.7**	16.70**	5.3	9.11**	29.90	9.39*	3.99	4.37**	29.14**
0.2% EMS + 0.02% MMS															
196	76	108	29.90**	7.80**	6.00	15.71*	22.9**	29.72**	5.2	12.16**	24.80**	21.74**	4.44	2.32	23.92**
197	76	108	32.90**	4.85*	5.80	22.70**	21.5**	19.88**	5.4*	15.62**	30.60	19.56**	5.04	2.68**	43.23**
198	76	107	25.80**	6.00*	7.20**	21.52**	23.6**	18.65**	5.9**	14.84**	32.30**	14.00**	5.12	3.08**	62.21**
199	75	108	26.10**	11.77**	5.00**	29.81**	22.8**	22.34**	4.9**	6.45	22.70**	13.78*	3.83	4.75**	29.72**
200	77	110	27.60*	8.23**	5.80	33.31**	20.1**	23.39**	5.3	9.11**	31.60**	6.00	5.19	2.70**	35.31**
201	76	107	23.60**	8.75**	4.60**	21.00*	17.2**	18.55**	4.4**	21.96**	20.70**	26.07**	5.32	1.76**	50.95**
202	76	108	24.30**	9.71**	5.40**	15.62	19.2**	26.19**	5.1	11.13**	28.80**	8.15	4.93	4.08**	68.84**
203	75	108	24.00**	7.61**	4.65**	30.43**	13.7**	26.66**	5**	9.43**	27.90**	16.33**	5.25	3.38**	60.81**
204	76	110	30.15**	9.83**	7.50**	21.08**	33.8**	28.81**	5.3	12.73**	30.00	14.74**	5.12	2.98**	27.93**
205	79	109	31.21**	6.14**	8.10**	24.31**	33.8**	26.34**	5.1	11.13**	30.60	11.85**	5.13	1.95**	37.31**
206	81	114	28.75	9.18**	8.50**	23.03**	33.5**	21.21**	5.1	11.13**	27.70**	8.85	4.62	4.40**	45.18**
207	77	110	32.00**	6.25**	8.50**	15.93**	27.4**	11.04*	6.1**	12.10**	30.40	6.62	4.5	3.78**	56.02**
208	75	108	26.30**	9.99**	5.50**	15.45	24.3*	24.00**	5**	9.43**	30.60	6.57	4.62	3.15**	42.93**
209	76	109	32.30**	10.53**	5.70	21.96**	28.9**	16.99**	5.1	11.13**	31.00	6.80	5.01	3.06**	19.62**
210	76	108	23.40**	8.11**	6.10	14.35	29.7**	12.60**	5.8**	15.84**	27.80**	12.67**	5.15	3.46**	34.94**
211	75	108	28.40	8.81**	5.20**	25.32**	20.9**	22.94**	4.8**	8.78*	23.50**	18.19**	4.98	2.01**	24.74**
212	75	108	29.60**	5.33*	6.00	22.22**	25.9	26.15**	5.2	15.17**	26.00**	18.67**	5.28	2.75**	37.15**
213	75	109	28.60	10.58**	7.40**	43.77**	28.3**	21.01**	5.1	6.20	31.30*	9.17*	3.74	3.05**	68.55**
214	75	109	30.50**	5.18*	4.80**	25.61**	21.5**	41.21**	5.9**	12.51**	35.00**	12.27**	5.00	3.14**	62.31**
215	79	116	28.50	7.98**	6.90**	14.41*	37.1**	13.11**	5*	16.33**	33.20**	8.96*	5.08	1.81**	63.38**
216	78	120	25.60**	11.38**	5.60*	25.53**	23.5**	18.08**	5.3	9.11**	27.70**	11.04*	4.59	2.75**	60.53**
0.2% EMS + 0.2 mM SA															
217	77	108	25.60**	13.05**	4.90**	15.06	17.3**	22.81**	5*	13.33**	24.70**	12.81*	5.22	2.04**	50.18**
218	75	109	24.80**	16.22**	7.20**	18.29**	28.6**	18.07**	5.6**	12.49**	29.80	15.96**	5.02	2.64**	41.73**
219	76	108	24.30**	5.50	5.30**	28.20**	16.5**	30.00**	5.1	6.20	29.00*	9.05*	4.89	3.40**	53.57**
220	77	108	29.00*	10.66**	7.10**	14.01*	27.1**	12.84**	6.2**	12.72**	34.30**	14.02**	4.76	3.23**	44.08**
221	77	108	27.80	8.10**	4.70**	22.54*	14.3**	40.52**	5**	9.43**	29.90	10.27*	5.23	3.18**	49.36**
222	77	109	27.30**	9.15**	4.40**	21.96*	14.6**	25.67**	5.2	8.11*	27.80**	12.67**	5.08	2.82**	33.01**
223	76	108	29.60**	5.79*	6.30	18.40**	18.9**	23.59**	5.2	12.16**	22.80**	11.29*	5.18	2.66**	28.47**
224	76	109	32.60**	6.50**	5.90	16.85*	27.5*	29.75**	5.1	6.20	28.10**	26.55**	4.58	3.68**	53.59**
225	76	110	31.60**	9.34**	6.00	26.06**	28.6**	33.91**	5.1	11.13**	28.90*	9.85*	4.70	4.29**	49.31**

Entries	Days to 50% flowering	Days to Maturity	Plant height		Branches per plant		Umbels per plant		Umbellets per umbel		Grains per umbel		Test weight	Yield per plant	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		Mean	CV
226	76	109	28.40	9.85**	5.30**	23.62**	17.8**	27.62**	4.9**	6.45	29.90	10.75**	4.90	3.27**	35.34**
227	76	110	30.20**	4.36	7.00**	15.06*	26.4	12.14**	6**	13.61**	27.30**	6.24	3.98	2.70**	32.50**
228	76	108	18.70**	9.78**	6.00	19.25**	22**	15.00**	5.7**	20.34**	26.40**	11.04*	5.32	2.09*	55.89**
229	75	107	29.30**	6.84**	5.50**	21.43**	19.4**	36.46**	4.8**	8.78*	24.90**	12.33*	5.16	2.70**	33.29**
230	76	109	27.70	7.43**	5.90	18.65*	23.7**	25.94**	5.1	11.13**	26.30**	28.74**	5.05	2.27	57.32**
231	76	109	28.10	8.46**	8.00**	13.18*	30.7**	8.42*	5.9**	16.85**	29.20	7.18	5.06	3.07**	55.43**
232	76	109	30.90**	5.38*	5.60**	15.06	27	27.10**	5.3	9.11**	28.20**	19.48**	5.64	3.97**	64.68**
233	75	108	30.10**	11.12**	4.90**	17.87	18.9**	22.09**	5.1	11.13**	30.30	13.74**	5.16	2.36	28.39**
234	75	108	22.80**	8.96**	6.20	16.66*	31**	13.26**	5.2	8.11*	27.60**	8.23	4.8	3.79**	43.48**
235	75	111	32.30**	5.85**	4.50**	21.60*	17.1**	36.10**	5.3	9.11**	28.50**	13.96**	4.62	3.43**	53.37**
236	75	112	24.30**	9.11**	4.30**	31.10**	15.4**	51.42**	5*	13.33**	25.30**	23.13**	4.61	1.86**	82.07**
0.02% MMS + 0.2 mM SA															
237	77	108	19.65**	9.67**	3.70**	22.25	13.3**	36.84**	5**	9.43**	29.60	7.99	5.07	2.01*	90.50**
238	76	109	32.27**	6.99**	7.00**	21.30**	36.9**	18.09**	5.4*	9.56**	32.30**	18.23**	5.21	3.82**	31.49**
239	76	110	27.85	10.57**	6.60**	19.17**	29**	7.45	5.8**	13.60**	28.70**	7.35	4.98	3.20**	49.25**
240	77	111	26.80**	9.92**	5.60*	29.40**	16.6**	50.74**	5.1	6.20	31.50*	10.61**	4.93	3.73**	26.29**
241	75	109	30.00**	4.97*	4.50**	21.60*	17.9**	31.54**	5.2	8.11*	30.20	20.99**	5.13	3.73**	31.71**
242	76	109	23.05**	13.03**	4.60**	21.00*	18.5**	38.58**	4.7**	14.36**	23.00**	17.15**	5.13	2.27	52.61**
243	78	111	28.90	9.57**	5.80	22.70**	27.5*	27.01**	5.1	6.20	29.50	16.16**	4.16	1.98**	56.92**
244	76	110	26.20**	11.77**	5.60*	22.59**	21.1**	27.13**	5.3	9.11**	28.50**	15.89**	4.26	2.77**	42.46**
245	75	108	25.20**	8.93**	6.30	15.06*	28.6**	14.85**	5.4*	9.56**	27.80**	10.96*	5.26	3.02**	62.69**
246	76	108	30.60**	7.58**	7.70**	12.32*	26	10.09*	6.5**	16.62**	37.00**	7.54*	5.5	3.54**	35.91**
247	75	107	28.30	6.67**	5.50**	17.67*	32.2**	16.49**	5**	9.43**	30.20	13.32**	5.22	4.12**	30.32**
248	75	105	28.50	6.24*	6.50*	16.62*	35.4**	10.83**	4.9**	6.45	37.10**	9.11**	4.81	4.79**	27.26**
249	76	108	29.20**	6.21**	5.50**	19.64*	26.7*	11.03*	5.3	9.11**	29.50	13.95**	5.11	2.50	60.96**
250	76	112	28.20	4.67	6.40	21.09**	36.3**	26.36**	5.5**	9.58**	40.50**	11.60**	4.65	3.57**	52.97**
251	75	113	24.50**	12.36**	3.70**	31.34**	13.2**	38.26**	4.9**	11.58**	30.80	5.03	5.21	2.79**	43.39**
Control	76.00	109	28.30	3.01	6.06	8.73	25.67	5.72	5.21	3.99	30.15	5.02	4.36	2.32	8.78

Appendix-III

Adjusted mean values for different characters of M₃ mutant lines (cumin variety RZ 19), check varieties along with CD values

M ₃ Pedigree	M ₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
1	107-9	94	111	14.8	4.1	15.7	3.3	14.3	4.12	0.41
2	182-4	93	114	21.5	4.8	12.2	4.3	20.5	3.69	0.68
3	78-6	93	115	20.2	3.5	9.7	3.7	20.5	3.53	0.56
4	97-2	92	116	24.1	4.7	11.9	3.4	19.3	3.27	0.64
5	67-1	92	112	23.8	4.7	12.4	3.6	19.9	3.28	0.75
6	185-7	94	115	26.0	4.5	12.5	3.6	21.6	3.57	0.88
7	146-9	93	114	29.3	4.9	14.5	3.7	20.9	4.18	1.08
8	94-3	92	113	30.4	4.8	17.1	4.2	25.8	4.40	1.18
9	93-1	94	113	29.5	4.9	15.8	3.8	23.8	4.02	1.20
10	13-8	94	116	32.2	4.7	20.4	3.8	22.9	4.01	1.35
11	116-6	94	115	30.5	4.4	16.9	3.7	23.3	3.86	1.40
12	140-10	92	115	30.5	3.7	16.2	3.9	25.2	4.23	1.34
13	59-3	91	112	28.6	4.6	17.2	4.2	27.2	4.05	1.49
14	78-7	93	115	30.6	5.9	18.8	4.5	29.3	3.85	1.37
15	116-1	93	116	31.2	7.2	19.1	4.0	26.9	4.01	1.54
16	48-4	96	114	26.1	3.7	10.9	4.0	26.7	3.31	0.60
17	92-1	93	117	31.8	4.9	23.7	3.7	25.0	3.86	2.11
18	129-3	92	115	30.5	7.4	15.7	4.2	27.9	3.83	0.95
19	188-8	95	115	32.1	7.0	13.5	4.5	30.3	4.21	1.41
20	7-9	93	119	32.1	4.8	17.4	3.9	26.8	4.24	1.81
21	68-3	89	115	32.2	4.8	22.3	3.7	24.6	3.98	2.00
22	34-2	90	114	35.1	5.8	22.7	4.3	20.9	3.38	0.76
23	79-7	94	113	32.1	5.8	21.7	4.0	26.7	3.37	1.64
24	164-6	92	114	34.6	4.6	18.6	4.4	28.2	4.32	1.43
25	28-9	93	115	32.4	5.2	22.6	4.3	28.3	4.15	1.71
26	45-1	88	116	37.3	5.7	20.0	5.0	33.2	3.22	1.63
27	16-3	87	115	35.6	6.8	25.5	4.7	30.2	3.33	1.67
28	199-2	93	115	32.0	5.7	15.1	4.9	32.8	4.20	1.16
29	87-6	91	114	32.8	7.8	37.6	4.5	31.5	4.42	3.07
30	133-6	86	113	34.3	6.5	29.3	4.7	32.2	3.54	2.39
31	2-6	93	114	34.9	7.6	18.2	4.6	28.3	4.12	1.08

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
32	113-7	93	115	31.3	5.0	18.6	4.3	27.6	4.01	1.05
33	55-7	93	115	34.9	6.0	29.3	4.4	27.3	4.22	1.77
34	150-2	95	115	28.0	4.6	16.1	4.6	27.6	3.95	1.26
35	100-3	96	113	31.1	5.1	19.9	4.8	24.9	3.66	1.20
36	16-1	94	113	35.4	7.4	34.2	5.2	32.2	2.87	2.35
37	26-2	95	115	31.8	5.2	19.2	4.5	27.1	3.99	1.36
38	51-9	94	113	27.8	5.2	19.6	4.8	23.1	3.49	1.40
39	207-5	93	115	31.9	8.4	19.2	5.2	30.9	3.32	1.01
40	89-1	91	113	35.1	5.6	22.1	4.7	28.5	3.71	1.59
41	65-7	92	113	34.5	6.6	27.2	4.7	28.5	4.17	2.20
42	51-7	90	112	37.4	7.5	24.3	4.7	28.2	3.42	1.93
43	108-3	93	115	27.4	4.1	8.8	4.4	28.5	3.95	0.44
44	8-3	89	114	20.1	7.2	9.6	3.4	17.5	3.57	0.50
45	177-6	91	113	29.1	4.6	16.3	4.2	27.8	4.35	1.12
46	102-2	90	114	29.8	4.7	18.3	4.2	28.1	4.84	1.12
47	3-5	93	113	29.4	4.5	17.0	4.4	28.8	3.58	0.98
48	37-8	91	115	32.1	5.5	20.5	4.2	27.7	3.83	1.60
49	124-1	93	116	22.8	4.8	20.0	4.2	29.2	3.31	0.92
50	105-9	92	114	31.4	5.4	23.1	4.2	27.9	3.60	1.69
51	14-7	93	113	31.5	4.4	16.7	4.3	28.5	3.87	0.99
52	143-5	89	114	31.9	4.9	20.6	4.4	29.3	3.57	1.25
53	120-8	95	117	23.8	3.5	13.1	3.7	21.4	3.36	0.75
54	87-10	96	117	25.8	3.0	12.9	3.8	20.4	3.56	0.61
55	88-8	91	113	34.1	5.6	25.2	4.2	27.2	3.96	2.06
56	47-1	94	115	26.3	4.2	13.2	3.9	24.6	3.28	0.49
57	115-4	93	114	20.6	2.3	17.1	4.2	24.6	3.76	1.02
58	28-2	92	114	38.5	6.4	21.3	4.5	28.5	4.08	1.51
59	102-4	95	115	33.2	3.2	21.8	3.9	24.9	3.37	0.86
60	37-1	90	112	31.9	5.9	21.7	4.4	28.0	3.31	1.54
61	119-10	95	116	31.2	2.7	21.2	4.4	29.2	3.30	1.72
62	118-7	95	116	30.5	5.6	24.1	4.2	24.4	2.57	1.19
63	117-9	94	115	35.6	1.8	23.0	4.6	28.4	4.07	1.21
64	23-2	93	114	31.7	6.6	21.5	4.2	24.5	3.26	1.15
65	118-2	93	114	29.6	5.5	16.9	3.8	21.4	4.06	1.23

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
66	72-1	90	113	34.7	7.4	15.4	4.4	21.5	3.82	0.67
67	81-7	89	113	35.8	5.7	23.7	4.0	25.5	3.69	1.78
68	84-1	89	114	35.8	7.4	21.8	4.6	28.8	4.24	1.67
69	77-9	94	115	29.7	4.6	14.0	4.3	24.2	3.94	0.66
70	25-8	90	113	19.8	4.1	12.5	3.9	23.2	4.32	1.02
71	54-6	93	114	33.6	7.0	22.6	3.9	26.5	4.05	1.50
72	41-1	94	115	20.2	6.1	17.5	4.1	22.1	3.99	0.53
73	157-4	94	115	30.4	3.6	14.7	4.5	24.4	3.49	0.97
74	164-8	93	114	30.8	2.3	22.7	4.2	21.8	3.81	0.77
75	67-4	93	114	30.1	4.4	19.0	4.2	23.2	3.91	0.97
76	135-3	91	114	29.1	2.1	16.5	3.7	24.3	4.17	0.99
77	21-5	93	113	22.3	4.2	16.1	3.9	23.7	4.10	0.92
78	128-3	90	113	37.3	5.4	21.4	4.5	28.6	4.10	1.30
79	53-8	93	114	31.9	7.4	19.6	5.2	31.5	4.30	1.13
80	56-9	93	113	30.7	4.5	18.8	4.4	25.7	3.78	1.37
81	60-1	91	112	32.9	4.1	23.1	4.8	22.6	3.92	1.09
82	95-10	94	114	35.8	4.0	27.2	4.5	30.6	3.72	1.52
83	82-5	94	113	31.2	3.8	14.4	4.5	23.6	4.09	0.74
84	205-4	90	112	33.2	3.8	24.7	4.5	24.1	4.26	1.10
85	83-1	88	113	35.5	4.5	22.9	4.8	27.4	3.88	1.15
86	104-10	94	113	37.5	6.3	28.5	4.5	28.9	3.26	1.46
87	173-6	89	116	31.3	5.3	20.4	4.4	24.8	3.23	0.89
88	190-9	93	115	30.6	5.8	20.9	4.6	27.1	3.15	1.29
89	133-7	94	113	30.2	4.6	13.7	4.8	24.7	4.16	0.74
90	191-10	93	112	31.8	6.1	23.6	4.7	25.3	3.33	1.21
91	77-7	93	113	36.6	4.9	17.2	4.0	26.0	3.87	1.45
92	87-1	91	113	30.7	5.5	16.9	4.2	27.3	3.82	1.22
93	137-3	93	114	32.7	5.3	21.6	4.2	26.3	4.38	1.26
94	124-6	90	111	34.4	6.1	19.8	4.5	26.7	3.45	1.40
95	145-10	89	112	35.1	5.6	19.8	4.8	29.7	3.46	1.73
96	208-8	93	113	32.9	5.9	19.2	4.3	26.3	3.83	1.37
97	109-7	93	111	31.7	5.5	20.1	4.3	25.7	4.28	1.09
98	170-9	94	114	30.8	5.0	20.0	3.9	22.4	3.19	1.20
99	89-7	94	116	30.8	4.7	14.7	4.0	22.5	3.38	1.04

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
100	116-8	90	112	35.2	7.2	21.9	4.1	24.2	4.23	1.65
101	15-2	94	115	33.1	4.9	15.2	4.3	23.8	3.64	1.01
102	61-4	87	114	18.8	6.2	24.3	4.5	25.5	3.34	1.82
103	9-4	94	114	28.7	4.7	12.0	3.5	22.2	3.98	0.85
104	154-10	94	115	29.7	6.5	14.9	4.3	23.2	2.92	0.64
105	157-3	93	114	29.2	4.5	11.0	4.0	25.9	3.23	0.81
106	111-6	94	113	31.7	5.8	19.3	3.9	22.4	3.05	0.67
107	188-1	94	113	30.8	5.2	17.9	4.1	21.3	3.58	0.88
108	23-4	94	114	28.3	6.4	20.7	3.9	22.6	3.98	0.93
109	38-10	91	113	20.3	5.6	12.8	3.8	19.8	4.12	0.61
110	94-5	94	115	28.0	4.0	11.1	3.7	25.6	3.69	0.93
111	171-4	93	113	26.1	4.6	11.0	4.4	22.6	3.62	0.76
112	137-2	90	112	32.5	7.1	15.1	3.9	19.8	3.70	0.45
113	55-3	91	113	31.0	4.8	15.2	4.0	18.2	2.27	0.49
114	45-6	87	112	29.2	4.9	13.0	4.0	20.9	4.27	0.94
115	80-9	92	115	28.0	5.2	14.7	4.0	21.4	3.92	0.62
116	207-9	92	113	30.7	4.9	12.9	3.9	19.9	3.40	0.73
117	104-1	92	113	30.4	4.3	12.8	4.1	20.4	3.89	0.80
118	100-1	93	114	30.7	5.3	13.9	4.0	21.1	4.25	1.07
119	41-6	93	114	30.6	5.0	10.7	4.0	23.5	3.21	0.67
120	94-9	92	111	31.2	3.9	16.0	4.0	20.7	3.62	0.79
121	11-5	93	113	28.4	4.9	13.9	3.8	17.9	3.80	0.64
122	155-4	94	115	30.6	4.8	16.6	4.0	26.9	3.44	1.32
123	58-5	86	112	29.5	5.1	13.2	3.9	21.1	3.27	0.89
124	188-4	87	111	33.0	5.5	20.1	4.2	23.9	4.38	1.43
125	25-6	94	113	29.6	4.5	13.1	4.1	20.8	3.60	0.96
126	59-2	89	112	32.0	5.1	12.0	4.1	22.8	3.57	0.74
127	89-10	94	115	38.7	5.6	19.9	4.1	23.9	3.56	1.17
128	84-8	90	113	33.2	5.6	18.3	4.5	24.3	3.25	1.34
129	188-3	89	113	32.2	5.5	18.2	3.7	21.9	3.58	1.04
130	175-1	94	115	29.1	4.2	10.6	3.7	20.3	4.08	0.69
131	118-4	99	117	28.4	5.2	13.0	4.0	27.2	3.49	1.07
132	15-6	93	114	33.0	5.1	14.2	4.1	28.7	3.34	1.26
133	95-7	94	114	30.8	4.2	14.7	4.0	23.9	3.58	0.38

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
134	145-5	93	113	34.1	5.4	22.4	4.3	23.9	3.40	1.47
135	127-4	93	114	32.2	5.0	19.5	4.2	25.4	3.70	1.66
136	138-1	89	115	29.8	4.9	18.9	4.2	25.9	4.23	1.50
137	136-2	93	110	36.9	5.0	19.5	4.7	29.1	3.68	1.70
138	166-8	94	114	28.1	4.1	14.9	3.9	24.2	3.77	1.22
139	98-4	94	114	27.5	4.7	17.0	4.3	26.7	3.78	1.11
140	69-6	91	114	23.6	5.2	16.4	3.9	24.0	3.80	1.18
141	157-9	95	115	28.6	5.0	15.1	4.4	27.1	3.95	1.06
142	16-9	95	113	36.1	6.5	33.0	4.9	32.6	2.87	2.20
143	34-5	92	113	35.2	5.8	26.8	4.3	28.0	3.17	2.11
144	56-3	94	113	29.3	4.8	15.3	3.9	22.8	4.02	1.10
145	26-9	95	115	33.0	5.0	17.6	4.1	26.6	3.99	1.29
146	98-5	91	113	31.8	5.9	20.1	4.5	28.7	4.33	1.59
147	96-1	93	113	30.7	4.6	19.4	4.2	26.1	3.66	1.00
148	58-1	90	112	37.9	7.3	23.0	4.2	28.7	3.42	2.14
149	198-1	94	114	37.6	6.6	20.2	4.8	22.1	3.67	0.54
150	194-1	93	113	29.9	5.1	21.0	3.9	24.6	3.80	1.26
151	60-2	94	113	28.7	3.1	9.6	4.4	24.1	3.28	0.61
152	9-6	88	115	33.9	6.1	23.4	4.6	28.8	4.10	2.09
153	108-10	94	114	32.6	5.5	23.2	4.2	26.3	3.36	1.72
154	56-5	93	113	31.6	5.6	22.8	4.1	26.3	4.24	1.55
155	112-7	93	114	32.8	5.4	22.1	4.3	27.9	3.71	1.44
156	81-9	94	114	33.0	6.8	21.0	4.1	26.1	3.97	1.40
157	141-6	92	115	32.5	5.8	22.7	4.6	29.1	4.24	1.49
158	11-4	93	116	34.6	6.9	29.8	5.0	32.5	4.13	2.13
159	204-9	93	113	33.2	6.5	23.8	4.9	32.4	3.64	2.01
160	90-3	94	113	35.2	6.8	26.0	4.6	28.7	3.06	1.97
161	8-1	94	117	38.9	4.8	20.5	4.0	25.9	3.46	1.34
162	168-2	93	115	35.3	5.1	21.2	4.3	27.7	3.98	1.90
163	188-6	98	116	38.4	6.8	18.6	4.0	24.8	3.44	1.28
164	210-4	89	113	33.9	5.6	17.0	4.1	25.2	3.44	1.10
165	170-10	93	115	19.8	4.5	14.5	3.9	24.4	4.33	0.97
166	118-3	90	113	29.9	5.4	18.3	4.1	26.8	3.53	1.42
167	161-4	91	112	31.8	7.1	22.5	4.7	30.6	2.80	1.01

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
168	69-8	93	113	31.7	4.9	21.0	4.7	31.1	3.25	1.30
169	88-4	94	115	30.3	4.4	12.9	4.5	28.7	3.94	0.90
170	7-1	93	114	28.9	4.8	14.6	3.8	25.2	3.78	0.68
171	110-5	94	114	30.9	4.3	12.1	4.0	26.2	4.15	0.64
172	190-1	93	116	29.0	4.5	15.6	4.2	28.8	3.92	0.98
173	35-2	92	113	36.6	5.7	19.5	4.4	28.6	3.54	1.09
174	210-2	91	112	39.3	6.0	20.9	4.1	28.4	3.62	1.17
175	112-2	97	114	30.2	5.7	16.1	4.2	27.7	3.46	0.90
176	103-8	95	113	38.6	6.7	24.8	4.9	32.5	3.35	1.60
177	179-9	94	113	16.9	7.2	27.7	4.4	30.7	3.73	1.52
178	107-5	93	113	31.1	5.7	20.5	4.1	26.7	3.33	1.04
179	139-10	94	114	30.0	7.4	19.6	4.4	29.6	4.18	1.35
180	202-2	90	112	34.0	3.2	24.5	4.9	33.1	4.28	1.71
181	26-7	91	111	36.6	7.2	27.4	5.0	33.7	3.32	1.83
182	112-9	94	114	32.7	4.9	17.5	4.5	28.9	3.84	1.20
183	82-10	93	113	30.1	5.6	16.0	3.8	21.4	3.79	0.54
184	172-7	94	112	26.7	4.2	9.7	4.6	26.4	3.78	0.68
185	79-3	94	114	29.5	4.7	12.2	4.1	26.8	3.41	0.48
186	94-7	93	113	32.5	4.9	19.8	4.7	29.1	3.13	0.74
187	122-1	90	113	19.2	4.2	12.0	4.2	25.0	4.07	0.65
188	146-4	93	112	31.8	3.5	14.6	4.1	26.3	3.90	0.79
189	30-1	94	113	35.0	7.1	18.0	4.1	26.3	3.85	1.02
190	30-2	93	114	35.5	3.9	19.2	4.3	27.1	3.96	1.44
191	117-8	93	113	15.8	4.1	15.5	4.3	27.8	3.44	0.97
192	38-2	94	113	29.1	8.2	16.8	4.7	19.5	4.61	0.88
193	171-6	93	114	32.9	2.6	19.6	4.1	25.4	4.06	1.18
194	191-6	92	113	30.9	4.7	14.7	4.1	25.4	3.24	0.84
195	8-2	93	112	29.3	3.6	18.5	4.4	27.7	3.59	0.86
196	1-9	94	113	29.1	4.6	13.7	3.9	24.6	3.97	1.03
197	171-2	92	113	38.4	7.5	23.7	4.9	32.9	5.31	2.52
198	134-8	93	112	35.4	3.3	14.3	5.0	32.9	3.74	1.13
199	205-9	93	113	35.2	6.9	23.6	4.3	22.4	4.21	1.57
200	76-6	94	113	34.8	5.3	19.3	4.8	29.3	3.57	1.54
201	192-7	94	115	35.3	5.7	20.8	4.4	26.6	4.12	1.45

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
202	41-3	90	112	38.1	6.9	18.5	4.8	29.2	4.08	1.39
203	4-1	93	113	28.3	3.2	10.4	4.1	27.9	3.17	0.76
204	74-5	92	113	31.1	5.3	11.1	4.5	28.6	3.97	1.09
205	119-6	92	114	30.3	2.4	11.0	4.5	30.6	3.84	1.10
206	128-9	93	113	27.2	3.4	15.0	4.6	29.7	3.15	1.00
207	98-7	91	113	29.3	7.9	14.2	4.4	31.3	3.23	1.19
208	177-9	94	114	29.3	7.0	12.5	4.0	31.1	3.81	0.78
209	138-4	94	113	18.4	5.4	16.8	4.6	30.7	4.10	1.95
210	132-5	93	113	28.5	4.9	15.9	4.1	31.7	4.22	0.99
211	33-7	93	114	33.5	6.2	16.1	4.3	23.7	3.58	0.65
212	133-9	90	113	34.2	4.3	11.4	4.1	30.0	4.03	0.67
213	104-3	93	114	16.1	5.9	16.0	4.2	29.2	4.21	1.03
214	141-5	92	113	36.1	5.7	17.1	4.5	33.4	3.48	2.05
215	34-4	93	112	29.8	4.3	13.7	4.5	32.1	2.62	0.88
216	159-7	90	113	37.9	5.6	16.4	4.6	34.1	3.86	1.80
217	49-3	93	113	33.6	7.5	14.8	4.5	32.5	3.27	1.12
218	88-3	93	114	35.3	6.1	19.1	4.1	33.3	3.28	1.68
219	71-7	94	114	29.6	7.6	15.3	4.3	26.2	2.68	0.96
220	147-1	93	114	31.2	4.6	15.7	4.7	23.4	4.06	1.30
221	67-8	93	113	34.0	5.3	21.2	4.7	30.2	3.57	1.60
222	139-5	94	114	33.9	4.0	22.7	5.0	31.1	4.27	1.62
223	106-6	89	113	35.4	4.1	19.3	4.5	27.2	3.40	1.54
224	34-9	92	113	35.8	4.9	23.1	4.9	30.4	3.62	1.89
225	117-4	93	113	34.9	4.6	21.0	4.9	28.4	3.66	1.87
226	72-6	89	114	37.9	4.4	19.7	4.8	29.1	4.01	1.65
227	75-3	88	114	16.6	3.1	27.5	4.7	29.0	3.41	2.11
228	110-6	90	114	34.9	4.3	23.2	4.6	26.1	3.82	1.42
229	114-2	88	113	32.8	4.0	20.7	4.0	20.9	3.62	1.29
230	106-9	89	113	36.3	4.3	23.4	4.7	28.2	4.12	1.91
231	8-10	94	114	34.7	4.7	24.6	5.0	30.8	3.95	1.49
232	9-5	94	114	15.9	3.5	25.5	4.9	28.4	3.28	1.15
233	103-4	93	114	32.5	2.6	18.1	4.3	28.8	3.16	0.82
234	157-8	93	114	32.8	4.4	18.2	4.6	29.5	3.42	0.87
235	116-4	95	115	33.1	5.1	24.6	5.0	30.0	3.22	1.16

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
236	10-4	93	114	35.5	7.2	19.9	4.9	22.5	3.62	0.99
237	1-6	94	114	35.1	3.2	18.5	4.9	29.4	3.34	0.89
238	108-9	96	115	33.6	4.1	17.4	4.8	30.9	3.14	0.86
239	183-2	94	116	33.3	3.9	17.8	4.6	21.7	3.66	0.79
240	68-6	93	114	32.6	5.0	19.0	4.7	23.6	3.86	0.82
241	29-3	92	114	35.4	5.1	20.5	4.5	21.3	4.24	1.23
242	208-9	93	113	31.4	5.4	19.2	5.1	24.2	3.57	0.93
243	21-1	94	113	32.1	5.2	21.3	5.0	32.9	4.40	1.21
244	24-5	94	115	24.2	5.3	16.6	4.9	30.2	3.44	0.97
245	138-9	90	116	19.6	3.2	15.2	5.0	23.9	3.87	0.56
246	182-6	93	113	31.9	5.2	22.9	5.2	29.5	3.58	1.17
247	144-7	94	113	29.3	4.6	19.3	5.3	27.6	3.51	0.75
248	75-7	94	113	31.8	4.7	18.9	5.0	30.6	3.70	0.89
249	120-7	93	112	27.6	6.0	17.7	4.8	30.6	3.19	0.85
250	49-5	93	112	32.7	5.2	25.8	4.8	29.6	4.13	2.15
251	198-9	93	112	32.7	5.8	18.6	5.0	29.6	3.55	1.13
252	171-7	88	114	30.7	5.5	17.5	4.9	29.6	3.90	1.09
253	208-3	94	115	33.4	5.6	21.6	4.8	29.6	3.84	1.36
254	81-6	93	114	30.9	4.3	22.2	4.9	23.1	3.72	1.10
255	42-1	86	112	37.5	6.1	23.3	5.6	35.7	3.24	1.86
256	174-2	92	112	32.3	5.7	20.8	5.0	32.4	3.95	1.14
257	67-5	93	112	34.2	5.0	20.3	5.1	30.4	4.06	1.14
258	133-4	93	113	34.5	4.9	21.7	4.8	30.2	3.72	1.31
259	176-8	95	113	29.6	5.0	20.5	4.9	29.6	3.55	0.94
260	142-3	93	115	32.9	4.8	20.6	5.1	24.9	4.27	1.01
261	100-2	90	113	34.2	6.2	21.5	4.8	27.1	4.15	1.46
262	23-6	92	113	33.1	4.7	18.5	4.3	24.9	4.21	0.98
263	26-1	92	112	17.4	5.4	22.2	4.9	28.9	3.55	1.17
264	2-9	93	114	33.7	5.2	18.7	4.7	27.2	3.94	1.46
265	168-7	93	112	31.9	4.1	20.5	4.7	26.8	3.27	0.81
266	152-2	92	112	35.9	5.2	20.0	4.7	26.8	4.24	1.27
267	25-5	92	116	30.0	4.9	19.3	4.3	23.0	3.52	0.74
268	209-6	94	115	31.3	4.9	19.0	4.1	21.3	3.61	1.11
269	87-8	94	115	32.2	4.9	17.2	5.2	24.5	3.81	0.70

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
270	81-4	94	115	36.3	4.9	15.2	4.8	24.6	3.45	0.79
271	190-5	94	116	35.5	3.6	11.9	4.9	28.0	3.77	0.65
272	67-9	93	113	19.1	7.4	23.0	4.7	27.4	3.54	1.19
273	7-2	92	114	33.4	3.1	14.0	4.6	31.3	2.99	1.14
274	115-8	90	113	36.8	5.4	19.2	4.7	27.3	3.15	0.92
275	199-4	94	115	36.0	3.8	15.6	5.7	34.0	3.40	0.97
276	41-4	90	116	34.2	7.5	12.3	4.5	27.1	3.82	0.78
277	64-3	91	111	30.4	5.0	17.5	4.7	29.1	3.59	1.48
278	116-3	91	112	33.2	4.0	10.8	4.5	26.9	3.72	0.72
279	126-1	92	112	16.8	4.0	11.2	4.6	26.8	3.99	0.85
280	22-2	91	112	34.6	4.2	10.9	4.8	28.7	3.97	0.99
281	162-3	93	116	29.6	2.8	7.0	4.7	28.1	3.66	0.65
282	134-5	92	113	33.9	4.9	13.2	4.8	30.3	3.20	0.88
283	18-7	90	112	21.6	3.8	9.1	4.5	27.6	3.36	0.77
284	135-7	90	113	27.9	3.9	11.1	4.8	28.3	3.24	0.67
285	12-1	91	112	30.0	2.7	8.3	4.9	30.2	3.37	0.57
286	94-1	92	112	31.9	2.6	9.5	5.0	29.9	3.20	0.81
287	166-1	93	111	31.7	5.5	11.9	4.6	27.2	3.54	0.79
288	11-8	93	113	27.9	3.7	10.1	4.5	25.2	3.87	0.56
289	10-3	91	115	29.5	4.4	10.8	4.9	29.3	3.22	0.80
290	182-10	91	112	30.2	5.1	14.1	4.5	26.6	3.67	0.77
291	19-1	91	112	30.4	4.2	11.6	4.3	25.4	4.00	0.78
292	136-4	91	113	31.1	4.9	12.5	4.7	26.9	3.62	0.74
293	24-4	92	112	30.9	3.4	8.1	4.9	29.9	3.35	0.81
294	194-6	92	112	27.1	2.7	6.6	3.9	19.8	3.77	0.38
295	109-3	91	113	29.5	2.9	19.5	4.6	25.9	4.09	0.84
296	144-6	91	114	30.5	7.8	11.1	4.4	26.2	3.59	0.77
297	154-6	91	115	31.6	4.8	9.7	4.4	25.8	3.90	0.70
298	181-3	92	112	26.3	3.3	11.9	4.4	25.4	3.68	0.89
299	110-4	93	116	29.9	5.5	14.5	4.4	25.9	3.97	1.12
300	25-1	91	110	33.3	4.8	12.3	4.5	22.0	4.10	0.50
301	11-2	91	112	32.6	3.8	10.1	4.6	26.1	3.57	0.47
302	180-8	90	111	30.7	4.4	10.4	4.5	26.7	3.88	0.65
303	7-4	93	111	31.4	3.3	8.3	4.4	25.0	3.48	0.33

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
304	105-6	92	112	31.7	3.4	10.5	4.7	28.2	3.64	0.76
305	199-8	91	115	31.1	4.0	10.6	4.8	28.1	3.43	0.52
306	94-10	91	113	33.9	3.7	11.3	4.7	27.4	3.27	0.72
307	73-4	92	112	33.4	5.5	14.8	4.7	28.3	4.40	1.41
308	77-10	90	112	32.2	4.5	10.5	4.7	28.0	4.24	0.67
309	7-10	91	111	33.9	7.2	10.3	4.7	28.0	3.80	0.72
310	146-5	90	111	34.8	4.8	13.3	5.0	28.7	4.03	1.06
311	155-1	90	114	30.5	3.8	9.4	4.8	29.9	3.65	0.68
312	146-6	91	112	34.7	4.2	11.6	4.9	30.0	3.50	1.01
313	192-4	92	112	15.9	7.1	18.5	4.7	26.7	3.17	1.10
314	139-4	92	115	30.3	3.1	8.3	4.2	24.9	3.59	0.53
315	81-10	90	118	30.2	2.5	5.5	4.3	26.5	3.72	0.57
316	114-7	91	117	31.6	3.9	9.1	4.5	27.4	3.39	0.59
317	135-6	90	111	27.0	3.3	8.1	4.7	29.7	3.68	0.74
318	103-3	91	112	27.7	3.4	9.1	4.5	29.1	3.58	0.68
319	114-1	91	113	27.6	3.3	7.9	4.5	30.1	3.66	0.75
320	143-2	90	115	33.4	4.6	11.4	4.8	29.8	3.42	1.10
Check varieties										
RZ 19		87.8	112.6	28.3	4.5	17.3	4.3	23.3	3.48	1.16
RZ 209		88.1	112.1	27.3	5.3	19.3	4.6	25.4	3.41	1.13
RZ 223		88.4	111.3	30.3	5.7	16.9	4.1	22.7	3.49	1.15
UC 198		86.8	111.6	27.1	4.8	15.7	4.3	23.3	3.32	0.96
JC 2000-72		86.8	111.4	27.4	5.0	17.4	4.1	22.9	3.68	1.24
C.D.										
Between check varieties		1.97	1.29	2.89	1.09	2.26	0.38	2.03	0.40	0.14
Between accessions within a block		4.41	2.88	6.46	2.43	5.06	0.84	4.54	0.88	0.32
Between accessions between blocks		4.83	3.15	7.08	2.66	5.55	0.92	4.97	0.97	0.35
Between check varieties and accessions		3.62	2.36	5.31	2.00	4.16	0.69	3.73	0.73	0.26

Appendix-IV

Adjusted mean values for different characters of M₃ mutant lines (cumin variety RZ 209), check varieties along with CD values

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
1	1-1	92	114	28.4	4.9	16.6	4.3	17.6	3.18	0.81
2	129-2	91	113	31.4	5.4	19.2	4.4	18.4	3.90	1.27
3	213-1	92	114	30.1	5.6	16.3	4.2	22.8	3.20	1.06
4	39-1	91	113	29.1	5.4	23.9	4.0	18.1	3.52	1.28
5	129-1	91	114	27.2	4.3	15.4	4.2	19.2	4.12	0.82
6	70-6	92	114	27.3	5.0	13.9	4.5	20.8	3.35	0.82
7	40-1	91	113	37.9	6.0	18.4	4.8	29.0	3.80	1.38
8	40-4	92	112	32.2	4.7	17.3	4.9	29.1	3.51	1.17
9	166-4	94	111	29.5	3.9	15.1	5.4	30.1	3.94	0.88
10	209-2	91	112	30.4	4.7	17.6	4.7	27.4	3.38	1.12
11	102-6	93	113	39.7	4.9	22.6	5.2	28.9	3.93	1.47
12	66-3	92	113	27.8	4.6	19.5	4.8	28.5	3.24	0.97
13	190-10	92	114	28.9	5.0	20.7	5.0	29.6	3.58	1.28
14	166-6	93	114	28.9	4.5	24.4	4.8	28.4	3.46	1.99
15	137-6	92	113	29.5	4.8	17.0	5.0	29.3	3.20	0.91
16	133-9	91	112	27.8	7.2	18.3	4.7	27.8	3.52	1.13
17	54-6	93	113	39.2	7.3	17.8	4.7	26.9	3.72	1.23
18	128-2	92	113	37.1	4.0	16.5	4.5	26.8	3.25	0.92
19	9-7	91	111	36.7	6.0	17.6	4.9	22.7	3.59	0.94
20	19-2	91	115	30.7	5.9	17.9	5.6	24.9	3.98	1.19
21	139-1	93	114	33.5	4.5	17.8	4.8	29.1	3.26	0.83
22	168-5	92	113	32.7	3.2	19.0	4.8	29.3	3.85	1.47
23	128-9	92	113	42.1	6.1	21.8	5.1	30.4	3.76	1.17
24	137-4	91	112	32.8	4.3	19.3	4.8	28.8	3.77	1.45
25	159-1	93	114	33.4	5.0	19.9	5.2	30.4	3.48	1.02
26	112-7	92	112	33.6	4.8	18.9	4.5	28.7	3.36	0.49
27	81-1	91	111	29.9	4.8	20.1	3.4	28.1	3.58	1.13
28	30-4	91	112	28.5	4.3	17.5	4.8	28.8	3.18	1.13
29	203-6	93	114	21.1	4.2	17.7	5.2	31.8	3.21	0.86
30	197-8	93	114	29.5	3.3	14.7	4.8	29.2	3.85	0.85
31	166-9	93	114	36.6	3.1	14.8	4.8	22.6	4.11	0.88

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
32	116-6	92	112	23.1	4.4	12.8	2.8	23.0	3.59	0.72
33	99-10	93	111	34.0	5.7	20.1	6.8	22.0	3.70	1.31
34	52-3	91	113	29.9	5.8	16.9	4.9	25.6	3.48	1.33
35	34-2	92	112	41.9	6.8	19.8	5.1	24.3	3.79	1.02
36	81-9	94	112	37.6	5.4	16.6	6.2	27.2	3.49	1.28
37	162-9	91	111	34.4	7.1	22.5	5.1	24.9	3.65	1.44
38	146-7	90	114	41.1	6.6	19.8	5.0	24.6	3.32	0.79
39	51-6	91	113	33.7	4.6	15.1	4.9	24.3	3.80	0.76
40	204-3	93	113	34.9	6.6	19.8	5.4	20.6	4.08	0.92
41	116-2	93	113	36.7	7.6	22.7	5.2	29.0	3.76	1.65
42	32-1	92	112	34.4	6.2	18.9	5.3	28.7	3.12	1.18
43	116-7	91	113	42.3	7.0	21.0	5.0	26.2	3.22	1.24
44	207-1	91	111	16.8	4.1	14.8	4.7	23.5	3.37	0.91
45	101-10	92	112	36.2	7.2	18.7	5.0	27.1	3.21	1.12
46	2-2	92	111	33.6	5.8	17.5	5.5	30.5	3.16	1.15
47	37-10	93	111	38.1	5.2	15.3	5.5	28.5	3.45	0.54
48	141-7	93	110	30.2	5.9	16.8	5.2	26.2	3.56	1.11
49	2-7	91	110	15.5	7.0	19.2	5.3	27.4	3.26	0.93
50	65-10	91	111	31.7	6.1	17.7	4.5	24.8	3.92	0.60
51	143-1	92	112	31.9	5.4	15.3	4.8	27.9	3.46	0.78
52	154-1	91	111	33.5	6.8	19.4	4.8	26.7	3.59	1.26
53	232-9	93	112	43.2	6.1	19.0	4.8	28.4	4.04	1.18
54	71-6	92	112	17.3	3.1	12.3	4.7	27.8	3.85	0.82
55	138-10	91	111	37.6	2.9	12.8	5.2	30.7	3.26	1.12
56	112-9	93	112	40.2	3.3	14.2	5.0	29.5	3.44	1.13
57	194-2	93	112	35.1	5.9	19.1	5.1	29.7	3.70	1.40
58	2-3	92	113	41.9	3.7	13.0	4.4	24.9	3.83	1.11
59	2-1	91	112	20.6	4.1	13.6	5.2	30.1	3.80	1.16
60	99-1	92	113	36.7	4.2	24.5	4.7	22.8	3.06	1.51
61	143-2	93	112	32.6	4.7	14.3	5.9	32.0	4.21	1.17
62	122-7	91	114	31.6	3.4	26.6	5.2	19.3	3.34	1.36
63	238-6	92	114	32.0	4.6	15.0	4.6	26.8	3.77	1.23
64	77-4	93	112	33.2	3.9	15.3	5.8	24.7	3.21	2.21
65	65-1	91	112	35.9	4.6	26.8	4.7	27.3	3.24	1.43

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
66	118-3	91	112	34.8	5.6	18.5	4.9	29.1	3.11	1.07
67	169-3	91	112	42.3	3.4	12.8	4.6	28.1	3.53	1.26
68	191-5	92	111	31.6	5.2	13.8	4.8	24.2	4.13	0.68
69	161-1	92	113	38.6	5.2	14.5	5.5	17.9	3.50	0.39
70	113-10	93	113	35.6	3.7	9.4	4.7	27.7	3.17	0.30
71	171-4	92	112	30.3	4.5	14.8	4.5	22.9	3.86	0.44
72	28-1	91	112	34.8	6.5	18.5	5.0	24.1	3.64	0.43
73	217-3	91	112	34.2	6.5	19.9	4.7	27.8	3.66	1.18
74	114-3	92	111	36.3	5.7	18.2	4.6	27.0	3.41	1.10
75	164-2	92	112	17.8	4.3	16.3	4.0	20.1	3.77	0.78
76	75-4	93	112	30.9	3.7	14.1	4.8	28.3	4.05	1.01
77	94-3	92	114	42.6	3.0	10.9	5.4	24.7	3.58	0.45
78	93-6	91	111	35.1	3.1	12.3	4.6	27.8	3.47	0.72
79	2-10	92	112	39.6	6.5	20.1	4.8	25.5	3.33	1.18
80	90-2	91	112	32.2	6.8	18.9	5.0	22.3	3.50	0.76
81	117-1	91	111	37.0	3.5	25.7	5.1	21.6	3.26	1.46
82	32-2	93	112	28.4	4.2	13.1	5.0	28.2	3.21	0.73
83	114-4	92	112	28.2	5.3	15.5	5.7	25.7	3.34	0.50
84	98-4	93	112	34.1	4.0	14.9	4.6	28.4	3.97	0.55
85	192-8	93	112	36.7	10.9	27.5	5.0	28.7	3.55	2.02
86	19-5	92	112	36.0	5.8	16.5	5.9	30.0	3.78	1.39
87	181-5	91	111	37.6	6.8	19.1	5.6	32.5	3.55	1.45
88	105-2	92	111	33.1	6.1	17.9	4.8	27.5	3.16	1.44
89	121-3	91	111	31.1	4.8	14.4	4.5	25.0	3.63	0.80
90	158-7	91	112	34.6	5.5	17.3	5.0	24.3	4.03	0.87
91	110-9	92	112	35.1	5.0	20.0	5.2	22.6	3.60	1.45
92	37-1	92	113	29.3	6.3	18.9	4.6	25.1	3.43	1.33
93	60-9	91	114	30.9	3.8	17.0	5.7	32.6	3.26	1.02
94	95-9	92	112	28.8	5.9	17.4	4.6	25.4	3.09	1.13
95	147-10	92	112	28.9	5.2	14.2	4.8	29.0	3.20	0.78
96	172-3	93	112	39.0	3.9	25.8	5.2	19.7	3.44	1.52
97	114-8	91	112	33.2	4.6	16.1	4.2	23.5	3.76	0.99
98	184-6	91	111	32.3	5.1	17.1	4.6	26.3	3.50	0.90
99	203-3	92	112	33.5	5.3	17.3	5.0	30.1	3.56	0.94

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
100	208-9	91	116	30.5	5.6	17.8	5.1	25.6	3.27	0.76
101	3-2	92	112	19.4	5.8	16.8	4.6	23.0	3.80	0.49
102	102-1	93	115	35.8	6.3	18.7	4.2	22.9	3.67	1.38
103	45-1	92	112	36.9	6.7	18.0	5.1	23.6	3.73	0.69
104	225-9	92	114	29.4	5.1	23.7	4.6	23.8	3.56	1.43
105	250-3	91	113	34.6	5.2	25.5	4.8	21.2	3.24	1.73
106	247-1	92	112	29.9	4.7	19.4	4.8	28.2	3.60	1.25
107	159-8	91	114	26.4	5.5	34.0	5.5	31.1	3.42	3.27
108	77-10	91	113	30.5	6.2	18.5	5.4	25.5	3.45	1.01
109	234-9	92	112	31.5	3.5	13.7	4.5	22.3	3.88	0.45
110	41-5	92	112	34.5	5.7	16.1	4.7	24.1	4.01	0.61
111	86-1	91	111	38.5	5.5	18.8	5.1	30.3	3.30	1.05
112	159-3	92	113	37.7	4.7	15.0	5.0	30.1	3.36	0.65
113	83-10	91	112	32.2	7.5	31.7	5.3	30.2	3.86	3.11
114	234-5	92	113	28.8	3.4	13.5	5.2	24.0	3.90	0.58
115	247-3	92	113	36.9	5.0	17.7	4.8	23.2	3.97	0.71
116	199-4	92	112	30.2	5.0	20.9	5.3	26.6	3.38	1.78
117	6-1	92	112	31.0	5.3	17.4	4.0	23.3	4.15	0.63
118	92-4	92	112	30.1	3.3	13.8	5.0	29.1	3.06	0.48
119	232-8	93	113	42.2	3.5	16.3	5.3	21.7	4.32	0.63
120	147-3	91	112	31.4	4.7	13.8	5.5	24.2	3.30	0.48
121	108-6	93	112	36.7	6.1	18.1	5.2	31.4	3.33	1.26
122	142-1	91	112	41.2	7.7	23.8	4.8	22.3	3.84	0.99
123	134-6	93	113	35.2	4.7	15.6	4.1	23.3	3.64	0.89
124	19-1	91	114	38.4	7.0	20.3	4.7	28.0	3.97	1.24
125	165-8	91	112	34.4	5.3	22.0	5.0	29.1	3.61	1.51
126	156-4	93	112	45.4	7.2	23.8	4.6	27.5	3.46	1.77
127	134-5	93	113	31.0	6.4	22.6	4.9	28.4	3.03	1.34
128	143-9	91	113	26.2	5.8	13.4	4.6	26.9	4.12	1.06
129	73-10	91	113	34.2	3.5	17.8	4.4	25.5	3.15	1.00
130	67-5	92	112	29.6	4.7	10.5	4.7	28.2	4.45	0.82
131	73-6	90	111	31.3	5.3	11.7	5.3	33.1	3.85	1.04
132	58-1	91	111	34.2	3.6	9.7	4.2	26.0	4.80	0.76
133	66-5	92	113	31.9	3.2	8.4	5.4	32.2	3.85	0.76

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
134	2-4	91	115	28.6	4.5	13.3	4.7	29.1	3.48	0.93
135	221-4	93	113	33.8	4.8	12.5	4.6	27.2	3.34	0.73
136	224-8	92	112	30.2	5.0	14.1	4.7	30.3	3.71	0.75
137	141-8	91	111	33.1	5.3	14.1	4.8	31.1	3.58	1.18
138	231-1	91	111	33.8	6.6	16.4	4.8	29.1	3.65	1.27
139	146-2	92	116	35.1	6.0	14.8	4.4	25.5	5.40	1.29
140	225-6	91	113	36.0	6.8	17.4	4.5	27.3	4.56	1.62
141	181-6	91	112	35.9	5.2	21.3	4.6	27.6	4.08	1.56
142	246-9	92	111	29.8	4.8	12.4	4.6	27.8	3.86	0.71
143	109-8	91	114	31.2	5.0	12.3	4.8	28.7	3.73	0.99
144	209-7	91	112	35.0	6.3	20.6	5.0	30.3	3.14	1.45
145	165-3	90	113	31.2	4.5	18.2	4.5	26.9	3.86	0.96
146	220-1	91	116	25.9	4.2	17.2	4.3	25.6	3.20	0.49
147	138-9	92	113	26.7	2.8	14.3	3.8	22.7	3.99	0.47
148	50-2	93	118	27.1	3.2	13.1	4.1	23.2	3.82	0.66
149	12-7	92	112	35.1	3.8	10.4	4.8	29.1	3.46	0.82
150	233-10	93	113	29.7	3.5	10.9	4.3	26.0	3.96	0.78
151	189-9	91	112	41.5	11.4	19.7	4.8	30.8	4.25	1.81
152	50-9	90	112	29.6	3.4	15.0	4.5	23.6	3.39	0.75
153	153-1	90	118	29.4	3.4	16.0	4.2	23.3	3.38	0.66
154	164-9	84	106	24.5	5.5	32.1	5.0	26.7	4.29	2.73
155	6-2	91	112	34.6	4.0	15.3	4.4	25.5	3.53	0.84
156	221-4	92	112	37.6	6.5	20.4	4.5	26.2	3.92	1.32
157	83-4	93	113	38.9	3.9	12.6	4.5	26.1	3.36	0.67
158	248-8	91	111	36.9	3.7	16.8	4.5	26.0	3.62	0.93
159	71-9	91	112	35.4	4.0	18.2	4.7	28.0	3.68	1.17
160	61-4	91	111	33.7	4.4	21.8	4.7	27.3	3.18	1.18
161	41-4	92	112	37.2	5.0	14.5	4.7	28.0	3.55	0.97
162	9-5	93	111	40.2	5.8	22.4	4.8	29.5	3.30	1.42
163	3-7	91	111	39.0	8.5	23.7	5.0	30.1	4.05	1.68
164	204-7	92	111	40.8	6.4	22.6	4.6	29.6	3.54	1.61
165	141-3	92	115	36.9	4.7	12.2	4.2	25.0	3.98	0.88
166	187-2	93	115	33.4	4.6	13.0	4.9	29.2	4.01	0.97
167	30-4	92	113	35.2	4.1	11.7	4.4	26.7	3.90	0.68

M₃ Pedigree	M₂ Pedigree	Days to 50% flowering	Days to Maturity	Plant Height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
168	121-7	91	112	35.9	5.9	15.0	4.7	28.1	3.15	0.96
169	144-5	91	113	35.3	2.4	13.6	4.2	26.2	3.92	0.42
170	226-6	91	111	37.1	5.2	15.7	4.8	29.5	3.70	1.12
171	199-3	91	114	34.7	4.0	19.6	4.9	30.5	3.46	0.94
172	226-5	92	116	34.8	5.4	24.1	4.8	22.9	3.89	1.79
173	157-1	90	116	32.0	5.4	14.7	4.6	27.9	3.61	0.84
174	190-2	93	112	33.2	3.4	15.2	5.0	27.7	3.53	0.97
175	183-4	91	113	34.4	6.9	29.6	4.7	26.4	4.02	2.61
176	167-10	91	115	33.7	4.1	18.0	4.6	27.7	3.79	0.94
177	205-2	90	114	30.4	3.7	16.5	4.7	25.3	3.88	1.07
178	178-1	91	114	30.5	3.3	12.6	4.5	26.6	3.85	0.54
179	57-1	91	117	34.6	3.4	13.1	4.6	27.4	3.20	0.66
180	219-2	91	115	35.0	4.4	11.8	4.5	27.4	3.40	0.89
181	240-6	90	112	27.3	4.6	13.0	4.5	27.0	3.84	0.92
182	53-5	91	112	26.8	4.3	11.4	4.5	26.5	4.15	0.64
183	250-9	91	112	30.5	6.2	16.7	4.5	26.9	3.63	0.98
184	79-7	91	115	29.0	4.3	10.4	4.6	27.0	3.63	0.67
185	132-6	92	116	34.9	4.6	19.0	4.6	28.3	4.80	1.22
186	134-1	92	112	35.5	6.3	16.2	4.7	27.6	3.74	0.88
187	56-10	92	112	34.4	5.6	15.6	4.9	29.2	5.36	1.54
188	204-4	91	112	32.5	4.3	11.1	4.7	26.2	4.36	0.79
189	142-3	91	113	30.9	5.5	14.4	4.8	29.5	3.33	0.99
190	206-8	93	111	35.4	5.8	15.1	4.9	29.0	3.86	1.01
191	70-5	92	112	29.0	4.9	11.8	4.8	28.7	4.58	1.01
192	224-1	92	112	30.6	4.7	14.1	4.6	30.3	3.67	0.75
193	135-2	91	111	32.7	5.0	16.1	5.1	32.8	4.48	1.48
194	231-6	91	108	32.9	6.9	25.8	5.0	30.1	3.43	2.04
195	20-1	88	108	37.4	6.5	21.1	5.1	28.5	3.46	1.34
196	167-2	91	112	34.8	5.6	23.1	5.3	29.9	3.68	1.61
197	154-8	93	112	43.6	6.8	24.5	4.9	28.6	3.16	1.87
198	167-6	82	102	30.3	5.8	20.7	5.2	28.4	4.25	1.54
199	142-4	91	113	27.0	5.4	15.4	4.8	27.5	3.46	1.06
200	64-6	81	102	33.6	3.7	18.2	4.7	26.3	3.18	1.10

Check varieties									
RZ 19	91.7	112.1	31.5	4.6	17.0	4.8	28.1	3.85	1.14
RZ 209	92.0	112.1	31.2	5.0	16.9	4.6	26.2	3.52	0.94
RZ 223	92.8	113.1	30.4	4.8	15.9	4.7	26.6	3.75	0.86
UC 198	92.3	112.1	27.9	4.9	15.1	4.5	24.7	3.45	0.83
JC 2000-72	92.7	111.8	31.4	4.4	15.5	4.8	27.0	3.61	1.01
C.D.									
Between check varieties	1.45	1.65	3.21	1.23	2.82	0.43	2.28	0.39	0.28
Between accessions within a block	3.24	3.70	7.18	2.75	6.30	0.96	5.09	0.87	0.62
Between accessions between blocks	3.55	4.05	7.87	3.01	6.91	1.05	5.58	0.96	0.68
Between check varieties and accessions	2.66	3.04	5.90	2.26	5.18	0.79	4.18	0.72	0.51

Table 4.2: Frequency of chlorophyll and morphological mutants observed in M₂ progenies of cumin genotype RZ 19.

Mutagenic Treatments	Total number of progenies* tested	Total plants observed	Chlorophyll mutants (<i>xantha</i>)	Morphological mutants						Total number of mutants	No. of progenies representing mutants	Mutation freq. (%) on population basis	Mutation freq (%) on family basis
				<i>bushy</i>	<i>miniature</i>	<i>loosely branched</i>	<i>thick stem</i>	<i>deformed</i>	<i>drooping type</i>				
Gamma rays													
50 kR	7	207	-	-	-	-	-	1	-	1	1	0.48	14.29
60 kR	8	229	-	1	2	-	-	-	-	3	3	1.31	37.50
70 kR	1	31	-	-	-	-	-	-	1	1	1	3.23	100.00
EMS													
0.2 %	11	385	-	-	-	-	-	-	1	1	1	0.26	9.09
0.4 %	16	576	-	-	-	1	-	-	1	2	2	0.35	12.50
0.6 %	16	552	2	5	8	-	-	-	-	15	5	2.72	31.25
MMS													
0.02 %	11	396	-	-	-	1	-	-	-	1	1	0.25	9.09
0.04 %	14	490	1	-	-	-	-	-	-	1	1	0.20	7.14
0.06 %	12	402	-	2	5	-	-	-	-	7	3	1.74	25.00
SA													
0.2 mM	10	370	-	-	-	-	-	1	-	1	1	0.27	10.00
0.4 mM	14	494	3	4	-	-	-	-	-	7	4	1.42	28.57
0.6 mM	11	388	-	-	-	20	-	-	-	20	1	5.15	9.09
Combinations													
50 kR gamma rays + 0.2% EMS	17	544	-	1	1	-	-	-	-	2	2	0.37	11.76
50 kR gamma rays + 0.02 % MMS	9	279	-	-	-	24	1	-	-	25	2	8.96	22.22
50 kR gamma rays + 0.2 mM SA	9	310	-	-	-	-	-	-	-	-	-	-	-
0.2% EMS + 0.02 % MMS	22	792	-	2	2	-	-	-	-	4	3	0.51	13.64
0.2% EMS + 0.2 mM SA	11	374	1	1	1	-	-	-	-	3	3	0.80	27.27
0.02% MMS + 0.2 mM SA	11	391	-	-	1	-	-	-	1	2	2	0.51	18.18
Total (excluding control)	210	7210	7	16	20	45	1	2	4	96	35	28.53	386.60
Mean												1.50	21.48

*Initially it was proposed to include equal number of progenies from each treatment group. But, due to poor growth of M₁ plants and very poor seed setting on M₁ plants which subsequently germinated very poor, only those M₂ progenies (out of 456 sown for RZ 19) were included for recording observation which had minimum of 15 plants growing.

Table 4.3: Frequency of chlorophyll and morphological mutants observed in M₂ progenies of cumin genotype RZ 209.

Mutagenic Treatments	Total number of progenies* tested	Total plants observed	Chlorophyll mutants		Morphological mutants						Total number of mutants	No. of progenies representing mutants	Mutation freq. (%) on population basis	Mutation freq (%) on family basis
			<i>xantha</i>	<i>albino</i>	<i>bushy</i>	<i>miniature</i>	<i>loosely branched</i>	<i>thick stem</i>	<i>deformed</i>	<i>drooping type</i>				
Gamma rays														
50 kR	8	280	1		1	-	-	-	-	-	2	2	0.71	25.00
60 kR	3	93	-	1	-	1	-	-	1	1	4	2	4.30	66.67
70 kR	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EMS														
0.2 %	18	648	1	-	-	-	-	-	-	-	1	1	0.15	5.56
0.4 %	18	594	-	-	-	1	-	-	5	-	6	2	1.01	11.11
0.6 %	26	837	1	-	3	2	1	9	1	-	17	8	2.03	30.77
MMS														
0.02 %	15	570	-	-	1	-	-	-	1	-	2	2	0.35	13.33
0.04 %	16	560	-	-	1	2	-	-	-	-	3	2	0.54	12.50
0.06 %	15	540	-	-	2	1	2	-	2	-	7	5	1.30	33.33
SA														
0.2 mM	12	444	1	-	-	-	-	-	-	-	1	1	0.23	8.33
0.4 mM	22	770	-	-	-	-	1	-	-	1	2	2	0.26	9.09
0.6 mM	11	379	1	-	20	1	3	1	-	-	26	6	6.86	54.55
Combinations														
50 kR gamma rays + 0.2% EMS	5	160	-	-	2	-	-	-	-	-	2	2	1.25	40.00
50 kR gamma rays + 0.02 % MMS	10	306	-	-	4	-	2	-	-	-	6	3	1.96	30.00
50 kR gamma rays + 0.2 mM SA	16	512	-	-	-	-	-	-	2	-	2	1	0.39	6.25
0.2% EMS + 0.02 % MMS	21	735	3	1	-	2	-	-	-	-	6	4	0.82	19.05
0.2% EMS + 0.2 mM SA	20	686	2	-	1	-	-	7	2	-	12	6	1.75	30.00
0.02% MMS + 0.2 mM SA	15	525	1	-	2	3	-	-	1	-	7	3	1.33	20.00
Total (excluding control)	251	8639	11	2	37	13	9	17	15	2	106	54	25.24	482.20
Mean													1.40	26.79

*Initially it was proposed to include equal number of progenies from each treatment group. But, due to poor growth of M₁ plants and very poor seed setting on M₁ plants which subsequently germinated very poor, only those M₂ progenies (out of 456 sown for RZ 209) were included for recording observation which had minimum of 15 plants growing.

Table 4.8: Distribution of M₂ progenies of cumin genotype RZ 19 showing significant increase or decrease in the mean performance for various traits in respect of different mutagenic treatments.

Progenies originally derived from mutagenic doses	Total number of progenies tested	Plant height (cm)			Branches per plant			Umbels per plant			Umbellets per umbel			Seeds per umbel			Seed yield per plant (g)		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Gamma rays																			
50 kR	7	4	1	2	5	1	1	3	3	1	2	4	1	5	-	2	6	1	-
60 kR	8	6	2	-	7	1	-	4	1	3	2	2	4	6	-	2	7	1	-
70 kR	1	1	-	-	1	-	-	1	-	-	-	-	1	1	-	-	1	-	-
EMS																			
0.2 %	11	4	6	1	9	2	-	2	8	1	2	6	3	7	2	2	8	3	-
0.4 %	16	12	3	1	13	-	3	4	7	5	3	6	7	12	3	1	15	-	1
0.6 %	16	10	1	5	13	-	3	6	8	2	5	4	7	13	1	2	15	-	1
MMS																			
0.02 %	11	7	4	-	5	6	-	2	7	2	2	6	3	8	1	2	7	2	2
0.04 %	14	11	2	1	12	1	1	3	8	3	4	6	4	11	-	3	12	1	1
0.06 %	12	7	2	3	9	2	1	5	6	1	5	2	5	9	1	2	11	1	-
Sodium Azide																			
0.2 mM	10	6	1	3	6	1	3	3	6	1	3	2	5	7	2	1	9	-	1
0.4 mM	14	6	4	4	14	-	-	2	8	4	4	3	7	13	1	-	12	2	-
0.6 mM	11	8	2	1	8	3	-	6	3	2	2	4	5	9	1	1	10	-	1
Combinations																			
50 kR gamma rays + 0.2% EMS	17	9	3	5	13	3	1	6	9	2	7	6	4	15	1	1	16	1	-
50 kR gamma rays + 0.02 % MMS	9	4	3	2	8	-	1	2	5	2	3	1	5	8	-	1	9	-	-
50 kR gamma rays + 0.2 mM SA	9	4	1	4	7	1	1	0	6	3	1	3	5	6	3	-	8	-	1
0.2% EMS + 0.02% MMS	22	13	8	1	15	6	1	6	14	2	7	10	5	19	1	2	18	2	2
0.2% EMS + 0.2 mM SA	11	6	4	1	6	1	4	3	5	3	1	5	5	10	1	-	9	1	1
0.02% MMS + 0.2 mM SA	11	7	3	1	5	4	2	2	9	-	3	5	3	7	3	1	6	2	3
Total	210	125	50	35	156	32	22	60	113	37	56	75	79	166	21	23	179	17	14

a=Number of M₂ progenies showing significantly higher mean values than the control

b= Number of M₂ progenies showing significantly lower mean values than the control

c= Number of M₂ progenies at par with the control

Table 4.9: Distribution of M₂ progenies of cumin genotype RZ 209 showing significant increase or decrease in the mean performance for various traits in respect of different mutagenic treatments.

Progenies originally derived from mutagenic doses	Total number of progenies tested	Plant height (cm)			Branches per plant			Umbels per plant			Umbellets per umbel			Seeds per umbel			Seed yield per plant (g)		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Gamma rays																			
50 kR	8	3	3	2	3	3	2	5	2	1	-	2	6	2	5	1	7	-	1
60 kR	3	1	2	-	1	2	-	1	2	-	-	1	2	1	2	-	1	2	-
70 kR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EMS																			
0.2 %	18	7	6	5	6	7	5	7	6	5	5	7	6	5	7	6	15	1	2
0.4 %	18	7	9	2	6	8	4	8	8	2	3	6	9	5	6	7	13	1	4
0.6 %	26	10	12	4	9	9	8	11	10	5	5	7	14	5	9	12	21	2	3
MMS																			
0.02 %	15	5	8	2	4	3	8	7	7	1	6	3	6	3	7	5	12	1	2
0.04 %	16	7	5	4	8	4	4	9	4	3	6	2	8	4	6	6	11	1	4
0.06 %	15	9	4	2	5	6	4	8	6	1	3	4	8	4	6	5	11	1	3
Sodium Azide																			
0.2 mM	12	8	3	1	4	5	3	6	4	2	1	-	11	2	4	6	12	-	-
0.4 mM	22	9	10	3	7	9	6	7	12	3	7	9	6	4	12	6	16	3	3
0.6 mM	11	2	5	4	3	6	2	5	5	1	1	4	6	2	3	6	10	-	1
Combinations																			
50 kR gamma rays + 0.2% EMS	5	2	3	-	1	3	1	2	2	1	1	1	3	3	1	1	5	-	-
50 kR gamma rays + 0.02 % MMS	10	3	5	2	4	5	1	5	3	2	3	1	6	-	5	5	6	2	2
50 kR gamma rays + 0.2 mM SA	16	5	9	2	8	7	1	7	4	5	7	2	7	3	7	6	13	1	2
0.2% EMS + 0.02% MMS	21	8	9	4	7	8	6	8	12	1	5	6	10	5	10	6	16	4	1
0.2% EMS + 0.2 mM SA	20	9	7	4	4	10	6	6	12	2	5	5	10	1	14	5	15	3	2
0.02% MMS + 0.2 mM SA	15	4	6	5	4	8	3	8	6	1	5	5	5	5	4	6	11	2	2
Total	251	99	106	46	84	103	64	110	105	36	63	65	123	54	108	89	195	24	32

a=Number of M₂ progenies showing significantly higher mean values than the control

b= Number of M₂ progenies showing significantly lower mean values than the control

c= Number of M₂ progenies at par with the control

Table 4.7: Range, mean and coefficient of variation observed for different quantitative traits in M₂ generation of two cumin genotypes.

Character	Genotype	Statistic	Control	Gamma rays			EMS			MMS			SA			Gamma rays + EMS	Gamma rays + MMS	Gamma rays + SA	EMS + MMS	EMS + SA	MMS + SA
				50kR	60kR	70kR	0.20%	0.40%	0.60%	2.00%	4.00%	6.00%	0.20%	0.40%	0.60%						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Plant height																					
	RZ 19	R	24.7-27.4	25.1-30.5	21.4-37.6	27.9	22.8-30.5	22.1-31.3	25.0-32.9	23.0-33.3	23.2-31.6	23.4-31.2	25.1-30.85	19.3-32	24.7-31.8	24.0-33.7	22.3-30.4	25.0-31.3	20.1-32.2	21.4-29.9	20.9-32.1
		M	25.82	27.81	27.69	27.90	25.78	27.92	27.90	27.02	28.10	27.68	27.41	26.55	27.86	27.58	26.40	27.53	26.92	26.26	26.46
		CV	3.12	13.37	18.84	12.00	11.32	13.01	11.80	13.15	12.14	13.34	9.99	16.06	14.77	12.66	14.11	12.12	13.94	13.78	14.47
	RZ 209	R	26.1-29.9	23.20-31.70	23.3-31.7	-	18.9-32.5	21.4-38.5	23.55-37.9	21.1-32.4	21.9-34.5	20.0-32.0	19.9-32.6	18.1-35.35	23.05-32.4	24.2-29.8	24.3-32.1	21.1-30.6	23.4-32.9	18.7-32.6	19.65-32.27
		M	28.30	27.88	26.30	-	27.52	28.06	28.48	27.60	28.51	28.03	28.98	27.27	27.37	27.08	28.11	26.73	28.07	27.77	27.28
		CV	3.01	14.00	16.74	-	15.22	16.41	13.61	14.23	14.59	14.16	14.92	18.15	13.01	10.87	12.02	13.33	13.05	14.88	14.04
Branches per plant																					
	RZ 19	R	4.6-5.1	4.4-7.5	4.6-10.6	7.7	4.2-7.7	4.8-7.5	4.9-7.5	4.0-6.6	3.8-7.4	4.4-8.0	3.7-7.3	5.2-7.6	4.0-8.1	4.5-8.4	4.9-6.6	4.6-7.2	3.8-8.5	4.6-6.8	3.2-8.0
		M	4.88	5.87	6.76	7.70	5.72	5.93	6.03	5.19	5.82	6.33	5.57	5.93	5.94	5.76	5.69	5.51	5.47	5.42	5.27
		CV	3.04	34.42	32.28	31.84	29.60	25.24	28.47	27.68	28.35	31.93	29.01	30.12	31.14	28.95	26.17	29.20	31.93	28.66	37.31
	RZ 209	R	5.1-7.00	4.80-7.60	4.7-6.8	-	3.9-10	4.2-9.9	4.5-8.9	4.8-9.2	4.8-8.7	3.9-8.4	4.4-8.3	4.0-8.0	4.5-8.2	4.4-7.8	4.2-8.2	4.7-8.8	4.6-8.5	4.3-8.0	3.7-7.7
		M	6.06	6.23	5.47	-	6.12	6.29	6.21	6.50	6.59	5.99	6.05	5.91	5.77	5.74	6.20	6.36	6.20	5.75	5.67
		CV	8.73	26.93	29.51	-	30.63	31.78	26.46	27.02	24.90	28.51	27.43	28.11	31.45	29.41	29.00	28.31	30.29	25.43	27.93
Umbels per plant																					
	RZ 19	R	23.4-26.7	16.2-43.2	16.5-47.9	28.3	9.3-28.3	17.4-32.9	16.0-32.3	14.6-33.4	10.0-32.1	12.5-38.8	14.3-28.1	9.3-34.4	18.0-35.6	15.9-36.0	16.3-31.2	17.8-25.7	11.7-41.6	12.7-36.2	14.2-47.1
		M	25.15	24.93	28.50	28.30	20.75	24.06	23.74	22.35	22.78	24.51	22.44	23.56	27.64	24.14	24.04	22.17	23.21	23.46	22.40
		CV	3.74	51.24	40.75	37.25	42.72	38.94	42.97	38.68	41.44	43.96	36.76	40.50	41.52	41.30	41.53	37.54	44.98	45.94	50.20
	RZ 209	R	23.6-27.7	20.2-39.9	17.8-32.7	-	11.1-42.5	12.0-41.4	15.9-35.2	12.7-41.1	20.1-37.8	17.2-40.8	17.4-34.7	10.3-39.8	17.3-31.4	13.5-31.9	14.5-30.2	16.4-34.7	13.7-37.1	14.3-31.0	13.2-36.9
		M	25.67	28.91	25.07	-	25.36	25.98	25.68	26.03	27.89	27.24	26.22	24.11	24.35	24.82	25.46	26.00	25.22	22.14	25.28
		CV	5.72	30.74	36.94	-	36.69	34.82	28.03	30.78	24.96	30.89	31.26	34.20	33.01	39.07	28.76	27.92	32.09	35.03	38.06

Table 4.7 continued.

Character	Genotype	Statistic	Control	Gamma rays			EMS			MMS			SA			Gamma rays + EMS	Gamma rays + MMS	Gamma rays + SA	EMS + MMS	EMS + SA	MMS + SA
				50kR	60kR	70kR	0.20%	0.40%	0.60%	2.00%	4.00%	6.00%	0.20%	0.40%	0.60%	EMS	+ MMS	+ SA	+ MMS	+ SA	+ SA
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Umbellets per umbel																					
	RZ 19	R	4.7-5.4	4.8-5.3	4.8-5.6	5.1	4.4-5.4	4.6-6.4	4.2-5.8	4.5-5.3	4.7-5.7	4.7-5.6	4.7-5.4	4.3-5.4	4.5-5.5	4.5-5.7	4.6-5.5	4.5-5.2	4.2-5.6	3.7-5.4	4.5-5.6
		M	5.04	5.00	5.09	5.10	4.93	5.04	5.05	4.93	5.04	5.14	5.06	5.04	5.02	5.10	5.09	4.99	4.98	4.89	5.01
		CV	3.27	10.22	10.46	11.13	11.24	12.45	12.72	9.80	10.76	9.86	10.44	11.28	11.76	12.74	10.88	9.73	12.28	11.86	12.83
	RZ 209	R	5.00-5.60	5.0-5.3	5.00-5.3	-	4.8-6.2	5.0-6.2	4.6-6.4	4.5-6.2	5.0-7.0	4.8-6.4	5.1-5.5	4.6-6.6	4.9-6.4	4.9-5.5	4.9-6.4	4.8-6.3	4.4-6.1	4.8-6.2	4.7-6.5
		M	5.21	5.11	5.13	-	5.22	5.24	5.25	5.29	5.36	5.25	5.18	5.29	5.20	5.14	5.35	5.34	5.24	5.29	5.27
		CV	4	13.20	12.25	-	13.93	12.85	13.93	14.11	15.44	13.81	11.46	15.07	14.46	11.12	14.40	13.11	14.11	13.35	12.98
Seeds per umbel																					
	RZ 19	R	25.1-27.7	26.6-31.6	25.9-34.5	29.7	23.6-32.2	23.2-42.9	25.6-37.7	23.1-33.3	26.9-30.9	25.5-33.8	23.5-33.6	22.7-34.5	22.3-33.4	24.5-31.6	26.6-32.7	25.0-30.7	24.9-35.6	24.0-35.1	22.6-33.8
		M	26.74	28.63	30.16	29.70	28.17	29.27	29.88	29.32	28.83	29.48	29.15	30.06	29.19	29.22	29.80	28.20	29.76	30.00	28.62
		CV	2.75	15.65	14.79	11.00	17.11	20.46	17.06	15.50	14.93	17.78	18.58	17.68	18.52	14.61	14.56	16.86	16.98	15.68	18.81
	RZ 209	R	27.5-33.20	27.8-32.3	28.8-32.00	-	18.2-36.8	24.6-36.5	22.5-33.0	19.1-34.5	25.8-34.4	23.0-35.9	26.6-32.1	20.6-38.0	26.1-32.5	25.0-32.9	23.7-30.9	24.1-34.6	20.7-35.0	22.8-34.3	23.0-40.5
		M	30.15	29.71	29.90	-	29.32	29.72	29.26	29.03	29.81	29.79	29.73	28.89	29.75	30.38	28.89	29.03	28.77	27.96	31.08
		CV	5.02	13.69	11.83	-	16.36	16.43	14.94	16.75	15.15	13.70	12.21	18.17	11.73	18.22	13.10	15.24	17.60	16.72	18.18
Seed yield per plant																					
	RZ 19	R	1.89-2.22	1.53-5.21	1.60-6.75	5.24	1.40-3.74	2.01-7.56	2.13-4.93	1.76-5.65	1.77-4.94	1.53-5.37	2.12-5.38	1.35-5.45	2.18-4.33	1.17-4.30	2.39-6.59	2.30-3.76	1.78-6.57	1.67-3.98	1.74-6.03
		M	2.05	3.37	3.98	5.24	2.81	3.10	3.45	2.89	3.45	3.61	3.32	3.13	3.02	3.11	3.47	2.97	3.00	3.10	2.84
		CV	5.12	59.71	60.04	70.14	59.83	57.83	56.00	67.21	63.94	59.63	57.29	58.12	56.21	58.35	58.44	48.71	53.59	50.11	60.34
	RZ 209	R	2.01-2.63	2.36-4.77	1.66-2.73	-	1.95-6.93	1.82-4.79	1.99-5.25	1.68-3.7	2.07-4.52	1.99-4.17	2.57-4.43	1.25-5.1	2.39-4.67	2.82-4.77	1.41-4.05	1.96-5.07	1.76-4.75	1.86-4.29	1.98-4.79
		M	2.320	3.73	2.03	-	3.22	3.08	3.13	2.96	3.03	3.19	3.46	3.25	3.37	3.74	2.65	3.54	3.00	2.97	3.19
		CV	8.790	53.25	74.69	-	67.61	53.19	56.32	56.55	53.30	57.30	47.71	60.86	47.88	52.61	61.61	52.45	54.67	52.49	48.59

R = Range, M = Mean and CV = Coefficient of variation

Table 4.10: Distribution of superior M₂ progenies of two cummin genotypes in various class intervals.

S. No.	Plant height (cm)		Branches per plant		Umbels per plant		Umbellets per umbel		Seeds per umbel		Seed yield per plant (g)	
	Class intervals	Freq.	Class intervals	Freq.	Class intervals	Freq.	Class intervals	Freq.	Class intervals	Freq.	Class intervals	Freq.
RZ 19												
1.	26.4-28.6	61	5.1-6.2	90	26.1-30.5	32	5.20-5.44	42	27.4-30.5	103	2.22-3.29	95
2.	28.7-30.9	48	6.3-7.3	44	30.6-34.8	17	5.45-5.68	10	30.6-33.6	54	3.30-4.36	59
3.	31.0-33.1	14	7.4-8.4	20	34.9-39.2	7	5.69-5.92	3	33.7-36.7	7	4.37-5.42	18
4.	33.2-35.4	1	8.5-9.5	1	39.3-43.5	2	5.93-6.16	0	36.8-39.8	1	5.43-6.49	3
5.	35.5-37.6	1	9.6-10.6	1	43.6-47.9	2	6.17-6.40	1	39.9-42.9	1	6.50-7.56	4
Total		125		156		60		56		166		179
RZ 209												
1.	29.0-30.9	60	6.5-7.2	39	26.7-29.9	55	5.4-5.7	35	31.2-33.1	39	2.51-3.39	103
2.	31.0-32.8	33	7.3-7.9	24	30.0-33.0	31	5.8-6.0	11	33.2-34.9	7	3.40-4.28	69
3.	32.9-34.7	3	8.0-8.6	14	33.1-36.2	12	6.1-6.4	14	35.0-36.8	4	4.29-5.16	21
4.	34.8-36.6	1	8.7-9.3	5	36.3-39.3	6	6.5-6.7	2	36.9-38.6	3	5.17-6.05	1
5.	36.7-38.5	2	9.4-10.0	2	39.4-42.5	6	6.8-7.0	1	38.7-40.5	1	6.06-6.93	1
Total		99		84		110		63		54		195

Table 4.11: Magnitude of various yield attributes of top 25 M₂ progenies of cumin genotype RZ 19 showing significantly higher seed yield per plant.

S.No.	Prog. No.	Seed yield per plant (g)		Plant height (cm)		Branches per plant		Umbels per plant		Umbellets per umbel		Seeds per umbel		Test weight (g)	Days to 50% flowering	Days to maturity
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV			
1	41	7.56**	29.35**	26.4*	8.60**	6.2**	16.66**	28.1**	18.79**	5.2**	8.11**	29.5**	8.19**	5.16	79	110
2	15	6.75**	31.11**	37.6**	4.89**	10.6**	12.73**	47.9**	18.48**	5.0	9.43**	34.5**	8.00**	5.10	79	111
3	157	6.59**	40.76**	25.6	10.45**	5.5**	19.64**	25.2	26.51**	5.2**	8.11**	28.9**	7.90**	5.19	81	112
4	188	6.57**	29.64**	31.9**	5.62**	8.5**	14.93**	41.6**	23.83**	5.4**	9.56**	35.6**	14.99**	5.09	84	119
5	205	6.03**	34.49**	27.6**	10.69**	7.5**	14.40**	47.1**	19.32**	5.0	13.33**	32.6**	12.29**	4.18	77	118
6	67	5.65**	59.82**	23.6**	7.26**	5.7**	23.46**	22.9**	28.26**	5.1	6.20*	29.6**	8.31**	5.16	80	110
7	119	5.45**	42.16**	26.3	11.34**	5.7**	29.88**	22.4**	39.89**	5.1	6.20*	29.7**	9.79**	4.8	77	118
8	90	5.38**	50.51**	31.2**	10.00**	6.2**	23.80**	27.1*	51.17**	5.4**	9.56**	32.9**	17.46**	5.02	77	114
9	98	5.38**	53.66**	26.2	7.15**	6.1**	19.63**	23.8*	36.62**	5.0	9.43**	30.0**	11.65**	4.85	80	111
10	16	5.24**	70.14**	27.9**	12.00**	7.7**	31.84**	28.3**	37.25**	5.1	11.13**	29.7**	11.00**	5.20	75	107
11	6	5.21**	32.68**	26.3	19.14**	6.2**	19.83**	28.0**	13.88**	4.9**	6.45*	28.6**	17.22**	5.11	79	111
12	11	5.04**	42.80**	27.7**	5.91*	6.7**	14.16**	35.2**	22.60**	5.5**	9.58**	34.1**	11.27**	4.81	79	119
13	79	4.94**	57.92**	31.6**	7.03**	6.3**	22.51**	30.5**	28.43**	5.0	9.43**	29.2**	8.20**	4.8	79	114
14	58	4.93**	33.76**	25.5	12.16**	6.5**	23.22**	26.1*	21.48**	5.3**	9.11**	31.3**	9.41**	4.27	79	110
15	7	4.90**	46.96**	25.4	7.47**	7.5**	33.41**	26.7*	34.06**	5.1	11.13**	28.7**	11.02**	4.04	81	114
16	83	4.82**	52.87**	29.5**	8.49**	6.8**	30.06**	25.8	23.67**	5.4**	9.56**	30.9**	13.07**	5.26	77	111
17	82	4.73**	48.19**	29.5**	6.24**	5.7**	24.88**	25.9	31.07**	4.7**	10.28**	28.0**	14.87**	5.23	79	110
18	96	4.73**	51.17**	26.1	11.34**	7.4**	25.64**	26.2*	25.43**	5.1	6.20*	27.7**	7.62**	4.35	79	112
19	100	4.67**	57.47**	26.3	12.16**	5.5**	33.47**	19.3**	41.38**	5.2**	15.17**	29.2**	20.15**	4.01	80	117
20	59	4.55**	67.52**	27.8**	5.82*	6.3**	23.72**	29.3**	43.89**	5.8**	10.90**	33.4**	16.04**	4.93	80	112
21	80	4.53**	70.69**	27.5**	7.12**	6.1**	22.46**	22.5**	30.88**	4.9**	6.45*	27.7**	17.61**	5.13	81	112
22	50	4.52**	72.51**	25.5	5.39*	7.1**	36.64**	27.5**	38.23**	5.0	13.33**	30.6**	16.10**	4.45	75	112
23	55	4.48**	53.92**	30.6**	8.18**	6.9**	25.97**	26.3	46.81**	4.7**	14.36**	26.3	22.10**	5.27	80	110
24	92	4.48**	62.29**	26.3	15.84**	7.6**	18.81**	31.2**	24.26**	5.2**	8.11**	29.4**	9.10**	5.17	76	117
25	8	4.45**	64.41**	26.5*	9.94**	6.5**	19.53**	26.7**	29.91**	5.0	9.43**	29.6**	7.67**	5.15	78	112
Control		2.05	5.12	25.8	3.12	4.87	3.03	25.1	3.74	5.04	3.27	26.7	2.75	4.69	76	112

* and ** significant at p= 0.05 and p= 0.01, respectively.

Table 4.12: Magnitude of various yield attributes of top 25 M₂ progenies of cumin genotype RZ 209 showing significantly higher seed yield per plant.

S.No.	Prog. No.	Seed yield per plant (g)		Plant height (cm)		Branches per plant		Umbels per plant		Umbellets per umbel		Seeds per umbel		Test weight (g)	Days to 50% flowering	Days to maturity
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV			
1	19	6.93**	63.78**	32.50**	8.24**	7.90**	12.59*	42.5**	37.39**	5.0**	9.43**	36.8**	9.48**	4.33	76	110
2	58	5.25**	56.94**	31.90**	5.00*	7.40**	25.64**	31.3**	22.49**	5.3	12.73**	31.3	14.61**	5.12	80	116
3	146	5.10**	36.14**	32.30**	5.27*	6.50*	13.07	27.2*	21.70**	5.1	6.20	29.7	13.66**	5.02	77	111
4	188	5.07**	34.50**	29.00*	8.75**	7.20**	18.29**	27.3**	9.47*	5.1	11.13**	29.7	11.56**	4.81	80	112
5	182	5.02**	19.42**	27.10**	8.06**	8.80**	8.96	28.0**	13.15**	6.0**	11.11**	34.6**	6.70	4.72	75	107
6	189	4.89**	52.33**	30.30**	6.79**	6.80**	27.56**	32.4**	21.04**	5.2	8.11*	31.3*	9.17*	5.27	76	110
7	248	4.79**	27.26**	28.50	6.24*	6.50*	16.62*	35.4**	10.83**	4.9**	6.45	37.1**	9.11**	4.81	75	105
8	32	4.79**	43.19**	31.60**	6.54**	8.00**	18.63**	31.5**	14.06**	5.0**	9.43**	32.2**	11.51**	5.29	75	108
9	167	4.77**	34.36**	29.50**	5.36*	5.60*	24.11**	26.6	26.06**	5.1	11.13**	31.3*	7.98	5.12	78	110
10	3	4.77**	53.71**	31.20**	7.97**	6.90**	35.14**	32.6**	28.42**	5.1	6.20	31.6*	14.01**	4.26	76	108
11	199	4.75**	29.72**	26.10**	11.77**	5.00**	29.81**	22.8**	22.34**	4.9**	6.45	22.7**	13.78*	3.83	75	108
12	134	4.71**	34.21**	22.50**	8.95**	5.20**	25.32**	24.4*	23.76**	5.0**	9.43**	31.8**	6.76	4.77	76	107
13	2	4.69**	50.24**	28.50	15.45**	7.20**	18.29**	33.3**	21.98**	5.1	11.13**	32.3**	8.26*	4.90	76	109
14	159	4.67**	42.10**	29.70**	10.17**	7.60**	32.35**	28.9**	38.48**	5.0**	9.43**	30.5	8.64*	3.54	77	109
15	143	4.66**	52.62**	35.35**	8.54**	8.00**	11.79*	39.8**	22.59**	5.4*	9.56**	38.0**	12.77**	5.23	76	109
16	101	4.52**	60.09**	27.00**	11.71**	7.60**	24.18**	29.1**	25.69**	5.2	12.16**	28.7**	7.54	3.96	76	115
17	147	4.49**	64.07**	30.80**	6.81**	6.90**	19.86**	30.3**	9.85*	5.5**	15.45**	30.9	12.62**	5.29	77	109
18	71	4.47**	45.23**	27.40**	8.51**	7.90**	28.27**	29.2**	25.62**	5.0**	9.43**	29.7	9.66*	5.25	76	109
19	126	4.43**	22.91**	29.80**	10.94**	5.80	13.60	26.5	11.97**	5.5**	9.58**	29.1*	9.78*	4.64	77	111
20	206	4.40**	45.18**	28.750	9.18**	8.50**	23.03**	33.5**	21.21**	5.1	11.13**	27.7**	8.85	4.62	81	114
21	168	4.38**	47.16**	26.31**	7.08**	7.80**	22.45**	29.4**	17.06**	5.1	6.20	32.9**	16.11**	4.88	76	108
22	195	4.37**	29.14**	28.50	8.47**	6.90**	17.35**	34.7**	16.70**	5.3	9.11**	29.9	9.39*	3.99	77	106
23	225	4.29**	49.31**	31.60**	9.34**	6.00	26.06**	28.6**	33.91**	5.1	11.13**	28.9*	9.85*	4.70	76	110
24	153	4.25**	63.36**	29.50**	10.26**	7.20**	10.96	25.0	16.00**	6.4**	10.93**	32.3**	12.30**	5.44	76	109
25	190	4.18**	68.00**	29.60**	5.09*	8.80**	19.17**	29.5**	6.03	6.3**	10.71**	30.8	3.35	4.61	76	110
Control		2.32	8.78	28.30	3.01	6.06	8.73	25.67	5.72	5.21	3.99	30.15	5.02	4.36	76.00	109.88

* and ** significant at p= 0.05 and p= 0.01, respectively.

Table 4.14: Mean squares and variances for different characters in M₃ progenies of cumin variety RZ 19.

Source of variation	d.f.	Days to 50% flowering	Days to Maturity	Plant height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
Blocks (ignoring accessions)	7	3.21	4.76**	18.71**	0.96	12.77**	0.47**	46.74**	0.14	0.05**
Entries (eliminating blocks)	324	6.48**	2.56**	21.54**	1.58**	26.07**	0.17*	12.41**	0.19*	0.2**
Checks	4	4.66	2.6	19.09*	1.82	13.97**	0.29*	9.04*	0.14	0.08**
Accessions (M ₃ progenies)	319	4.00*	2.28**	21.33**	1.56**	26.22**	0.16*	12.24**	0.18*	0.2**
Checks v/s Accessions	1	805.44**	93.91**	97.05**	7.55**	26.27**	3.32**	77.63**	1.61**	0.17**
Error	28	2.32	0.99	4.98	0.7	3.06	0.08	2.46	0.09	0.01
Genotypic variance (v _g)		1.68	1.29	16.35	0.86	23.16	0.08	9.78	0.09	0.19
Phenotypic variance (v _p)		4.00	2.28	21.33	1.56	26.22	0.16	12.24	0.18	0.2
Error variance (v _e)		2.32	0.99	4.98	0.7	3.06	0.08	2.46	0.09	0.01

* Significant at p= 0.05 and **significant at p= 0.01

Table 4.16: Genotypic and phenotypic coefficient of variation, heritability in broad sense and genetic advance as percentage of mean for different characters in M₃ mutant lines of cumin variety RZ 19.

Characters	Genotypic coefficient of variation (GCV)	Phenotypic coefficient of variation (PCV)	Heritability in broad sense (%)	Genetic advance as percentage of mean
Days to 50 % flowering	1.40	2.17	42.00	1.87
Days to Maturity	1.00	1.33	56.73	1.55
Plant height (cm)	13.05	14.90	76.65	23.53
Branches per plant	18.30	24.74	54.72	27.89
Umbels per plant	27.44	29.19	88.34	53.13
Umbellets per umbel	6.28	9.11	47.56	8.93
Seeds per umbel	11.74	13.13	79.94	21.62
Test weight (g)	8.05	11.50	49.05	11.62
Seed yield per plant (g)	37.81	39.02	93.87	75.46

Table 4.15: Mean squares and variances for different characters in M₃ progenies of cumin variety RZ 209.

Source of variation	d.f.	Days to 50% flowering	Days to Maturity	Plant height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)	Seed yield per plant (g)
Blocks (ignoring accessions)	9	3.71*	3.59*	20.01**	2.30*	18.34**	0.28*	14.26**	0.26*	0.15**
Entries (eliminating blocks)	204	2.15*	3.42**	25.80**	1.75*	18.82**	0.21*	10.09**	0.16*	0.20**
Checks	4	2.15	2.48	22.30*	0.63	22.79**	0.37*	19.40**	0.24	0.16*
Accessions (M ₃ progenies)	199	2.13*	3.39**	24.74**	1.76*	18.61**	0.20*	9.61**	0.15*	0.20**
Checks v/s Accessions	1	6.28*	14.34**	252.17**	4.02*	45.07**	1.18**	67.81**	1.51**	0.40**
Error	36	1.27	1.66	6.26	0.92	4.82	0.11	3.14	0.09	0.05
Genotypic variance (v _g)		0.86	1.73	18.48	0.84	13.79	0.09	6.47	0.06	0.15
Phenotypic variance (v _p)		2.13	3.39	24.74	1.76	18.61	0.20	9.61	0.15	0.20
Error variance (v _e)		1.27	1.66	6.26	0.92	4.82	0.11	3.14	0.09	0.05

* Significant at p= 0.05 and **significant at p= 0.01

Table 4.17: Genotypic and phenotypic coefficient of variation, heritability in broad sense and genetic advance as percentage of mean for different characters in M₃ mutant lines of cumin variety RZ 209.

Characters	Genotypic coefficient of variation (GCV)	Phenotypic coefficient of variation (PCV)	Heritability in broad sense (%)	Genetic advance as percentage of mean
Days to 50 % flowering	1.01	1.59	40.17	1.32
Days to Maturity	1.17	1.64	51.08	1.72
Plant height (cm)	12.99	15.03	74.70	23.13
Branches per plant	17.94	25.91	47.94	25.58
Umbels per plant	21.30	24.75	74.09	37.77
Umbellets per umbel	6.06	9.21	43.21	8.2
Seeds per umbel	9.51	11.59	67.30	16.07
Test weight (g)	6.66	10.66	38.99	8.56
Seed yield per plant (g)	36.00	41.18	76.41	64.82

Table 4.19: Magnitude of yield and yield attributes of 20 M₃ progenies of cumin genotype RZ 19 sowing significantly higher yield than their parents.

M ₃ accession no.	M ₂ progenies No.	Seed yield per plant (g)	Days to 50% flowering	Days to maturity	Plant height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)
29	87-6	3.07	91	114	32.8	7.8	37.6	4.5	31.5	4.42
197	171-2	2.52	92	113	38.4	7.5	23.7	4.9	32.9	5.3
30	133-6	2.39	86	113	34.3	6.5	29.3	4.7	32.2	3.54
36	16-1	2.35	94	113	35.4	7.4	34.2	5.2	32.2	2.87
41	65-7	2.2	92	113	34.5	6.6	27.2	4.7	28.5	4.17
142	16-9	2.2	95	113	36.1	6.5	33	4.9	32.6	2.87
250	49-5	2.15	93	112	32.7	5.2	25.8	4.8	29.6	4.13
148	58-1	2.14	90	112	37.9	7.3	23	4.2	28.7	3.42
158	11-4	2.13	93	116	34.6	6.9	29.8	5	32.5	4.13
17	92-1	2.11	93	117	31.8	4.9	23.7	3.7	25	3.86
143	34-5	2.11	92	113	35.2	5.8	26.8	4.3	28	3.17
227	75-3	2.11	88	114	16.6	3.1	27.5	4.7	29	3.41
152	9-6	2.09	88	115	33.9	6.1	23.4	4.6	28.8	4.1
55	88-8	2.06	91	113	34.1	5.6	25.2	4.2	27.2	3.96
214	141-5	2.05	92	113	36.1	5.7	17.1	4.5	33.4	3.48
159	204-9	2.01	93	113	33.2	6.5	23.8	4.9	32.4	3.64
21	68-3	2	89	115	32.2	4.8	22.3	3.7	24.6	3.98
160	90-3	1.97	94	113	35.2	6.8	26	4.6	28.7	3.06
209	138-4	1.95	94	113	18.4	5.4	16.8	4.6	30.7	4.1
42	51-7	1.93	90	112	37.4	7.5	24.3	4.7	28.2	3.42
Mean of checks										
RZ 19		1.16	88	113	28.32	4.54	17.30	4.26	23.25	3.48
RZ 209		1.13	88	112	30.25	5.46	19.33	4.58	25.35	3.41
RZ 223		1.15	88	111	30.34	5.73	16.86	4.10	22.74	3.49
UC 198		0.96	87	112	27.09	4.84	15.66	4.25	23.25	3.32
JC 2000-72		1.24	87	111	27.39	5.04	17.40	4.11	22.88	3.68
C.D.										
Between check varieties		0.14	1.97	1.29	2.89	1.09	2.26	0.38	2.03	0.40
Between accessions within a block		0.32	4.41	2.88	6.46	2.43	5.06	0.84	4.54	0.88
Between accessions between blocks		0.35	4.83	3.15	7.08	2.66	5.55	0.92	4.97	0.97
Between check varieties and accessions		0.26	3.62	2.36	5.31	2.00	4.16	0.69	3.73	0.73

Table 4.20: Magnitude of yield and yield attributes of 20 M₃ progenies of cumin genotypes RZ 209 sowing significantly higher yield than their parents.

M ₃ accession no.	M ₂ progenies No.	Seed yield per plant (g)	Days to 50% flowering	Days to maturity	Plant height (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	Test weight (g)
107	159-8	3.27	91	114	26.4	5.5	34.0	5.5	31.1	3.42
113	83-10	3.11	91	112	32.2	7.5	31.7	5.3	30.2	3.86
154	164-9	2.73	84	106	24.5	5.5	32.1	5.0	26.7	4.29
175	183-4	2.61	91	113	34.4	6.9	29.6	4.7	26.4	4.02
64	77-4	2.21	93	112	33.2	3.9	15.3	5.8	24.7	3.21
194	231-6	2.04	91	108	32.9	6.9	25.8	5.0	30.1	3.43
85	192-8	2.02	93	112	36.7	10.9	27.5	5.0	28.7	3.55
14	166-6	1.99	93	114	28.9	4.5	24.4	4.8	28.4	3.46
197	154-8	1.87	93	112	43.6	6.8	24.5	4.9	28.6	3.16
151	189-9	1.81	91	112	41.5	11.4	19.7	4.8	30.8	4.25
172	226-5	1.79	92	116	34.8	5.4	24.1	4.8	22.9	3.89
116	199-4	1.78	92	112	30.2	5.0	20.9	5.3	26.6	3.38
126	156-4	1.77	93	112	45.4	7.2	23.8	4.6	27.5	3.46
105	250-3	1.73	91	113	34.6	5.2	25.5	4.8	21.2	3.24
163	3-7	1.68	91	111	39.0	8.5	23.7	5.0	30.1	4.05
41	116-2	1.65	93	113	36.7	7.6	22.7	5.2	29.0	3.76
140	225-6	1.62	91	113	36.0	6.8	17.4	4.5	27.3	4.56
196	167-2	1.61	91	112	34.8	5.6	23.1	5.3	29.9	3.68
164	204-7	1.61	92	111	40.8	6.4	22.6	4.6	29.6	3.54
141	181-6	1.56	91	112	35.9	5.2	21.3	4.6	27.6	4.08
Mean of checks										
RZ 19		1.14	92	112	31.47	4.60	16.99	4.76	28.14	3.85
RZ 209		0.94	92	112	31.16	5.06	18.86	5.01	28.04	3.74
RZ 223		0.86	93	113	30.42	4.75	15.91	4.67	26.64	3.75
UC 198		0.83	92	112	27.90	4.88	15.09	4.48	24.70	3.45
JC 2000-72		1.01	93	112	31.37	4.41	15.51	4.77	27.03	3.61
C.D.										
Between check varieties		0.28	1.45	1.65	3.21	1.23	2.82	0.43	2.28	0.39
Between accessions within a block		0.62	3.24	3.70	7.18	2.75	6.30	0.96	5.09	0.87
Between accessions between blocks		0.68	3.55	4.05	7.87	3.01	6.91	1.05	5.58	0.96
Between check varieties and accessions		0.51	2.66	3.04	5.90	2.26	5.18	0.79	4.18	0.72

